

COWLITZ RIVER FLOODPLAIN STUDY

Cowlitz River and Tributaries at Packwood, WA

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INTRODUCTION

Watershed Science & Engineering (WSE) was retained by the Lewis County Public Works Department (County) to perform detailed hydrologic analysis, hydraulic modeling, and flood inundation mapping to evaluate flood risk along 16.7 river miles of the Cowlitz River and 8.7 river miles of tributary creeks in and near the town of Packwood in Lewis County, Washington. The upstream extents of the Cowlitz River study reach are just downstream of the Tatoosh Wilderness boundary on the Muddy Fork and just upstream of Forest Road 1270 on the mainstem Cowlitz River. The downstream boundary of the study reach is 0.3 river miles downstream of Cora Bridge on U.S. Highway 12. Four tributaries to the Cowlitz River were also included in the study: Hall, Butter, Skate, and Willame Creeks. Hydraulic model results were used to prepare floodplain mapping and supporting technical documentation necessary to update effective Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs).

BACKGROUND

The existing FEMA FIRMs for the Cowlitz River were based on a 1979 study which concluded that a natural ridge along the left bank of the river upstream of Skate Creek Road would be overtopped resulting in the inundation of the Packwood downtown area. The effective FEMA maps show the entire Packwood downtown area inundated to a depth of 3 feet during a 100-year flood event. However, during the extreme flood of 2006 estimated to be nearly a 100-year event, flooding of Packwood by the Cowlitz River was not observed. Hall Creek has been observed to flood the eastern portion of Packwood seasonally, and it is necessary to evaluate how changes in flow splits from the Cowlitz River might affect the floodplain mapping of that creek. Further, in the effective FEMA mapping, tributary creeks Butter, Skate, Willame Creek and the upstream portion of Hall Creek are mapped as Zone A (approximate) studies. In some locations the Zone A delineation excludes significant portions of the active channel and in other locations the effective mapping includes areas on high terraces well above the historical floodplain and obviously not subject to inundation. Discrepancies between the effective FEMA maps and observed flooding have motivated the County to seek updated analyses and floodplain mapping which more accurately reflects expected flood extents in the Packwood downtown core and along the tributary creeks.

MODELING METHODS

To evaluate flood conditions on the Cowlitz River and selected tributary creeks at Packwood, WSE modeled 10-, 4-, 2-, 1- and 0.2-percent annual-chance exceedance floods using HEC-RAS version 6.0 1D and 2D hydraulic models. Model geometries were based on topographic LiDAR data and bathymetric cross section surveys collected in September 2020. The majority of the model was configured as one-dimensional model with surveyed cross sections, while the town of Packwood and Hall Creek were modeled with a 2D computational area. Because 2D areas in HEC-RAS cannot be modeled using steady flows, the model uses “pseudo-steady state” flows, wherein the flow hydrograph gradually increases to the appropriate flow quantile which is then maintained until steady state conditions are achieved throughout the model domain. For the tributaries Butter, Skate, and Willame Creeks, 1D steady-state hydraulic models were used.

HYDROLOGIC ANALYSIS

To determine steady state flow inputs at sites throughout the study area, WSE performed hydrologic analyses for the 10-, 2-, 1- and 0.2-percent annual chance exceedance flood quantiles. Methods used to produce inflows for use in the hydraulic models are described in the next sections.

Mainstem and Muddy Fork Cowlitz River Flood Frequency Analyses

The hydrologic analysis for determining flows on the mainstem and Muddy Fork of the Cowlitz River involved performing a frequency analysis on gaged streamflow data at the USGS gage near the middle of the study reach, and then using regional regression equations to determine flow adjustments upstream and downstream along the study reach.

The frequency analysis used annual peak discharges reported at the USGS Cowlitz River at Packwood (#14226500) gage from water years 1912 to 2020. This gage is located on the right bank just upstream of the Skate Creek Road bridge in Packwood. Nine annual peak discharges are missing from the record for water years 1921 to 1929. Therefore, the record was collapsed to 100 years of data which assumes no knowledge about the floods during the missing period. The software program, HEC-SSP version 2.2, was used to perform flood frequency analysis using the methods of *Guidelines for Determining Flood Flow Frequency Bulletin 17C* (England et al., 2016). Frequency analysis results are reported in Table 1. A full summary of HEC-SSP input and output data is provided in Appendix A.

Table 1. Flow frequency analysis results from Bulletin 17C analysis for USGS Cowlitz at Packwood Gage (#14226500) and their comparison to effective FEMA discharges.

PERCENT CHANCE EXCEEDANCE	RETURN PERIOD	COWLITZ RIVER AT PACKWOOD (CFS)	
		EFFECTIVE FEMA ANALYSIS	CURRENT ANALYSIS
10	10-year	27,300	26,700
4	25-year	-	33,400
2	50-year	39,800	38,500
1	100-year	45,600	43,800
0.2	500-year	60,800	56,800

Table 1 also reports the effective FEMA discharges for the Cowlitz River at Packwood. As shown in Table 1 the discharges estimated for this study are within 10% of the FIS values. The current study provides greater definition of flows through the study reach by including more flow change locations. The current study uses updated frequency analysis techniques and includes additional annual peak data recorded subsequent to the effective study, which only had data through water year 1975.

To define flows at significant tributary locations along the Cowlitz River, regional regression equations were used to adjust frequency analysis results from the Packwood gage to each flow change location. The applicable regional regression equations for the modeled reach of the Cowlitz River are those from Region 4 in the USGS report *Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014* (Mastin et al., 2016). The rearranged form of the Region 4 regression equation is as follows:

$$Q_2 = \left(\frac{A_2}{A_1}\right)^b \left(\frac{10^{c \cdot P_2}}{10^{c \cdot P_1}}\right) Q_1$$

where,

Q_1 = Flow at Packwood Gage

Q_2 = Flow change location

A_1 = Drainage area at Packwood Gage (square miles)

A_2 = Drainage area at flow change location (square miles)

P_1 = Mean annual precipitation at Packwood Gage from PRISM 1981 – 2010 normals (inches)

P_2 = Mean annual precipitation at flow change location from PRISM 1981 – 2010 normals (inches)

b = regional regression coefficient (see Table 6 in Mastin et al., 2016)

c = regional regression coefficient (see Table 6 in Mastin et al., 2016)

The online USGS tool StreamStats (Ries, 2017) was used to calculate input parameters to the regression equations. The basin parameters used in the regression equations are drainage area in square miles and mean annual precipitation in inches, from the PRISM Climate Group (2015), Oregon State University for the 1981–2010 annual precipitation normals.

Drainage areas delineated using StreamStats for the mainstem and Muddy Fork of the Cowlitz River at their confluence were edited to reflect the higher resolution topographic data collected for this project. StreamStats was also not able to compute the mean annual precipitation for the Cowlitz River drainage area to the Hall Creek and Johnson Creek confluences. Therefore, PRISM precipitation data were downloaded and the mean annual precipitation for these locations were determined using GIS methods for input into the regression equations. In all other cases, the StreamStats computed drainage areas and mean annual precipitation values were used directly. Table 2 and Table 3 report discharges at each flow change location in the hydraulic model along the mainstem and Muddy Fork Cowlitz River.

Table 2. Table of discharges reflecting inflow locations to the mainstem and Muddy Fork Cowlitz River.

FLOW CHANGE LOCATION	COWLITZ RIVER AT CONFLUENCE WITH MUDDY FORK	MUDDY FORK AT CONFLUENCE WITH COWLITZ RIVER	DOWN-STREAM OF LAKE CREEK	DOWN-STREAM OF BUTTER CREEK	AT PACKWOOD GAGE	DOWN-STREAM OF SKATE CREEK	DOWN-STREAM OF HALL CREEK
Drainage area (mi ²)	174	54	257	280	282	317	334
PERCENT CHANCE EXCEEDANCE	DISCHARGE (CFS)						
10	16,000	7,300	24,300	26,500	26,700	29,800	31,000
4	20,200	8,800	30,500	33,100	33,400	37,200	38,800
2	23,400	10,000	35,200	38,300	38,500	43,000	44,800
1	26,700	11,200	40,000	43,500	43,800	48,900	51,000

0.2	34,800	14,000	51,900	56,400	56,800	63,400	66,200
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Table 3. Table of discharges reflecting inflow locations to the mainstem and Muddy Fork Cowlitz River (continued).

