LOWER SATSOP RIVER ASSESMENT AND DESIGN

BASIS OF DESIGN REPORT AND GEOMORPHIC ASSESSMENT

October 7, 2019

Lower Satsop Restoration and Protection Program

GRAYS HARBOR COUNTY

1854

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1 INTRODUCTION

The Lower Satsop River Assessment and Design Project includes a conceptual level reach scale design and a preliminary design focused on priority actions near a neck cutoff avulsion. The reach spans from the confluence of the Satsop and Chehalis Rivers, River Mile (RM) 0.0, to the State Highway 12 bridge, RM 2.0. The project was prompted by a neck cutoff avulsion at RM 0.4 which occurred November, 27 2018. The avulsed channels proximity to landowner residences and the highly erodible soils have placed homes and valuable farmland in imminent danger. River discharge at the time of the avulsion coincided approximately with a 2-year peak flow recurrence event.

Project stakeholders include Grays Harbor County (GHC), Grays Harbor Conservation District (GHCD), Chehalis River Basin Flood Authority (CRBFA), Washington Department of Fish and Wildlife (WDFW) and affected landowners. In addition to project stakeholders whom may also issue permits on this project; the US Army Core of Engineers (USACE), Washington Department of Natural Resources (WDNR), and the Washington Department of Ecology are engaged in consultation as permitting agencies.

Natural Systems Design (NSD) was contracted by GHC to work with GHCD, CRBFA and WDFW to assess the history and future trajectory of channel migration within the reach and to develop a reach scale conceptual design and a preliminary design for the avulsion site. The geomorphic assessment provides the context that will underly any future restoration actions. Additionally, it summarizes the habitat conditions within the reach to help identify ecological goals for future restoration work. The reach scale conceptual design provides the context for restoration activities planned at the avulsion site. The preliminary design focuses on the avulsion site and integrates with WDFW Phase I work planned for completion in 2019 and Phase II scheduled to begin and finish in 2020. The WDFW Floodplain Restoration Project includes salvage of stockpiled soils (spoils) to shallow ponds remaining from historic gravel mining on the eastern floodplain of the Satsop River. Project elements are being planned in coordination with Phase II of WDFW floodplain restoration project, Figure 1.

1.1 Project Goals and Objectives

Project goals and objectives have been developed by as follows:

- Analyze flood and erosion hazards in the project area.
    - Develop reach-scale designs to address flood and erosion hazard/risk to landowners in the project area.
- Protect public and private infrastructure and agricultural lands from bank erosion in the Lower Satsop River, Grays Harbor County, WA.
    - Designs will utilize bioengineering techniques and process-based restoration tools.
    - Designs will, to the extent possible, provide for an expedited permitting process for accelerated/phased construction during the summer of 2019 near the site of the recent avulsion where a private residence is imminently threatened.
- Improve floodplain connectivity to spread flood flows throughout the floodplain and restore side channel and off channel habitats for anadromous and resident fish and wildlife.
    - Develop reach-scale designs that incorporate floodplain connectivity.
- Protect and maintain recreational opportunities.
    - Conduct outreach to recreational community during design process (GHCD).
    - Align designs with concerns of recreational community.

