# Chehalis Basin Strategy

## Geomorphology, Sediment Transport, and Large Woody Debris Report

Reducing Flood Damage and
Restoring Aquatic Species Habitat

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# ACRONYMS AND ABBREVIATIONS LIST

| | |
|---|---|
| cfs | cubic feet per second |
| DNR | Washington State Department of Natural Resources |
| FRFA | flood retention flow augmentation |
| FRO | flood retention only |
| GPS | global positioning system |
| HWM | high water mark |
| LiDAR | Light Detection and Ranging |
| LWD | large woody debris |
| mm | millimeters |
| PGS | Pacific Geomatics Services |
| RM | river mile |
| USGS | U.S. Geological Survey |
| WSE | Watershed Science and Engineering |

# EXECUTIVE SUMMARY

Previous studies of the effects of potential flood retention structures at river mile (RM) 108.2 in the upper Chehalis River on geomorphology, bedload transport, and large woody debris (LWD) focused on the river between the structure and Porter (RM 40) (Watershed GeoDynamics and Anchor QEA 2012, 2014). Information collected and analyzed during the 2015-2017 biennium focused on potential geomorphic changes and bedload transport modeling of the channel areas subject to impoundment under the flood retention only (FRO) and flood retention flow augmentation (FRFA) facility operations. This included the channel between the dam site and RM 118 (above the upper end of potential impoundment areas). Scour monitors were installed at several locations to measure scour and fill of gravel areas close to salmonid spawning sites. An estimate of potential wood and debris that could enter the impoundment area from upstream landslide inputs during floods was made to assist with planning for wood and debris removal operations.

The existing bed in the upper Chehalis River (between RM 104 and 127) is extremely mobile and it continues to process sediment deposited during the 2007 flood. Scour monitors were installed near spawning sites between Ceres Hill Bridge (RM 88) and RM 116. The scour monitors recorded from no scour or fill at some sites to up to 0.4 feet of scour and 1 foot of fill following an approximately 1.5-year flood and a minimum of 1 foot of scour and 0.5 foot of fill following a nearly 5-year flood. However, scour and fill was locally much greater; only 4 of the 12 scour monitors were re-located following the 5-year flood, the remaining 8 monitors were likely covered with gravel/cobble bed material.

A HEC-RAS hydraulic and sediment transport model was developed for the reservoir area to investigate long-term changes in sediment transport under the with-FRO and with-FRFA operations scenarios using a 27-year record of flows (1988-2015). The results provide information on sediment deposition and transport under the two with-impoundment operation scenarios as well as three climate change scenarios (existing conditions, FRO, and FRFA). The model was not able to accurately represent the extremely high sediment loads and debris torrent phenomenon that occurred during the 2007 event.

The FRO facility was predicted to impound water seven times over the 27-year modeling period, for approximately 1 month during each flood, with an impoundment of approximately 2 months for the extreme 2007 event (Hill 2016). When the reservoir would impound water, it would trap bedload sediment (cobble, gravel, sand) and some portion of the finer silt and clay-sized particles coming from upstream. This material would be deposited at the head of the reservoir (which would move as the reservoir elevation raised and lowered) and subsequently re-entrained and transported downstream when the reservoir no longer impounded water. The deposited sediments would initially include some fine-grained sediment, but these would be transported downstream when the gravel was re-entrained and would be transported through the reservoir. The sediment transport modeling predicts that 23 to

45 percent of the incoming bedload and 20 percent of the incoming suspended load would be retained within the FRO reservoir footprint over the long term.

Operation of the FRFA facility would impound water at all times and would trap all of the bedload and approximately 75 percent of the finer sediment (silt, clay). A delta would form near the upstream end of the reservoir between RM 114 and 115 and at the head of each of the major tributaries. The delta and reservoir fluctuation zone (RM 114 to 117) would contain a mix of fine and coarse substrate and have a relatively unstable channel configuration, little riparian vegetation, and would not provide high quality aquatic habitat. The sediment transport modeling predicts that a total of 1,300 acre feet of sediment would be stored within the FRFA reservoir over the 27 years of model runs. This is small in comparison to the total reservoir volume of 65,000 acre feet in the conservation pool plus another 65,000 acre-feet of flood storage (total reservoir volume of 130,000 acre feet). Over 100 years, estimated stored sediment volume (including additional sediment volume for the 2007 event) is approximately 7,500 acre feet, or 6 percent of the total reservoir volume.

An event of the size of the 2007 flood would have a major impact on the impoundment area under either the FRO or FRFA facility; 5 to 7 million cubic yards (approximately 2,200 acre feet) of sediment and wood/debris were estimated to have been delivered to streams above the reservoir area during the 2007 flood. This material would have been deposited or trapped in either the FRO or FRFA impoundment. This magnitude of disturbance would have had a major effect on the area for more than a decade, with mobile channel substrate and higher fine sediment levels, as the 2007 flood has had on the Chehalis River channel.

The mainstem Chehalis River wood load is very low and is less than the large wood piece quantities or volumes for natural and unmanaged watersheds referenced by Fox and Bolton (2007). The primary mechanism for wood and debris input to streams upstream of the potential impoundment is via landslides that bring rock, soil, trees, and brush into the stream system. During large floods, the wood and debris is transported downstream. The 2007 flood provided a huge input of LWD from landslides, but due to the intense nature of the flows and landslides, most of the LWD was moved downstream through the channel or up into the floodplain and is not accessible to the current wetted channel.

The FRO dam is designed to pass sediment and debris up to a 3-foot-diameter and root wad or logs up to 15 feet long. However, if the FRO facility is impounding water during a flood, much of the wood and debris would be retained in the reservoir. The FRFA impounds water at all times and would also capture wood and debris during all floods. An estimated 2,000 to 10,000 cubic yards of wood and debris could enter the impoundment area from upstream sources during a 5-year flood, with up to 35,000 cubic yards during a 75-year flood. During the 2007 flood, and estimated 3 million cubic yards of wood entered the upper Chehalis River. Wood and debris that is captured in the reservoir would be removed and large logs and root wads could be made available for aquatic species restoration projects.

# 1 INTRODUCTION

## 1.1 Introduction

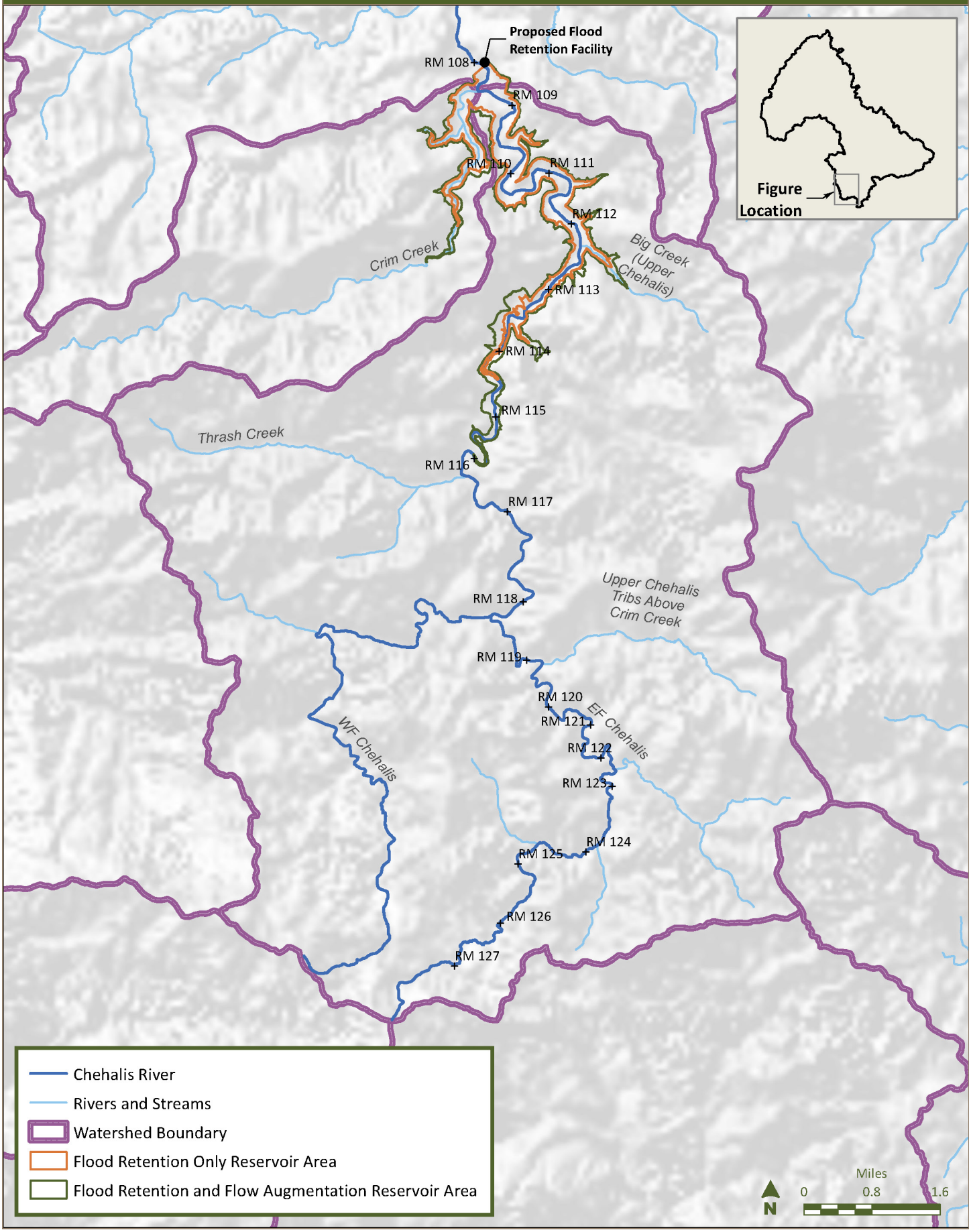
The State of Washington is conducting an evaluation of the feasibility of constructing a flood retention structure in the headwaters of the Chehalis River at river mile (RM) 108.2 (upstream of Pe Ell) to reduce downstream flooding. As part of the investigation of the effects of the structure on fish populations in the watershed, evaluations of the changes to the geomorphology, sediment transport, and large woody debris (LWD) in the river between the dam site and Porter (RM 40) were conducted in the 2011 to 2013 and 2013 to 2015 bienniums (Watershed GeoDynamics and Anchor QEA 2012, 2014). These previous analyses looked at historical channel migration, sampled channel substrate for grain size analysis, investigated sediment and wood inputs from the 2007 flood, and summarized potential effects on river geomorphology, bedload transport, and LWD input and transport that could result from construction and operation of the flood retention structure.

Additional information collected and analyzed during the current biennium (2015-2017) focused on potential geomorphic changes of the channel areas subject to impoundment under the flood retention only (FRO) and flood retention flow augmentation (FRFA) facility operations; areas between the dam site and RM 117 (approximate upper end of potential impoundment). Specific data and analyses during the current biennium included the following:

- Collection of additional substrate data (pebble counts of surficial grain size) between RM 105 (near Pe Ell) and RM 118 (upstream of potential impoundment)
- Installation of scour monitors in locations similar to areas where salmonids spawn at RM 88, 105.5, 107.5, 108.5, 110, and 116 to provide information on scour and fill near redds
- Count of LWD at ten locations between RM 87 and 118
- Analysis of potential LWD input from landslides during past floods (1965 to 2009) to provide more detail on wood loading estimates for the reservoirs
- Survey of cross sections in the mainstem Chehalis River and Crim/Lester creeks to supplement 2015 Light Detection and Ranging (LiDAR) data (for the HEC-RAS model)
- Analysis of potential sediment transport using the HEC-RAS one-dimensional model developed for the reservoir area between RM 107 (just downstream of potential dam location) and RM 117

The area of potential impoundment(s) for the two facilities and study area for this geomorphology report are shown in Figure 1.1

**Figure 1.1**
**Study Area**



# 2 METHODS

## 2.1 Large Woody Debris

### 2.1.1 Field Work

Anchor QEA conducted an inventory of the large wood load within the bankfull width of the mainstem Chehalis River between RM 87 and RM 118, in October and November 2015. Wood pieces meeting the minimum size criteria of Fox and Bolton (2007) were inventoried at each site with a handheld global positioning system (GPS) device. The Fox and Bolton (2007) criteria are wood pieces at least 2 meters (6.5 feet) in length and at least 10 centimeters (4 inches) diameter. A technical memorandum detailing the methods and results of this wood inventory is available in Appendix A.

Large wood within the bankfull channel width was inventoried at ten sites along 31 miles of mainstem Chehalis River in the upper watershed. The wood inventory was conducted October 6 through 9, 2015, between RM 87 and 105.5. A second wood survey was conducted on November 4 and 5, 2015, between RM 110 and 118 (confluence of the East and West Forks) and at one site on the West Fork Chehalis River. The large wood data collected as part of this inventory represents only a snapshot of the wood load in the upper Chehalis Basin.

Fox and Bolton (2007) conducted a study of the number and volume of large wood found in unmanaged streams and rivers in Washington and developed distributions (75th, median, and 25th percentiles) for the number of pieces, volume, and number of key pieces per 100 meters (328 feet) of channel length based on bankfull widths of these unmodified watersheds. As part of their study, Fox and Bolton (2007) recommended large wood restoration targets (number of pieces, volumes, key pieces) meet the 75th percentile for degraded rivers and streams (defined as a system where the existing wood volume and numbers are below the median wood distribution for unmanaged streams).

### 2.1.2 Wood and Debris Input Upstream of RM 108

Inputs of wood and debris upstream of the dam site (RM 108.2) were estimated based on estimates of past landslide rates. Landslides were inventoried as part of the Chehalis Headwaters Watershed Analysis Mass Wasting Module using the 1955, 1965, 1978, 1987, and 1993 aerial photographs (Ward and Russell 1994). The data on each landslide area and forest stand age category from the Ward and Russell report were compiled in a spreadsheet for the current analysis. These data were supplemented with landslides that were digitized from the 1996 digital orthophotographs and 2007 landslides provided in the Washington State Department of Natural Resources (DNR) landslide database (Sarikhan et al. 2008 and GIS data provided by DNR). The 2007 DNR landslide database was further edited by comparing with the 2008 digital orthophotographs to add missing landslides and remove landslides that were not present on the orthophotographs. Stand age and delivery for each

landslide was estimated and coded based on observations made on the digital aerial photographs. Note that the landslide area and volume estimate provided using aerial photographs should be considered an estimate; Brardinoni et al. (2003) found that landslide inventories based on aerial photographs miss up to 40% of the smaller landslides when compared to ground-based inventories. This is consistent with observations within the upper Chehalis watershed. Comparison of LiDAR topographic data from 2006 (pre-2007 flood) and 2015 was possible over a small portion of the upper Chehalis area (approximately 10,000-acre area; see Section 2.1.3) and showed that there were numerous areas with small land movements that were not visible on the aerial photographs, but no attempt was made to quantify this difference because ground-based surveys would be needed to verify results, which was out of the scope of the present study.

Volume estimates of woody debris within areas of different forest stand ages were made based on a number of sources. Estimates of the volume of harvestable wood in 40-year-old second growth Douglas fir stands have been made based on average number of trees per acre (237 to 276) and diameter (diameter breast height 12.1 to 12.2 inches) to yield approximately 10,000 cubic feet of tree boles per acre (Marshall and Turnblom 2005). This volume does not include limbs, understory, soil duff, stumps, or roots that would be moved downslope during a landslide. These additional volumes were not found in the literature, but estimated at an additional 5% for branches per brush and 10% for the stump and roots. The volume of slash, logs, and stumps left within recently clearcut areas was estimated based on digitizing logs over a 10-acre recently clearcut area in the upper Chehalis watershed on the 2006 digital orthophotographs. Resolution in these photos was sufficient to see logs as small as 5 feet long. In addition, a recently clearcut area was visited in October 2015 to estimate number of stumps and volume of slash on the ground based on visual observations. The actual amount of wood and debris delivered from an individual landslide depends on the vegetation type (e.g., upland forest, riparian forest, deciduous, conifer) and exact stand age, but these observations provided an estimate of wood and debris volumes for different representative stand age conditions.

An average woody debris input was estimated for each landslide based on the area of the slide in each forest stand age category (see Table 2.1) and percent of slide delivered to a stream.

**Table 2.1**
**Estimated Volume of Wood and Debris for Different Stand Age Categories**

| STAND AGE CATEGORY | VOLUME OF WOOD AND DEBRIS |
|---|---|
| 0 – 20 years | 5,750 cubic yards |
| 20 – 50 years | 11,500 cubic yards |
| > 50 years | 17,250 cubic yards |

### 2.1.3 Comparison of Pre- and Post-2007 Storm LiDAR Data

LiDAR data from 2006 and 2015 were used to analyze changes in ground elevation between 2006 and 2017 in the area of overlap (approximately 8,300 acres; see Figure 2.1). The elevation value of each 1-meter square grid cell in the 2006 coverage was subtracted from the value in the corresponding 2015 grid cell. These data were used, in combination with digital aerial photographs, to delineate areas of landslides, channel/floodplain erosion and aggradation, and areas of LWD accumulation related to the 2007 flood. Landslides identified using the LiDAR data were compared to mapped landslides to check for:

- Mapped landslides that were not visible on the aerial photographs or were not previously mapped
- Areas mapped as landslides that were not landslides
- The volume of actual soil movement compared to estimated volumes
- The volume of ground loss at the top of the slide, the volume (if any) of accumulation at the bottom of the slide, and the resulting percent delivery of total slide volume to a stream channel

Sediment accumulation and erosion depths were identified along the mainstem Chehalis River. Areas of wood accumulation were also identified using the LiDAR and aerial photograph data and accumulation depths were determined.

## 2.2 Sediment Transport

### 2.2.1 Pebble Counts

Wolman pebble counts were conducted at several locations between RM 105 and 118 on October 23 to 24, 2015, to supplement data collected in 2010 (see Figures 2.2a to 2.2c). At each location, a representative patch of substrate was chosen that was reflective of either bedload transported at the site (e.g., the head of a gravel bar) or substrate that was being used by spawning fish in that location (to provide data on scour; see also Section 2.2.2). Pebbles were chosen in a heel-to-toe walk manner along the chosen area of substrate. Each pebble was passed through a gravelometer and the size class was recorded (e.g., less than 2 millimeters [mm], 2 to 4 mm, 4 to 8 mm, 8 to 16 mm). A minimum of 100 pebbles were sampled at each location.