FLOW CHANGE LOCATION	DOWNSTREAM OF JOHNSON CREEK	DOWNSTREAM OF SMITH CREEK	DOWNSTREAM OF DRY CREEK	DOWNSTREAM OF WILLAME CREEK	DOWNSTREAM LIMIT OF STUDY
Drainage area (mi ²)	382	399	403	425	442
PERCENT CHANCE EXCEEDANCE	DISCHARGE (CFS)				
10	34,800	36,000	36,300	38,200	39,500
4	43,600	45,200	45,600	48,000	49,600
2	50,400	52,200	52,700	55,500	57,400
1	57,400	59,500	60,100	63,200	65,300
0.2	74,700	77,500	78,200	82,300	85,100

Hall Creek Frequency Analyses

Flows for Hall Creek were determined using regional regression equations because no gaging data were available for Hall Creek and no gaged creeks could be found near the basin that were similar to Hall Creek. StreamStats was used to obtain an initial delineation of the Hall Creek basin. The basin delineation was refined using the LiDAR topographic data collected for this project. The basin was also subdivided to more precisely model the inflows to Hall Creek which is represented as a 2D area in the hydraulic model. Mean annual precipitation for each Hall Creek subbasin was computed using GIS methods and the PRISM 1981–2010 normals dataset. Table 4 reports the flows in the Hall Creek basin between Snyder Road and the confluence with the Cowlitz River. Table 5 reports flows for the Hall Creek subbasins delineated upstream (north) of Snyder Road. The flows reported in Table 4 and Table 5 do not reflect overflows from the Cowlitz River which begin to contribute to Hall Creek at some level between a 4 percent and 2 percent chance exceedance event on the Cowlitz River.

Table 4. Table of discharges reflecting inflow locations to Hall Creek basin in 2D hydraulic model.

FLOW CHANGE LOCATION	HALL CREEK AT POWER HOUSE FLUME	HALL CREEK AT NATIONAL FOREST ROAD 48 (NF-48)	HALL CREEK AT HIGHWAY 12	HALL CREEK AT COWLITZ RIVER
Drainage area (mi ²)	3.29	11.53	12.66	13.32

PERCENT CHANCE EXCEEDANCE	DISCHARGE (CFS)			
10	272	895	968	1,010
4	352	1,160	1,250	1,310
2	417	1,370	1,480	1,550
1	486	1,600	1,730	1,810
0.2	650	2,130	2,320	2,420

Table 5. Table of discharges reflecting inflow locations to Hall Creek basin in 2D hydraulic model (continued).

FLOW CHANGE LOCATION	CULVERT 800 FEET WEST OF SNYDER RD AND HWY 12 INTERSECTION	CULVERT 535 FEET NORTH OF SNYDER RD AND HWY 12 INTERSECTION	SNYDER RD AND HWY 12 INTERSECTION	CULVERT 480 FEET EAST OF SNYDER RD AND HWY 12	UPSTREAM OF JONATHAN CREEK	JONATHAN CREEK
Drainage area (mi ²)	0.07	0.02	0.02	0.08	1.21	0.59
PERCENT CHANCE EXCEEDANCE	DISCHARGE (CFS)					
10	7	2	2	8	111	46
4	10	3	3	11	144	60
2	11	4	4	13	169	72
1	13	4	4	15	197	83
0.2	18	6	6	20	261	112

Tributary Flow Frequency Analyses

Gage data are not available for the modeled tributaries to the Cowlitz River: Butter, Skate, and Willame Creeks. The 10-, 4-, 2-, 1- and 0.2-percent annual-chance exceedance flood quantiles for these tributaries were determined using the USGS StreamStats program (Ries, 2017). The downstream boundary used for drainage basin delineation in StreamStats for all tributary creeks was the Cowlitz River. The flows used in the tributary models are shown in Table 6.

Table 6. Flow frequency results from StreamStats for Butter, Skate, and Willame Creeks.

TRIBUTARY	BUTTER CREEK	SKATE CREEK	WILLAME CREEK
Drainage area (mi ²)	19	34	21
PERCENT CHANCE EXCEEDANCE	DISCHARGE (CFS)		
10	1910	2890	1850
4	2380	3660	2350
2	2760	4280	2750
1	3160	4940	3180
0.2	4080	6490	4180

HYDRAULIC MODEL GEOMETRY

Channel and Floodplain Topography

Topographic LiDAR data, aerial imagery, and bathymetric cross section surveys were collected for use in developing the hydraulic model geometries. The aerial photography was collected on June 26, 2020 and LiDAR data were collected on September 29, 2020. A total of 184 bathymetric cross sections were surveyed on the Cowlitz River in September and October 2020. The channel in the study reach has shifted significantly since the effective FEMA study in 1979. During this cross-section survey, some cross sections from the effective FEMA model were reoccupied where the effective cross sections are properly oriented with respect to the current channel. Cross sections were added to improve the modeling between most of the effective cross section where there were long reaches between sections. Cross sections in the hydraulic model are cut from the LiDAR surface with the bathymetric survey data incorporated for the portion of the cross section underwater when the LiDAR was collected. The 2D computation area covering the town of Packwood and Hall Creek used the LiDAR as the model terrain. A 1-foot resolution LiDAR dataset was used for two areas: 1) the portion of the terrain immediately surrounding Hall Creek and 2) a small area on the left bank of the Cowlitz River, just upstream of the Skate Creek Road bridge where an overflow channel begins. All other areas in the terrain used 3-foot resolution LiDAR.

Additional survey was conducted in the town of Packwood and near Hall Creek in May and July 2021 to define culvert and bridge geometry. The survey included 2 cross sections on Hall Creek at Snyder Road, 8 culverts in the Packwood area, and 4 bridges (2 on the Cowlitz River at overflow channel crossings at Skate Creek Road and Highway 12, and 2 on Hall Creek at Snyder Road and Highway 12).

Because the topographic LiDAR data were collected during a period of low flows, it was assumed that differences between the actual channel bathymetry and the topographic LiDAR elevations in the channel were negligible for the purposes of the tributary creek modeling. Therefore, no bathymetric cross section data were used in the development of the hydraulic models for Butter, Skate and Willame Creeks.

Hydraulic Structures

Two bridges on the Cowlitz River and two bridges and one culvert on Hall Creek are included in the HEC-RAS model. Bridge geometry was estimated from aerial and ground photos, LiDAR data and field measurements. On the Cowlitz River, the crossings include the Cora Bridge on U.S. Highway 12 and the Skate Creek Road Bridge. The bridges on the Cowlitz River were modeled using the energy equation approach, as simulated water levels do not reach the low chords of either bridge. The Highway 12 and Snyder Road bridges on Hall Creek were modeled using the energy equation method (for low flows) and the Pressure and/or Weir method (for high flows) to account for pressure flow when water levels reach the bridge low chords. The CMP pipe arch culvert on Hall Creek at Forest Road 48 was modeled using the HEC-RAS culvert routines.

In addition to the Hall Creek bridges and culvert, the 2D portion of the model includes 10 culverts including: 3 on Snyder Road, 1 on Alpine Drive, 1 on Highway 12 (north of Snyder Road), 4 on Bonnie Sue Lane, 1 on Forest Road 48 near Highway 12. Culvert properties, including dimensions and materials, were determined by field observation. Invert elevations were surveyed for all culverts in the immediate vicinity of the town of Packwood. Invert elevations at Bonnie Sue Lane and along Forest Road 48 were estimated from the LiDAR data together with field measurements relative to road elevations.

For the tributary models, there was one bridge crossing on Butter Creek at Cannon Road, one bridge crossing on Skate Creek at Craig Road, and no crossings along Willame Creek. The span between bridge abutments as well as the depth between the road deck and the low chord of the bridge were measured in the field and used together with the LiDAR data to define the bridge openings in the hydraulic models. Bridges were modeled using the energy equation approach as the maximum simulated water surface elevations were well below the bridge low chords for the modeled flood events.