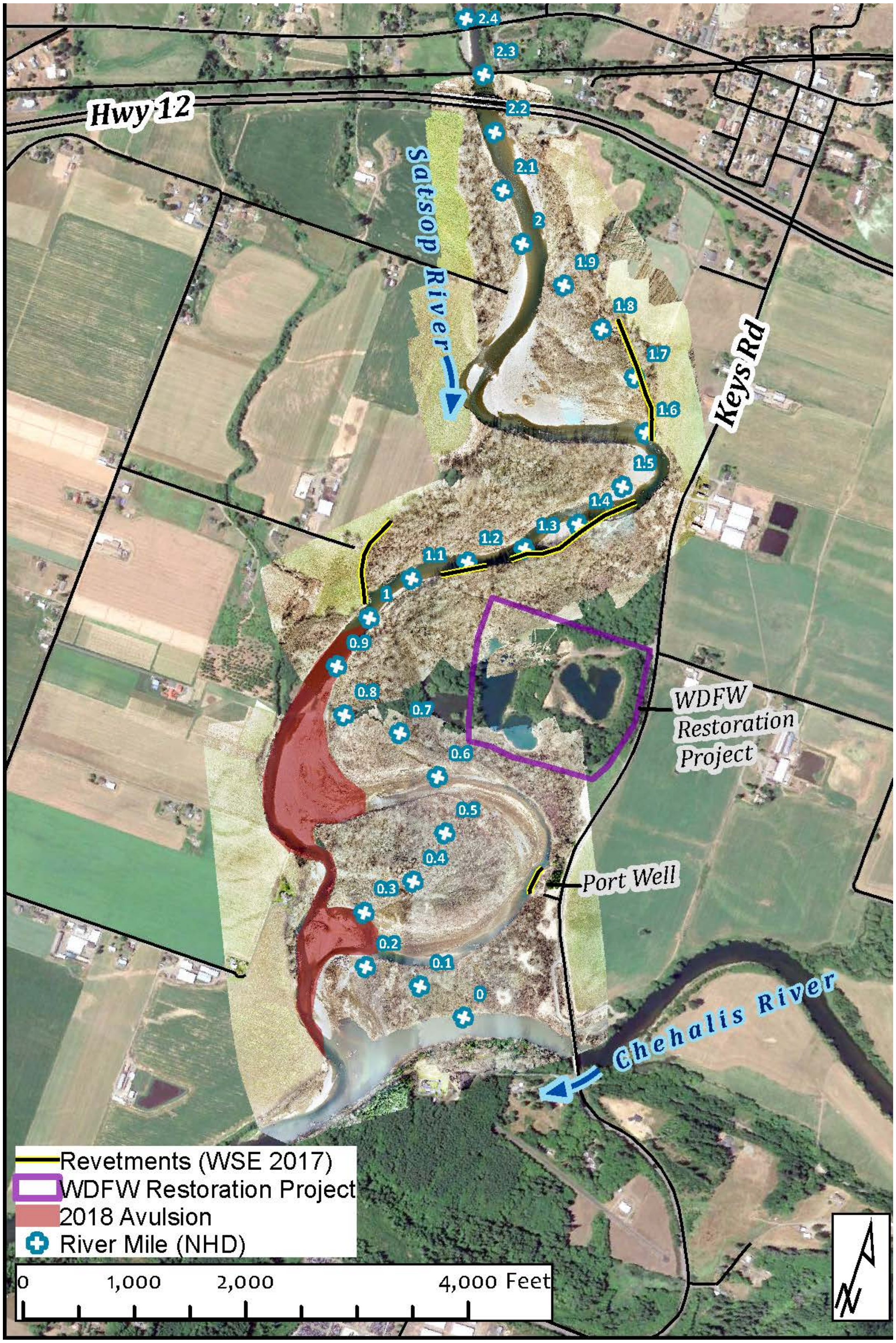

Figure 1. Lower Satsop River reach vicinity.

2 REACH CHARACTERISTICS AND CHANNEL MORPHOLOGY

The Satsop River watershed begins on the south side of the Olympic Mountains in Olympic National Forest, and extends through Grays Harbor County and Mason County, Washington, to the confluence of the Satsop and Chehalis Rivers. The mainstem Satsop River is fed from the East, Middle, and West Fork Satsop Rivers. The watershed experiences a climate with a narrow annual range of temperature, typically mild, cloudy and wet winters and comparatively dry summers that is typical of western Washington. Snowfall is light in the foothills and along the coast, with most winter precipitation occurring as rain.

The majority of the valley bottom has been developed for agricultural use, while the upper portion of the watershed is primarily in silvicultural rotation. The geology of the watershed is primarily glacial outwash, with the upper West Fork extending partially into areas of basaltic volcanic rock (NSD 2019a). The basin's largest residential hub is the town of Satsop, which had a population of 675 as of 2010.