**Figure 2.1**
**LiDAR Comparison Area**

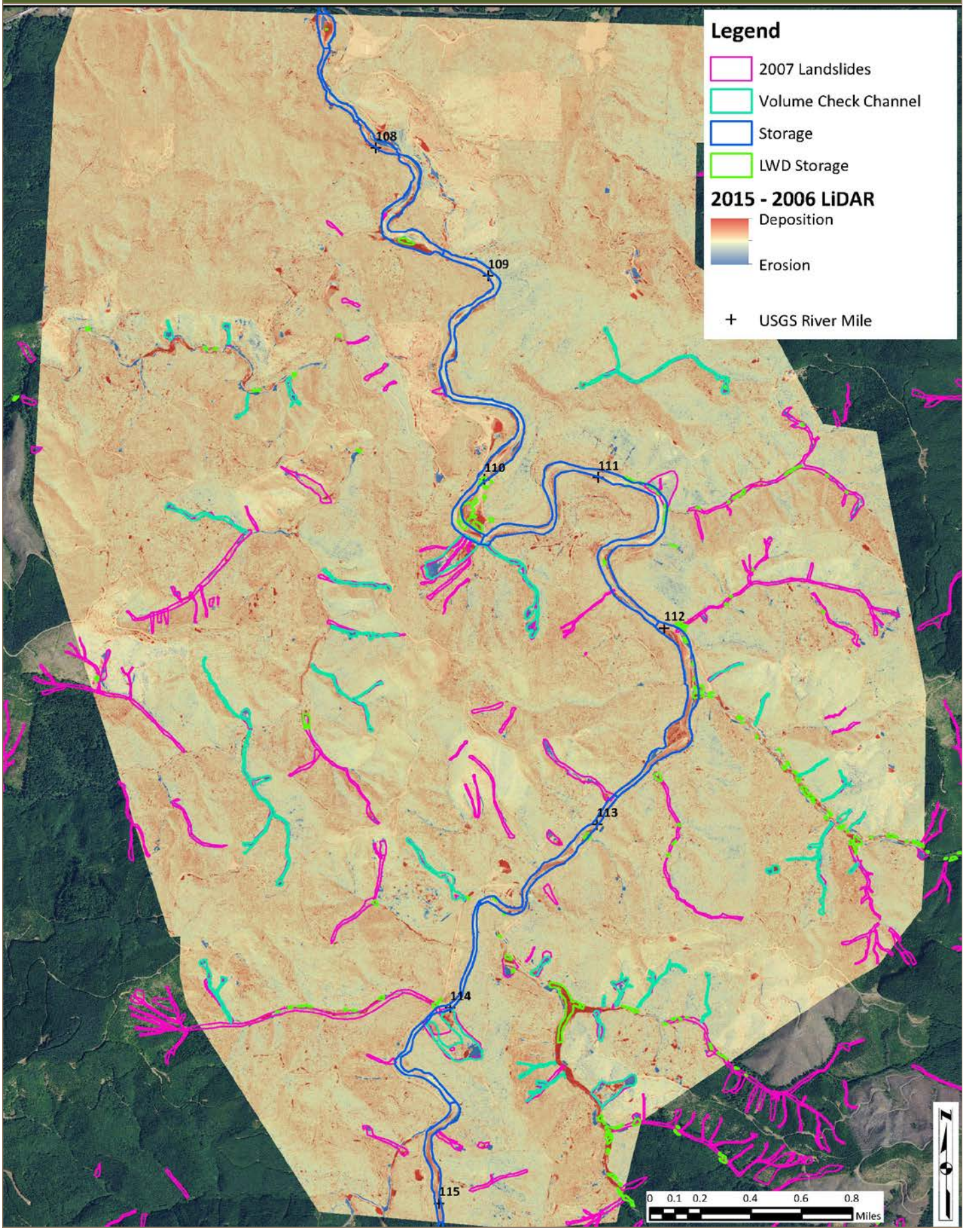


**Figure 2.2a**
**Sample Sites**

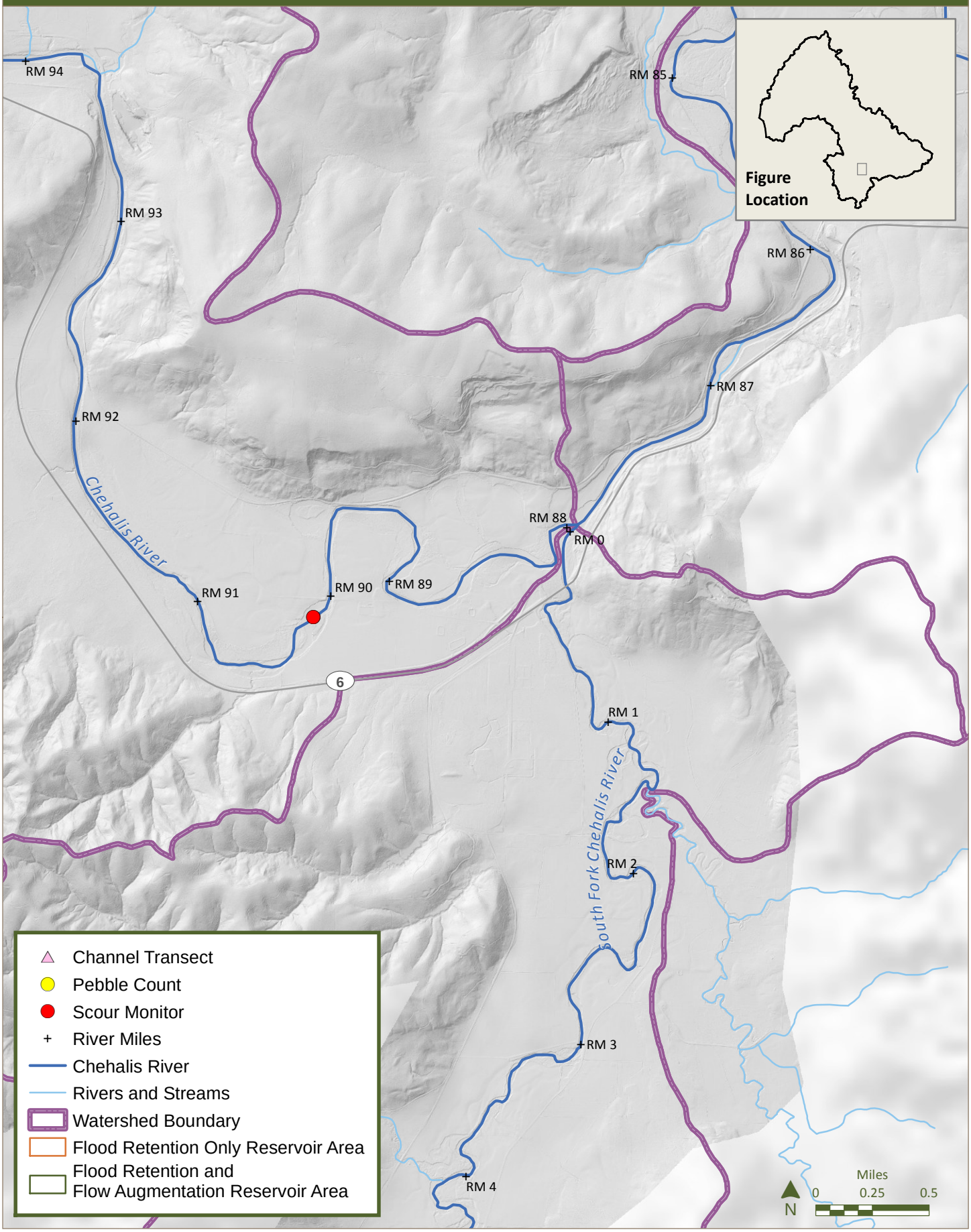


**Figure 2.2b**
**Sample Sites**

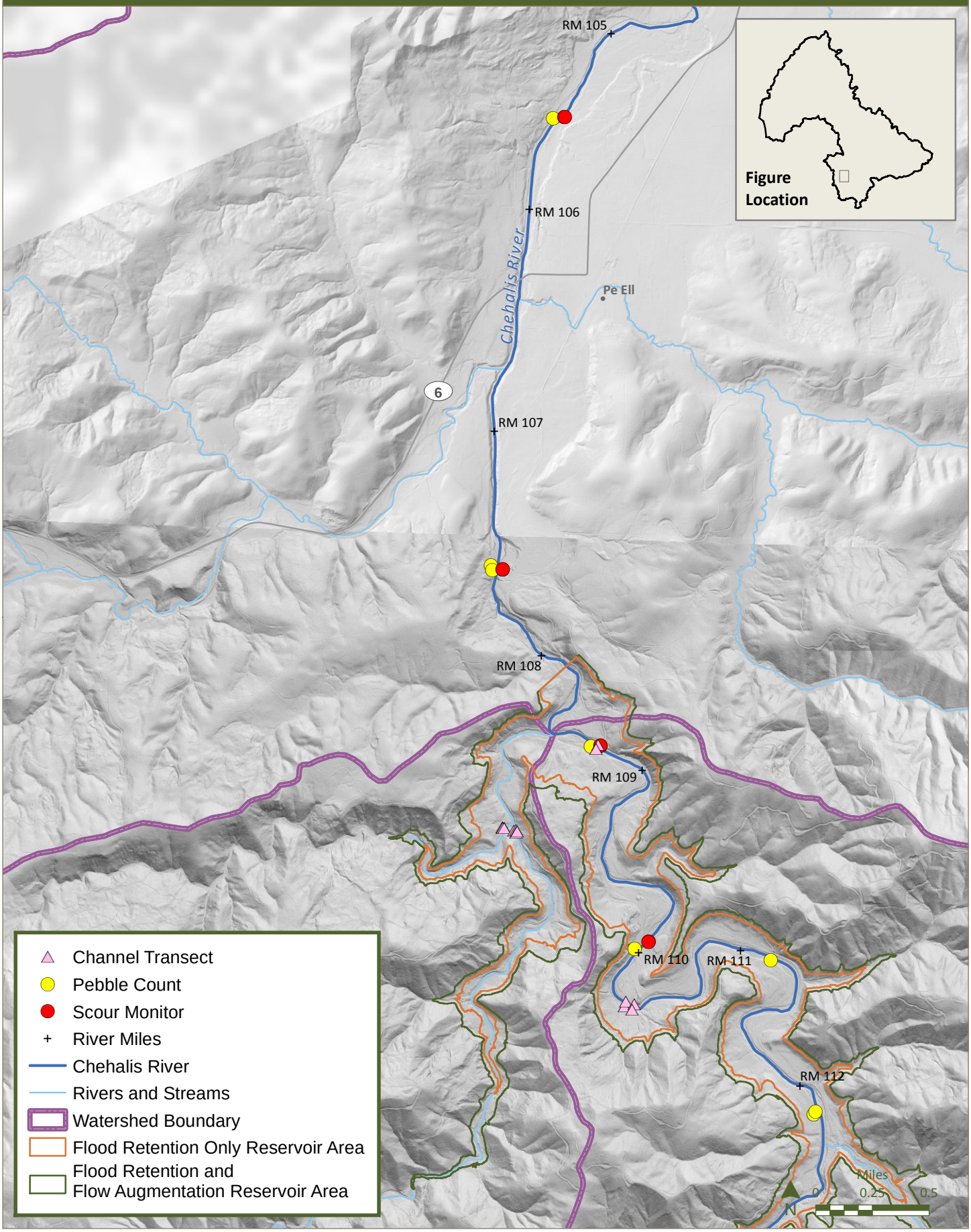
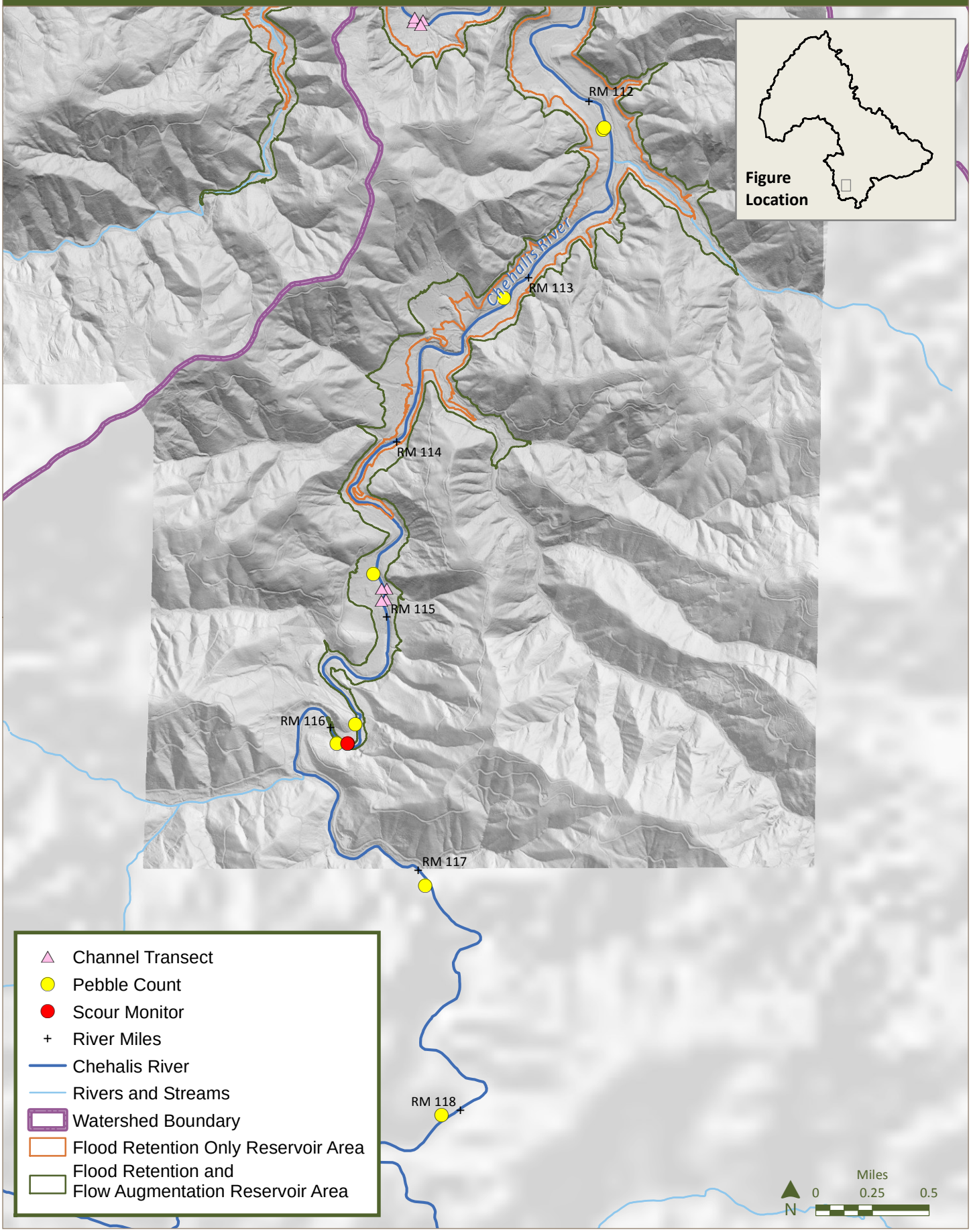


**Figure 2.2c**
**Sample Sites**



### 2.2.2 Scour Depth Monitoring

Sliding bead scour monitors (Schuett-Hames et al. 1999) were deployed at six locations between RM 88 (just upstream of the Ceres Hill Bridge) and RM 116 (near the upper end of potential impoundment) to measure gravel scour and fill (see Figures 2.2a to 2.2c). Two monitors were installed at each location (RM 88—Ceres Hill Bridge; RM 105.5—Doty Sewage Plant; RM 107.5—Weyerhaeuser office; RM 108.5—Panesko Bridge; RM 110—Sorting Yard Bridge; and RM 116—south of Cutoff Road). Monitors were buried in the riverbed near fish spawning areas because depth of redd scour is an element of interest for fisheries studies. Monitors were placed on October 22 to 24, 2015, and checked on November 6, 2015, and December 2, 2015, following high flows. The peak flows recorded in the Chehalis River are provided in Table 2.2 for the Chehalis River above Mahaffey Creek near Pe Ell gage and the Chehalis River near Doty gage.

**Table 2.2**
**Peak Flows in the Chehalis River During Scour Depth Monitoring**

| DATE (TIME) IN 2015 | PEAK FLOW (CFS) | |
|---|---|---|
| | CHEHALIS RIVER ABOVE MAHAFFEY CREEK NEAR PE ELL, WA (USGS 12019310) | CHEHALIS RIVER NEAR DOTY, WA (USGS 12020000) |
| October 31 (15:15) | 5,830 | |
| November 17 (15:15) | 9,230 | |
| October 31 (16:30) | | 5,820 |
| November 17 (18:45) | | 14,000 |

Notes:
Data are provisional.
cfs: cubic feet per second
USGS: U.S. Geological Survey

## 2.3 Sediment Transport Modeling

In order to investigate potential reservoir accumulation and transport regimes, a one-dimensional HEC-RAS hydraulic and sediment transport model was developed.

### 2.3.1 Hydraulic Model

Watershed Science and Engineering (WSE) developed the Upper Chehalis HEC-RAS hydraulic model used for this sediment transport study. The model covers a reach of the river from RM 117 (HEC-RAS Station 118.17) and RM 107.4 (HEC-RAS Station 107.43), which extends from downstream of the proposed dam site to upstream of the proposed reservoir. Cross sections 107.43 through 108.53 were part of the original model developed by WSE for the Flood Authority in 2012 using survey data collected in 2011 by Minister & Glaeser Surveying (WSE 2012). WSE extended the model through RM 118.17 using cross-sections prepared with HEC-GeoRAS, an ArcGIS extension that processes GIS data for import into HEC-RAS. Cross sections were cut from a LiDAR terrain surface developed by GeoTerra from a LiDAR flight on

November 27th, 2015. Bathymetry for the new cross sections came from three sources. Three cross sections were surveyed by Watershed GeoDynamics. Fifteen additional cross sections were surveyed by Pacific Geomatics Services (PGS) during the winter of 2016-2017. For the remaining cross sections without surveyed bathymetry, a shallow triangular channel with maximum depth of 2 feet was cut into the wetted area of the LiDAR surface to approximate the low flow channel. Discharge in the river was low (100 to 200 cubic feet per second [cfs] at the Mahaffey Creek U.S. Geological Survey [USGS] gage) during the LiDAR acquisition, so this channel geometry is assumed to be sufficiently accurate for sediment transport modeling because sediment movement occurs primarily during high flow events, and any errors introduced by the low flow channel approximation would be negligible. The model cross sections and their data sources are shown in Figure 2.3.

The Upper Chehalis hydraulic model was calibrated using high water marks (HWMs) obtained during two high flow events during the winter of 2016-2017. WSE staff visited the site after each flood event and marked the estimated maximum water surface elevation based on the presence of flow debris, leaf litter, or bent grasses. WSE staff staked six HWMs within the model reach following the first flood event on November 25, 2016, which had peak discharge of 8,930 cfs measured at the USGS gage (12020000) near Doty, Washington. This discharge corresponds to approximately a 1 year recurrence interval event. HWM locations were selected near the existing scour monitors where possible. The HWMs were later surveyed by PGS. WSE staff selected and surveyed 11 HWMs following a second flood event on February 9, 2017, which had a peak discharge of 13,800 cfs measured at Doty. This discharge corresponds to approximately a 4 to 5 year event. These HWMs were set at the location of the newly surveyed channel cross sections.

The modeled discharge within the reach was estimated by scaling the discharge measured at Doty using a ratio of local watershed area to the watershed area at the Doty gage site. Manning's n values were adjusted to obtain modeled water surface elevations at the two discharges that match the observed HWM elevations. Manning's n values were set to 0.035 and 0.045 within the reach to obtain the best fit with the observed data (Table 2.3) across the entire model domain. The lower n value was used in the middle of the modeled reach (RM 110.18-113.89) where the bed slope is generally flatter and the bed material is predominantly alluvial. The bed material of the upper and lower reaches is generally mixed bedrock/alluvial and these reaches are steeper than the middle of the reach. The modeled water surface elevations are generally within a foot of the observed water levels, with a mean difference close to zero, so the model does a reasonable job of simulating hydraulic conditions within the reach. However, the difference between the observed and modeled water surface elevations was significant in places, which is likely due to incorrect interpretation/placement of the high water marks, but could also be caused by local flow effects that are not captured by the coarse cross section spacing in the model.

**Figure 2.3**
**Upper Chehalis River HEC-RAS Cross Sections**

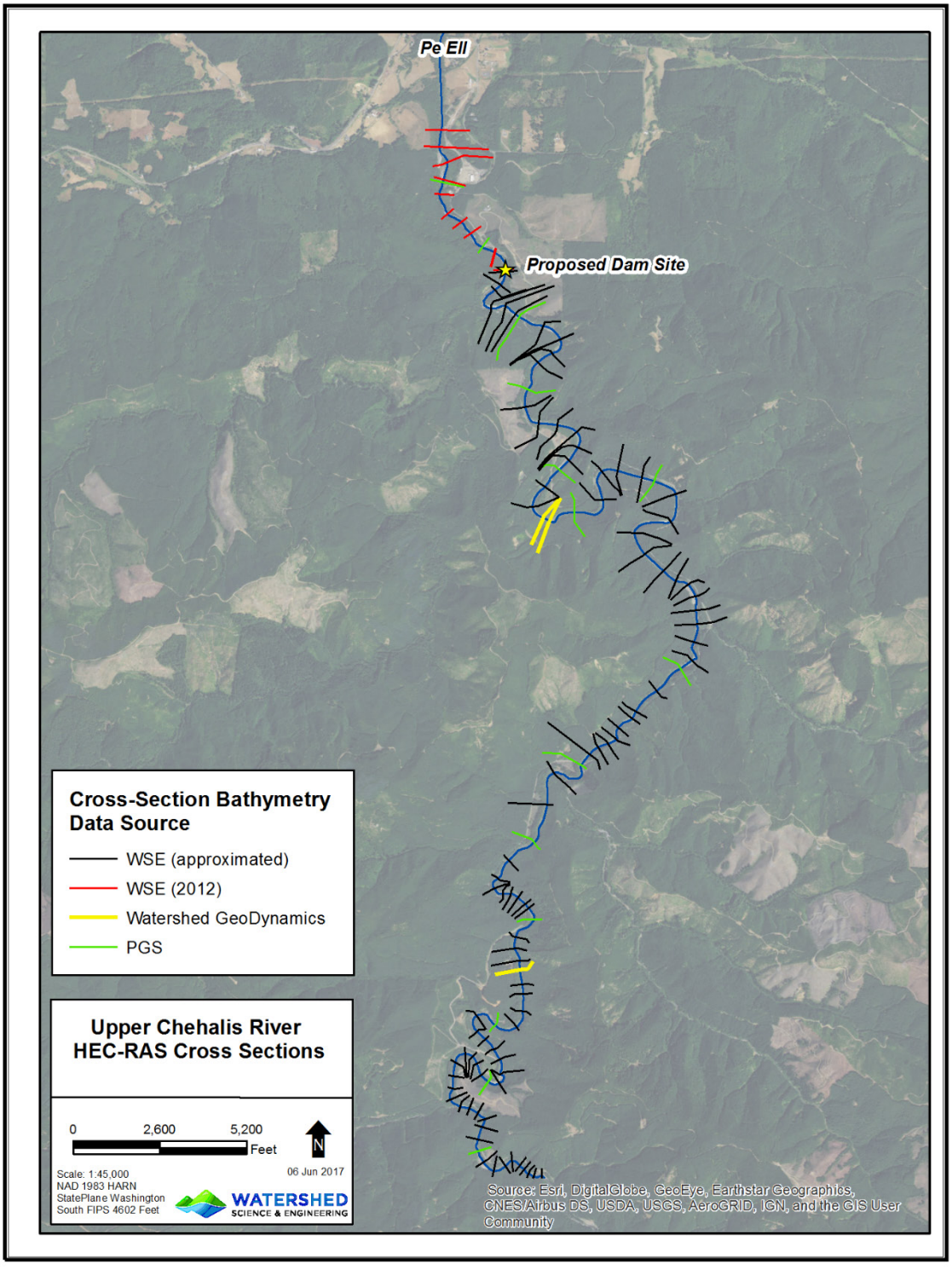


**Table 2.3**
**Summary of Observed and Modeled Water Surface Elevations**

| CROSS SECTION | MANNINGS N VALUE | NOVEMBER 25, 2016, 8930 CFS AT DOTY | | | FEBRUARY 9, 2017, 13800 CFS AT DOTY | | |
|---|---|---|---|---|---|---|---|
| | | MODELED WATER SURFACE ELEVATION (FEET) | OBSERVED WATER SURFACE ELEVATION (FEET) | DIFFERENCE (FEET) | MODELED WATER SURFACE ELEVATION (FEET) | OBSERVED WATER SURFACE ELEVATION (FEET) | DIFFERENCE (FEET) |
| 117.7 | 0.045 | | | | | | |
| 116.75 | 0.045 | 688.8 | 687.6 | 1.2 | 690.3 | 689.9 | 0.4 |
| 116.07 | 0.045 | | | | | | |
| 115.25 | 0.045 | | | | 636.9 | 637.1 | -0.2 |
| 114.56 | 0.045 | | | | 606.9 | 606.8 | 0.1 |
| 113.89 | 0.045 | 571.1 | 570.8 | 0.4 | 572.9 | 574.2 | -1.3 |
| 113.07 | 0.035 | | | | | | |
| 112.34 | 0.035 | | | | 540.9 | 541.0 | -0.1 |
| 111.53 | 0.035 | 518.5 | 518.0 | 0.5 | 519.8 | 520.1 | -0.3 |
| 110.81 | 0.035 | | | | 501.8 | 503.6 | -1.8 |
| 110.25 | 0.035 | 490.5 | 489.3 | 1.1 | 491.8 | 490.9 | 0.9 |
| 109.53 | 0.045 | 473.2 | 475.0 | -1.8 | 474.4 | 476.8 | -2.4 |
| 108.88 | 0.045 | | | | 453.9 | 452.7 | 1.2 |
| 108.18 | 0.045 | | | | | | |
| 107.72 | 0.044 | 387.2 | 387.9 | -0.8 | 388.5 | 390.5 | -2.0 |
| | | | Mean | -0.20 | | Mean | -0.20 |
| | | | RMS | 1.16 | | RMS | 1.56 |

Note:
cfs: cubic feet per second
RMS: root mean square

### 2.3.2 Sediment Transport Modeling

The quasi-unsteady sediment transport analysis within HEC-RAS with hourly flow/reservoir elevation data was used to calculate sediment transport between the RM 117 (HEC-RAS Station 118.17) and RM 107.4 (HEC-RAS station 107.43) cross section locations. The Wilcock-Crowe, Ackers-White, and Meyer-Peter-Muller sediment transport algorithms were tested because they are algorithms available for coarse gravel substrate similar to substrate in the Chehalis River. All algorithms were run using hourly flows for the October 24 to December 15, 2015 period which corresponded to the scour and fill data available from the scour monitor deployment (Section 2.2.2). The scour monitors and anecdotal observations of the streambed material suggest that the existing bed of the upper Chehalis River is very mobile, with frequent bedload transport and bedform movement. The Meyer-Peter-Muller formula produced very little, if any, transport at the majority of the transects. The Wilcock-Crowe formula

produced some transport, but not as much bed change as was measured at the scour monitors. The Ackers-White formula produced results that were more similar to the scour monitor data, but still not as much movement as measured at the scour monitor locations. To test if a lower critical shear stress value could produce results more similar to the scour monitor and observational data, several different runs were made with adjustments to the transport formulae variable that represents the critical shear stress using the "Calibrate Transport Functions" dialog box. Adjusting the critical shear stress variable within a physically reasonable range did not appreciably improve model results. Because there was such limited data for calibration, the Ackers-White method with no adjustments was chosen for further modeling runs. The Ackers-White algorithm is a total load transport equation and represents transport of suspended and bedload sediment.

There are no direct measurements of incoming sediment load in the upper Chehalis River. Initial runs of the model were made with the incoming sediment load at the upstream end of the model set to "equilibrium load." However, it became apparent that this did not replicate the long-term pattern of bar formation at the major tributaries between RM 118 and RM 107. Therefore, lateral inflows of water and sediment were added to represent tributary inputs at RM 117.33, RM 113.88, 112.77, and RM 108.69.

Measurements of suspended load were made by the USGS at the Doty gage from 1962-1965 (Glancy 1971). The USGS used these measurements to produce a suspended sediment rating curve; this curve was used to estimate incoming suspended sediment loads at the upstream end of the model and the four major tributary input points based on relative tributary basin area. Bedload sediment was not measured at Doty, but was set at 6 percent of the suspended sediment load based on studies in other rivers in the Pacific Northwest (King et al. 2004; Emmett 1981). A range of bedload input from 5 to 10 percent of suspended load was used to test model sensitivity to this variable; 6 percent provided the most reasonable long-term patterns of deposition and transport.

The USGS sediment rating data and curve extends only to flows of up to 10,000 cfs at Doty. In order to extend the USGS rating curve for higher peak flows, an estimate of sediment loading to streams in the upper Chehalis watershed was made based on inputs from landslides inventoried using the 1955, 1965, 1978, 1987, 1993, 1987, 2009, and 2013 aerial photographs (Ward and Russell 1994; Clark 1999; Watershed GeoDynamics and Anchor QEA 2012, 2014) as shown in Table 2.4. These values are difficult to use directly in a flow/sediment input relationship because they are based on aerial photograph periods that included multiple peak flow events, and there is not a direct relationship between the magnitude of peak flow(s) that occurred during the aerial photograph period and the magnitude of estimated sediment inputs. In addition, not all of the sediment from the slides was delivered to the streams. To provide a reasonable way to convert total landslide volume to amount of sediment input to streams, it was assumed that 65 percent of the total volume was delivered to streams in the basin over a 2-day period to produce an estimate of total tons per day (Table 2.4). The USGS published rating curve was extended to higher flows based on the estimated landslide input data as shown in Figure 2.4.

**Table 2.4**

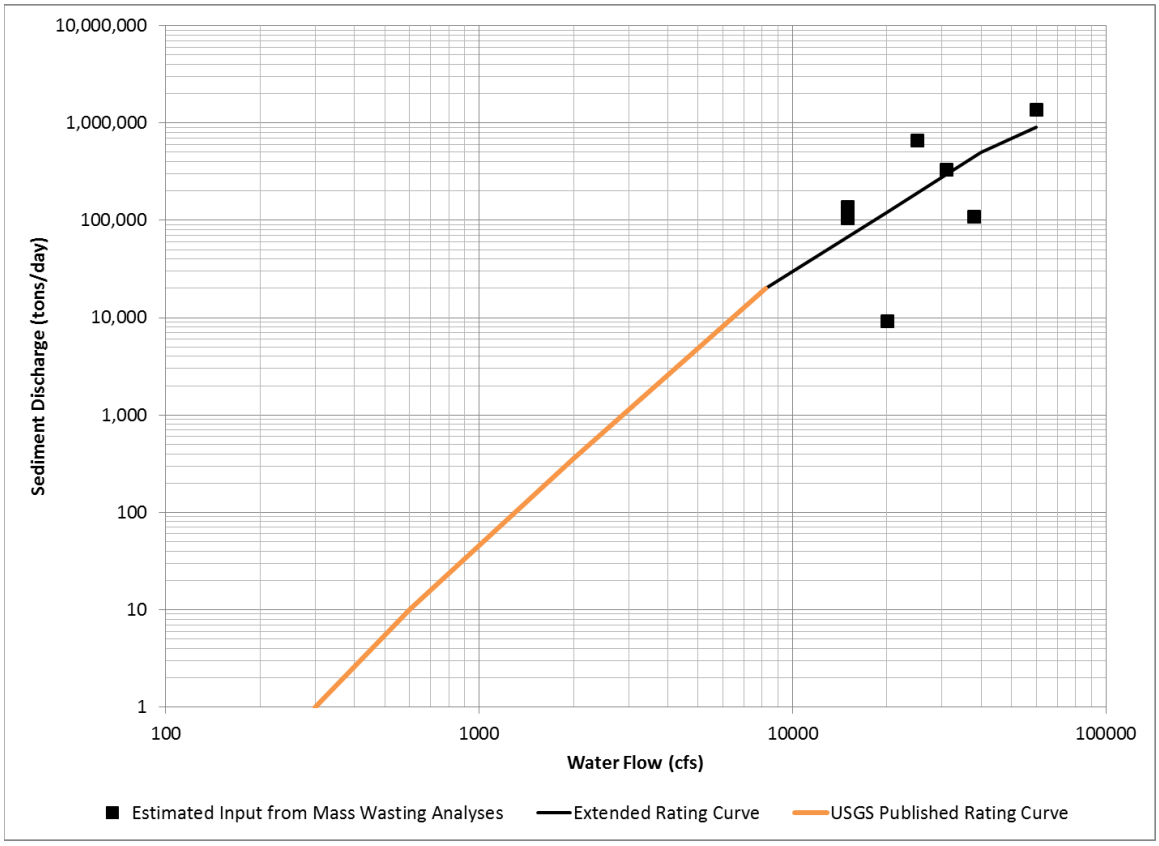
**Estimated Landslide Inputs to the Upper Chehalis Basin (upstream of impoundment)**

| AERIAL PHOTOGRAPH YEAR | LARGEST PEAK FLOW RECURRENCE INTERVAL (YEARS) DURING AERIAL PHOTO PERIOD | ESTIMATED TOTAL LANDSLIDE AMOUNT (TONS) | ESTIMATED INPUT TO STREAMS (TONS/DAY) |
|---|---|---|---|
| 1955 | 5 | 457,800 [1] | 137,340 |
| 1965 | 5 | 402,900 [1] | 120,859 |
| 1978 | 21 | 2,197,000 [1] | 659,232 |
| 1987 | 5 | 347,900 [1] | 104,378 |
| 1993 | 42 | 1,099,000 [1] | 329,616 |
| 1997 | 75 | 366,200 [2] | 109,872 |
| 2007 | 500 | 4,558,000 [3] | 1,367,385 |
| 2009 | 13 | 30,800 [3] | 9,240 |

Notes:
1. Based on Ward and Russell 1994
2. Based on Clark 1999
3. Based on Watershed GeoDynamics and Anchor QEA 2012, 2014

**Figure 2.4**

**Sediment Rating Curve Compiled from USGS Suspended Sediment Data and Estimated Landslide Inputs**



Total incoming loads at each of the HEC-RAS model sediment input points were initially calculated based on the proportion of the watershed at that input point and later adjusted based on the proportion of sediment to each tributary sub-basin from the landslide analyses. Input amounts used in the HEC-RAS model are shown in Table 2.5. Grain size for incoming loads were set based on the sand/silt/clay proportions measured by the USGS at Doty and surficial pebble count data measured in the Chehalis River closest to the incoming sediment load location (Section 3.2).