Model Geometry

The HEC-RAS model layout is shown in Figure 1. The model includes 1D cross sections through the entire study reach of the Cowlitz River as well as a branch on the Muddy Fork of the Cowlitz River near the model's upstream end. Left overbank flow from the Muddy Fork was allowed to discharge to the old, pre-avulsion Muddy Fork channel through a flow split via lateral structures. This flow was subsequently transferred directly to the mainstem Cowlitz River cross sections. This overflow channel was mapped based on simulations with a separate 2D model that was not included in the main stem model for simplicity. To accurately model complex flow patterns through the town of Packwood and Hall Creek, a 2D computation area was used in the model covering the area from just upstream of the Skate Creek Road bridge to just downstream of Hall Creek's confluence with the Cowlitz River. The 2D area used a nominal mesh size of 50 feet and breaklines to better define side channels and topographic controls on flow. The mesh around Hall Creek was refined to use cells with a nominal size of 10 feet to 30 feet to better define the channel and complex topography. Flow transfers between the 1D and 2D portions of the model are controlled by lateral structures. Approximate methods were used to map a small area near Wapiti Drive between the mainstem Cowlitz River 1D cross sections and the 2D computation area.

Hydraulic models for Butter, Skate and Willame Creeks are composed of 1D cross sections through the entire study reach of each creek. On Butter Creek, approximate methods were used to map the alluvial fan between where flow breaks out of the main channel and subsequently enters the Cowlitz River.

Floodplain land cover was delineated from the aerial imagery and assigned appropriate Manning's n roughness values. Channel roughness was initially estimated from field photos using engineering judgement and based on channel substrate and bank vegetation. Manning's n values were adjusted during calibration as described in the following section. Table 7 and Table 8 give the Manning's n roughness values used in the Cowlitz River and tributary models.

Table 7. Manning's n roughness values for Cowlitz River and Hall Creek.

LAND COVER TYPE	MANNING'S N
Main Channel & Side Channels	0.035 - 0.085
Vegetated Floodplain	0.045
Non-Vegetated Floodplain	0.04
Lawn, Grass	0.04
Pasture	0.06
Mature Forest	0.1
New-Growth Forest	0.08
Rural Development with Shrubs	0.065
Rural Development with Trees	0.075
Packwood Developed Areas	0.055
Packwood Industrial Areas	0.045
Open Water	0.02
Irrigation Ditch	0.025

Table 8. Manning's n roughness values for tributary creeks.

LAND COVER TYPE	STREAM AND VALLEY GRADIENT	MANNING'S N
Main channel and low-density vegetated areas	Low	0.06
	Moderate	0.09
	High	0.12
Moderate-density vegetated areas	Low	0.08
Forest and high-density vegetated areas	Low	0.09
	Moderate and High	0.20

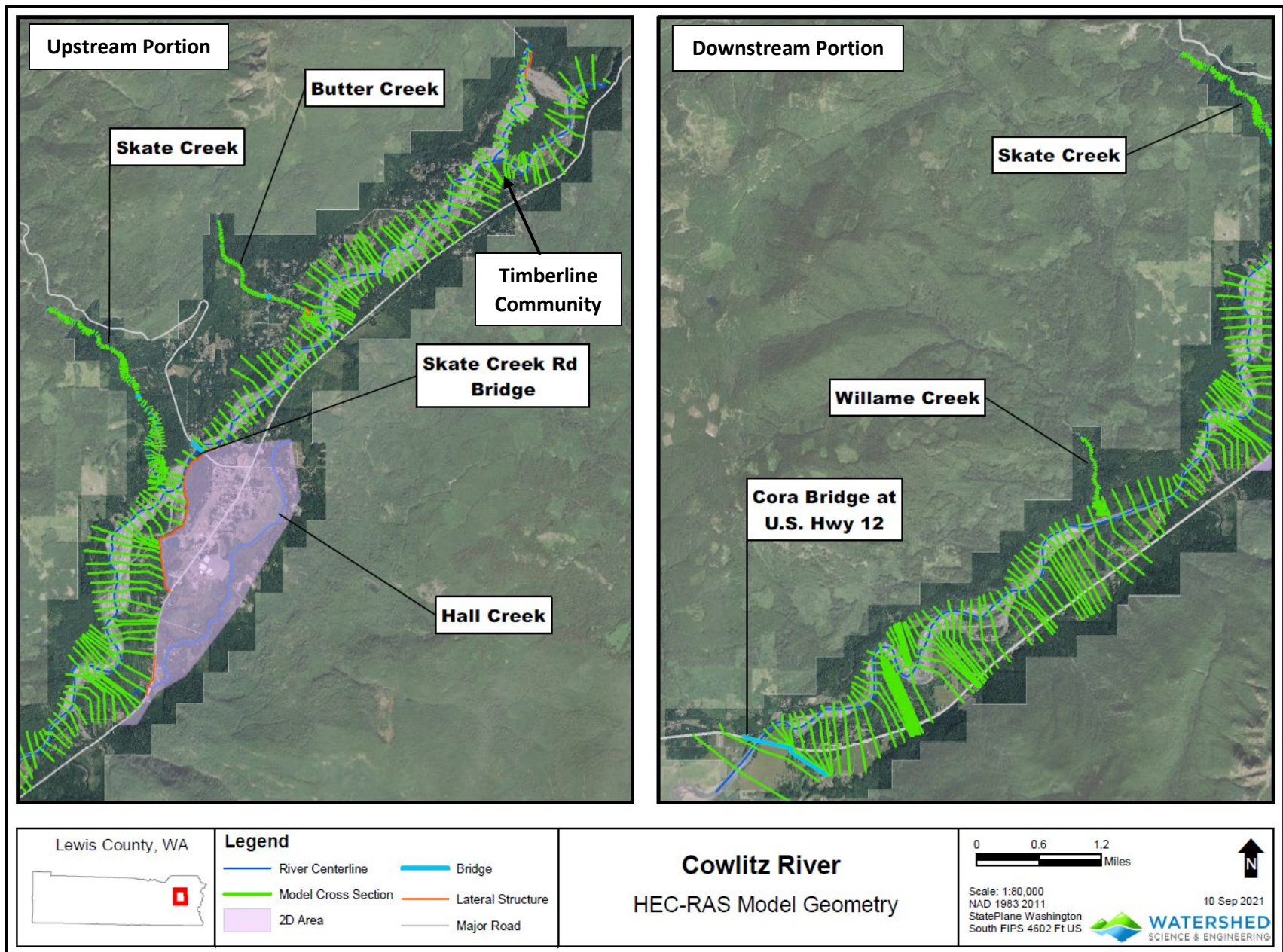


Figure 1. HEC-RAS model geometry for the Cowlitz River and Hall Creek model.