The project reach spans from RM 0.0 at the confluence of the Satsop and Chehalis Rivers to the State Highway 12 bridge at RM 2.0. The river has a single thread planform with an average slope of 0.17 percent. The river is moderately confined on the east bank from RM 1.4 to RM 1.0 where rock revetments were placed to isolate gravel mining on the floodplain. There are two meanders which have been migrating towards Keys Road over the last decade with the upper (RM 1.5) and lower (RM 0.5) meanders within 180 feet of Keys Road. On the west bank of the river, agricultural lands have been eroding into the stream leaving vertical cut banks with poor soil cohesion. The 2018 avulsion has exacerbated two of these cut banks at RM 0.7 and RM 0.2 taking approximately 100 feet of bank when the neck cutoff propagated. Between the cut banks, the Willis residence is at risk. The abandoned meander has aggraded slightly since becoming a secondary channel with deposition of fine material observed on gravel bars and the overbank.

3 CHANNEL MIGRATION ASSESSMENT

3.1 Geomorphic Setting

The project area of the Lower Satsop River lies in a unique geomorphic setting within the confluence with the Chehalis River which can help explain its active rates of channel migration. The Satsop River leaves its own valley and enters the Chehalis River valley directly downstream from Highway 12 (the start of the project area) (Figure 2). Here, it forms a region of elevated land that surrounds the Satsop River and extends above the Chehalis River floodplain. Bank stratigraphy indicates that the underlying material is composed of silt which is highly erodible and was likely deposited by floods from both river basins (Figure 3). Because the "Confluence Ridge" lies within the over-widened Chehalis River Valley[1], there are no hillslopes to constrain lateral migration of the river and thus, the Satsop River moves through the valley with few resistant features.

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[1] The Chehalis River was one of the main drainage paths of the Puget Lobe of the Cordilleran Ice Sheet at the end of the last ice age. As the ice sheet melted, large quantities of water, ice, and rock were transported through the modern-day Chehalis River Valley into the ocean. During these flood waves, the valley was scoured and widened with forces much greater than the modern-day river can exert. Because of this, the valley is wider than it would have been, had it only been subject to erosion from the river alone.
(First discussed in Bretz, J.H. 1913. Glaciation of the Puget Sound Region. *Washington Geological Survey Bulletin* No. 8).