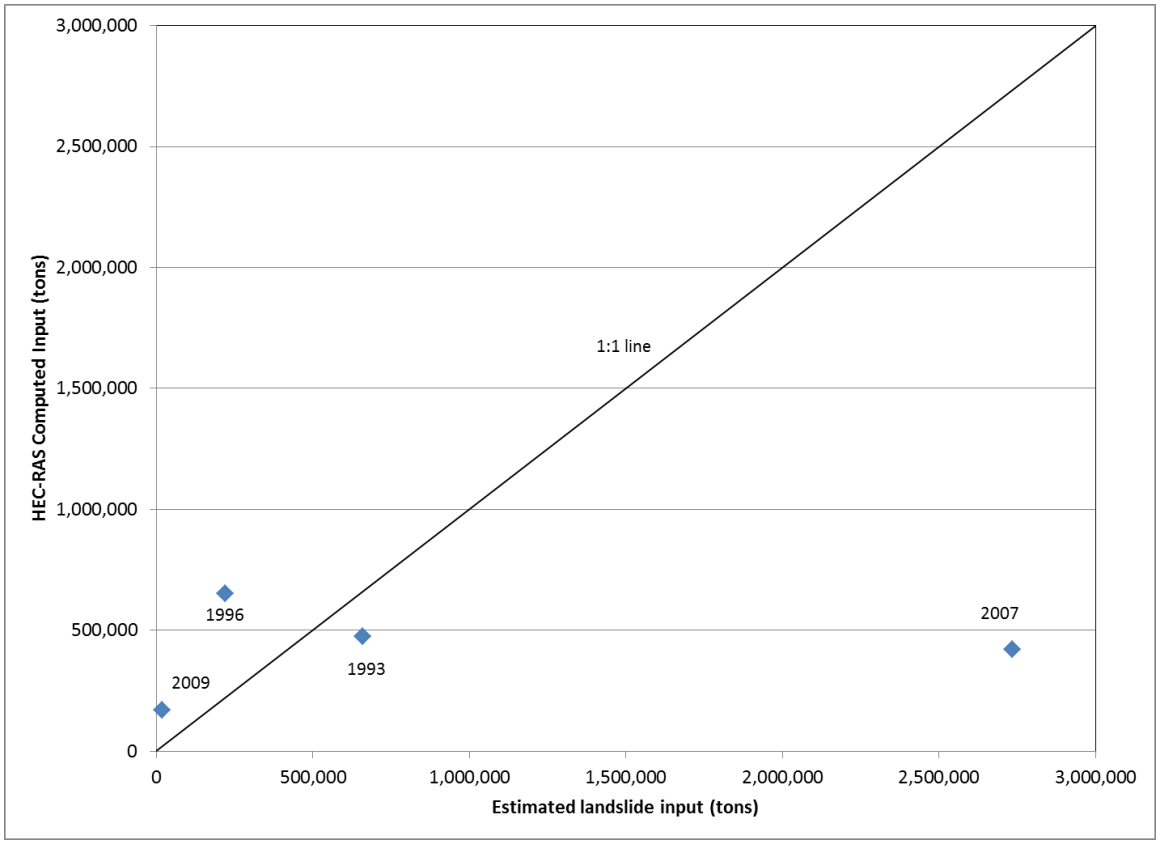
**Table 2.5**
**Flow vs. Total Sediment Discharge (tons/day) Input Rating Curves for HEC-RAS Model**

| RM 118.174 31% OF BASIN AREA[1] 33 % OF SEDIMENT[2] | | RM 117.33 8% OF BASIN AREA 12% OF SEDIMENT | | RM 113.88 6% OF BASIN AREA 12% OF SEDIMENT | | RM 112.77 5% OF BASIN AREA 11 % OF SEDIMENT | | RM 108.69 15% OF BASIN AREA 5 % OF SEDIMENT | |
|---|---|---|---|---|---|---|---|---|---|
| **FLOW (CFS)** | **SEDIMENT DIS-CHARGE (TONS/ DAY)** | **FLOW (CFS)** | **SEDIMENT DIS-CHARGE (TONS/ DAY)** | **FLOW (CFS)** | **SEDIMENT DIS-CHARGE (TONS/ DAY)** | **FLOW (CFS)** | **SEDIMENT DIS-CHARGE (TONS/ DAY)** | **FLOW (CFS)** | **SEDIMENT DIS-CHARGE (TONS/ DAY)** |
| 186 | 3 | 48 | 1 | 36 | 1 | 30 | 1 | 90 | 1 |
| 620 | 119 | 160 | 43 | 120 | 43 | 100 | 40 | 300 | 18 |
| 2,542 | 7,260 | 656 | 2,640 | 492 | 2,640 | 410 | 2,420 | 1,230 | 1,100 |
| 6,200 | 43,560 | 1,600 | 15,840 | 1,200 | 15,840 | 1,000 | 14,520 | 3,000 | 6,600 |
| 12,400 | 181,500 | 3,200 | 66,000 | 2,400 | 66,000 | 2,000 | 60,500 | 6,000 | 27,500 |
| 18,600 | 326,700 | 4,800 | 118,800 | 3,600 | 118,800 | 3,000 | 108,900 | 9,000 | 49,500 |

Notes:
1. The percentage of basin area for each input point is percentage of drainage area for that point compared to total drainage area for the USGS Doty gage.
2. The percent of sediment is based on basin area adjusted for sediment loading based on landslide analyses.
cfs: cubic feet per second
RM: river mile

Using these input values, the total incoming sediment load to the modeled reach (upstream of RM 107.4) over the long-term 1988-2015 period was 3,880,000 tons. Estimated landslide input in Table 2.4 for the 1988-2015 period was 6,054,000 tons, but this includes nearly 4,500,000 tons from the 2007 storm which is not well represented (see discussion below). Figure 2.5 shows estimated landslide input versus HEC-RAS computed sediment input for four periods that have estimated landslide inputs from aerial photograph analysis: 1993, 1996, 2007, and 2009. Because there is such a wide range of landslide inputs compared to flow (see Figure 2.4), HEC-RAS overestimates input for some storm events and under-estimates it for other events, particularly the 2007 storm event.

**Figure 2.5**
**Estimated Landslide Inputs Versus HEC-RAS Computed Sediment Input for Four Storm Events**




The 2007 storm event had extremely high concentrations of sediment and woody debris and resulted in deposition of up to 5 feet of sediment in the river channel and valley, with inputs via debris torrent and deposition behind temporary debris dams (Nelson and Dube 2016). This type of an extreme event is not modeled well by the sediment transport equations within the HEC-RAS program. One model run was attempted for the 2007 storm with incoming loads set to try to emulate input estimated based on the mass wasting analysis (Section 2.1.2 and Table 2.4), but resulted in unrealistic accumulations at each of the sediment input points. The final sediment input rating curves resulted in a much lower 2007 input (411,000 tons) than the mass wasting input estimate (nearly 4,500,000 tons). The HEC-RAS model results are not representative of the actual 2007 storm event inputs and transport, but provide an estimate of potential effects of a fairly high magnitude storm event.

Calibration of aggradation and degradation patterns at individual cross sections, primarily in bedrock and coarse cobble/boulder areas, was made via adjustments to grain size characteristics, adjustments to the moveable bed limit (e.g., depth of degradation allowed) or setting bedrock cross sections downstream of the dam to pass-through nodes. The model was set to allow sediment deposition

outside of the moveable bed limits (e.g., outside of the main channel) so that deposition patterns of delta and reservoir deposition for the FRO and FRFA scenarios could be modeled.

#### *2.3.2.1 FRO, FRFA, and Climate Change Scenarios*

Following calibration of the HEC-RAS sediment transport model for existing (e.g., no impoundment) conditions, the model was run to simulate the FRO and FRFA impoundments. The HEC-RAS model was initially run for several month time periods around the peak flow events in each of the 5 years with predicted impoundments (January, February, and November 1990, April 1991, February 1996, December 2007, and January 2009) to check for model stability and calibrate gate openings to obtain correct reservoir elevations at each time step. After reservoir operations were calibrated, the record of historic inflows from March 1988 through March 2015 was used to provide a long-term estimate of sediment transport for the FRO and FRFA scenarios. For these long-term runs, time steps were set to 1 day (24 hours) for low flow periods when reservoirs were not operating as flood control facilities and 1-hour time steps for high flow periods when bedload transport occurs and/or the reservoirs were operating as flood retention facilities.

Climate change scenarios for the Existing Conditions (no impoundment), FRO, and FRFA conditions were run using a flow record developed by Anchor QEA and WSE based on climate change modeling for the Chehalis Basin. Peak flows were increased from 16 percent (for 2-year recurrence interval peak flow) to 66 percent (for a 100-year recurrence interval peak flow) which resulted in increased peak flow and sediment input magnitudes and frequencies.

# 3 RESULTS

## 3.1 Large Woody Debris

### 3.1.1 Large Woody Debris in the Chehalis River

The mainstem Chehalis River wood load is very low and is less than the large wood piece quantities or volumes for natural and unmanaged watersheds referenced by Fox and Bolton (2007). The wood load results for the upper Chehalis River sites are summarized in Table 3.1. In the mainstem Chehalis River (downstream of the confluence of the East and West Forks), the large wood load (volume) ranged from 0.9% to 5.6% of the Fox and Bolton (2007) recommended restoration target, and for the wood load (pieces) the count ranged from 0.6% to 7.5% of the recommended restoration target (see Table 3.1). However, the one site surveyed on the West Fork Chehalis River did exceed the 25th percentile of the restoration target for wood pieces (see Table 3.1). During the 2015 surveys, no logs were identified along the mainstem Chehalis River that met the referenced Fox and Bolton (2007) definition of a key log (minimum volume of 10.75 cubic meters [264.8 cubic feet]) for a channel of 50 to 100 meters (164 to 328 feet) bankfull width.

**Table 3.1**
**Upper Mainstem Chehalis River Existing Wood Load Summary**

| RIVER MILE | WOOD LOAD (VOLUME)[A,B] $M^3$/100 METERS (FEET3/328 FEET)[C] | RESTORATION TARGETD $M^3$ ($FEET^3$) | PERCENT OF RESTORATION TARGET[D] | WOOD LOAD (COUNT) PIECES/100 METERS (328 FEET)[C] | RESTORATION TARGET[C,E] PIECES/100 METERS (328 FEET)[C] | PERCENT OF RESTORATION TARGET[D] |
|---|---|---|---|---|---|---|
| West Fork (RM 1) | 22 (776.8) | 99 (3,496) | 22.2 | 21.3 | 63 | 33.8 |
| 118 | 17.9 (632) | 317 (11,193) | 5.6 | 15.7 | 207 | 7.5 |
| 116 | 3.1 (109.5) | 317 (11,193) | 1.0 | 6.7 | 207 | 3.2 |
| 115 | 4.2 (148.3) | 317 (11,193) | 1.3 | 4.7 | 207 | 2.3 |
| 112 | 4.2 (148.3) | 317 (11,193) | 1.3 | 6.0 | 207 | 2.9 |
| 110 | 2.8 (98.9) | 317 (11,193) | 0.9 | 3.0 | 207 | 1.4 |
| 105.5 | 13.7 (483.7) | 317 (11,193) | 4.3 | 10.0 | 207 | 4.8 |
| 101.5 | 4.2 (148.3) | 317 (11,193) | 1.3 | 3.3 | 207 | 1.6 |
| 93.5 | 2.8 (98.9) | 317 (11,193) | 0.9 | 1.3 | 207 | 0.6 |
| 92.3 | 11 (388.41) | 317 (11,193) | 3.5 | 9.7 | 207 | 4.7 |
| 87 | 10 (353.1) | 317 (11,193) | 3.2 | 8.7 | 207 | 4.2 |

Notes:
a. Wood data were collected October 6 through 9, 2015 and November 4 through 6, 2015, by Anchor QEA.
b. For wood volume, Fox and Bolton (2007) identify the 75th percentile as 317 cubic meters ($m^3$) per 100 meters (11,193 cubic feet [$feet^3$] per 328 feet) for these unmanaged systems.
c. Per 100 meters of channel length.

d. Restoration targets were obtained from Fox and Bolton (2007). These targets are the 75th percentile distribution of wood inventory, are based on bankfull width, and are presented in Table 4 of Fox and Bolton 2007.
e. Fox and Bolton (2007) identify the 75th percentile as 207 pieces per 100 meters (328 feet) for natural and unmanaged watersheds in Western Washington that have a bankfull width between 30 and 100 meters (98 to 328 feet)

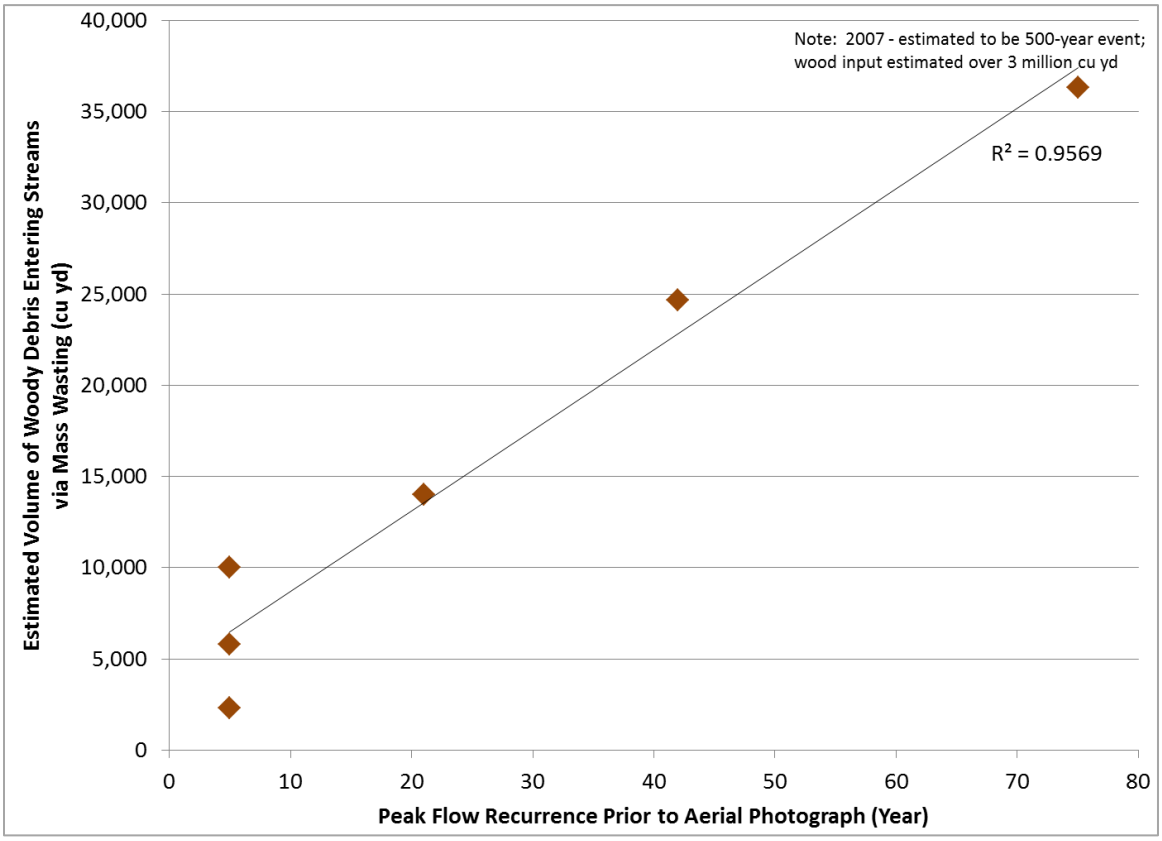
### 3.1.2 Wood and Debris Input Upstream of RM 108

The primary mechanism for wood and debris input to streams upstream of the potential impoundment is via landslides that bring rock, soil, trees, and brush into the stream system. During peak flows, the soil and debris is transported downstream. The FRO dam is designed to pass sediment and debris up to a 3-foot-diameter root wad or logs up to 15 feet long. However, if the FRO facility is impounding water during a flood, much of the wood and debris would be retained in the reservoir. The FRFA impounds water at all times and would also capture wood and debris during all floods. An estimate of the total volume of logs, root wads, limbs, and woody debris based on landslide inputs during past storms is provided in Table 3.2 and Figure 3.1.

**Table 3.2**
**Estimated Volume of Wood and Debris Input to Streams from Past Storms**

| AERIAL PHOTOGRAPH YEAR | VOLUME OF WOOD AND DEBRIS (CUBIC YARDS) | HIGHEST FLOW RECURRENCE IN AERIAL PHOTOGRAPH PERIOD |
|---|---|---|
| 1955 | 5,800 | 5 |
| 1965 | 10,000 | 5 |
| 1978 | 14,000 | 21 |
| 1987 | 2,300 | 5 |
| 1993 | 25,000 | 42 |
| 1996 | 36,000 | 75 |
| 2008 | 3,300,000 | 500 +/- |

**Figure 3.1**
**Estimated Volume of Wood and Debris Versus Flood Recurrence Interval**




Wood and debris from large floods in the FRO and FRFA facilities would be collected by floating log booms and boats and towed to a debris handling site near RM 109.9 to 109.6 (Anchor QEA 2016). Collected wood would be removed from the reservoir impoundment area. Some of the logs and root wads could be trucked downstream of the dam or used in aquatic species restoration or riparian enhancement projects. A wood and debris management plan would be developed as part of future planning documents to specify handling and placement of collected wood and debris.

### 3.1.3 Comparison of Pre- and Post-2007 Storm LiDAR Data

LiDAR data are available for parts of the upper Chehalis Basin from 2006 and 2015; the data from the two datasets, which is a representation of the ground surface, were overlain to show differences between the 2006 and 2015 topography. The two datasets had an overlapping area of approximately 8,300 acres in the upper Chehalis Basin between RM 107.5 and 115. Each of the LiDAR datasets consists of 1-meter square grids, with each grid cell assigned an elevation representative of that 1-meter square area. Inaccuracies in the datasets themselves, as well as the potential for differences in the average elevation assigned to a particular grid cell in steeply sloping areas, provide potential sources of error in the comparison between the two datasets. However, overlaying the two datasets does provide the opportunity to identify areas of changing topography, such as areas evacuated by landslides, landslide

runout/accumulation zones, channel erosion and accumulation areas, and constructed topographic changes, such as road re-alignments. Though the datasets show net change between 2006 and 2015, the majority of landslides are assumed to have occurred during the 2007 flood. This is based on the extremely high magnitude of that storm, much lower magnitude of other storms between 2006 and 2015, and few landslides observed on aerial photographs between 2007 and 2015. Aerial photographs were used to determine the type of feature represented by net accumulation and degradation—primarily landslide areas, channel changes, accumulations of woody debris, or road re-alignments.

LiDAR data from 2006 and 2015 were used to check the estimates of 2007 flood landslide areas, landslide presence or absence, and estimated slide volumes that were made during previous Chehalis Basin studies (Watershed GeoDynamics and Anchor QEA 2012, 2014). The LiDAR comparison showed that some landslide features were missed, some were inaccurately delineated (either larger or smaller than actual feature), and the volumes of many of the features were overestimated using the average depth method in previous studies (see Figures 3.2 and 3.3). It appears that many of the smaller landslides and narrower debris torrents were not evident on the aerial photographs and thus were not identified, as has been shown in detailed studies in other watersheds in the Pacific Northwest (e.g., Brardinoni et al. 2003 found that 85% of landslides were missed in heavily timbered areas). Based on the analysis of 34 landslides shown in Figure 3.3, the average depth method used in previous studies overestimated landslide volume by 70%. Because the LiDAR comparison area did not cover the entire study area, the total area and volume of 2007 landslides could not be calculated from the LiDAR data. As a result, the magnitude of the inaccuracies in the previous analysis over the entire Chehalis Basin could not be determined, but it is clear that the total calculated volume of sediment delivered from the 2007 landslides should be regarded as an estimate.

The comparison of 2006 and 2015 LiDAR also showed areas of channel/floodplain erosion and aggradation. Based on field observations, it is likely that the majority of this change took place during the 2007 flood when large inputs of sediment, temporary log jams, and bank erosion (often around the log jams) took place. Figure 3.4 shows the net difference in volume of stored sediment in the channel/floodplain between 2006 and 2015, showing the pattern of net bank erosion (areas with net negative storage volume) and aggradation (areas with net positive storage). Note that this analysis does not include changes within the wetted channel at the time of the 2006 and 2015 LiDAR data acquisition since the LiDAR technology used does not penetrate the water surface; only areas above water provide topographic data.

**Figure 3.2**
**Detail of LiDAR Comparison Area**

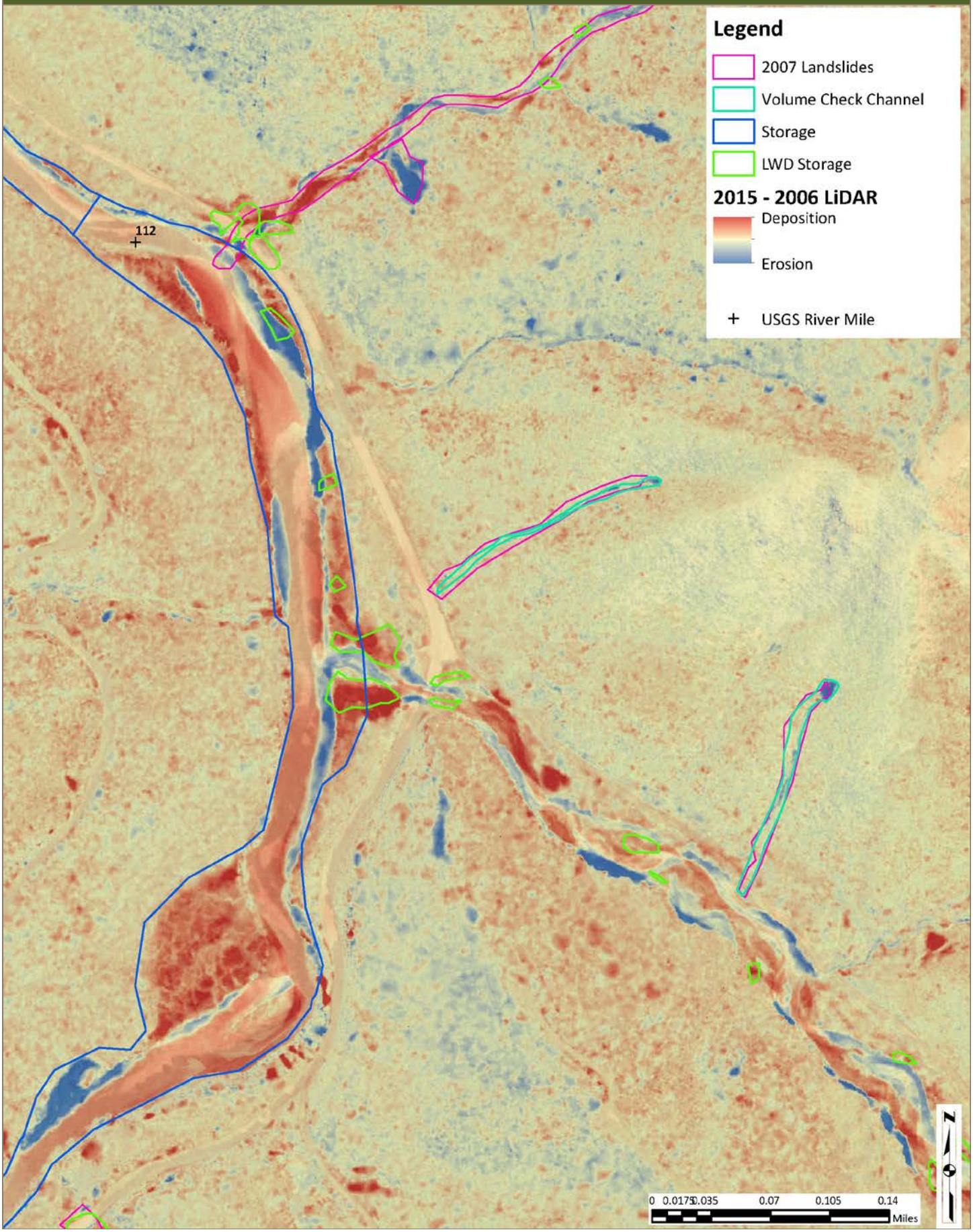
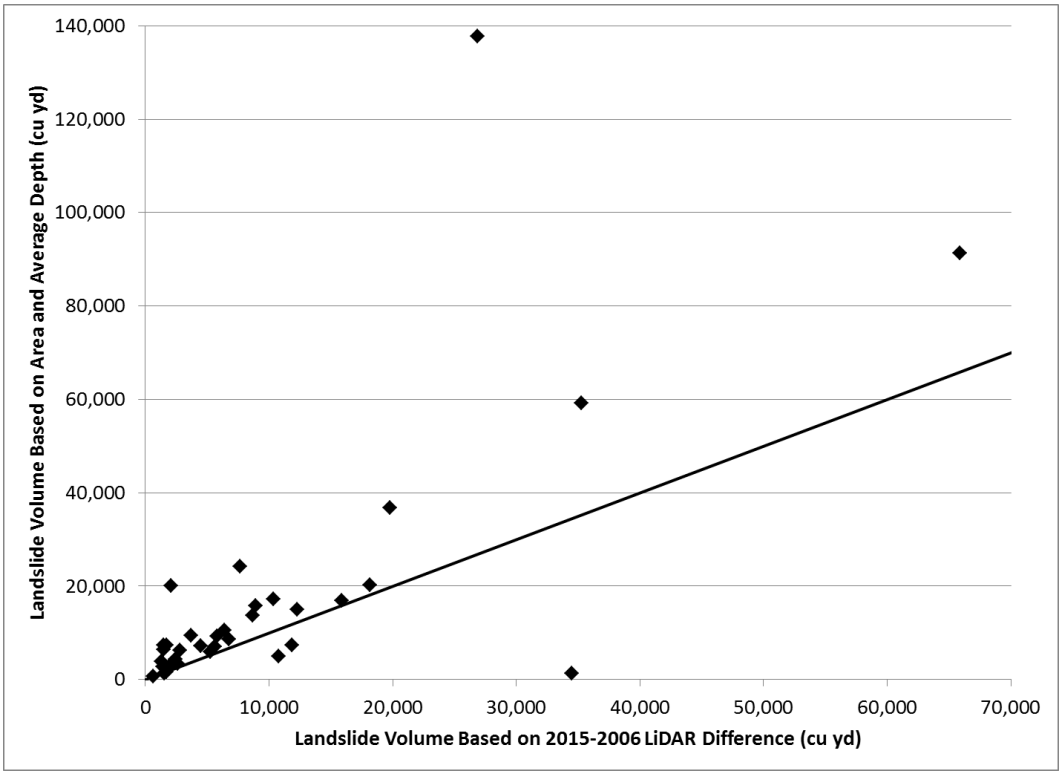
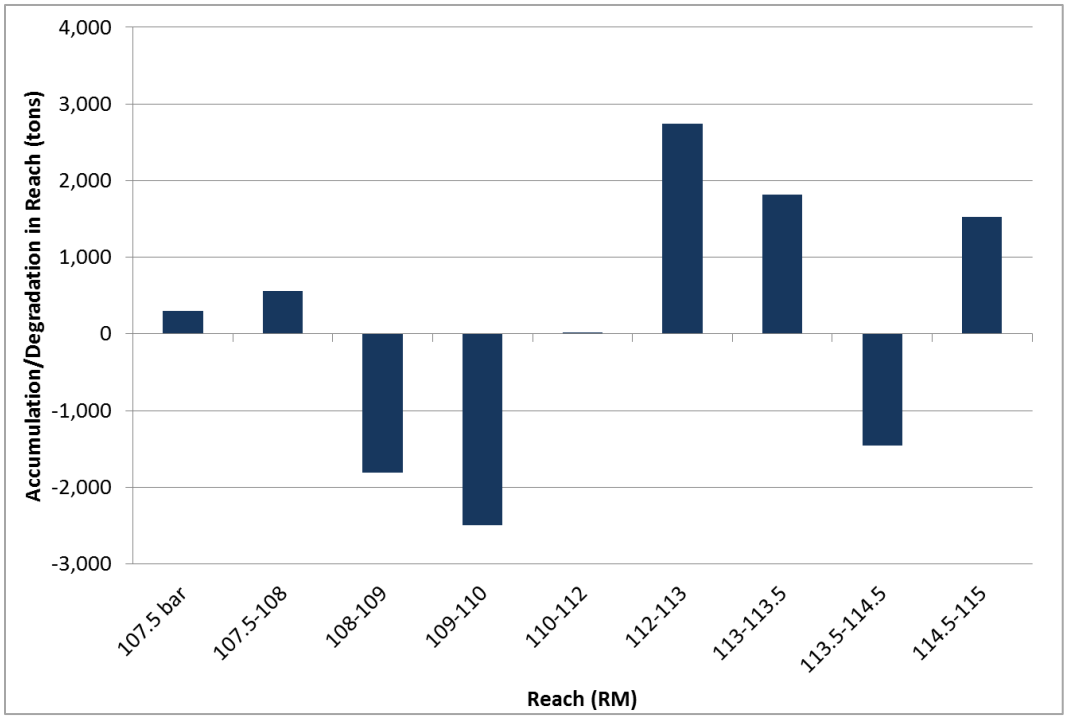


**Figure 3.3**
**Landslide Volume Comparison: LiDAR Versus Area/Average Depth Methods**




Note: Solid black line is 1:1 line; the "Area and Average Depth" method shows results reported in previous analyses (Watershed GeoDynamics and Anchor QEA 2012, 2014)

**Figure 3.4**
**Channel and Floodplain Aggradation/Erosion Based on Comparison of 2006 to 2015 LiDAR**



# 3.2 Substrate Size

Additional pebble counts were collected in 2015 within and just downstream of the proposed impoundment location to supplement previous data collected in 2010. The median ($D_{50}$) and 65th percentile ($D_{65}$; 65% of the particles are finer than this size) grain size of surficial substrate from all samples (2010 and 2015) are shown in Table 3.3 and Figures 3.5 and 3.6. Detailed pebble count data for the 2015 counts are included in Appendix B.