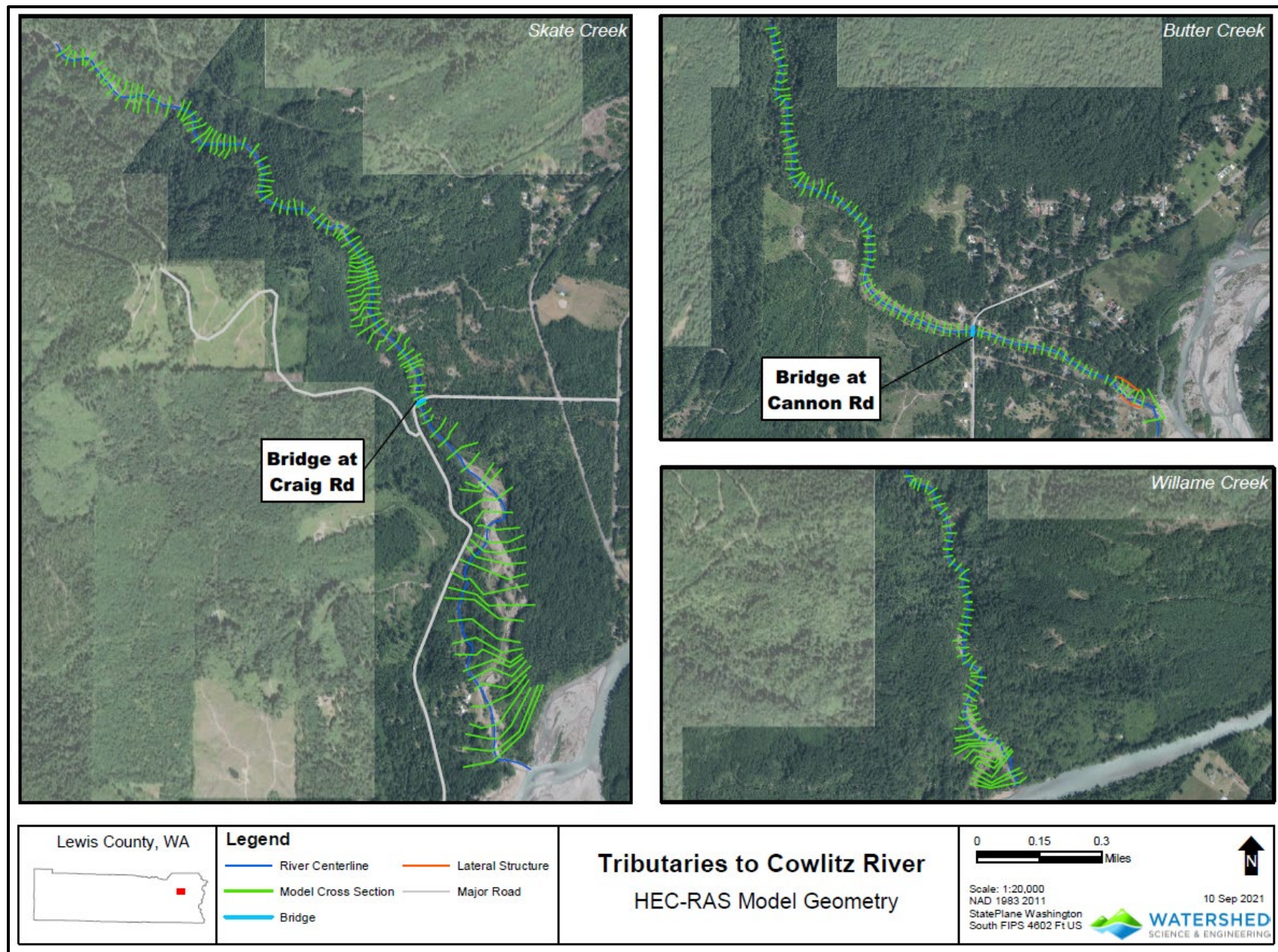


Figure 2. HEC-RAS model geometry for Butter, Skate and Willame Creeks.

MODEL CALIBRATION AND VALIDATION

The Cowlitz River is very dynamic and the channel likely reconfigures itself during every major flood. In one extreme case, the Muddy Fork of the Cowlitz River avulsed to its current location during a large flood event in November 2006. The dynamic nature of the Cowlitz River channel makes calibration datasets applicable for only a limited period of time. Therefore, calibration data from the most recent flood events were the primary focus of calibration efforts.

A peak flow of 28,900 cfs was recorded at the Packwood gage during the December 9, 2015 event which is estimated to be between a 10- and 25-year event. After the December 2015 flood, Lewis County set and surveyed 20 high water marks (HWMs) between the Cora Bridge and the upstream end of the study reach. These HWMs were used to calibrate the hydraulic model of the mainstem and Muddy Fork of the Cowlitz River.

To achieve calibration, flows were input to the hydraulic model to simulate the December 2015 event. At the Packwood gage flows were gradually ramped up to the event peak flow of 28,900 cfs and held at that level. Flows upstream and downstream of the gage were scaled using the same method as described in the hydrology section. Regional regression equations for the 10-year event were used in the scaling of December 2015 flows throughout the study reach.

Model calibration was achieved by adjusting Manning's n roughness values to minimize differences between simulated water surface elevations and HWM elevations. Manning's n values were initially set using aerial imagery collected in June 2020 and engineering judgement on relative Manning's n values of the various landcovers observed. Adjustments to Manning's n values based on the December 2015 HWM were limited to reasonable ranges. Throughout the entire reach, in-channel Manning's n values needed to be increased to achieve good model calibration. In the lower portion of the model up to approximately 2 miles upstream from the Skate Creek Road Bridge, channel Manning's n values were increased to 0.045. Upstream from this location channel Manning's n values were gradually increased up to 0.085 near the Timberline community (Figure 1).

The calibration effort tried to match all HWMs to within 1 foot or better, with the exception of a few HWMs which were determined to be erroneous and excluded. Particular attention was given to two HWMs, one on the left bank just upstream of the Skate Creek Road bridge and a second just upstream of the Timberline community. Upstream of Skate Creek Road Bridge, mainstem flows overtop the left overbank between a 10- and 50-year event. These overflows head toward the town of Packwood and enter the Hall Creek floodplain. Because of the impact of these overflows, special care was taken to calibrate the model well to this HWM. The second HWM is located on the left bank of the mainstem Cowlitz River, just upstream of the Timberline community. Channel Manning's n values near the Timberline HWM were adjusted while taking extra care to achieve good calibration at that point in particular. Model calibration was less successful in 1D portions of the model where HWMs were set in side channel areas where flows are suspected to differ significantly from the mainstem. Figure 3 compares the simulated December 2015 water surface profile to the observed HWMs. Table 9 provides the comparison of simulated December 2015 water surface elevation to the observed HWMs in tabular form.

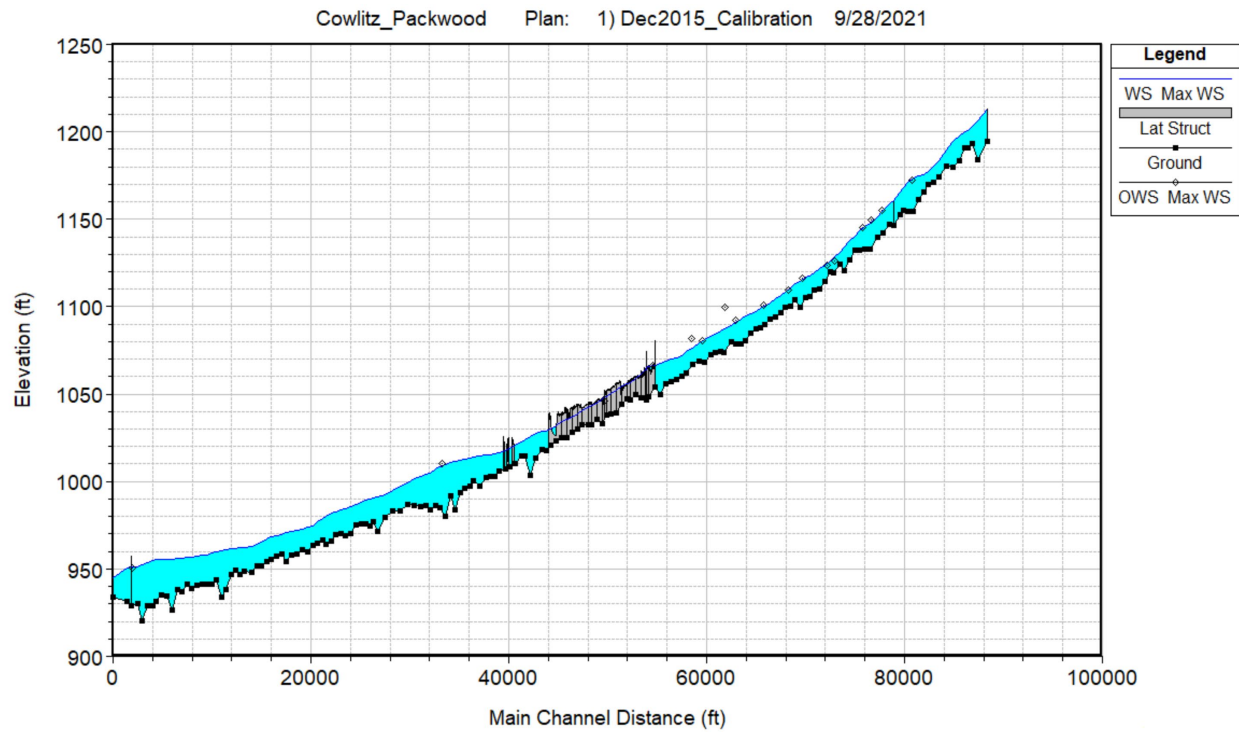


Figure 3. December 2015 simulated water surface profile compared to observed high water marks.

Table 9. Model calibration to high water marks for December 2015 event.