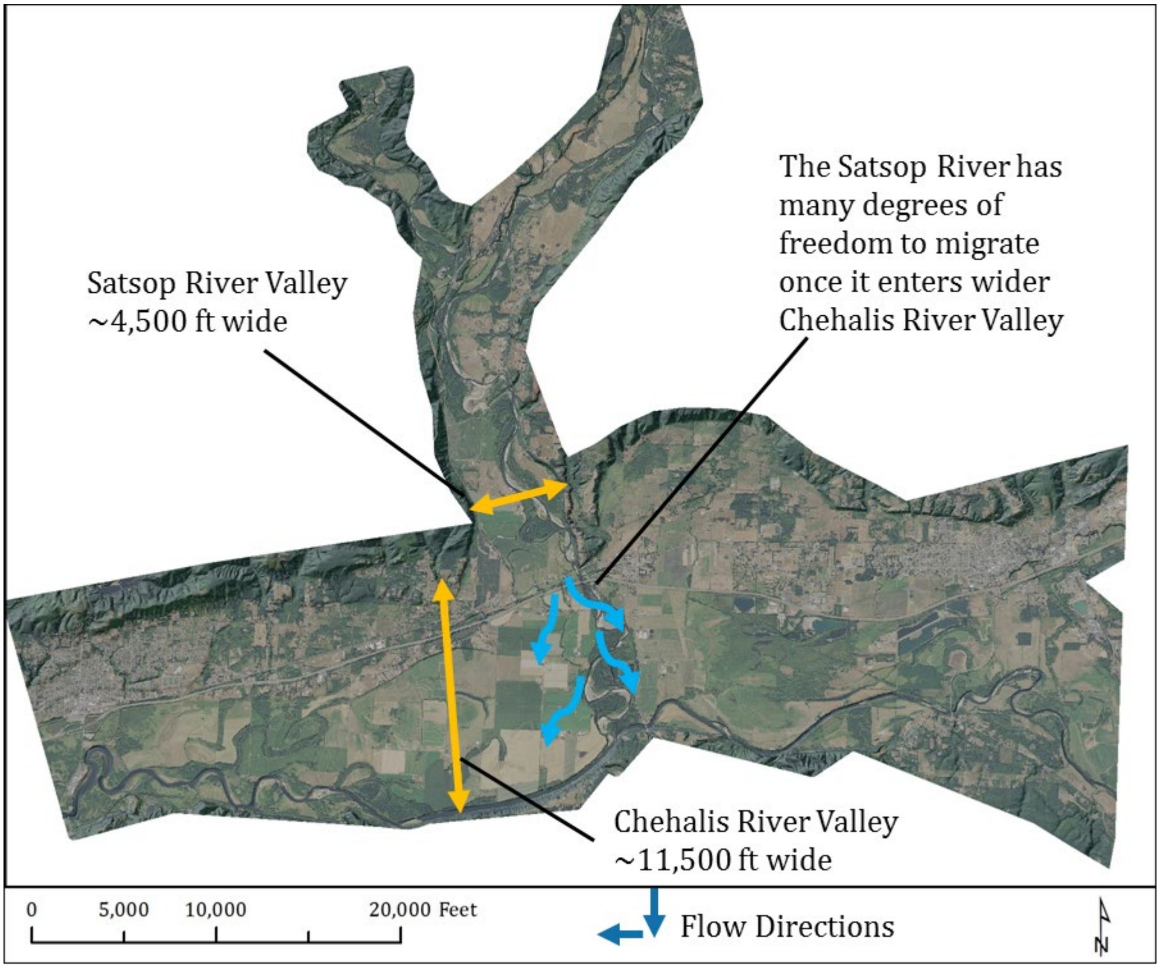

Figure 2. Geomorphic Context of Lower Satsop Project Reach. The project reach is located on the Satsop River within the Chehalis River Valley. The Chehalis River Valley is ~2 times wider than the Satsop River Valley and thus, the Satsop River has many degrees of freedom to migrate as it is no longer controlled by the valley hillslopes.

Figure 3. Eroding right bank near RM 0.2 illustrates that much of the material underlying the Satsop/Chehalis River confluence area is composed of highly erodible silts. Similar bank stratigraphic analyses were used throughout the project reach to confirm that most of the confluence area is of similar composition. Photo taken on 3/13/19.

Prior to European Settlement, resistance to erosion on the landscape was likely provided by old-growth conifer forests and the stable logjams that they created. Logjams and patches of mature forest would have provided stability to the river channel banks (logjams by deflecting flow, roughening and strengthening banks and trees through their extensive root systems). The mature trees were also a source of the "key pieces" of large wood essential for forming stable logjams (e.g. Abbe and Montgomery 1996, 2006) and creating an important ecosystem function referred to as the floodplain large wood cycle in which stable logjams create stable areas where trees can mature within areas of frequent channel migration.

Today however, the resistance provided by the old-growth forest and stable logjams is no longer present on the landscape and the system is lacking natural material that can provide erosional resistance. Thus, the only features that are resisting lateral migration within the project area are man-made structures, such as roads and revetments. These features do not react dynamically to the river in a manner that slows erosion (such as a tree falling in and forming a stable log jam) and thus, act as static features that direct the river. The following section describes the patterns of channel migration within the reach since 1940 (much after

European settlement) and the influence that man-made features within the project area has had on those patterns.

3.2 Historical Context

Evidence of the Satsop River's location prior to the aerial photo record can be seen through analysis of the surrounding topography (Figure 4). Figure 4 shows a relative elevation model (REM) which is a depiction of valley topography "relative" to the river. The REM helps identify relict and current channel features in tans/greens and blues/greens respectively and can be used to delineate other geomorphic surfaces such as terraces and wetlands. Analysis of the relict channel features shown in the REM indicates that the Satsop River likely occupied an area ~4,500 ft wide since the last glaciation. This area was perpendicular to the Chehalis River and entered the valley in the same direction that the river passes under the Highway 12 bridge in a South-Southeasterly direction. In recent history however (Since ~1960), the river has been migrating farther towards the west – particularly in the lower portion of the reach – where infrastructure, such as the revetment on WDFW property and Keys Road, are likely contributing to the shift in direction (Figure 5, Appendix F - Mapbooks).