**Figure 3.5**
**Median and $D_{65}$ Grain Size of Surficial Sediment in the Chehalis River**

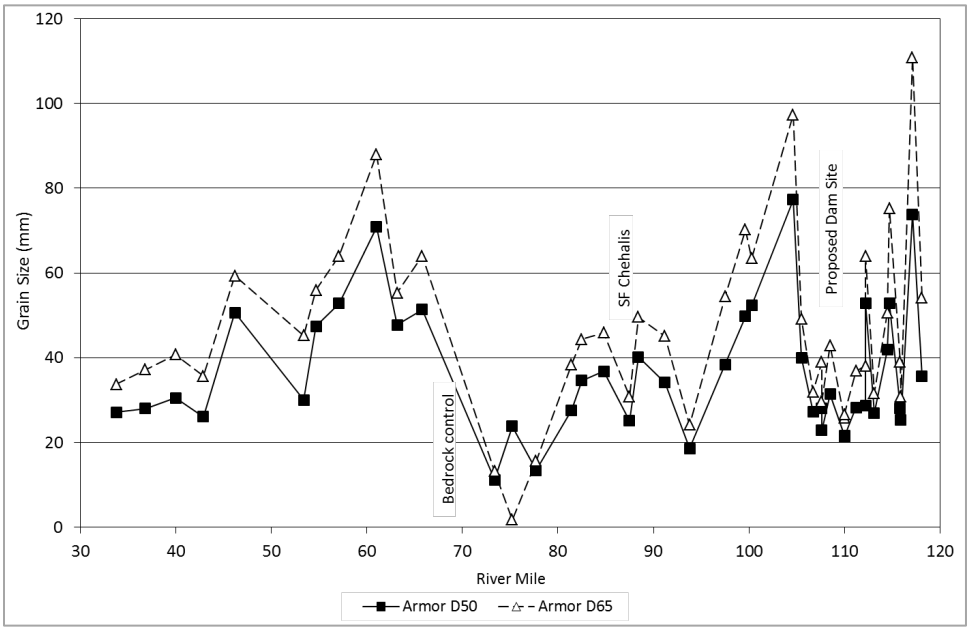



**Figure 3.6**
**Chehalis River Armor Layer Grain Size Distribution**

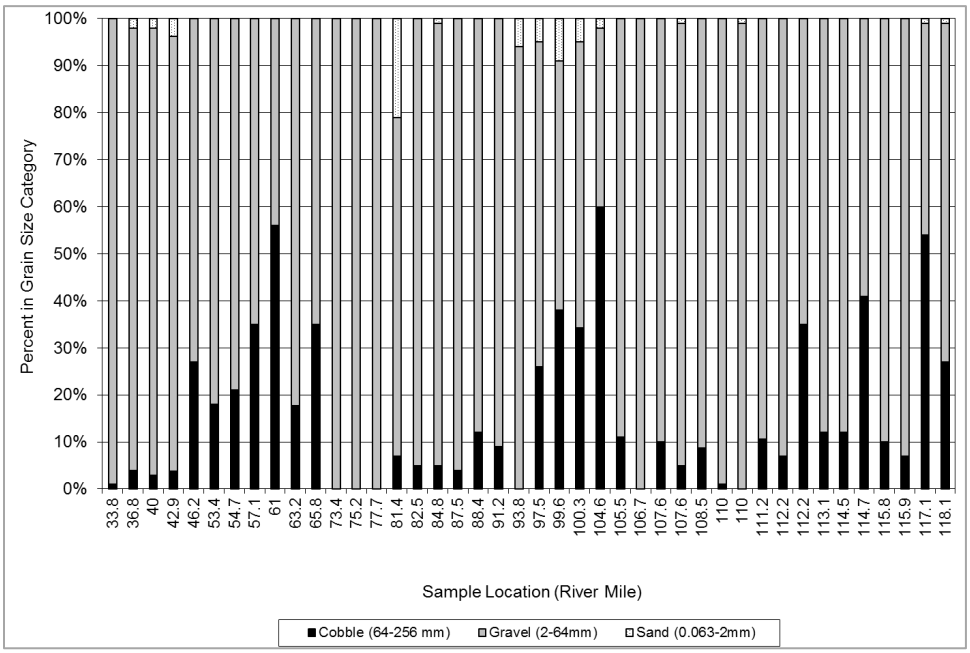


**Table 3.3**

**Chehalis River Surficial Substrate Sample Summary**

| SAMPLE DESIGNATION | RIVER MILE | YEAR SAMPLED | $D_{50}$ (MM) | $D_{65}$ (MM) | COBBLE (64 – 256 MM) | GRAVEL (2 – 64 MM) | SAND (0.063 – 2 MM) |
|---|---|---|---|---|---|---|---|
| Chehalis 1 | 33.8 | 2010 | 34 | 27 | 1% | 99% | 0% |
| Chehalis 2 | 36.8 | 2010 | 37 | 28 | 4% | 94% | 2% |
| Chehalis 3 | 40 | 2010 | 41 | 31 | 3% | 95% | 2% |
| Chehalis 4 | 42.9 | 2010 | 36 | 26 | 4% | 92% | 4% |
| Chehalis 5 | 46.2 | 2010 | 59 | 51 | 27% | 73% | 0% |
| Chehalis 7 | 53.4 | 2010 | 45 | 30 | 18% | 82% | 0% |
| Chehalis 8 | 54.7 | 2010 | 56 | 47 | 21% | 79% | 0% |
| Chehalis 9 | 57.1 | 2010 | 64 | 53 | 35% | 65% | 0% |
| Chehalis 10 | 61 | 2010 | 88 | 71 | 56% | 44% | 0% |
| Chehalis 11 | 63.2 | 2010 | 55 | 48 | 18% | 82% | 0% |
| Chehalis 12 | 65.8 | 2010 | 64 | 51 | 35% | 65% | 0% |
| Chehalis 12.5 | 73.4 | 2010 | 13 | 11 | 0% | 100% | 0% |
| Chehalis 13 | 75.2 | 2010 | 2 | 24 | 0% | 100% | 0% |
| Chehalis 14 | 77.7 | 2010 | 16 | 13 | 0% | 100% | 0% |
| Chehalis 15 | 81.4 | 2010 | 38 | 28 | 7% | 72% | 21% |
| Chehalis 16 | 82.5 | 2010 | 44 | 35 | 5% | 95% | 0% |
| Chehalis 17 | 84.8 | 2010 | 46 | 37 | 5% | 94% | 1% |
| Chehalis 18 | 87.5 | 2010 | 31 | 25 | 4% | 96% | 0% |
| Chehalis 19 | 88.4 | 2010 | 50 | 40 | 12% | 88% | 0% |
| Chehalis 20 | 91.2 | 2010 | 45 | 34 | 9% | 91% | 0% |
| Chehalis 21 | 93.8 | 2010 | 24 | 19 | 0% | 94% | 6% |
| Chehalis 22 | 97.5 | 2010 | 54 | 38 | 26% | 69% | 5% |
| Chehalis 23 | 99.6 | 2010 | 70 | 50 | 38% | 53% | 9% |
| Chehalis 24 | 100.3 | 2010 | 63 | 52 | 34% | 61% | 5% |
| Chehalis 25 | 104.6 | 2010 | 97 | 77 | 60% | 38% | 2% |
| RM 105 | 105.5 | 2015 | 49 | 40 | 11% | 89% | 0% |
| Chehalis 26 | 106.7 | 2010 | 32 | 27 | 0% | 100% | 0% |
| RM 107 boulder bar | 107.6 | 2015 | 39 | 28 | 10% | 90% | 0% |
| RM 107 spawning riffle | 107.6 | 2015 | 30 | 23 | 5% | 94% | 1% |
| RM 108.5 Panesko Bridge | 108.5 | 2015 | 43 | 31 | 9% | 91% | 0% |
| RM 110 Sorting Yard Bridge | 110 | 2015 | 26 | 22 | 1% | 99% | 0% |
| Chehalis 27 | 110 | 2010 | 27 | 21 | 0% | 99% | 1% |
| RM 111 | 111.2 | 2015 | 37 | 28 | 11% | 89% | 0% |
| RM 112 (current bed [finer]) | 112.2 | 2015 | 38 | 29 | 7% | 93% | 0% |
| RM 112 (pre-2007 bed [coarser]) | 112.2 | 2015 | 64 | 53 | 35% | 65% | 0% |
| RM 113 | 113.1 | 2015 | 32 | 27 | 12% | 88% | 0% |
| Chehalis 28 | 114.5 | 2010 | 51 | 42 | 12% | 88% | 0% |
| RM 114 | 114.7 | 2015 | 75 | 53 | 41% | 59% | 0% |
| RM 116 (scour monitor site) | 115.8 | 2015 | 39 | 28 | 10% | 90% | 0% |
| RM 116 (spawning-sized gravel deposit) | 115.9 | 2015 | 31 | 25 | 7% | 93% | 0% |
| RM 117 | 117.1 | 2015 | 111 | 74 | 54% | 45% | 1% |
| RM 118 | 118.1 | 2015 | 54 | 36 | 27% | 72% | 1% |

Notes:
mm: millimeters
RM: river mile

## 3.3 Scour Monitors

Scour monitors at the six sites in the Chehalis River recorded a range from no scour or fill to up to 0.4 foot of scour and 1 foot of fill following a flow of 5,840 cfs at the Doty gage and 5,830 cfs at the Mahaffey Creek gage (see Table 2.2 and Section 2.2.2). Following a flow of 14,000 cfs at the Doty gage (9,230 cfs at the Mahaffey Creek gage), a minimum of 1 foot of scour and 0.5 foot of fill was recorded, but only 4 of the 12 scour monitors were found after the 14,000 cfs flow; visual observations suggested that the channel had filled and buried the monitors (see Table 3.4) and was likely 1 to 2 feet deep. The channel had scoured locally around a newly fallen tree at the RM 105.5 site; these monitors were not found and presumably scoured out. Substrate up to 64 mm was mobilized during the 5,840 cfs event and up to 300 mm during the 14,000 cfs event.

**Table 3.4**
**Scour and Fill Measurements**

| LOCATION | ESTIMATED WATER DEPTH (FEET) AND GRAVEL SIZE MOVED AT 5,840 CFS | SCOUR AFTER 5,840 CFS (FEET) | FILL AFTER 5,840 CFS (FEET) | ESTIMATED WATER DEPTH (FEET) AT 14,000 CFS | SCOUR AFTER 5,840 CFS (FEET) | FILL AFTER 5,840 CFS (FEET) |
|---|---|---|---|---|---|---|
| RM 88 A | 8 feet deep; little moved | 0 | 0.08 | 8.8 feet | 0.3 | Unknown |
| RM 88 B | | 0 | 0 | | 0.4 | Unknown |
| RM 105.5 A | 5 feet deep; 45-64 mm | 0 | 0.80 | 9.7 feet | Not found | Not found |
| RM 105.5 B | | 0.4 | 0.5 – 0.8 | | Not found | Not found |
| RM 107.5 A | 5 feet deep; up to 64 mm | 0 | 0.5 – 0.8 | 6.8 feet | Not found | Not found |
| RM 107.5 B | | 0.1 | 0.5 – 0.8 | | Not found | Not found |
| RM 108.5 A | 5 feet deep; up to 64 mm | 0.2 | 0.2 | Not recorded | Not found | Not found |
| RM 108.5 B | | 0 | 0.3 | | Not found | Not found |
| RM 110 A | 4 feet deep; up to 64 mm | 0.1 | 0.2 | 5.7 feet; 300 mm boulder moved | 0.5 | 0 |
| RM 110 B | | 0 | 0.3 | | 1 | 0.5 |
| RM 116 A | 4.5 feet deep; up to 64 mm | Not found | Not found | 6 feet | Not found | Not found |
| RM 116 B | | 0.2 | 0.8 – 1 | | Not found | Not found |

Notes:
cfs: cubic feet per second
mm: millimeter
RM: river mile

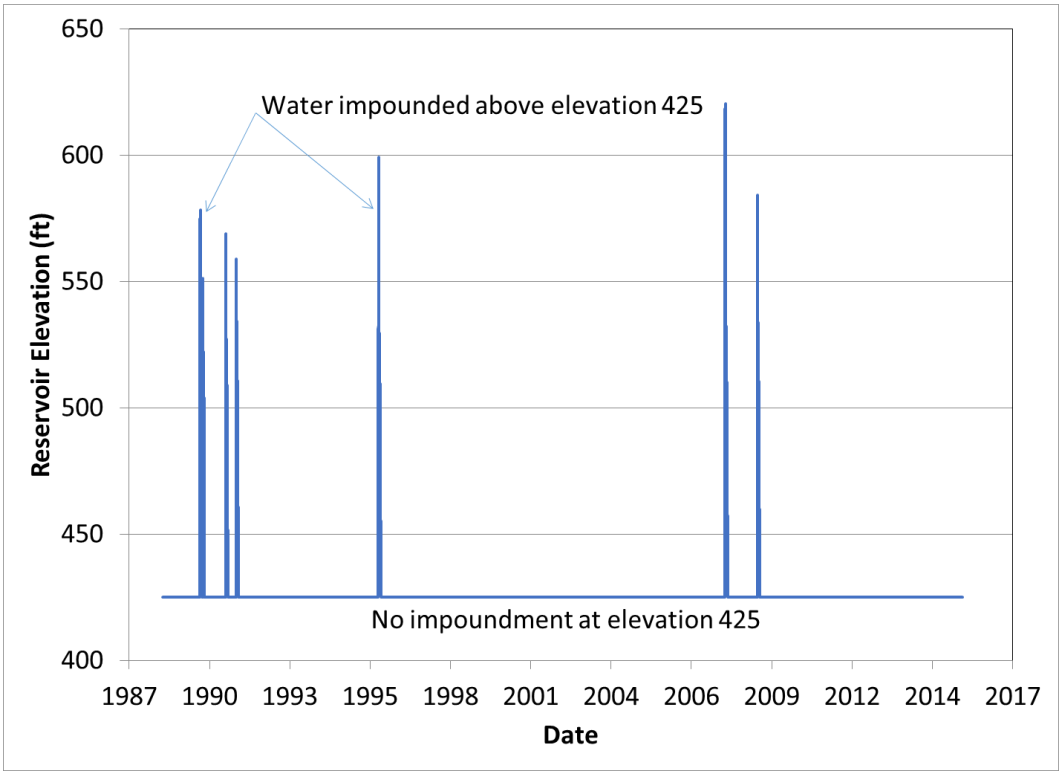
## 3.4 Sediment Transport Potential Through Impoundments

### 3.4.1 Flood Retention Only Reservoir

The FRO facility reservoir (dam at RM 108.2) would impound water when flows at the Grand Mound gage are predicted to exceed 38,800 cfs. Water would be impounded until the flow at Grand Mound is

below 38,800 cfs, at which point the reservoir will be drawn down at a rate of 10 feet per day until it reaches elevation 528 feet (approximately RM 109.9), then drawdown would slow to 2 feet per day for debris management. When the reservoir reaches elevation 500 feet (approximately RM 109.6), the 10-foot-per-day drawdown rate would resume. Based on modeling by Anchor QEA for historical flows from 1988 to 2015, the reservoir would have impounded water seven times during this 27-year period (see Figure 3.7.)

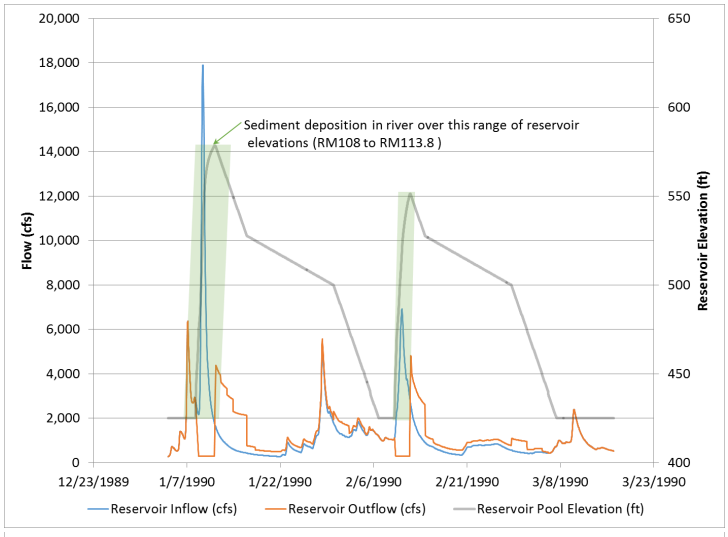
**Figure 3.7**
**FRO Facility Reservoir Elevation for 1988 to 2015 Flows**

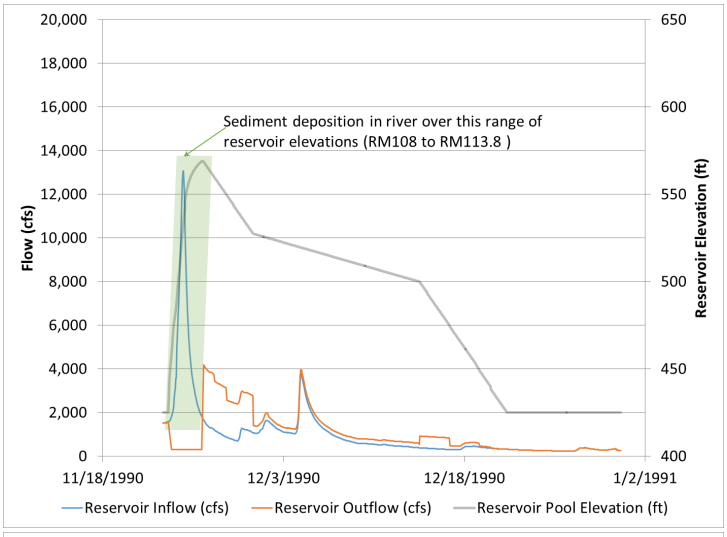


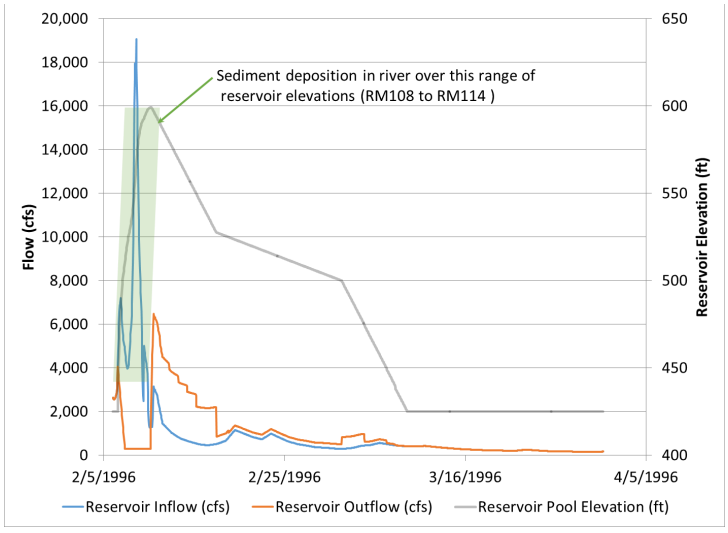

During times when the reservoir is not impounding water, water, sediment, and LWD would flow through the lower outlet structures of the dam and be transported downstream. When the reservoir is impounding water, sand and coarser sediment and woody debris would be deposited or trapped in the reservoir. Based on the 1988 to 2015 flows, water would have been impounded approximately 1 month during six of the seven floods, and approximately 2 months during the 2007 event (see Figure 3.8). Incoming sediment would be deposited in the channel at the elevation of the reservoir as the impoundment filled, and then the deposited sediment would be transported downstream as the reservoir emptied if inflow was large enough to transport the deposited sediment.