LOCATION	OBSERVED HWM ELEVATION (FEET, NAVD)	MODELED WATER SURFACE ELEVATION (FEET, NAVD)	DIFFERENCE (MODEL – OBSERVED), FEET
Upstream of Timberline Community, end of Coal Creek Drive	1172.52	1172.48	-0.04
169 Mountain View Drive	1145.34	1144.70	-0.64
Upstream of Lake Creek Road, left bank	1123.42	1124.50	1.08
163 Tatoosh View Drive	1116.31	1115.56	-0.75
End of River Dance Lane	1109.49	1108.90	-0.59
Intersection of River Side Drive and Crescent Beach Drive	1100.74	1099.73	-1.01
Across from mouth of Butter Creek, left bank	1092.04	1091.31	-0.73
Intersection of Rainbow Lane and Elk Horn Drive	1080.35	1080.40	0.05
Upstream of Skate Creek Road bridge, left bank	1066.2	1066.17	-0.03
Downstream of Skate Creek Road bridge, left bank in overflow channel	1064.01	1063.65	-0.36
North of Stover Road	967.34	967.21	-0.13
Upstream of Cora Bridge, 11377 Highway 12	950.80	951.22	0.42

The 100-year mainstem hydraulic model results were validated using limited HWM data from the November 2006 event. The Packwood gage recorded a peak flow of 42,100 cfs during this event which is slightly less than a 100-year event. Lewis County mapped an estimated November 2006 floodplain using the limited HWM data and provided the mapping to WSE. This mapping was useful in validating the simulated 100-year floodplain particularly near the Highway 12 bridge. The model simulated overtopping of Highway 12 east of the Cora bridge, and this overtopping was similarly represented in the November 2006 mapping. Furthermore, the model predicted a maximum of 3.5 feet of highway overtopping during the 100-year event, which was validated through WSDOT maintenance records which indicated the highway was overtopped by 2-3 feet during the November 2006 event (Bob Kofstad, personal communication). Lewis County staff also recalled Highway 12 overtopping near Bevin Lake Road and the intersection of Highway 12 and Hall Creek, both of which are simulated in the 100-year hydraulic modeling (Matt Hyatt, personal communication).

Model simulated overflows from the mainstem toward the town of Packwood and Hall Creek could not be validated because there are no available high water marks for the overflow reach. Discussions with residents of the town of Packwood could not recall significant flooding in town from the Cowlitz River, even during the November 2006 flood which approached a 100-year flood.

High water marks were also not available to calibrate the 2D Hall Creek area of the model. However, results observed in this portion of the model were validated through discussions with and photos provided by landowners which showed significant flooding of Hall Creek near Snyder Road. This flooding was reported to occur regularly.

No high water marks were available to calibrate the tributary models for Butter, Skate and Willame Creeks. Special consideration was taken when assigning Manning's n values in the relatively steep gradient tributary creeks. The Manning's n values were assumed to increase with increased channel bed and valley slopes. Secondary to observations and engineering judgment, the Froude number was used as a rough calibration parameter for selecting Manning's n values for these creeks. It is expected that supercritical flows cannot be sustained over long streamwise distances (Trieste, 1987). Manning's n values were adjusted to generally maintain Froude numbers throughout the model below 1.0, with a few localized exceptions.

FLOOD EVENT MODELING

Following model calibration, the HEC-RAS models were used to simulate the 10-, 4-, 2-, 1- and 0.2-percent annual-chance exceedance flood events on the Cowlitz River and tributary creeks. The 2D portions of the Cowlitz River model cannot be run using the steady flow option, so a "pseudo-steady state" flow approach was used instead. Pseudo-steady state flow input hydrographs gradually increase up to the desired flow level, and are then held constant until steady state conditions are attained throughout the model. For all runs the downstream model boundary condition on the Cowlitz River was set to normal depth and the friction slope adjusted to achieve the effective FEMA study water surface elevations for each simulated flow event at that location. This approach ensured that modeled water surface elevations from this study tie seamlessly into the effective FEMA study. The 4-percent annual-chance exceedance event was not included in the effective FEMA study, so the water surface elevation was interpolated between the 10- and 2-percent annual-chance exceedance events using flow at the boundary for those events.

In the tributary creek models, the upstream and downstream model boundary conditions were set to normal depth with friction slopes based on localized channel or floodplain slopes. Normal depth boundary conditions were chosen on the tributary creeks because the water surface elevations in the Cowlitz River were lower than the corresponding water surface elevations of the tributary creeks at their confluences for the modeled flood events, i.e., there are no backwater effects from the Cowlitz River.

MODEL RESULTS

The inundation extents for the 1- and 0.2-percent annual-chance exceedance flood events and base flood elevations (BFEs) for the 1-percent annual-chance exceedance flood event were derived from the results of the hydraulic modeling. WSE used these results to create flood inundation work maps for the

study reaches on the Cowlitz River and its tributaries in and through the town of Packwood (Appendix A).

INUNDATION MAPPING

Inundation extents for the 1- and 0.2-percent annual-chance exceedance floods were produced in shapefile format using HEC-RAS's automated inundation boundary function, which overlays the modeled water surface on the model terrain. The inundation boundaries between cross sections in the 1D portion of the model were computed across an interpolation surface bounded by the user-defined edge lines in HEC-RAS. The inundation boundaries were then manually edited to remove isolated, disconnected floodplain areas, unrealistic backwater conditions, and to fill small dry islands within the floodplain. Hydraulic connectivity was verified in the detailed HEC-RAS outputs for any isolated flood inundation areas that were retained and manually connected in the final mapping.

Detailed floodplain mapping for this study on the Cowlitz River begins at the model's downstream end, 0.35 miles downstream of the U.S. Highway 12 (Cora) bridge. The water surface elevation at the downstream boundary in this current study was forced to match the effective FEMA study through adjustment of the downstream boundary friction slope, as discussed above. Therefore, there is no difference in water surface elevation between the current study and the effective downstream mapping. Minor differences in the inundation extent mapping at the boundary, due to the higher resolution topography used in the current study, were smoothed out.

On Butter Creek, the flood extents outside the main channel near the mouth of the creek consist of shallow flooding across the Butter Creek alluvial fan, as it transitions to the Cowlitz River floodplain. These areas were mapped as Zone AO1 based on approximate analyses conducted using a separate HEC-RAS 2D model.

FLOODWAY DELINEATION

The HEC-RAS model was used to delineate the regulatory floodway for the Cowlitz River and Hall Creek following applicable FEMA Guidelines. For the floodway analyses, the baseline 1-percent annual-chance exceedance models were modified to include floodplain encroachments that maintained a flow corridor that could pass the base flood event without exceeding a 1.0-foot surcharge at any location. For the Cowlitz River, the surcharge was initially evaluated using encroachments corresponding to the effective FEMA floodway. Floodway encroachments were then adjusted to reflect changes in the river alignment and widened as necessary to reduce surcharges to the allowable limit. The Cowlitz River floodway was modeled using blocked obstructions. Floodway widths were extracted from the model at each cross section. Between cross sections, the floodway boundary was delineated to reflect topographic conditions and anticipated flow paths in the floodplain.

For the Hall Creek floodway analysis, a separate baseline 1-percent annual-chance exceedance flow model was developed, eliminating the Cowlitz River overflow into Packwood, to evaluate the effects of the baseline flood and associated floodway solely due to flooding caused by Hall Creek. Along Hall Creek, the effective FEMA floodway did not align with the current creek channel in several locations. The floodway was therefore re-delineated in areas where the effective floodway did not include the channel. Since Hall Creek was modeled as a 2D flow area, the floodway was modeled using artificially elevated

terrain to define the floodway encroachments. The re-delineated floodway required substantial widening beyond the effective FEMA floodway in some locations to pass the 1-percent annual-chance exceedance event without exceeding a 1.0-foot surcharge. This is likely the result of refined hydraulic modeling methods used in this study. The final floodway delineations for the Cowlitz River and Hall Creek are shown on the work maps in Appendix B. The base floodway elevations without the floodway, with the floodway and the increase due to the floodway are provided in tables in Appendix D.