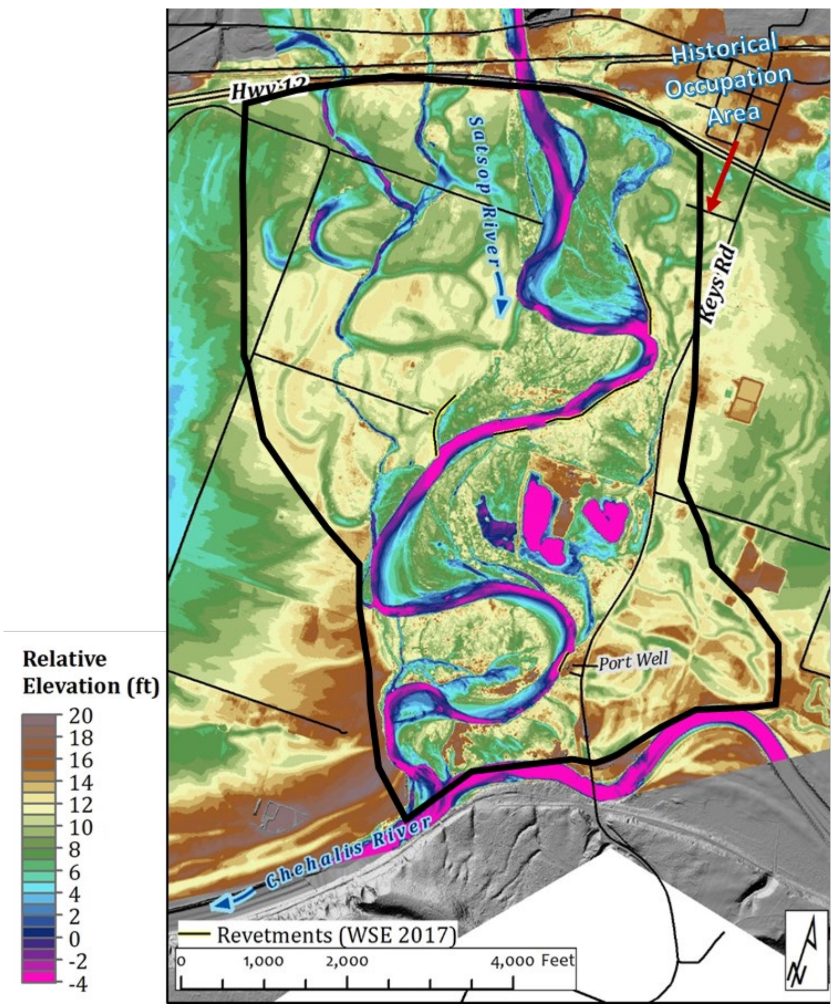

Figure 4. Historical occupation zone of the Lower Satsop River. The zone is delineated on a relative elevation model (REM) which helps identify relict and current channel features in existing topography. The REM was developed using 2017 LiDAR topography.