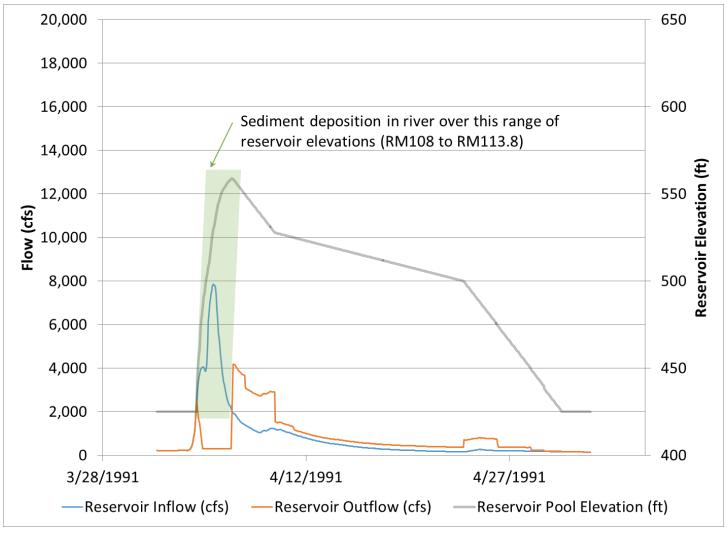
**Figure 3.8**

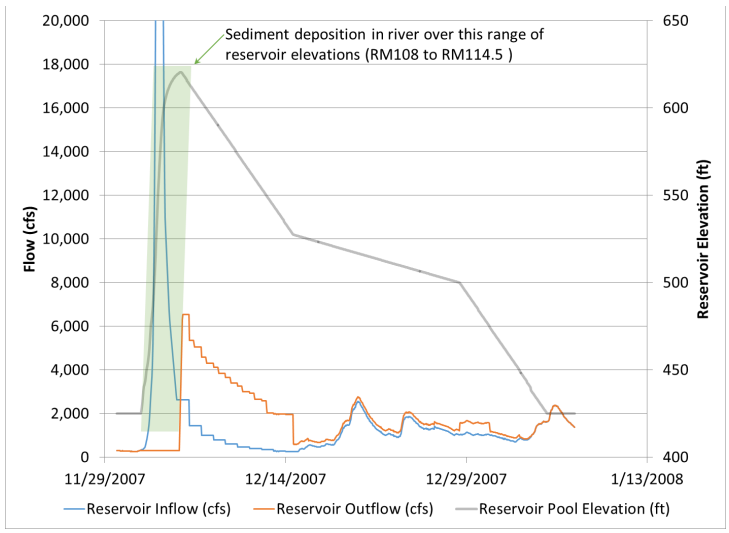
**FRO Facility Reservoir Elevation, Inflow, and Outflow for Peak Flow Events**

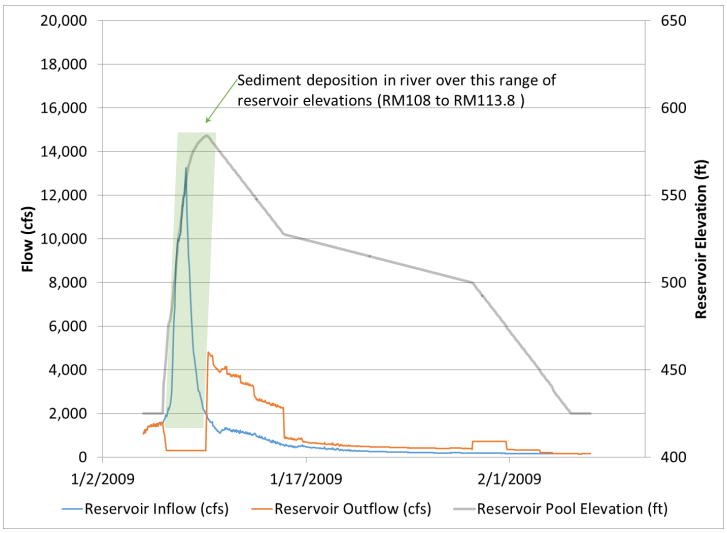


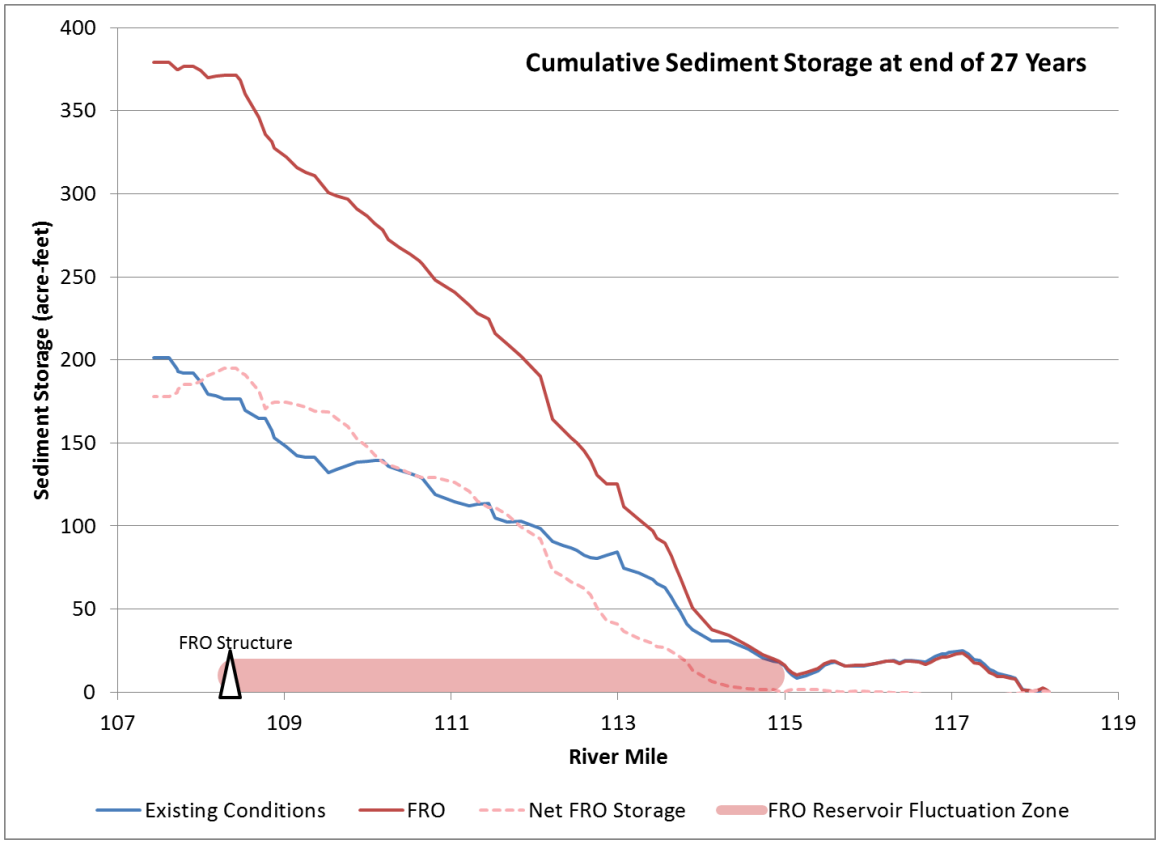



Modeling of long-term sediment transport trends using 1988-2015 flows was performed to compare a no-dam (existing conditions) scenario to the with-FRO scenario. The operating range of the FRO is between elevation 425 to 619 feet; the resulting reservoir fluctuation zone extends between the dam at RM 108.2 and RM 115. During times when the reservoir impounds water, sediment deposits at the head of the reservoir. When the reservoir drains, much of the deposited sediment is transported through the reservoir. Figure 3.9 shows the cumulative change in sediment storage plotted longitudinally along the channel at the end of the 1988-2015 model runs. The FRO facility would retain approximately 23 to 45% of the bedload and 20% of the fine sediment load, an estimated 200 acre-feet more than under existing/no impoundment conditions.

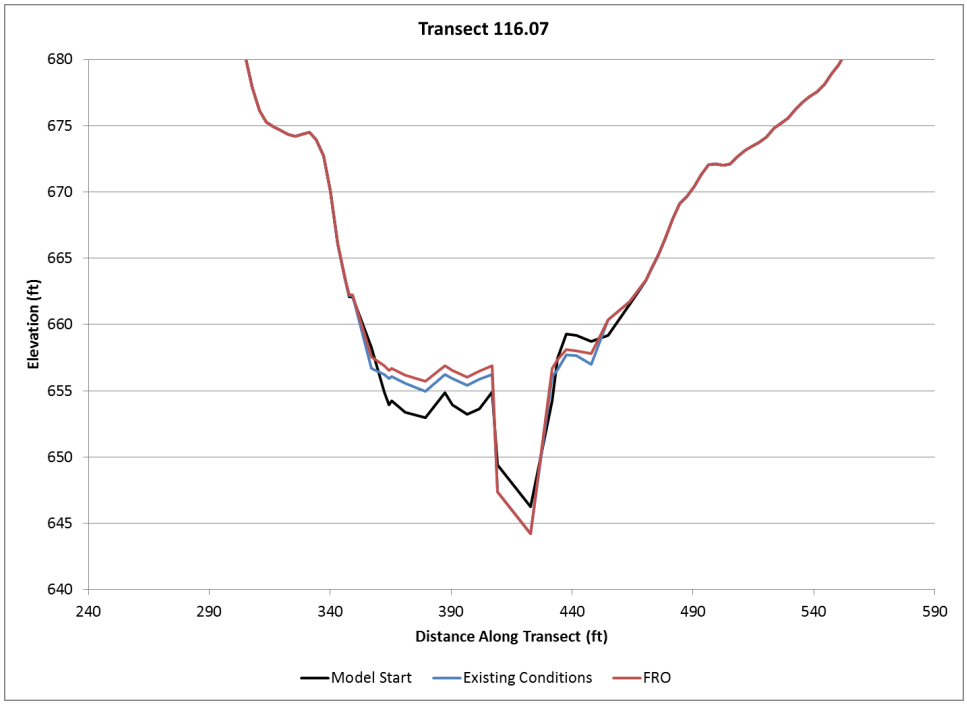
**Figure 3.9**
**Cumulative Sediment Storage at End of 1988-2015 HEC-RAS Model Run – FRO and Existing Conditions**



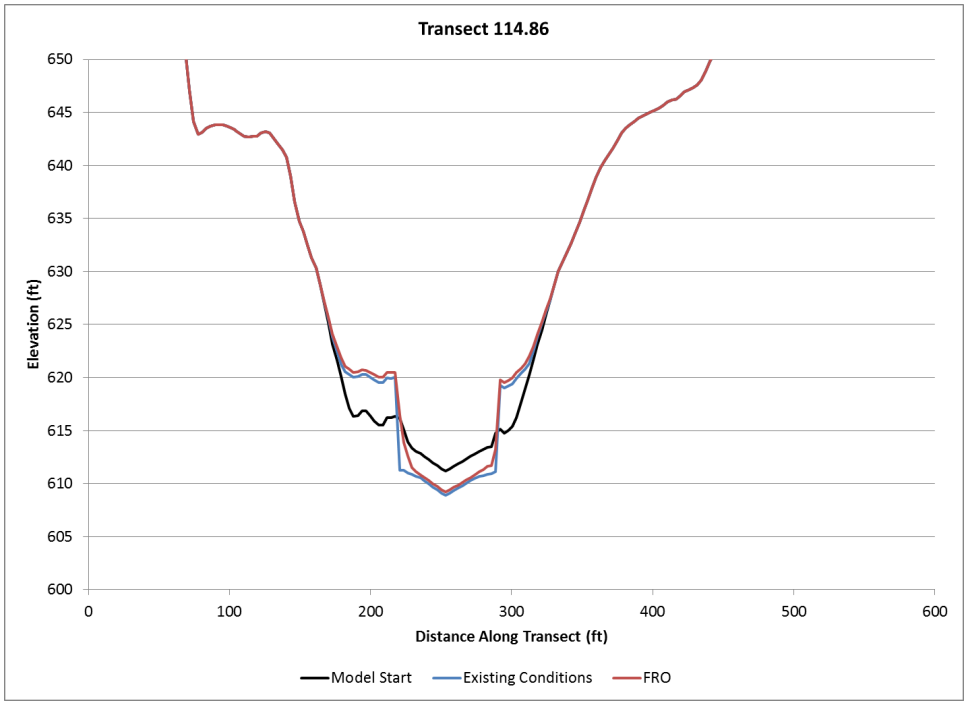

The longitudinal plot (Figure 3.9) as well as plots of cross sections at individual transects (Figure 3.10) show net aggradation within the fluctuation zone and net degradation downstream of the FRO structure. The majority of deposition is between RM 111 and 114, but there is also net deposition between the dam (RM 108.2) and RM 111. Much of the long-term deposition occurs outside of the low flow channel. Cross sections show that while deposits occur at the upstream end of the pool across the wetted channel during times of impoundment, much of the deposited sediment is moved out of the

channel itself by subsequent high flows when there is no impoundment (Figure 3.10). There would be larger deposits at the upstream end of the reservoir during large floods as material is deposited at the (moving) head of the reservoir, with higher concentrations of fine sediment in the deposits compared to existing conditions. The deposits would be similar to the channel deposits upstream of the transient log jams during the 2007 flood; the channel responded to the 2007 features by temporarily widening within the deposition zone and then cutting a new channel through the deposits; this provides a good analogy for how the channel would respond to the FRO delta deposits.

**Figure 3.10**
**Transect Cross Sections, 1988-2015 HEC-RAS Model Run – Existing Conditions and FRO**



Transect 115.25
Elevation (ft)
670
665
660
655
650
645
640
635
630
625
620
200
250
300
350
400
450
500
550
600
650
700
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO


Transect 114.86
Elevation (ft)
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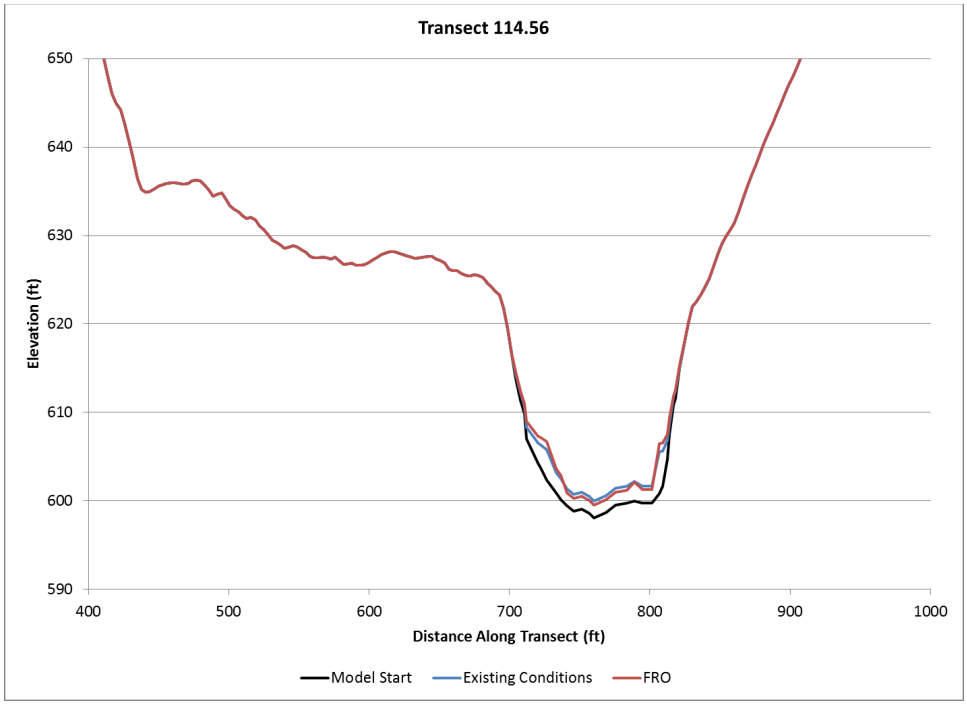
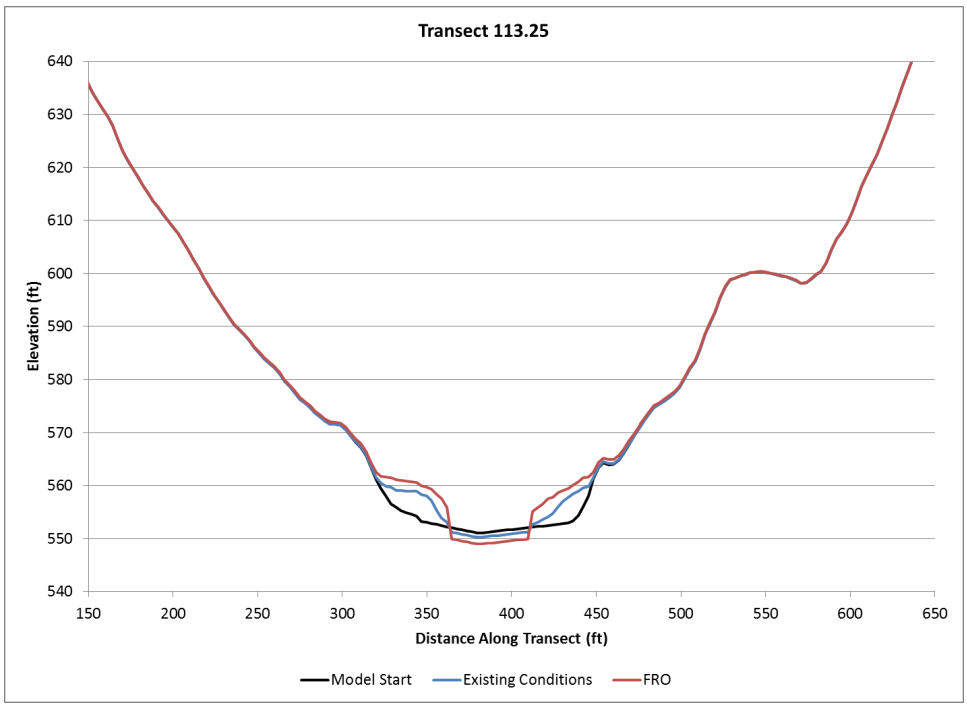
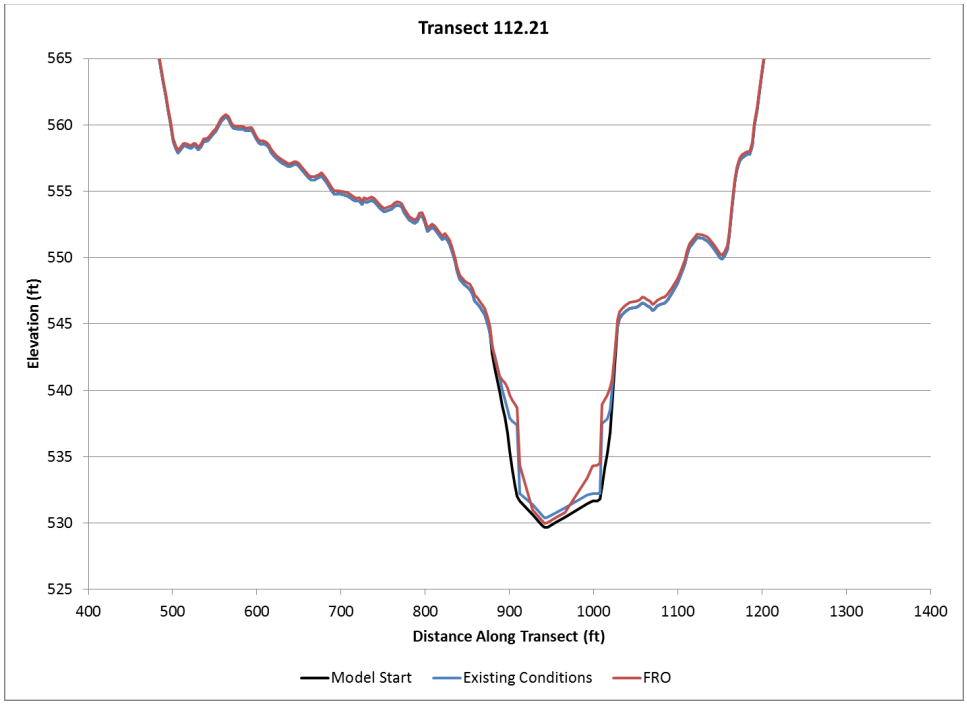
645
640
635
630
625
620
615
610
605
600
0
100
200
300
400
500
600
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO


Transect 114.56
650
640
630
620
610
600
590
Elevation (ft)
400
500
600
700
800
900
1000
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO


Transect 113.25
640
630
620
610
600
590
580
570
560
550
540
Elevation (ft)
150
200
250
300
350
400
450
500
550
600
650
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO


Transect 112.21
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545
540
535
530
525
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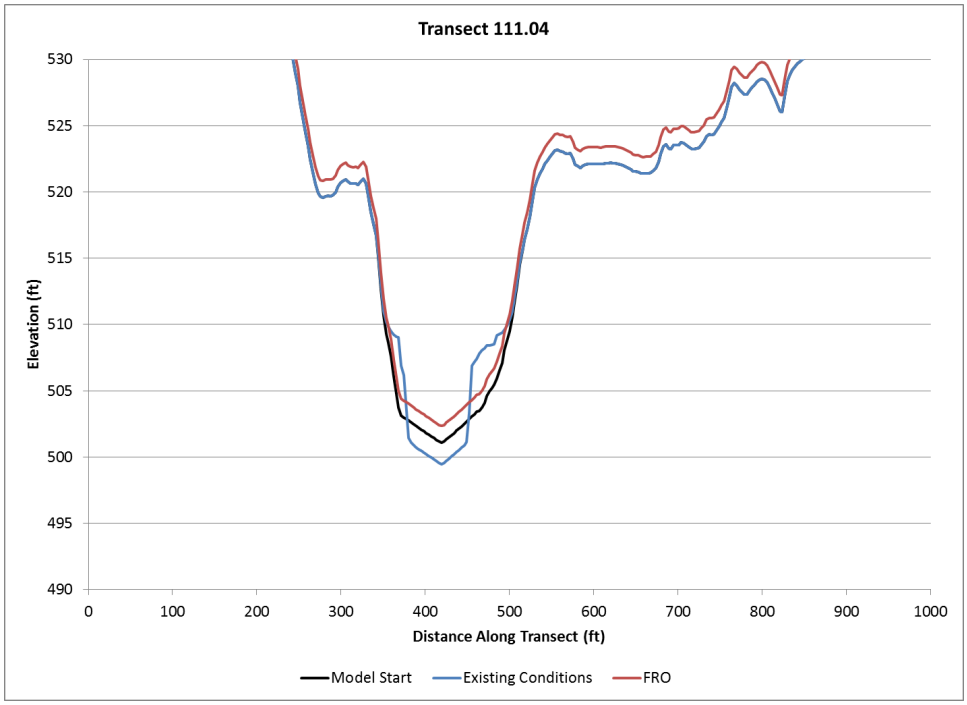
600
700
800
900
1000
1100
1200
1300
1400
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO


Transect 111.04
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525
520
515
510
505
500
495
490
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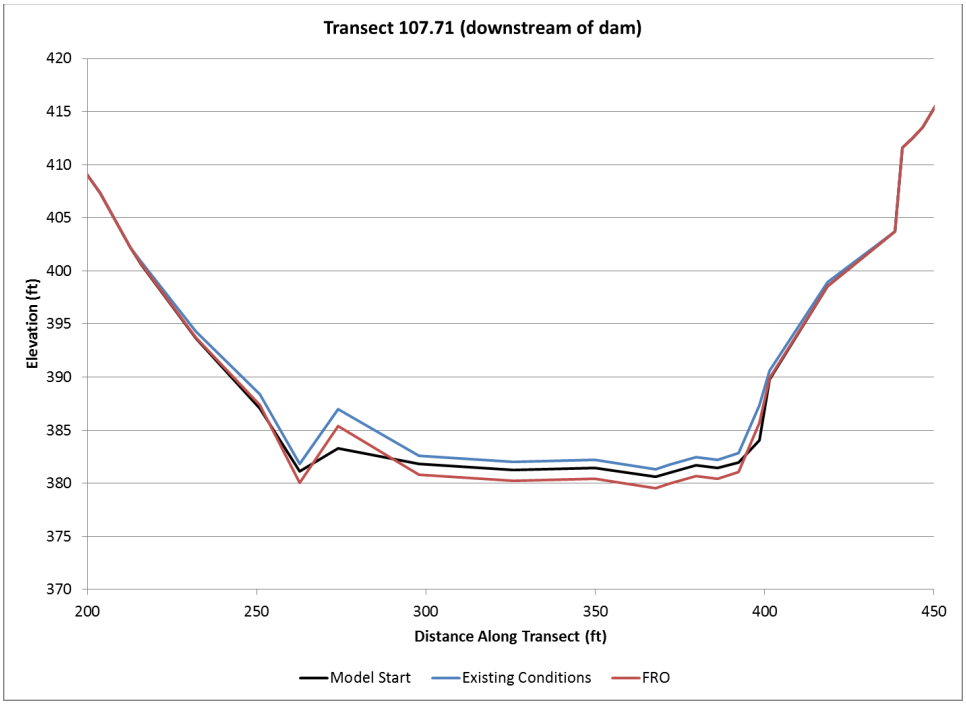
100
200
300
400
500
600
700
800
900
1000
Distance Along Transect (ft)
Model Start
Existing Conditions
FRO



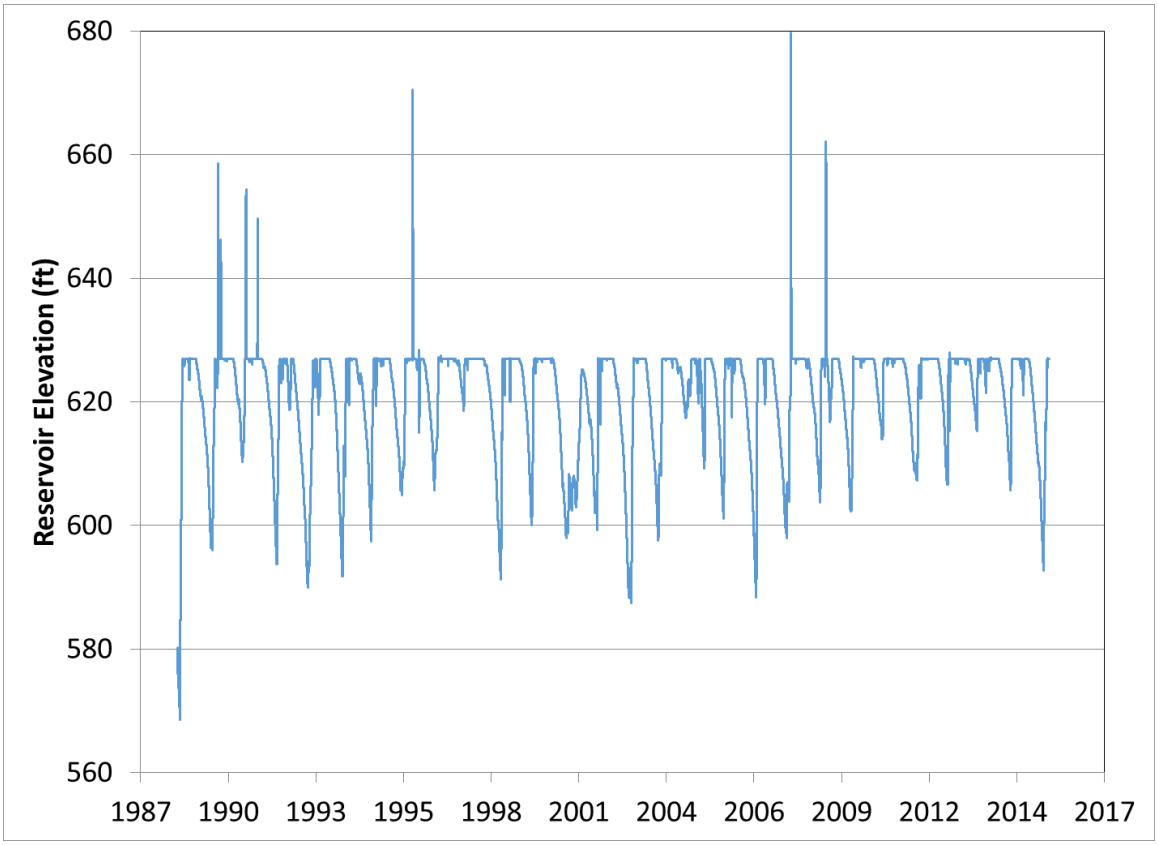

The HEC-RAS model does not replicate the 2007 flood event for existing conditions well, so the predicted FRO model results for the 2007 event are not well represented. During the 2007 flood (an event with an approximately 500-year return period or 0.2% chance of occurrence in any single year), 5 to 7 million cubic yards of sediment and debris were predicted to have been delivered to streams upstream of the FRO reservoir during that flood. If the FRO was in operation, the majority of this material would have been deposited or retained within the reservoir. The coarse material would have formed a delta between RM 113 to 115 and within the major tributary valleys (Crim, Lester, and other reservoir tributary creeks). The fine sediment (silt, clay, fine sand) would have been transported into the reservoir and some portion would have been deposited over the bottom of the pool area. Some of the fine sediment would have been re-entrained during rainfall events and/or shoreline erosion as the reservoir dropped and would potentially increase downstream turbidity during subsequent storm events until the material stabilized or revegetated. Wood and floatable debris (an estimated 2 to 3 million cubic yards) would have been retained in the reservoir. This magnitude of disturbance would have had a major impact on the entire impoundment area for over a decade, as the river reworked the large delta deposit (not modeled, but likely a 25- to 30-foot-deep delta between RM 115 and 114 that would be re-worked as the reservoir level dropped).