CONCLUSION

Detailed hydraulic modeling and analysis was completed for the Cowlitz River from 0.35 miles downstream of the Highway 12 Cora bridge over the Cowlitz River at the downstream end, to approximately 1.8 miles upstream of the confluence of the Muddy Fork and the mainstem of the Cowlitz River at the upstream end. Detailed modeling and analyses were also undertaken for 3.8 miles of Hall Creek, 2.4 miles of Skate Creek, 1.6 miles of Butter Creek, and 0.9 miles of Willame Creek. Hydrologic inputs for these studies were determined using available gage data and regional regression equations. A combined 1D/2D HEC-RAS model was created for the Cowlitz River and Hall Creek using LiDAR topographic data, bathymetric survey, and aerial imagery collected in 2020. The model was calibrated to high water marks from a recent high flow event and then used to simulate the 10-, 4-, 2-, 1- and 0.2-percent annual-chance exceedance floods. For the tributaries Butter, Skate, and Willame Creeks, 1D HEC-RAS models were created based on LiDAR topographic data and aerial imagery collected in 2020.

Inundation extents were mapped for the 1- and 0.2-percent annual-chance exceedance events and BFEs were mapped for the 1-percent annual-chance exceedance event for the Cowlitz River and the mapped tributaries. Regulatory floodways were also delineated for the Cowlitz River and Hall Creek. The floodways, inundation extents, BFEs, and base map features were compiled in a set of work maps.

The floodplain mapping study described in this report and presented on the accompanying work maps includes updated hydrology, recent and more accurate topographic data and channel surveys, and refined hydraulic modeling methods compared to the effective flood insurance studies. As such, this update provides the County with more accurate and up-to-date information about flood hazards on the Cowlitz River, and Hall Creek, Butter Creek, Skate Creek, and Willame Creek in and near the town of Packwood.

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APPENDIX A: FLOOD FREQUENCY ANALYSIS RESULTS

APPENDIX B: WORK MAPS

APPENDIX C: WATER SURFACE ELEVATION PROFILES

APPENDIX D: FLOODWAY DATA TABLES

Table D1. Floodway Data – Cowlitz River

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
AR	115.5	1238.4	8039.2	10.2	947.71	947.71	948.54	0.83
AS	115.77	999.8	8157.2	9.9	951.57	951.57	952.46	0.89
AT	115.84	553.1	7347.6	9.6	952.15	952.15	953.11	0.97
AU	115.86	556.3	7499.8	9.0	952.78	952.78	953.62	0.85
AV	115.96	395.3	5502.4	12.9	952.97	952.97	953.77	0.80
AW	116.05	263.3	4919.5	13.5	954.55	954.55	955.00	0.45
AX	116.15	338.3	7032.0	9.4	957.02	957.02	957.51	0.48
AY	116.25	638.7	11374.0	5.8	958.26	958.26	958.86	0.60
AZ	116.33	1126.4	20179.5	3.3	958.77	958.77	959.35	0.58
BA	116.43	1042.2	16061.1	4.3	958.87	958.87	959.41	0.53
BB	116.52	1087.9	14859.4	5.4	959.01	959.01	959.56	0.55
BC	116.62	1270.6	17354.9	4.6	959.20	959.20	959.89	0.69
BD	116.72	1212.7	14717.8	5.5	959.37	959.37	960.06	0.69
BE	116.82	1285.1	16368.3	5.3	959.67	959.67	960.43	0.76
BF	116.92	1574.3	18465.9	5.2	959.98	959.98	960.81	0.84
BG	117.01	1820.2	19358.4	5.2	960.24	960.24	961.11	0.87
BH	117.1	2385.7	22457.3	4.7	960.59	960.59	961.49	0.90
BI	117.2	2735.0	22146.4	4.9	960.86	960.86	961.74	0.88
BJ	117.28	2994.2	20292.7	5.9	961.11	961.11	961.97	0.85
BK	117.38	3306.7	19551.5	6.2	961.55	961.55	962.36	0.81
BL	117.48	3327.2	17488.5	7.4	961.98	961.98	962.73	0.75
BM	117.57	3417.7	17587.9	8.4	962.56	962.56	963.28	0.72
BN	117.66	3539.9	20869.9	6.3	963.08	963.08	963.85	0.77
BO	117.76	4129.9	22499.6	5.7	963.52	963.52	964.34	0.82
BP	117.85	4580.6	24597.4	5.2	963.83	963.83	964.70	0.87

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
BQ	117.93	4552.9	22578.8	5.9	964.01	964.01	964.91	0.90
BR	118.01	4264.4	22540.9	5.4	964.23	964.23	965.17	0.94
BS	118.15	3716.2	19894.1	5.1	964.78	964.78	965.75	0.97
BT	118.25	3330.1	16826.5	7.2	965.67	965.67	966.49	0.82
BU	118.34	2930.5	13230.7	9.3	966.90	966.90	967.41	0.51
BV	118.44	2774.5	13679.4	7.6	968.61	968.61	968.82	0.21
BW	118.53	2570.6	11557.9	8.4	969.60	969.60	969.83	0.24
BX	118.63	2506.4	13081.2	7.1	970.61	970.61	971.20	0.59
BY	118.72	2481.8	13667.6	7.2	971.37	971.37	972.09	0.73
BZ	118.82	2606.6	15742.9	6.3	972.23	972.23	973.02	0.79
CA	118.92	2524.5	16622.6	6.1	973.00	973.00	973.72	0.72
CB	119.02	2404.5	13668.6	7.2	973.66	973.66	974.31	0.65
CC	119.11	2349.7	14701.6	6.3	974.46	974.46	975.14	0.68
CD	119.21	2324.8	14207.4	6.1	975.20	975.20	975.85	0.65
CE	119.32	2249.5	12370.0	6.9	976.24	976.24	976.72	0.48
CF	119.42	2069.3	10042.0	8.6	978.41	978.41	978.63	0.22
CG	119.5	1616.4	8540.9	9.7	979.95	979.95	980.22	0.27
CH	119.57	1151.5	6680.3	12.4	981.38	981.38	981.46	0.08
CI	119.68	1815.1	14096.1	5.6	984.14	984.14	984.35	0.21
CJ	119.77	1762.4	13142.4	5.8	984.67	984.67	984.88	0.21
CK	119.85	1652.7	12155.9	6.4	985.41	985.41	985.58	0.17
CL	119.94	1622.7	11158.9	7.3	986.30	986.30	986.45	0.14
CM	120.05	1966.2	10316.6	9.1	987.65	987.65	987.77	0.12
CN	120.15	2211.2	11753.5	8.5	988.79	988.79	989.26	0.48
CO	120.24	2253.4	12673.0	7.4	989.58	989.58	990.31	0.74

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
CP	120.33	2440.0	14462.2	6.3	990.68	990.68	991.30	0.63
CQ	120.42	2478.9	15297.7	6.2	991.33	991.33	992.01	0.68
CR	120.49	2490.1	12743.7	7.6	991.89	991.89	992.47	0.58
CS	120.57	2596.8	12394.7	7.2	992.77	992.77	993.37	0.60
CT	120.7	2360.9	11474.3	8.6	994.06	994.06	994.77	0.70
CU	120.84	2015.6	10409.7	11.0	996.43	996.43	997.05	0.62
CV	121	1669.2	9878.8	10.3	999.10	999.10	1000.01	0.92
CW	121.14	1141.1	7554.7	11.0	1001.26	1001.26	1002.01	0.75
CX	121.27	793.4	6408.5	11.0	1003.43	1003.43	1004.09	0.66
CY	121.39	538.1	5313.0	12.3	1005.00	1005.00	1005.78	0.78
CZ	121.48	497.5	6288.8	11.2	1007.03	1007.03	1007.88	0.85
DA	121.57	600.0	5474.2	14.1	1007.61	1007.61	1008.55	0.94
DB	121.67	677.7	6736.3	10.8	1010.43	1010.43	1010.99	0.56
DC	121.76	377.7	5296.9	11.8	1011.56	1011.56	1011.93	0.38
DD	121.86	228.2	4843.8	12.1	1012.78	1012.78	1013.06	0.27
DE	121.96	325.2	6157.2	9.5	1014.67	1014.67	1014.94	0.27
DF	122.04	473.9	7740.9	7.7	1015.45	1015.45	1016.01	0.56
DG	122.14	764.6	9566.8	6.5	1016.33	1016.33	1016.83	0.50
DH	122.23	986.4	12054.9	4.9	1017.09	1017.09	1017.56	0.47
DI	122.33	1722.0	16733.8	4.4	1017.55	1017.55	1017.99	0.44
DJ	122.4	2103.7	16508.4	5.0	1017.78	1017.78	1018.19	0.41
DK	122.52	2731.0	20741.0	3.7	1018.19	1018.19	1018.55	0.35
DL	122.63	3056.7	22628.6	3.4	1018.44	1018.44	1018.76	0.32
DM	122.72	3728.1	24143.2	3.3	1018.65	1018.65	1018.95	0.30
DN	122.81	3877.1	21723.7	4.3	1018.82	1018.82	1019.10	0.28