### 3.4.2 Flood Retention Flow Augmentation Facility

The FRFA facility reservoir (dam at RM 108.2) would impound water at all times with a normal pool elevation of approximately 627 feet. When flows at the Grand Mound gage are predicted to exceed 38,800 cfs, the pool would gradually be filled until the flood at Grand Mound is passed, at which point

the reservoir will be drawn down at a rate of 10 feet per day until it reaches elevation 627 feet. During times of low flow, the reservoir would be drawn down below elevation 627 feet to supplement downstream base flows. Based on modeling by Anchor QEA for historical flows from 1988 to 2015, the reservoir would have impounded water above elevation 626 feet six times over this 27-year period, and the lowest the pool would have been drawn down to supplement flows was approximately 588 feet (see Figure 3.11).

**Figure 3.11**
**FRFA Facility Reservoir Elevation for 1988 to 2015 Flows**




The FRFA conservation pool would always have some level of impoundment, so all sand and coarser sediment and most woody debris would be deposited or trapped in the reservoir along with some fraction of the fine-grained sediment (silt, clay). Based on the 1988 to 2015 flows, water would have been impounded in the flood storage pool (above elevation 625 feet) for 1 month during five of the six floods, and for up to 2 months during the 2007 event. The operating range of the FRFA facility is between elevation 587 to 689 feet and extends between RM 114 and 117. Incoming sediment would be deposited in the channel at the elevation of the reservoir as the impoundment filled, and then the deposited sediment would be transported downstream as the reservoir water levels decreased if inflow was large enough to transport the deposited sediment.

Modeling of sediment transport using 1988-2015 flows was performed to compare the existing conditions scenario to the with-FRFA scenario. The change in the volume of stored sediment (Figure 3.12) shows the formation of a delta between RM 114 and RM 115, as well as deltas at the mouths of the major tributaries between RM 108 and 114. The comparison of cross sectional profiles (Figure 3.13) shows that shows up to 25 feet of aggradation in the FRFA mainstem delta area with a channel cut through the deposits. The delta and total fluctuation zone (RM 114-117) would contain a mix of fine and coarse substrate, would have a relatively unstable configuration with little riparian vegetation, and would not provide high quality aquatic habitat.

The FRFA facility would retain all bedload and approximately 76% of the suspended load (fine sand, silt, clay), which is equivalent to approximately 1,300 acre feet over the 27 years of modeled flows. Silt and clay which remains in suspension through the reservoir would be transported through the dam and into the river downstream. There would be net erosion (degradation) of substrate in the channel areas immediately downstream of the FRFA dam as high flows scour gravel and cobble accumulations, but many of the cross sections are bedrock canyons so little erosion would occur in those areas.

**Figure 3.12**
**Sediment Storage at End of 1988-2015 HEC-RAS Model Run – Existing Conditions and FRFA**

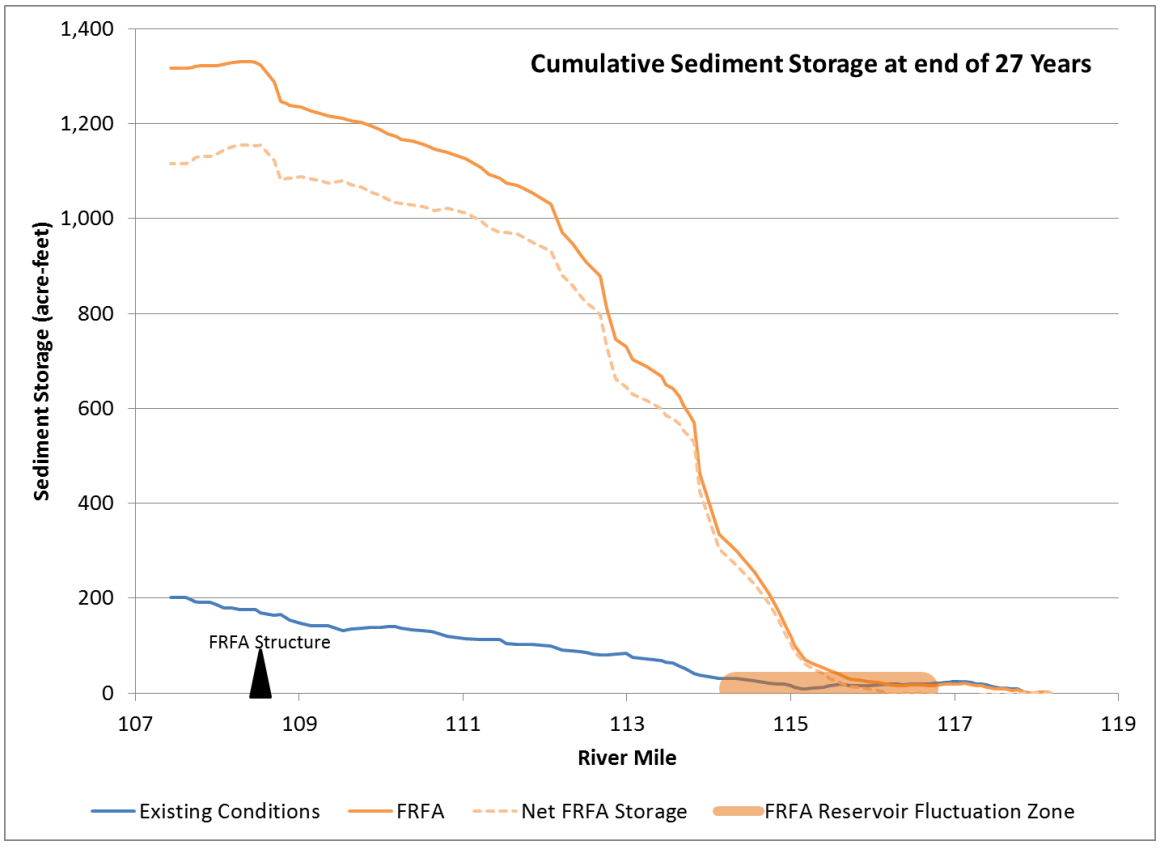
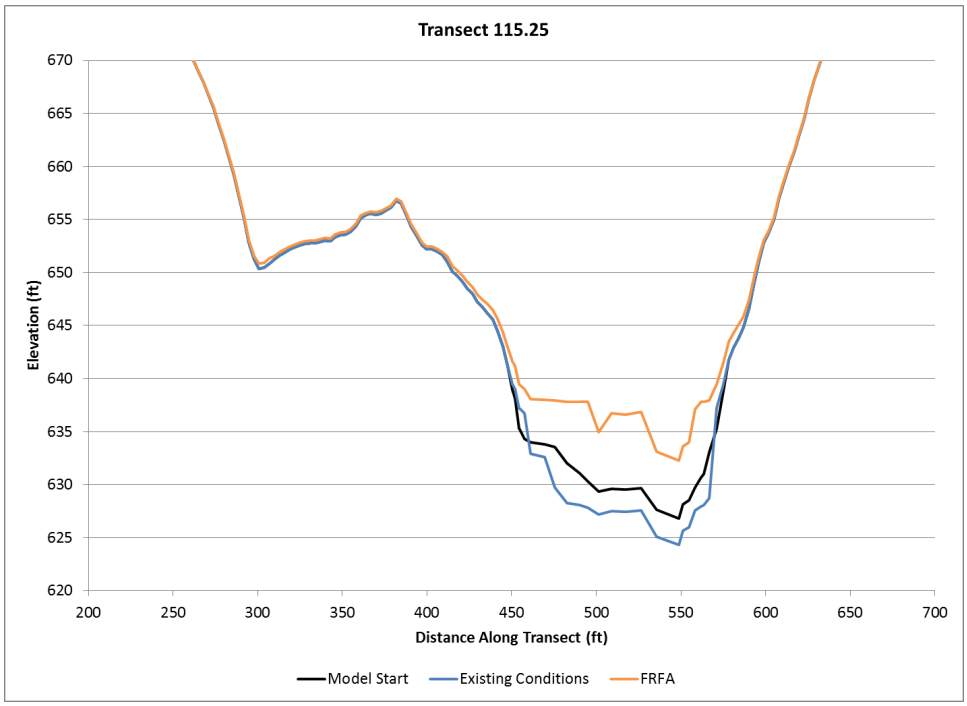
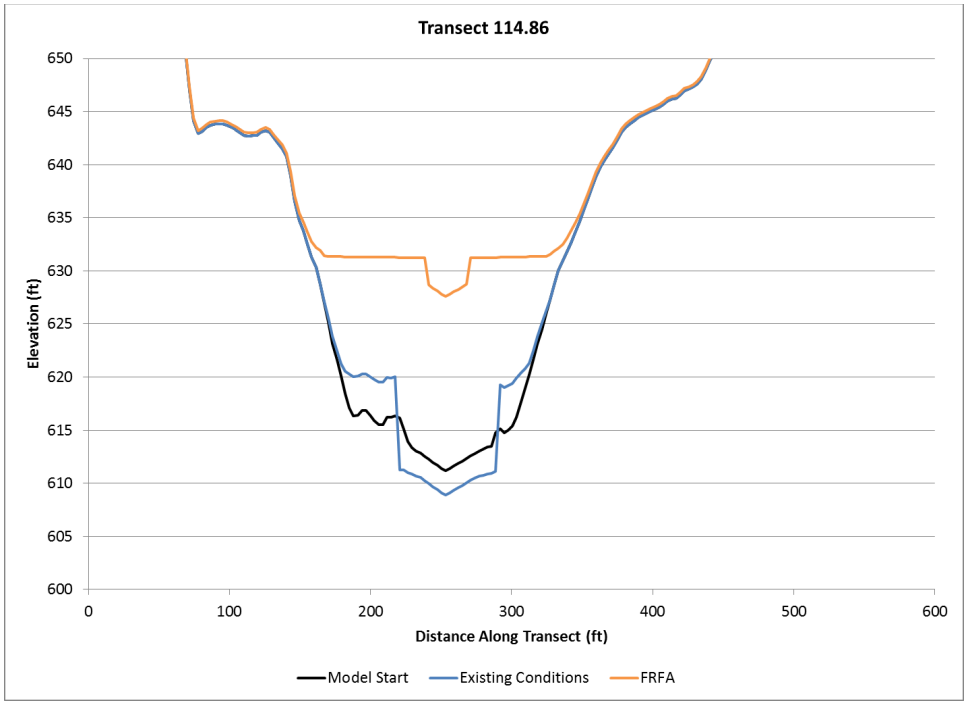


**Figure 3.13**
**Transect Cross Sections, 1988-2015 HEC-RAS Model Run – No Dam and FRFA**




Transect 114.86
650
645
640
635
630
625
620
615
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605
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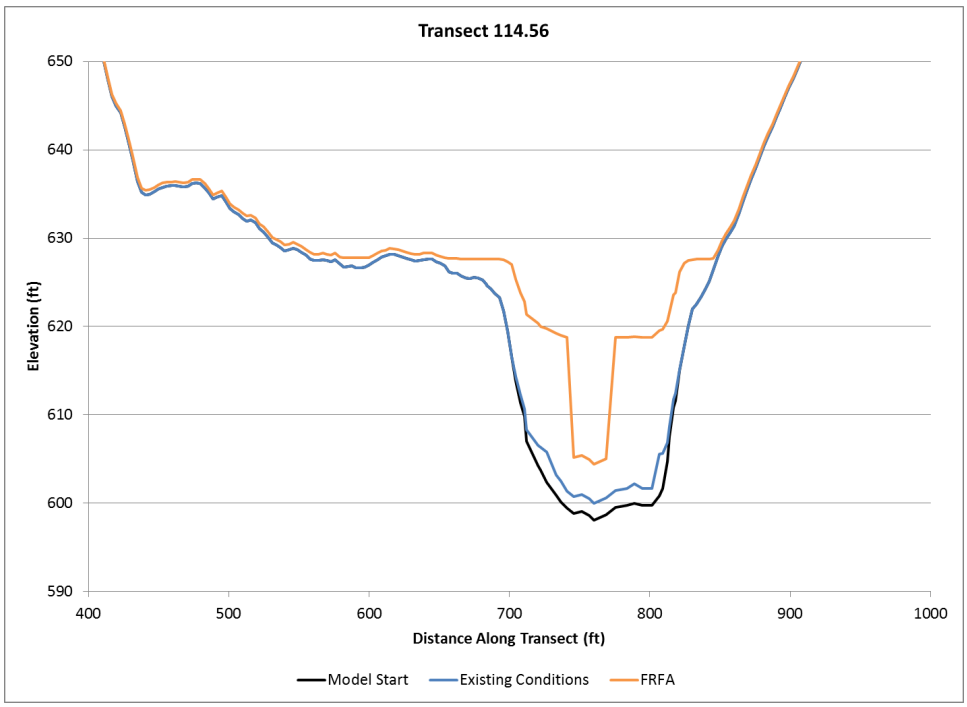
Elevation (ft)
0
100
200
300
400
500
600
Distance Along Transect (ft)
Model Start
Existing Conditions
FRFA


Transect 114.56
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640
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600
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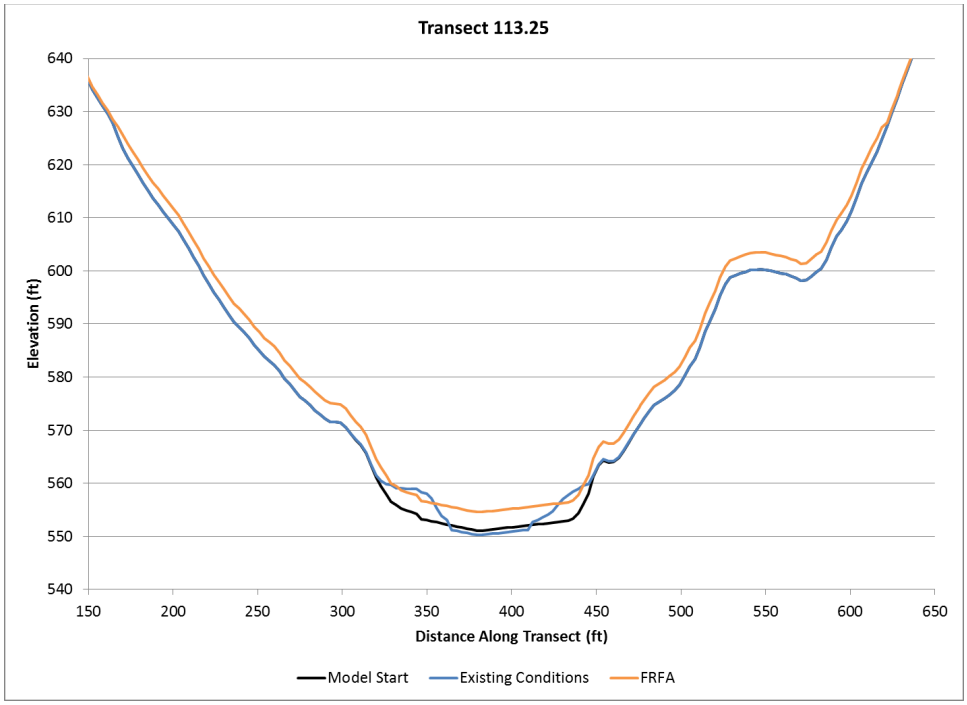
Elevation (ft)
400
500
600
700
800
900
1000
Distance Along Transect (ft)
Model Start
Existing Conditions
FRFA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Elevation (ft)
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450
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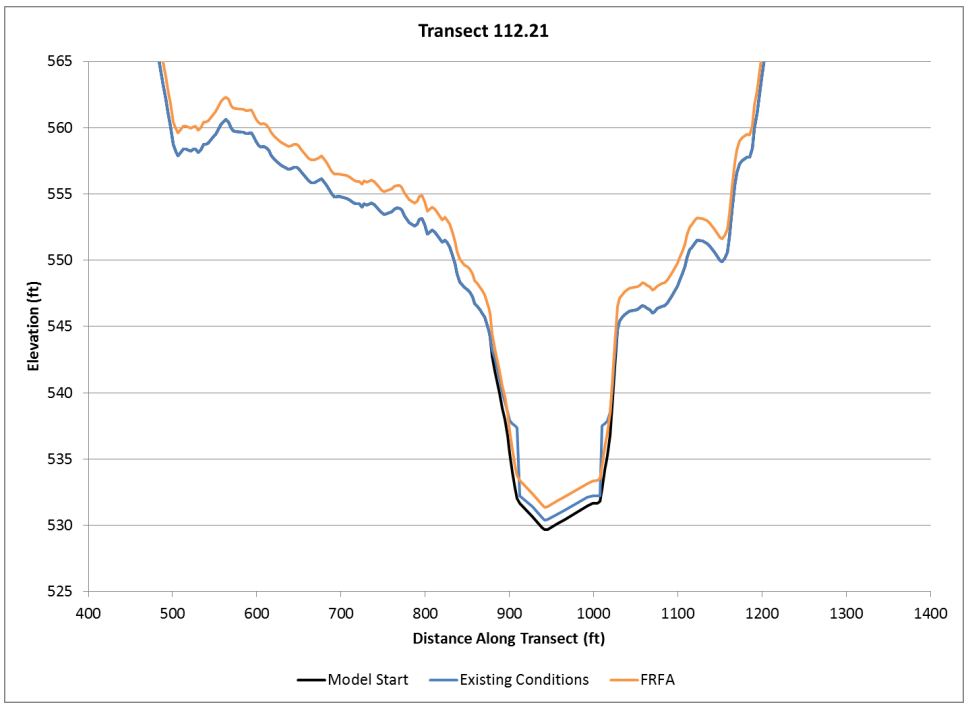
600
650
Distance Along Transect (ft)
Model Start
Existing Conditions
FRFA


Transect 112.21
Elevation (ft)
565
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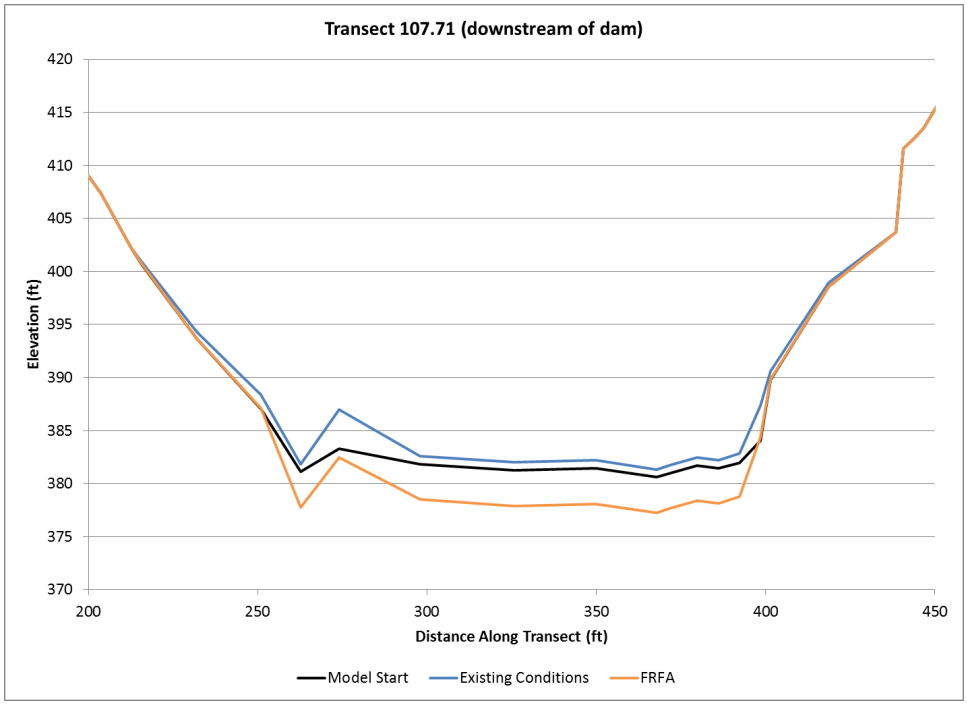
1400
Distance Along Transect (ft)
Model Start
Existing Conditions
FRFA




The total sediment storage of approximately 1,300 acre feet over 27 years is small in comparison to the total reservoir volume of 65,000 acre feet in the conservation pool plus another 65,000 acre-feet of flood storage (total reservoir volume of 130,000 acre feet). Note that this estimated 1,300 acre feet of stored sediment does not represent the actual volume of the sediment contributed during the 2007

flood (estimated to be 2,200 acre feet). Adding the 2007 sediment volume to the long-term estimate is still a small percentage of total reservoir volume. Over 100 years, estimated stored sediment volume (including the 2007 event) is approximately 7,500 acre feet, or 6% of the total reservoir volume.

As mentioned previously, the HEC-RAS model does not replicate the 2007 flood event for existing conditions accurately. During that flood, 5 to 7 million cubic yards of sediment and debris were predicted to have been delivered to streams upstream of the FRFA reservoir. If the FRFA was in operation, the majority of this material would have been deposited or retained within the reservoir. The coarse material would have formed a delta between RM 115 and 117 and within the major tributary valleys (Crim, Lester, and other reservoir tributary creeks). The fine sediment (silt, clay, fine sand) would have been transported into the reservoir and most would have been deposited over the bottom of the pool area. Wood and floatable debris (an estimated 2 to 3 million cubic yards) would have been retained in the reservoir.

### 3.4.3 Effects of Climate Change

The effects of climate change on the hydrology of the Chehalis Basin were investigated by Mauger et al. (2016). They summarized previous research that suggested an increase in winter rainfall and intense storms and a decrease in summer precipitation could occur in the future, leading to higher peak (flood) flows, a potential for increased mass wasting/erosion, and lower summer flows. Mauger et al. (2016) ran two different hydrologic models for the Chehalis Basin using a range of potential climate changes. The result was a wide range of potential changes in streamflow, but a general increase in winter streamflow/flood risk and decrease in summer low flows in the Chehalis watershed.

The Anchor QEA team used the Mauger et al. (2016) data to produce a synthetic 27-year flow record based on the 1988-2015 actual flows. This data was used as input to the HEC-RAS model to calculate changes in sediment transport and storage in the FRO and FRFA reservoirs for comparison with results that were calculated using the original 1988-2015 data. The higher peak flows under the climate change scenarios result in an increase in the incoming sediment load since sediment load is based directly on inflow, so no additional adjustments were made to sediment inputs for the climate change scenarios.

The higher peak flows under the climate change scenarios would result in more frequent use of the dam, triggering its operation more frequently and at higher reservoir elevations (see Figure 3.14; Anchor QEA 2016). Based on the scenario selected, the FRO facility would impound water above elevation 450 an additional six times over the 27-year modeling period. The FRFA facility would also impound water above the normal pool elevation an additional four times over the 27-year period, impoundments would be slightly higher during floods, and summer drawdowns would be slightly lower as a result of lower summer flows (see Figure 3.15)

**Figure 3.14**
**Reservoir Elevation, FRO Climate Change Scenario**

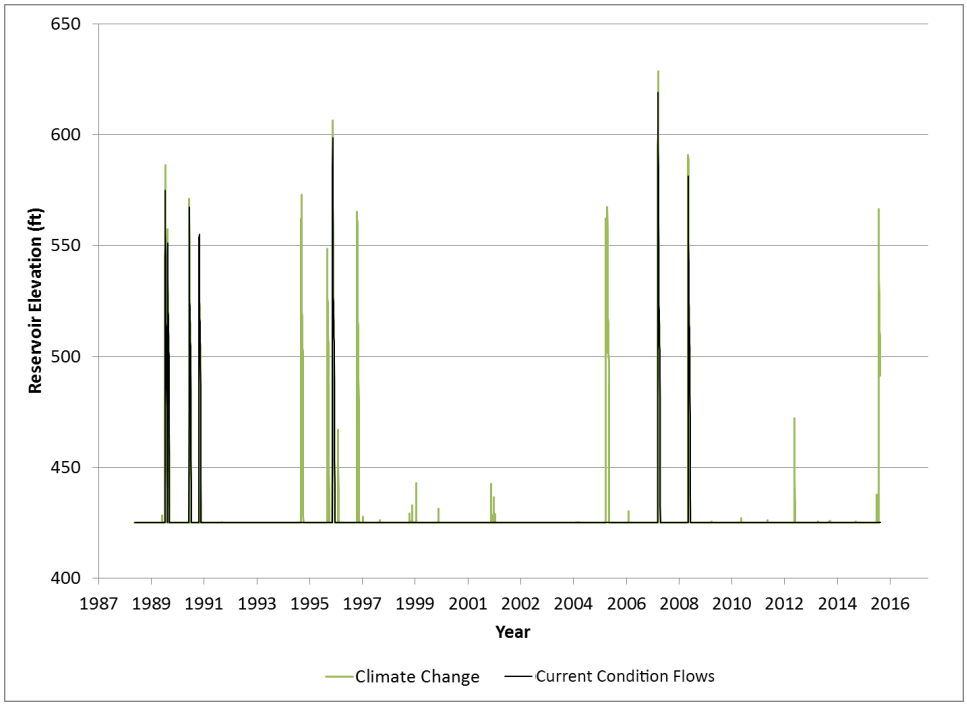
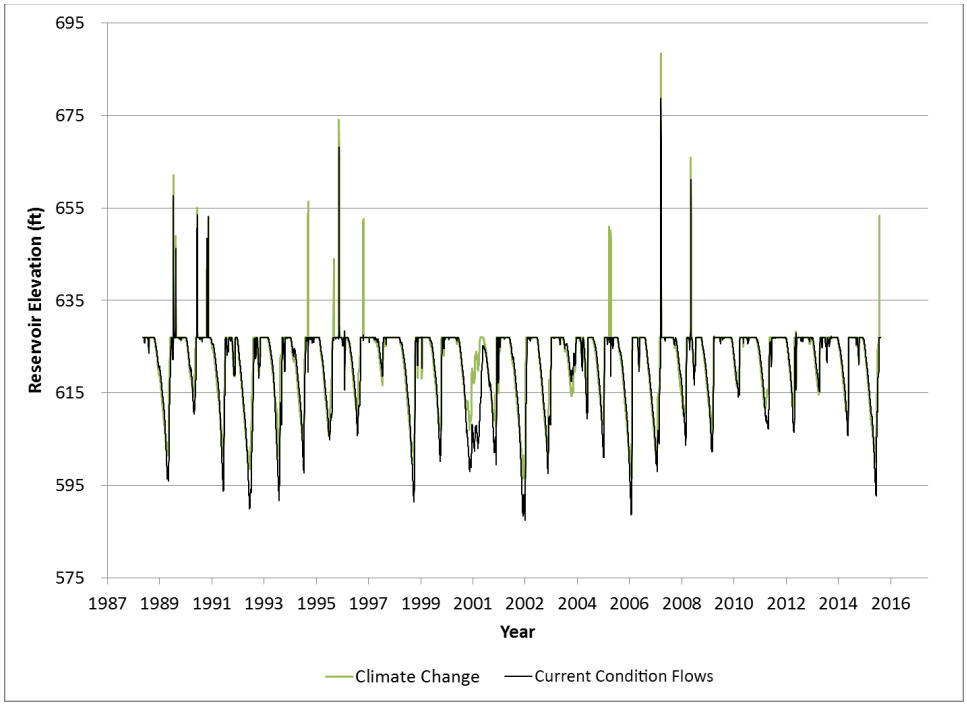



**Figure 3.15**
**Reservoir Elevation, FRFA Climate Change Scenario**



The HEC-RAS model predicts higher incoming sediment loads and additional storage within the reservoir area for all three climate change scenarios (e.g., existing conditions, FRO, and FRFA) when compared to non-climate change scenarios (Figure 3.16). The more frequent impoundment of the FRO reservoir would also mean that there would be less time between impoundment occurrences for fine sediment to be flushed from the channel, so it is likely that there would be more fine sediment in the gravel substrate which could decrease spawning habitat quality (Table 3.5). Total stored sediment in the FRFA impoundment would be approximately 1,600 acre feet, still a small percentage of total reservoir volume (130,000 acre feet). Note that the actual 2007 event input would be more than the modeled 2007 event input as discussed in previous sections.

**Figure 3.16**
**Cumulative Sediment Storage at End of 1988-2015 HEC-RAS Model Run – Effects of Climate Change**

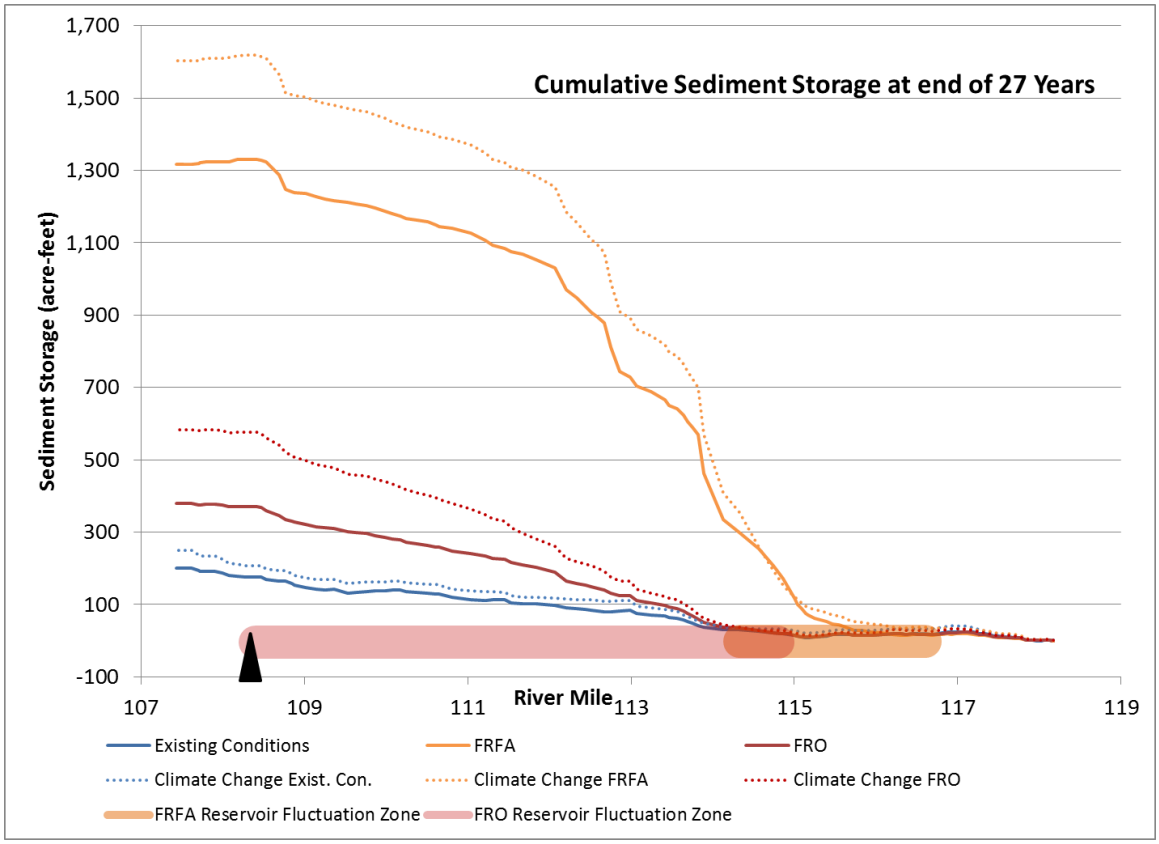


**Table 3.5**

**Summary of Modeled Net Sediment Accumulation Upstream of Dam Site**

| SCENARIO | ESTIMATED NET SEDIMENT ACCUMULATION AT END OF 27 YEARS (ACRE-FEET)[1] |
|---|---|
| Existing Conditions | 170 |
| FRO | 370 |
| FRFA | 1,300 |
| Climate Change – Existing Conditions | 210 |
| Climate Change - FRO | 580 |
| Climate Change - FRFA | 1,600 |

Notes:
1. Estimated sediment accumulation does not include actual 2007 event volumes as discussed in text.
FRO: flood retention only
FRFA: flood retention flow augmentation

# 4 DISCUSSION

One of the resources affected by geomorphic and LWD conditions in the upper Chehalis watershed is aquatic/fisheries habitat. As part of the environmental review of the potential flood retention dam, information on potential effects on anadromous fish spawning habitat (habitat availability, habitat quality, and redd scour potential) was requested.

## 4.1 Spawning Habitat in the FRO/FRFA Facility Reservoir Areas

The Washington Department of Fish and Wildlife provided the locations of Chinook salmon, steelhead, and coho salmon redds inventoried during 2013, 2014, 2015, and early 2016 in the Chehalis watershed upstream of RM 107. Spawning for all species occurred in the mainstem Chehalis River and the tributaries within the potential impoundment area, with higher densities of redds located between RM 111 and 113.5 (see Figures 4.1a and 4.1b).

Scour and fill under existing conditions was measured at six locations near spawning sites between RM 88 and 116 in 2015. Scour of up to 0.38 feet and fill of up to 1 foot was measured following a flow of 5,840 cfs (at Doty gage, an approximately 1.2-year flood). Substrate up to 64 mm had been mobilized. Following a flow of approximately 14,000 cfs (an approximately 4-year flood), scour monitors were found at two of the six locations; presumably scour or fill had removed or covered the monitors at the other four sites. Scour of up to 1 foot was measured at one of the sites where the monitors were found (RM 110), with deeper scour and fill observed at the other sites where the monitors were not found. Substrate up to 300 mm had been mobilized. These results indicate that the existing substrate in the Chehalis River is quite mobile, particularly in the areas where the 2007 flood deposits are still being processed and the channel is not yet in equilibrium (primarily upstream of Elk Creek).

Under FRO facility operations, scour and fill would occur within the inundation zone as the reservoir level drops. The 2007 flood deposits provide a potential analogy for the effects of deposition and re-distribution of sediment associated with operation of the FRO facility reservoir. The 2007 flood caused widespread deposition within the channel and within the floodplain behind numerous log jams. A comparison of the 2015 and 2006 (pre-flood) LiDAR data shows that deposition of up to 10 feet occurred in the floodplain where the channel was blocked by log jams (see Figures 4.2 and 4.3). As the log jams broke, the flows eroded a channel through the sediment wedge, leaving a portion of the deposit in the floodplain and along the channel margins. This is analogous to how the river will deposit sediment when the reservoir is impounded and erode a channel through the deposits when the reservoir drops, although deposition depths will likely be less and over a shorter channel distance during smaller floods.

**Figure 4.1a**

**Locations of Anadromous Fish Spawning in FRO and FRFA Inundation Areas (2013 to 2016)**

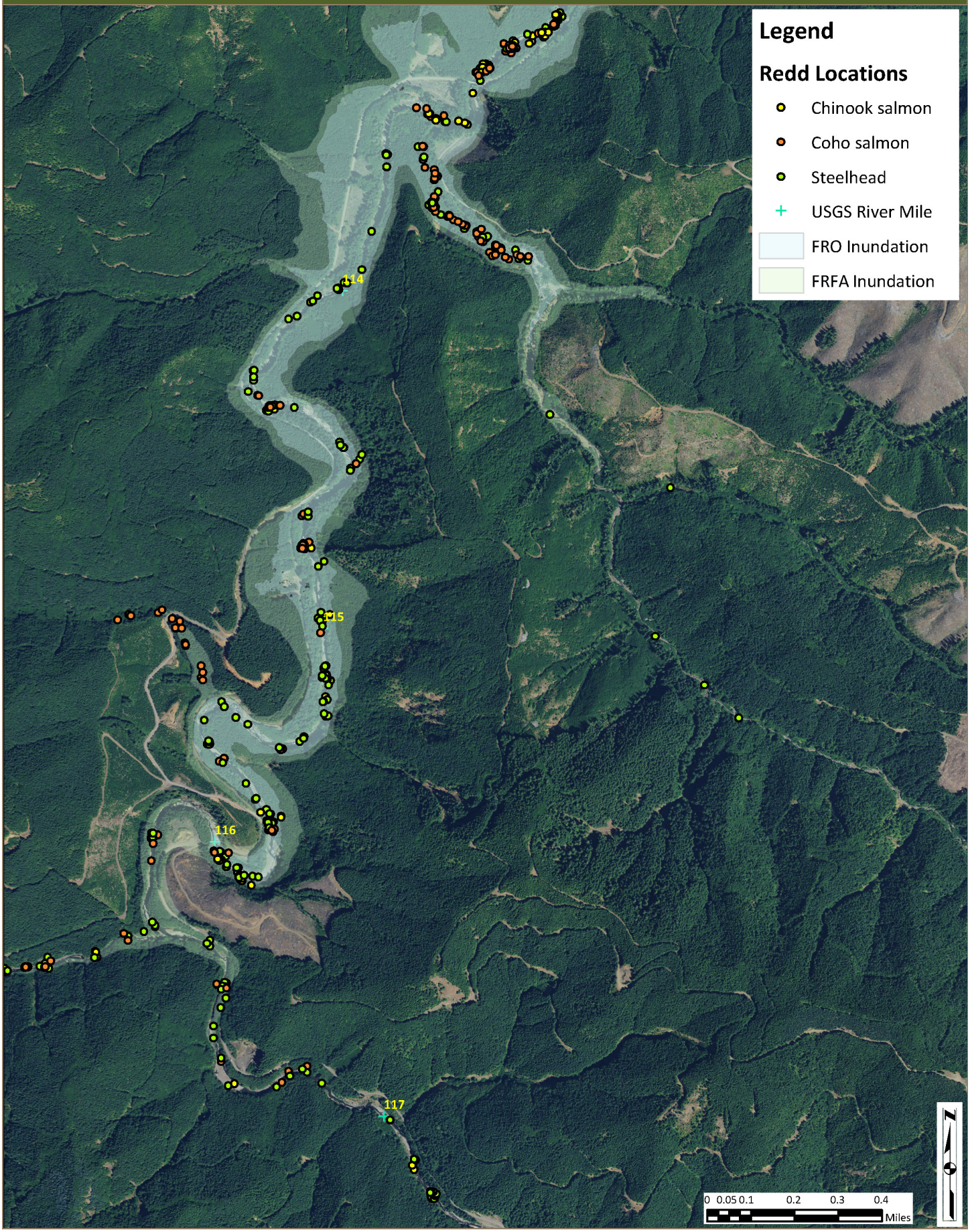


**Figure 4.1b**

**Locations of Anadromous Fish Spawning in FRO and FRFA Inundation Areas (2013 to 2016)**

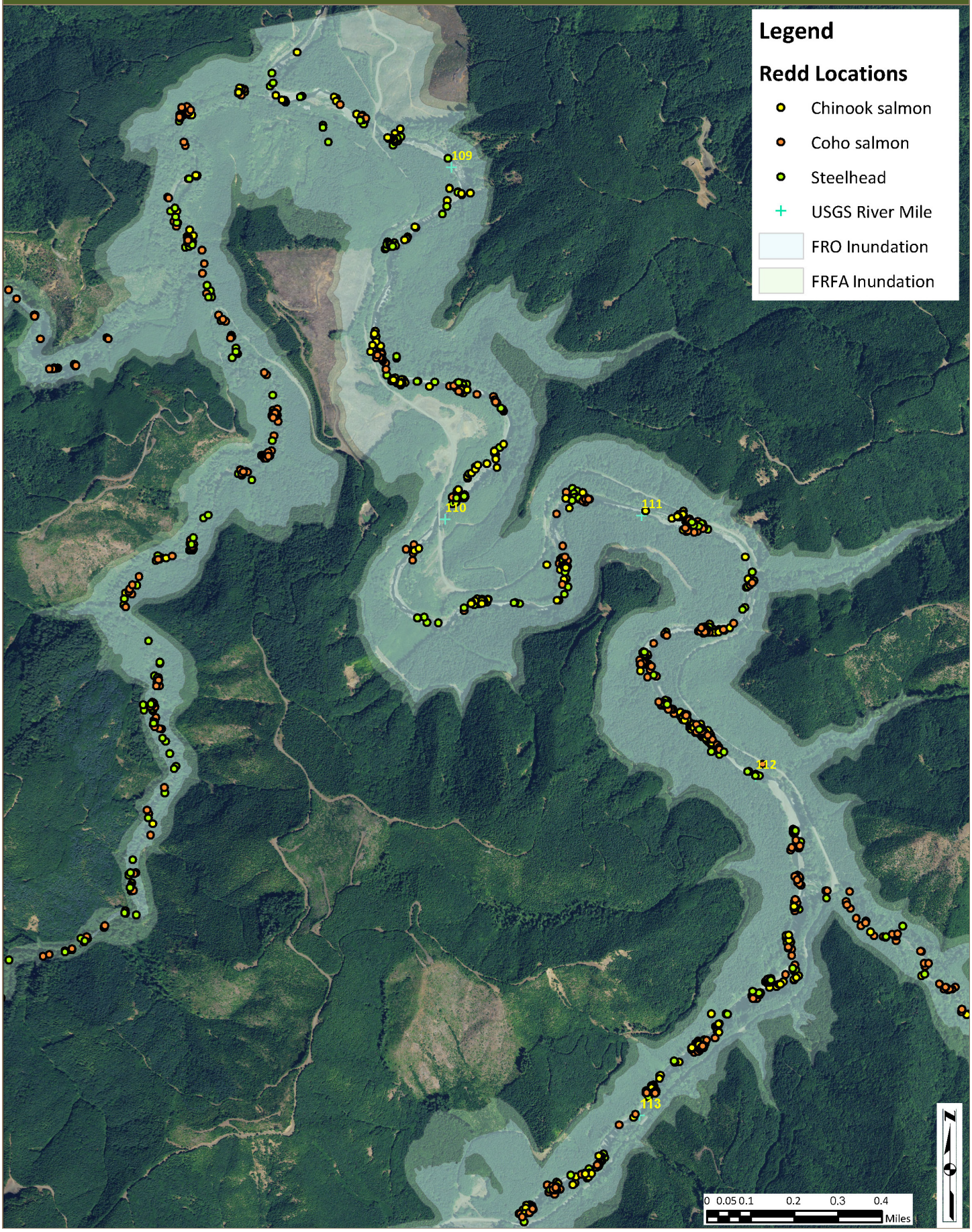


**Figure 4.2**

**2007 Flood Deposits in Chehalis River near RM 118**

**Figure 4.3**

**2007 Flood Deposits in Chehalis River near RM 115**

During an extreme event like the 2007 flood, there would be a large delta deposited in the FRO reservoir which would be re-worked as the reservoir level dropped. This would result in high levels of fine sediment and substantially more scour and fill for several (5 to 10-plus) years as the river processed the sediment. The 2007 flood under existing conditions is continuing to process the sediment provided to the channel.

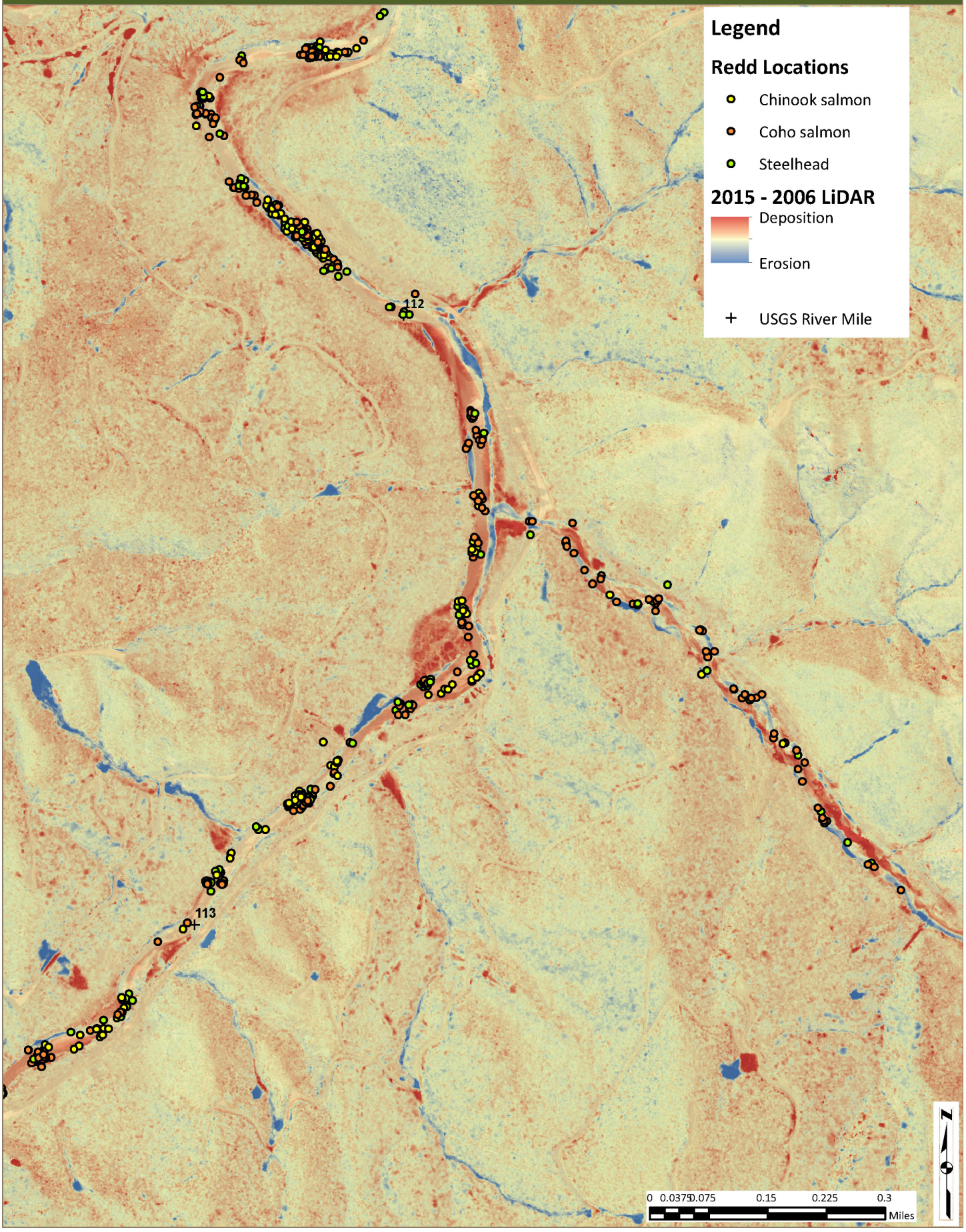
Based on the LiDAR comparison, deposits of up to 3 feet thick persist in some areas of the channel. These areas are being used by spawning Chinook salmon, coho salmon, and steelhead under current conditions (see Figure 4.4).

Initially, deposited sediment within the FRO facility impoundment area would contain a high level of fine sediment, but as the flows entrain the deposits when the reservoir drops, the fine sediments will move into suspension and be transported downstream quickly. This is similar to the effects of the 2007 flood, which had an extremely high fine sediment content. Subsequent high flows and spawning fish removed fine sediment from the surficial layer. If the FRO facility reservoir impounded water every year, the substrate would be subjected to an annual deposition of fine sediment and would have persistent high levels of fines, which would be detrimental to embryo survival. However, the FRO facility would impound water relatively infrequently (seven times in 27 years based on 1988 to 2015 flows), often during the February to May timeframe. As a result, fine sediment in accumulated gravel deposits would have the opportunity to be flushed through the reservoir during years when there was no impoundment and surficial substrate would be relatively free from fines.

Under FRFA facility operations, the channel between the dam (RM 108.2) and approximately RM 114 would be continuously inundated and would be too deep for spawning fish. Between RM 114 and 117, the channel would be intermittently inundated and available to fish for spawning. However, due to the deposition and re-working of the deltaic deposits between RM 114 and 116, there would likely be poor quality spawning habitat (high levels of fine sediment and frequent channel movement, scour, and deposition) that would limit spawning success in many years.

**Figure 4.4**

**Spawning Locations and 2007 Flood Deposits**



## 4.2 Channel Width

Deposition of sediment and predicted loss of riparian vegetation within the FRO facility impoundment area would likely result in some channel widening in unconfined reaches. There are many confined and bedrock-controlled reaches within the FRO inundation zone channel that would have limited widening. It is anticipated that widening would be similar to the effects of the 2007 flood, where the wetted channel increased from an average of 65 to 74 feet in 2008, and the active channel width (which includes unvegetated bars) increased from an average of 80 to 120 feet. It should be noted that these width increases occurred over most of the channel in 2007 because of the widespread deposition that filled the channel and spilled out into the floodplain along much of the river. Deposition associated with FRO facility operation will not be as deep and widespread as the 2007 flood; therefore, sediment-associated increases in width will be limited to small lengths of the channel. Increases in width associated with loss of riparian vegetation will occur where vegetation is lost. Between impoundment events, widened areas of channel will slowly decrease in width. In 2013 (6 years following the 2007 flood), the average wetted channel width had returned to 65 feet and the average active channel width to 112 feet.

Under FRFA operations, the channel within the fluctuation zone would have little riparian vegetation and would re-work deposited deltaic deposits quite frequently (deltaic deposits are sediment that is deposited in a delta-like setting at the upstream end of a reservoir). As a result, the channel would likely be fairly wide and shallow compared to the existing channel within the fluctuation zone.

## 4.3 Large Woody Debris

Current levels of LWD in the upper Chehalis River are very low. The highest wood loads were found in the upstream extent of the Chehalis Basin (in the West Fork Chehalis River) and below the confluence of the East and West Forks (in the mainstem Chehalis River) near RM 118. A previous riparian analysis as part of the Upper Chehalis River Basin Watershed Analysis (Beak Consultants 1994) also concluded that the in-channel large wood was inadequate along the upper mainstem Chehalis River, as well as the East Fork and West Fork.

Because of the confined nature of the channel and bedrock channel margins, most LWD in the upper Chehalis River comes from infrequent inputs associated with mass wasting events. There is little channel migration, and near-channel riparian stands are relatively small and contain short-lived species (e.g., alder), perhaps as a result of past harvesting practices. The 2007 flood provided a huge input of LWD from landslides, but due to the intense nature of the flows and landslides, most of the LWD was moved downstream through the channel or up into the floodplain and is not accessible to the current wetted channel.

Under the FRO facility operations, large and small woody debris that is moving through the system during floods would be trapped within the reservoir and then removed as the reservoir drops to

between elevation 528 and 500 feet. As a result, there would be little input of LWD provided to the channel in the inundation zone channel. LWD from upstream sources would be transported into the channel in the inundation zone during peak flows during years when the reservoir is not operated.

Under the FRFA facility operations, large and small woody debris that is moving through the system during floods would be trapped within the reservoir; some portion of this wood would remain trapped in the reservoir or sink to the bottom and some would be removed.

Based on observations, LWD begins to move at flows of approximately 10,000 cfs (flow measured at the Doty gage). It is anticipated that much of the LWD that would be removed from the reservoir would be available for restoration projects or moved into the river downstream from the dam. However, details of a LWD management plan have not been worked out yet; they will be determined during the next biennium studies.

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# Appendix A
# Large Wood Loading Inventory Memorandum

# UPPER CHEHALIS BASIN LARGE WOOD LOADING INVENTORY: FINAL

**Date:** June 20, 2017
**To:** Bob Montgomery, Anchor QEA, LLC
**From:** Jennifer Goldsmith, Anchor QEA, LLC

## Introduction

Anchor QEA conducted an inventory of the large wood load within the bankfull width of the mainstem Chehalis River between river mile (RM) 87 and RM 118, and in five upper Chehalis River tributaries on October 6 through 9 and November 4 through 6, 2015. Wood pieces meeting the minimum size criteria of Fox and Bolton (2007) were inventoried at each site with a handheld global positioning system (GPS) device. Fox and Bolton (2007) criteria are wood pieces at least 2 meters (6.5 feet) in length and at least 10 centimeters (cm; 4 inches) diameter. This survey focused on the geographic area of the upper Chehalis Basin.

Large wood plays an important role in creating and maintaining channel morphology and functional salmonid habitat, and is the foundation for most salmonid habitat restoration projects in the Pacific Northwest. Fox and Bolton (2007) conducted a study of the number and volume of large wood found in unmanaged streams and rivers in Washington and developed distributions (75th percentile, median, and 25th percentiles) for the number of pieces, volume, and number of key pieces per 100 meters (328 feet) of channel length based on bankfull widths of these unmodified watersheds. As part of their study, Fox and Bolton (2007) recommended large wood restoration targets (number of pieces, volumes, key pieces) meet the 75th percentile for degraded rivers and streams (defined as a system where the existing wood volume and numbers are below the median wood distribution for unmanaged streams). Based on the wood inventory results conducted by Anchor QEA, the Chehalis River and upper tributaries generally did not meet the 25th percentile for wood volume or number of pieces based on the Fox and Bolton (2007) distribution for unmanaged systems. It is recommended that the 75th percentile wood load be the interim target (for restoration wood placement) for the upper Chehalis River and tributaries until wood is able to meet the unmanaged wood-loading ranges.