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
DO	122.88	3740.2	19835.2	4.2	1019.04	1019.04	1019.29	0.25
DP	123.01	2974.8	15338.5	5.0	1019.64	1019.64	1019.87	0.23
DQ	123.1	2647.0	12686.5	6.0	1020.55	1020.55	1020.81	0.26
DR	123.2	2104.0	11072.3	6.3	1022.15	1022.15	1022.28	0.13
DS	123.32	1994.8	9862.7	8.0	1023.79	1023.79	1024.00	0.21
DT	123.39	1355.0	6897.5	9.5	1024.89	1024.89	1025.10	0.21
DU	123.48	1067.8	5413.4	12.2	1026.83	1026.83	1027.15	0.32
DV	123.58	1336.3	9195.0	8.1	1029.23	1029.23	1029.89	0.66
DW	123.71	1675.6	12915.0	3.9	1030.17	1030.17	1030.89	0.72
DX	123.79	1801.7	12075.6	4.1	1030.58	1030.58	1031.28	0.70
DY	123.88	1822.9	10149.3	5.6	1031.57	1031.57	1032.05	0.48
DZ	123.98	1764.5	8543.3	7.1	1033.35	1033.35	1033.57	0.22
EA	124.08	1855.8	9519.7	6.6	1035.52	1035.52	1035.67	0.15
EB	124.18	2119.4	11634.1	5.0	1036.85	1036.85	1037.07	0.21
EC	124.28	2336.2	12352.2	4.2	1037.99	1037.99	1038.23	0.24
ED	124.39	2142.3	8077.9	6.6	1039.43	1039.43	1039.89	0.46
EE	124.47	1946.4	7799.1	6.6	1041.18	1041.18	1041.94	0.77
EF	124.59	1597.9	8951.9	5.6	1043.28	1043.28	1044.19	0.91
EG	124.67	1528.6	8935.1	5.6	1044.47	1044.47	1045.09	0.62
EH	124.76	1600.8	8126.7	6.0	1046.04	1046.04	1046.49	0.45
EI	124.86	1746.0	8772.6	5.6	1048.32	1048.32	1048.64	0.32
EJ	124.95	2009.2	9230.9	5.3	1050.02	1050.02	1050.28	0.26
EK	125.03	1831.5	7726.0	6.4	1051.48	1051.48	1051.67	0.18
EL	125.13	1549.5	7356.9	6.8	1053.54	1053.54	1053.79	0.25
EM	125.24	1154.3	7339.1	6.1	1055.67	1055.67	1055.89	0.22

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
EN	125.33	946.5	6112.7	8.4	1056.86	1056.86	1057.12	0.26
EO	125.39	866.4	5264.9	10.2	1057.75	1057.75	1058.12	0.37
EP	125.5	417.7	3524.0	12.5	1060.42	1060.42	1060.79	0.37
EQ	125.6	360.5	3725.1	12.6	1063.26	1063.26	1064.00	0.74
ER	125.7	391.0	3631.1	13.2	1065.70	1065.70	1066.40	0.69
ES	125.71	440.2	5006.3	9.3	1067.90	1067.90	1068.87	0.98
ET	125.75	439.7	6109.7	7.3	1068.74	1068.74	1069.68	0.94
EU	125.87	570.7	7137.8	6.3	1069.65	1069.65	1070.65	1.00
EV	125.98	782.1	7193.6	7.3	1070.33	1070.33	1071.32	0.99
EW	126.07	822.8	7677.2	6.4	1071.35	1071.35	1072.28	0.93
EX	126.18	875.3	7914.2	6.3	1072.21	1072.21	1073.11	0.90
EY	126.29	1177.2	10028.2	4.6	1073.08	1073.08	1073.96	0.89
EZ	126.38	1272.1	7388.2	6.5	1073.85	1073.85	1074.51	0.67
FA	126.47	970.5	5660.2	7.8	1075.66	1075.66	1075.89	0.23
FB	126.58	912.1	5349.6	9.0	1078.03	1078.03	1078.16	0.13
FC	126.71	991.3	5923.8	8.1	1081.07	1081.07	1081.20	0.14
FD	126.81	1084.1	6656.8	6.9	1082.70	1082.70	1083.03	0.33
FE	126.94	1091.1	7104.8	6.7	1084.42	1084.42	1084.97	0.55
FF	127.03	810.4	5355.7	9.2	1085.53	1085.53	1086.13	0.60
FG	127.13	705.4	5614.9	8.0	1087.53	1087.53	1088.20	0.67
FH	127.2	596.7	4942.7	8.8	1088.72	1088.72	1089.24	0.52
FI	127.33	1617.0	7584.1	7.8	1091.13	1091.13	1091.94	0.82
FJ	127.42	1439.0	6792.7	7.6	1092.80	1092.80	1093.04	0.24
FK	127.51	1559.0	6396.0	8.6	1094.30	1094.30	1094.38	0.09
FL	127.61	1530.3	7093.0	7.8	1095.94	1095.94	1095.96	0.01

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source		Floodway		1% Annual-Chance Water Surface Elevation				
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
FM	127.71	1612.8	8250.0	5.9	1097.38	1097.38	1097.40	0.02
FN	127.8	1286.1	6200.2	7.3	1098.52	1098.52	1098.58	0.07
FO	127.89	1443.1	7587.0	6.0	1100.33	1100.33	1100.46	0.13
FP	127.98	1359.0	6960.3	6.4	1101.52	1101.52	1101.72	0.20
FQ	128.08	1252.6	5837.7	7.4	1103.24	1103.24	1103.49	0.25
FR	128.17	1236.6	6997.6	6.1	1105.68	1105.68	1106.12	0.44
FS	128.27	1266.2	8819.6	4.7	1107.80	1107.80	1108.19	0.39
FT	128.37	1501.5	8218.6	5.3	1109.38	1109.38	1109.71	0.33
FU	128.46	1169.5	5958.3	7.6	1111.66	1111.66	1111.95	0.29
FV	128.55	1055.9	6886.2	7.5	1114.09	1114.09	1114.57	0.48
FW	128.65	1181.1	7645.3	7.7	1116.09	1116.09	1116.61	0.52
FX	128.75	1775.7	11529.9	3.9	1118.10	1118.10	1118.49	0.39
FY	128.83	1795.4	10248.1	4.3	1118.81	1118.81	1119.24	0.43
FZ	128.93	1573.8	8040.7	5.1	1120.35	1120.35	1120.91	0.55
GA	129.03	1313.2	6484.4	6.1	1122.87	1122.87	1123.52	0.65
GB	129.12	1375.1	7731.2	5.1	1124.84	1124.84	1125.77	0.93
GC	129.23	1712.1	8097.3	5.4	1127.23	1127.23	1127.86	0.63
GD	129.3	1645.8	6930.3	6.9	1129.29	1129.29	1129.64	0.34
GE	129.41	1311.3	6306.5	7.8	1132.25	1132.25	1132.95	0.69
GF	129.5	1133.0	5563.4	9.5	1135.22	1135.22	1136.04	0.82
GG	129.59	1024.5	6183.6	7.3	1139.22	1139.22	1139.24	0.02
GH	129.69	1075.9	6533.4	6.6	1141.49	1141.49	1141.94	0.45
GI	129.79	1176.2	6827.6	6.6	1144.68	1144.68	1144.86	0.19
GJ	129.89	1606.9	9034.3	6.5	1147.33	1147.33	1147.39	0.06
GK	129.99	1591.0	8432.1	5.9	1149.22	1149.22	1149.31	0.08

Table D1. Floodway Data – Cowlitz River (continued)