# Mainstem Chehalis River Large Wood Load

Large wood within the bankfull channel width was inventoried at ten sites along 31 miles of mainstem in the upper watershed. From October 6 through 9, 2015, the inventory was conducted during very low flows, where flows at the Doty gage (RM 101) ranged from approximately 24 to 27 cubic feet per second (cfs; USGS 2015). Conditions were mostly dry and air temperatures were approximately 55°F to 65°F during the October wood inventory. During this October inventory, mainstem Chehalis River sites between RM 87 and RM 105.5 were inventoried. A second wood survey was conducted on November 4 through 6, 2015, between RM 110 and RM 118 (confluence of the East and West Forks) and at one site on the West Fork Chehalis River. November flow conditions were higher than during the October inventory, with river flows at the Doty gage ranging from approximately 650 cfs at the start of the inventory (November 4) to 375 cfs at the end of the inventory (November 6).

## Existing Wood Load Characteristics

The inventory included measuring the length and diameter of each wood piece meeting the minimum criteria that is located within the bankfull width. Based on the inventory results, the overall Chehalis River mainstem average wood length was 7.7 meters (25.3 feet) and diameter was 34.5 cm (13.6 inches). Based on the Chehalis River sites inventoried (including the West Fork), the site with the longest average length of 11.4 meters (37.3 feet) was measured at RM 93.5, and largest average diameter of 44.2 cm (17.4 inches) was measured at RM 101.5 (see Table 1). Both of these sites are located downstream of the town of Pe Ell and the managed forestlands in the upper watershed. However, these logs are small and do not meet the minimum criteria of a key log within a river that has a bankfull width the size of the Chehalis River. Key logs are large logs that are big enough to provide the stable foundation for the formation of a log jam.

## Wood Load

The mainstem Chehalis River wood load is very low and is less than the large wood piece quantities or volumes for natural and unmanaged watersheds referenced by Fox and Bolton (2007). Fox and Bolton identify the 75th percentile as 207 pieces per 100 meters (328 feet) for a natural and unmanaged watershed in Western Washington that has a bankfull width between 30 and 100 meters (98 to 328 feet). For wood volume, Fox and Bolton (2007) identify the 75th percentile as 317 cubic meters ($m^3$)/100 meters (11,193 cubic feet ($ft^3$)/328 feet) for these unmanaged systems. The wood load results for the upper Chehalis River sites are summarized in Table 2.

The highest wood loads were found in the upstream extent of the Chehalis Basin (in the West Fork Chehalis River) and below the confluence of the East and West Forks (in the mainstem Chehalis River) near RM 118. A previous riparian analysis as part of the *The Upper Chehalis River Basin Watershed Analysis* (Beak Consultants 1994) also determined that the in-channel large wood was inadequate along the upper mainstem Chehalis River, as well as along the East Fork and West Fork.

The wood load (number of pieces or volume) in the Chehalis River mainstem is very low, and did not even meet the 25th percentile of levels found in unmanaged forests (Fox and Bolton 2007). In the mainstem Chehalis River (downstream of the confluence of the East and West Forks), the large wood load (volume) ranged from 1% to 5.6% of the Fox and Bolton (2007) recommended restoration target, and for the wood load (pieces) the count ranged from 0.6% to 7.5% of the recommended restoration target (see Table 2). However, the one site surveyed on the West Fork Chehalis did exceed the 25th percentile of the restoration target for wood pieces (see Table 2).

During the 2015 surveys, no logs were identified along the mainstem Chehalis River that met the referenced Fox and Bolton (2007) definition of a key log (minimum volume of 10.75 $m^3$ [264.8 $ft^3$]) for a channel of 50 to 100 meters (164 to 328 feet) bankfull width.

# Chehalis River Tributary Large Wood Load

Anchor QEA conducted an inventory of the large wood load within the bankfull width of Lincoln Creek and the South Fork Chehalis, Newaukum, Skookumchuck, and Black rivers from October 7 to 9, 2015. Large wood within the bankfull channel was inventoried at several sites along each of these tributaries to the Chehalis River. Wood that met the minimum size criteria of Fox and Bolton (2007) were inventoried at each site with a handheld GPS device where pieces measured at least 2 meters (6.5 feet) in length and 10 cm (4 inches) diameter. During October the inventory was conducted during low flow conditions. Conditions were mostly dry and air temperatures were approximately 55°F to 70°F (12.8°C to 21.1°C) during the wood inventory.

## Wood Characteristics

Based on inventory results, the average wood length ranged from 3.8 meters (12.6 feet; Lincoln Creek at RM 9.5) to 9.3 meters (30.5 feet; Skookumchuck River at RM 21). Average piece diameters ranged from 24.4 cm (9.6 inches; Skookumchuck River) to 63.5 cm (25 inches; Lincoln Creek at RM 1.0), although this was based on a single log measurement (see Table 3). The next largest diameter was measured at RM 18.5 in the South Fork Newaukum River ( see Table 3). The majority of the wood inventoried did not have a rootwad.

## Wood Load

The wood load in the tributaries is low and does not meet the large wood piece quantities or volume criteria for natural and unmanaged watersheds set by Fox and Bolton (2007). Fox and Bolton identify the 75th percentile as 63 pieces per 100 meters (328 feet) for an unmanaged system in Western Washington that has a bankfull width between 6 and 30 meters (19.7 and 98.4 feet), which is the average bankfull width of the tributaries surveyed (with the exception of the Skookumchuck River that had a greater bankfull width). For wood volume, Fox and Bolton (2007) identify the 75th percentile as 99 $m^3$/100 meters (3,496 $ft^3$/328 feet) for natural and unmanaged systems in Western Washington having a bankfull width up to 30 meters (98.4 feet).

The wood load results for the upper Chehalis River tributaries are summarized in Table 4. The lowest wood load volumes were found in the lower Skookumchuck River (RM 0.5 and RM 4.5) and in Lincoln Creek (RM 1 and RM 9.5). The highest wood load volumes were found in the South Fork Chehalis River (RM 11) and Skookumchuck River (RM 21), but still these volumes are very low and did not even meet the 25th percentile for unmanaged forests. The same is true for the number of pieces; the number of pieces per 100 meters of channel was very low and mostly did not meet the 25th percentile of unmanaged forests, with the exception of three sites—the South Fork Chehalis River (RM 11), Newaukum River (RM 0.1), and Skookumchuck River (RM 21; see Table 4).

In summary, the large wood load (volume) ranged from 0.4% to 20.0% of the Fox and Bolton (2007) restoration target, and the wood load (pieces) ranged from 1.3% to 42.8% of the restoration target (see Table 4). No tributary sites met the 75th percentile (recommended Fox and Bolton [2007] restoration target) for either wood volume or wood pieces.

## Data Limitations

The large wood data collected as part of this inventory represents only a snapshot of the wood load in the upper Chehalis River and major tributaries during fall 2015. The wood load counts in the Chehalis River and tributaries are not based on a comprehensive inventory of the entire river or tributary extents. The wood load counts in the upper Chehalis Basin (within the boundaries of the Weyerhaeuser Timberlands) are based on an inventory that was conducted approximately every 2 RMs. Along the tributaries, the wood count was conducted in the lower extents of the river where land use is mostly agriculture, and was conducted at locations where public river access was available. The tributary wood load counts did not include upper watershed areas where the majority of the lands are in timber production; therefore, the overall wood load for the tributaries may represent lower wood loads than what is actually present throughout the entire tributary watersheds.

Log jams were noted at a few locations along the mainstem Chehalis River; however, they were located outside of the large wood load inventory sites. The presence of log jams within a survey reach would alter the wood load numbers in the counts represented. However, the number of log jams in the mainstem Chehalis River is low, and the overall wood load numbers for the mainstem would not increase significantly with the addition of this woody material.

**Table 1**

**Mainstem Chehalis River Large Wood Survey Length and Diameter**

| RIVER MILE | COUNT/100 METERS (N)[1] | LENGTH METERS (FEET) | DIAMETER CENTIMETERS (INCHES) |
|---|---|---|---|
| West Fork Chehalis (RM 1) | 20.7 | 6.8 (22.8) | 33.8 (13.3) |
| 118 | 15.7 | 7.1 (23.2) | 35.1 (13.8) |
| 116 | 6.7 | 5.9 (19.4) | 27.2 (10.7) |
| 115 | 4.7 | 5.3 (17.4) | 28.7 (11.3) |
| 112 | 6 | 8.1 (26.6) | 29.5 (11.6) |
| 110 | 3 | 8.1 (26.6) | 29.5 (11.6) |
| 105.5 | 10 | 10.8 (35.4) | 33.0 (13.0) |
| 101.5 | 3.3 | 7.9 (25.8) | 44.2 (17.4) |
| 93.5 | 1.3 | 11.4 (37.3) | 42.7 (16.8) |
| 92.3 | 9.7 | 7.4 (24.2) | 39.4 (15.5) |
| 87 | 8.7 | 5.0 (16.4) | 27.2 (10.7) |

Note:
1. Per 100 meters of channel length.

**Table 2**

**Upper Mainstem Chehalis River Existing Wood Load Summary**

| RIVER MILE | WOOD LOAD (VOLUME)[A] $M^3$/100 METERS ($FT^3$/328 FEET)[B] | RESTORATION TARGET[C] $M^3$ ($FT^3$) | PERCENT OF RESTORATION TARGET[C] | WOOD LOAD (COUNT) PIECES/100 METERS (328 FEET)[B] | RESTORATION TARGET[C] PIECES/100 METERS (328 FEET)[B] | PERCENT OF RESTORATION TARGET[C] |
|---|---|---|---|---|---|---|
| West Fork (RM 1) | 22 (776.8) | 99 (3,496) | 22.2 | 21.3 | 63 | 33.8 |
| 118 | 17.9 (632) | 317 (11,193) | 5.6 | 15.7 | 207 | 7.5 |
| 116 | 3.1 (109.5) | 317 (11,193) | 1.0 | 6.7 | 207 | 3.2 |
| 115 | 4.2 (148.3) | 317 (11,193) | 1.3 | 4.7 | 207 | 2.3 |
| 112 | 4.2 (148.3) | 317 (11,193) | 1.3 | 6.0 | 207 | 2.9 |
| 110 | 2.8 (98.9) | 317 (11,193) | 0.9 | 3.0 | 207 | 1.4 |
| 105.5 | 13.7 (483.7) | 317 (11,193) | 4.3 | 10.0 | 207 | 4.8 |
| 101.5 | 4.2 (148.3) | 317 (11,193) | 1.3 | 3.3 | 207 | 1.6 |
| 93.5 | 2.8 (98.9) | 317 (11,193) | 0.9 | 1.3 | 207 | 0.6 |
| 92.3 | 11 (388.41) | 317 (11,193) | 3.5 | 9.7 | 207 | 4.7 |
| 87 | 10 (353.1) | 317 (11,193) | 3.2 | 8.7 | 207 | 4.2 |

Notes:
a. Wood data were collected October 6 through 9, 2015, and November 4 through 6, 2015, by Anchor QEA.
b. Per 100 meters of channel length.
c. Restoration targets were obtained from Fox and Bolton (2007). These targets are the 75th percentile distribution of wood inventory, are based on bankfull width, and are presented in Table 4 (Fox and Bolton 2007).

**Table 3**

**Chehalis River Tributary Large Wood Length and Diameter**

| TRIBUTARY RIVER MILE | COUNT/100 METERS | LENGTH METERS (FEET) | DIAMETER CENTIMETERS (INCHES) |
|---|---|---|---|
| **SOUTH FORK CHEHALIS** | | | |
| RM 1 | 13.0 | 6.7 (22.1) | 19.6 (7.7) |
| RM 5.5 | 4.0 | 8.8 (28.8) | 43.2 (17.0) |
| RM 11 | 27.0 | 4.8 (15.7) | 31.2 (12.3) |
| **NEWAUKUM[1]** | | | |
| RM 0.1 | 16.0 | 5.0 (16.4) | 27.2 (10.7) |
| RM 1.5 | 11.7 | 8.9 (29.1) | 31.0 (12.2) |
| RM 18.5 | 2.0 | 9.1 (29.8) | 50.8 (20) |
| **SKOOKUMCHUCK** | | | |
| RM 0.5 | 2.7 | 8.2 (26.8) | 32.0 (12.6) |
| RM 4.5 | 2.7 | 8.8 (28.8) | 24.4 (9.6) |
| RM 10.5 | 5.3 | 6.2 (20.3) | 26.9 (10.6) |
| RM 21.0 | 22.0 | 9.3 ( 30.5) | 29.2 (11.5) |
| **BLACK[2]** | | | |
| RM 14.5 | 10.0 | 8.0 (26.2) | 26.7 (10.5) |
| RM 17.5 | 0 | NA | NA |
| **LINCOLN** | | | |
| RM 1 | 1.0 | 6.1 (20) | 63.5 (25.0) |
| RM 9.5 | 5.0 | 3.8 (12.6) | 27.9 (11.0) |

Note:
1. RM 18.5 is located on the South Fork Newaukum River.
2. No wood was found at the Black River at the RM 17.5 monitoring site.

**Table 4**

**Upper Chehalis Basin Tributary Existing Wood Load Summary**

| TRIBUTARY/ LOCATION | WOOD LOAD (VOLUME) $M^3$/100 METERS[A] ($FT^3$/328 FEET) | RESTORATION TARGET[B] $M^3$ ($FT^3$) | PERCENT OF RESTORATION TARGET[B] | WOOD LOAD (COUNT) PIECES/100 METERS[A] (328 FEET) | RESTORATION TARGET[B] PIECES/100 METERS[A] (328 FEET) | PERCENT OF RESTORATION TARGET[B] |
|---|---|---|---|---|---|---|
| **SOUTH FORK CHEHALIS** | | | | | | |
| RM 1 | 2.6 ( 90.2) | 99 (3,496) | 2.6 | 13.0 | 63 | 20.6 |
| RM 5.5 | 9.3 (328.1) | 99 (3,496) | 9.4 | 4.0 | 63 | 6.3 |
| RM 11 | 14.3 (504.7) | 99 (3,496) | 14.4 | 27.0 | 63 | 42.8 |
| **NEWAUKUM[C]** | | | | | | |
| RM 0.1 | 5.3 (187.0) | 99 (3,496) | 5.4 | 16.0 | 63 | 25.4 |
| RM 1.5 | 11.3 (397.2) | 317 (11,193) | 3.6 | 11.7 | 63 | 18.6 |
| RM 18.5 | 3.6 (124.5) | 99 (3,496) | 3.6 | 2.0 | 63 | 3.2 |
| **SKOOKUMCHUCK** | | | | | | |
| RM 0.5 | 3.8 ( 133.4) | 317 (11,193) | 1.2 | 2.7 | 207 | 1.3 |
| RM 4.5 | 1.4 (50.1) | 317 (11,193) | 0.4 | 2.7 | 207 | 1.3 |
| RM 10.5 | 2.8 (99.6) | 99 (3,496) | 2.8 | 5.3 | 63 | 8.4 |
| RM 21.0 | 19.8 (698.4) | 99 (3,496) | 20.0 | 22.0 | 63 | 34.9 |
| **BLACK** | | | | | | |
| RM 14.5 | 6.3 (223.7) | 99 (3,496) | 6.4 | 10.0 | 63 | 15.9 |
| **LINCOLN** | | | | | | |
| RM 1 | 1.9 (68.2) | 99 (3,496) | 1.9 | 1.0 | 63 | 1.6 |
| RM 9.5 | 1.8 (65.0) | 99 (3,496) | 1.8 | 5.0 | 63 | 7.9 |

Notes:
a. Per 100 meters of channel length.
b. Source: Fox and Bolton 2007
c. RM 18.5 is located on the South Fork Newaukum River.

# References

Beak Consultants, 1994. *The Upper Chehalis River Watershed Analysis: Riparian Module Upper Chehalis Watershed Analysis*. Prepared for Weyerhaeuser Company. Kirkland, Washington.

Fox, M., and S. Bolton, 2007. A regional and geomorphic reference for quantities and volumes of instream wood in unmanaged forested basins of Washington State. *North American Journal of Fisheries Management* 27:342-359.

USGS (U.S. Geological Survey), 2015. National Water Information System Web Interface: USGS Gage 12020000 Chehalis River near Doty, Washington. Available from: http://waterdata.usgs.gov/usa/nwis/uv?site_no=12020000.

# Appendix B
# Grain Size Data

# PEBBLE COUNT DATA

## Station River Mile (RM) 105

| | | $D_{65}$= | 49 | mm | 1.9 | inches |
|---|---|---|---|---|---|---|
| **Armor Layer** | | $D_{50}$= | 40 | mm | 1.6 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 7% | 0% | 0.21 | | 7 | |
| 4 | 4% | 7% | 0.24 | | 4 | |
| 8 | 6% | 11% | 0.72 | | 6 | |
| 16 | 20% | 17% | 4.80 | | 20 | |
| 32 | 52% | 37% | 24.96 | | 52 | |
| 64 | 11% | 89% | 10.56 | | 11 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 41.49 | mm | 100 | |
| | | | 0.1361 | feet | | |

## Station RM 107 – Boulder Bar

| | | $D_{65}$= | 39 | mm | 1.5 | inches |
|---|---|---|---|---|---|---|
| **Armor Layer** | | $D_{50}$= | 28 | mm | 1.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 5% | 0% | 0.15 | | 5 | |
| 4 | 4% | 5% | 0.24 | | 4 | |
| 8 | 16% | 9% | 1.92 | | 16 | |
| 16 | 33% | 25% | 7.92 | | 33 | |
| 32 | 32% | 58% | 15.36 | | 32 | |
| 64 | 9% | 90% | 8.64 | | 9 | |
| 128 | 1% | 99% | 1.92 | | 1 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 36.15 | mm | 100 | |
| | | | 0.1186 | feet | | |

# Station RM 107 – Riffle Used for Anadromous Spawning

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 30 | mm | 1.2 | inches |
| **Armor Layer** | | $D_{50}$= | 23 | mm | 0.9 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 1% | 0% | 0.01 | | 1 | |
| 2 | 0% | 1% | 0.00 | | 0 | |
| 4 | 7% | 1% | 0.42 | | 7 | |
| 8 | 27% | 8% | 3.24 | | 27 | |
| 16 | 35% | 35% | 8.40 | | 35 | |
| 32 | 25% | 70% | 12.00 | | 25 | |
| 64 | 5% | 95% | 4.80 | | 5 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 28.87 | mm | 100 | |
| | | | 0.0947 | feet | | |

# Station 108.5 – Panesko Bridge

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 43 | mm | 1.7 | inches |
| **Armor Layer** | | $D_{50}$= | 31 | mm | 1.2 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 0% | 0% | 0.00 | | 0 | |
| 4 | 0% | 0% | 0.00 | | 0 | |
| 8 | 12% | 0% | 1.40 | | 12 | |
| 16 | 40% | 12% | 9.55 | | 41 | |
| 32 | 40% | 51% | 19.11 | | 41 | |
| 64 | 9% | 91% | 8.39 | | 9 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 38.45 | mm | 103 | |
| | | | 0.1261 | feet | | |

# Station 110 Sorting Yard Bridge

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | $D_{65}$= | 26 | mm | 1 inches |
| **Armor Layer** | | | $D_{50}$= | 22 | mm | 0.9 inches |
| **Size (mm)** | **Percent** | **% Finer** | | **Avg size** | | **No.** |
| 1 | 0% | 0% | | 0.00 | | 0 |
| 2 | 0% | 0% | | 0.00 | | 0 |
| 4 | 0% | 0% | | 0.00 | | 0 |
| 8 | 29% | 0% | | 3.48 | | 29 |
| 16 | 59% | 29% | | 14.16 | | 59 |
| 32 | 11% | 88% | | 5.28 | | 11 |
| 64 | 1% | 99% | | 0.96 | | 1 |
| 128 | 0% | 100% | | 0.00 | | 0 |
| 256 | 0% | 100% | | 0.00 | | 0 |
| | | | | 23.88 | mm | 100 |
| | | | | 0.0783 | feet | |

# Station RM 111

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | $D_{65}$= | 37 | mm | 1.5 inches |
| **Armor Layer** | | | $D_{50}$= | 28 | mm | 1.1 inches |
| **Size (mm)** | **Percent** | **% Finer** | | **Avg size** | | **No.** |
| 1 | 0% | 0% | | 0.00 | | 0 |
| 2 | 2% | 0% | | 0.06 | | 2 |
| 4 | 1% | 2% | | 0.06 | | 1 |
| 8 | 13% | 3% | | 1.50 | | 13 |
| 16 | 45% | 15% | | 10.85 | | 47 |
| 32 | 29% | 61% | | 13.85 | | 30 |
| 64 | 11% | 89% | | 10.15 | | 11 |
| 128 | 0% | 100% | | 0.00 | | 0 |
| 256 | 0% | 100% | | 0.00 | | 0 |
| | | | | 36.46 | mm | 104 |
| | | | | 0.1196 | feet | |

# Station RM 112 – Current Substrate (Finer)

| | | $D_{65}$= | 38 | mm | 1.5 | inches |
|---|---|---|---|---|---|---|
| **Armor Layer** | | $D_{50}$= | 29 | mm | 1.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 0% | 0% | 0.00 | | 0 | |
| 4 | 0% | 0% | 0.00 | | 0 | |
| 8 | 18% | 0% | 2.14 | | 18 | |
| 16 | 41% | 18% | 9.74 | | 41 | |
| 32 | 35% | 58% | 16.63 | | 35 | |
| 64 | 7% | 93% | 6.65 | | 7 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 35.17 | mm | 101 | |
| | | | 0.1154 | feet | | |

# Station RM 112 – Representative of Pre-2007 Bed (Coarser)

| | | $D_{65}$= | 64 | mm | 2.5 | inches |
|---|---|---|---|---|---|---|
| **Armor Layer** | | $D_{50}$= | 53 | mm | 2.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 0% | 0% | 0.00 | | 0 | |
| 4 | 0% | 0% | 0.00 | | 0 | |
| 8 | 3% | 0% | 0.36 | | 3 | |
| 16 | 19% | 3% | 4.56 | | 19 | |
| 32 | 43% | 22% | 20.64 | | 43 | |
| 64 | 35% | 65% | 33.60 | | 35 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 59.16 | mm | 100 | |
| | | | 0.1941 | feet | | |

# Station RM 113

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 32 | mm | 1.2 | inches |
| **Armor Layer** | | $D_{50}$= | 27 | mm | 1.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 1% | 0% | 0.03 | | 1 | |
| 4 | 2% | 1% | 0.12 | | 2 | |
| 8 | 12% | 3% | 1.44 | | 12 | |
| 16 | 51% | 15% | 12.24 | | 51 | |
| 32 | 22% | 66% | 10.56 | | 22 | |
| 64 | 12% | 88% | 11.52 | | 12 | |
| 128 | 0% | 100% | 0.00 | | 0 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 35.91 | mm | 100 | |
| | | | 0.1178 | feet | | |

# Station RM 114

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 75 | mm | 3 | inches |
| **Armor Layer** | | $D_{50}$= | 53 | mm | 2.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 0% | 0% | 0.00 | | 0 | |
| 4 | 1% | 0% | 0.06 | | 1 | |
| 8 | 10% | 1% | 1.20 | | 10 | |
| 16 | 22% | 11% | 5.28 | | 22 | |
| 32 | 26% | 33% | 12.48 | | 26 | |
| 64 | 34% | 59% | 32.64 | | 34 | |
| 128 | 6% | 93% | 11.52 | | 6 | |
| 256 | 1% | 99% | 1.28 | | 1 | |
| | | | 64.46 | mm | 100 | |
| | | | 0.2115 | feet | | |

# Station RM 116 – Scour Monitor Site

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 39 | mm | 1.5 | inches |
| **Armor Layer** | | $D_{50}$= | 28 | mm | 1.1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 5% | 0% | 0.15 | | 5 | |
| 4 | 4% | 5% | 0.24 | | 4 | |
| 8 | 16% | 9% | 1.92 | | 16 | |
| 16 | 33% | 25% | 7.92 | | 33 | |
| 32 | 32% | 58% | 15.36 | | 32 | |
| 64 | 9% | 90% | 8.64 | | 9 | |
| 128 | 1% | 99% | 1.92 | | 1 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 36.15 | mm | 100 | |
| | | | 0.1186 | feet | | |

# Station RM 116 – Spawning-sized Gravel Deposit

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 31 | mm | 1.2 | inches |
| **Armor Layer** | | $D_{50}$= | 25 | mm | 1 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 0% | 0% | 0.00 | | 0 | |
| 2 | 0% | 0% | 0.00 | | 0 | |
| 4 | 2% | 0% | 0.12 | | 2 | |
| 8 | 23% | 2% | 2.76 | | 23 | |
| 16 | 43% | 25% | 10.32 | | 43 | |
| 32 | 25% | 68% | 12.00 | | 25 | |
| 64 | 6% | 93% | 5.76 | | 6 | |
| 128 | 1% | 99% | 1.92 | | 1 | |
| 256 | 0% | 100% | 0.00 | | 0 | |
| | | | 32.88 | mm | 100 | |
| | | | 0.1079 | feet | | |

# Station RM 117

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 111 | mm | 4.4 | inches |
| **Armor Layer** | | $D_{50}$= | 74 | mm | 2.9 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 1% | 0% | 0.01 | | 1 | |
| 2 | 1% | 1% | 0.03 | | 1 | |
| 4 | 2% | 2% | 0.12 | | 2 | |
| 8 | 10% | 4% | 1.20 | | 10 | |
| 16 | 10% | 14% | 2.40 | | 10 | |
| 32 | 22% | 24% | 10.56 | | 22 | |
| 64 | 26% | 46% | 24.96 | | 26 | |
| 128 | 20% | 72% | 38.40 | | 20 | |
| 256 | 6% | 92% | 23.04 | | 6 | |
| 512 | 2% | 98% | 5.12 | | 2 | |
| | | | 105.84 | mm | 100 | |
| | | | 0.3472 | feet | | |

# Station RM 118

| | | | | | | |
|---|---|---|---|---|---|---|
| | | $D_{65}$= | 54 | mm | 2.1 | inches |
| **Armor Layer** | | $D_{50}$= | 36 | mm | 1.4 | inches |
| **Size (mm)** | **Percent** | **% Finer** | **Avg size** | | **No.** | |
| 1 | 1% | 0% | 0.01 | | 1 | |
| 2 | 0% | 1% | 0.00 | | 0 | |
| 4 | 4% | 1% | 0.24 | | 4 | |
| 8 | 9% | 5% | 1.08 | | 9 | |
| 16 | 33% | 14% | 7.92 | | 33 | |
| 32 | 26% | 47% | 12.48 | | 26 | |
| 64 | 19% | 73% | 18.24 | | 19 | |
| 128 | 7% | 92% | 13.44 | | 7 | |
| 256 | 1% | 99% | 1.28 | | 1 | |
| | | | 54.69 | mm | 100 | |
| | | | 0.1794 | feet | | |