Flooding Source			Floodway		1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
GL	130.14	1394.0	7278.8	6.8	1152.94	1152.94	1153.01	0.07
GM	130.24	1215.7	7174.2	6.2	1156.33	1156.33	1156.40	0.07
GN	130.36	1450.1	8725.7	5.8	1160.44	1160.44	1160.44	0.00
GO	130.44	1578.9	9125.9	5.8	1162.06	1162.06	1162.17	0.12
GP	130.59	864.8	3913.6	8.1	1166.89	1166.89	1167.52	0.63
GQ	130.65	671.5	4258.7	8.3	1169.78	1169.78	1170.24	0.46
GR	130.73	593.4	4934.3	7.1	1172.90	1172.90	1173.48	0.58
GS	130.84	720.4	6445.8	5.1	1175.44	1175.44	1175.97	0.53
GT	130.93	965.3	8646.9	4.0	1176.76	1176.76	1177.26	0.50
GU	131.03	1167.5	8837.8	3.8	1177.57	1177.57	1178.14	0.56
GV	131.12	1184.9	7552.4	4.7	1178.80	1178.80	1179.56	0.76
GW	131.22	1446.4	7929.3	5.0	1181.40	1181.40	1182.27	0.87
GX	131.31	1047.4	5700.2	6.6	1184.99	1184.99	1185.31	0.32
GY	131.46	608.8	4647.6	6.6	1191.49	1191.49	1191.71	0.22
GZ	131.59	602.1	5228.5	6.1	1195.91	1195.91	1196.74	0.83
HA	131.71	777.9	6038.4	5.4	1199.24	1199.24	1199.91	0.67
HB	131.81	825.7	6553.5	4.1	1201.85	1201.85	1202.21	0.36
HC	131.87	771.7	5850.4	4.7	1202.86	1202.86	1203.23	0.37
HD	131.96	593.9	5074.5	5.8	1205.19	1205.19	1205.42	0.23
HE	132.07	190.1	2546.2	10.6	1208.77	1208.77	1208.85	0.09
HF	132.24	172.6	3222.9	8.4	1216.93	1216.93	1216.95	0.02

Table D2. Floodway Data – Muddy Fork of the Cowlitz River

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section	Distance	Top Width	Section Area	Velocity	Regulatory	Without Floodway	With Floodway	Increase
	(Miles Above Mouth) ¹	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
A	0.18	709.4	1868.2	6.0	1169.76	1169.76	1169.81	0.05
B	0.26	497.7	1621.5	5.9	1174.51	1174.51	1174.96	0.45
C	0.36	491.5	1853.9	5.2	1180.26	1180.26	1181.04	0.78
D	0.45	464.4	1457.1	7.2	1185.64	1185.64	1185.76	0.12
E	0.52	757.9	2033.0	5.1	1190.49	1190.49	1190.51	0.02
F	0.66	895.1	2264.4	4.1	1195.78	1195.78	1195.89	0.11
G	0.75	737.3	1687.2	6.5	1203.18	1203.18	1203.42	0.24
H	0.88	222.5	1261.9	7.3	1213.18	1213.18	1213.27	0.09
I	0.94	343.2	1305.0	7.3	1217.42	1217.42	1217.59	0.16
J	1.04	247.5	1402.0	6.2	1223.42	1223.42	1223.42	0.00
K	1.15	204.1	1329.6	8.2	1230.14	1230.14	1230.39	0.26
L	1.22	261.1	1909.4	6.2	1235.31	1235.31	1235.57	0.26
M	1.32	162.4	1218.5	9.2	1241.54	1241.54	1241.83	0.29

1. Stream distance in miles above confluence with Cowlitz River

Table D3. Floodway Data – Hall Creek

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section ⁴	Distance ¹	Top Width	Section Area	Mean Velocity ³	Regulatory	Without Floodway ^{2,3}	With Floodway ^{2,3}	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
A	0.21	143.7	940.2	2.0	1020.22	1020.22	1020.63	0.41
B	0.23	150.4	1100.1	1.5	1021.89	1021.66	1022.47	0.81
C	0.34	182.6	1397.9	1.2	1022.07	1021.77	1022.71	0.94
D	0.50	699.8	2800.7	0.7	1022.37	1022.00	1022.91	0.91
E	0.69	321.5	1220.3	1.3	1023.25	1022.99	1023.95	0.96
F	0.85	326.6	1377.6	1.3	1024.46	1024.01	1024.91	0.90
G	0.91	134.2	602.7	2.7	1025.43	1025.00	1025.91	0.91
H	0.98	342.1	1072.9	1.5	1026.44	1026.00	1026.89	0.89
I	1.09	621.6	1295.7	1.1	1027.53	1027.01	1027.82	0.81
J	1.18	534.9	1204.3	1.0	1028.55	1028.00	1028.35	0.35
K	1.25	540.6	867.5	1.4	1029.38	1029.01	1029.16	0.15
L	1.27	287.4	299.5	1.6	1032.33	1031.99	1032.30	0.31
M	1.28	246.6	291.5	1.8	1033.42	1033.01	1033.50	0.49
N	1.46	439.8	1365.7	1.0	1034.45	1034.00	1034.50	0.50
O	1.56	193.7	633.6	1.9	1035.42	1035.01	1035.62	0.61
P	1.65	200.8	627.4	2.0	1036.41	1036.02	1036.68	0.66
Q	1.71	157.9	616.3	2.1	1037.45	1037.02	1037.69	0.67
R	1.77	123.5	637.0	2.3	1038.41	1038.01	1038.73	0.72
S	1.86	231.8	748.6	2.0	1039.43	1039.01	1039.81	0.80
T	1.91	189.6	709.0	1.9	1040.45	1040.01	1040.70	0.69
U	1.95	85.2	340.5	3.1	1041.53	1041.03	1041.74	0.71

1. Stream distance in miles above confluence with Cowlitz River
2. Computed without overflow influence from Cowlitz River at Packwood
3. Values reported are based on averages computed across evaluation lines. Refer to model result grids for modeled variability in elevation and surcharge across the Floodway.
4. Floodway computed by 2D model at all cross section locations on Hall Creek.

Table D3. Floodway Data – Hall Creek (continued)

Flooding Source		Floodway			1% Annual-Chance Water Surface Elevation			
Cross Section ⁴	Distance ¹	Top Width	Section Area	Mean Velocity ³	Regulatory	Without Floodway ^{2, 3}	With Floodway ^{2, 3}	Increase
	(Miles Above Mouth)	(feet)	(square feet)	(feet/sec)	(feet NAVD88)			
V	2.02	320.3	1514.1	1.1	1042.62	1042.00	1042.83	0.83
W	2.12	225.9	931.0	1.8	1043.57	1043.01	1043.49	0.48
X	2.25	441.1	1326.5	1.1	1044.61	1044.01	1044.43	0.42
Y	2.33	399.0	994.8	1.4	1045.53	1045.00	1045.21	0.21
Z	2.38	353.1	885.3	1.6	1046.44	1046.01	1046.28	0.27
AA	2.45	337.7	1055.1	1.5	1047.41	1046.99	1047.64	0.65
AB	2.61	338.3	1308.4	1.2	1048.04	1047.63	1048.37	0.74
AC	2.76	494.9	1558.0	1.0	1048.45	1048.00	1048.73	0.73
AD	3.02	354.1	1073.7	0.4	1049.25	1048.67	1049.17	0.50
AE	3.23	748.6	735.3	0.7	1049.66	1049.01	1049.80	0.79
AF	3.29	324.1	275.3	1.4	1050.40	1050.01	1050.47	0.46
AG	3.35	205.5	130.3	2.8	1052.06	1052.01	1052.55	0.54
AH	3.41	99.9	132.9	3.2	1053.98	1053.98	1054.50	0.52
AI	3.45	79.7	163.7	2.7	1056.03	1056.03	1056.57	0.54

1. Stream distance in miles above confluence with Cowlitz River
2. Computed without overflow influence from Cowlitz River at Packwood
3. Values reported are based on averages computed across evaluation lines. Refer to model result grids for modeled variability in elevation and surcharge across the Floodway.
4. Floodway computed using 2D model at all cross section locations on Hall Creek.

APPENDIX E: ANNOTATED FIRMS