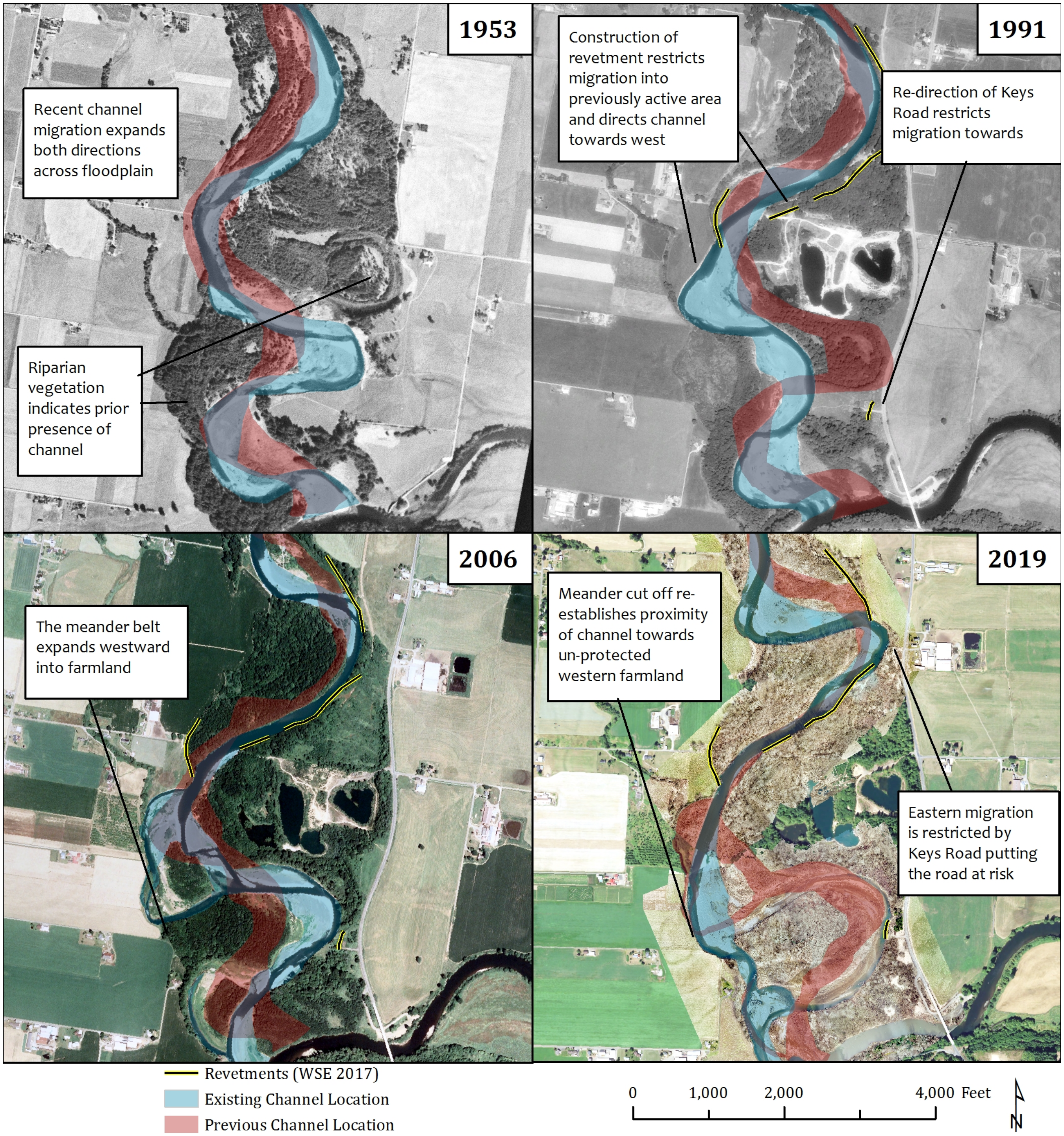

Figure 5. Influence of infrastructure, such as the revetment on WDFW property and Keys Road, on channel migration patterns within the Lower Satsop River.

In 1953, prior to the construction of the revetment on WDFW property or the re-routing of Keys Road in the lower portion of the reach, the river migrated fairly equally in both directions across the floodplain. However, the construction of the revetment restricted channel migration into a previously active area and directed the channel towards the west. This was further exacerbated by the re-routing of Keys Road in the lower portion of the reach which restricted migration towards the east. Both of these actions translated the river's erosive energy westward where it began eroding into farmland and expanding its meander belt in an area that it likely had previously not encountered given the lack of channel features present on the landscape (Figure 6). This shift in meander belt location will likely have implications to future channel migrations trends and patterns as the channel location is re-established adjacent to unprotected farmland.

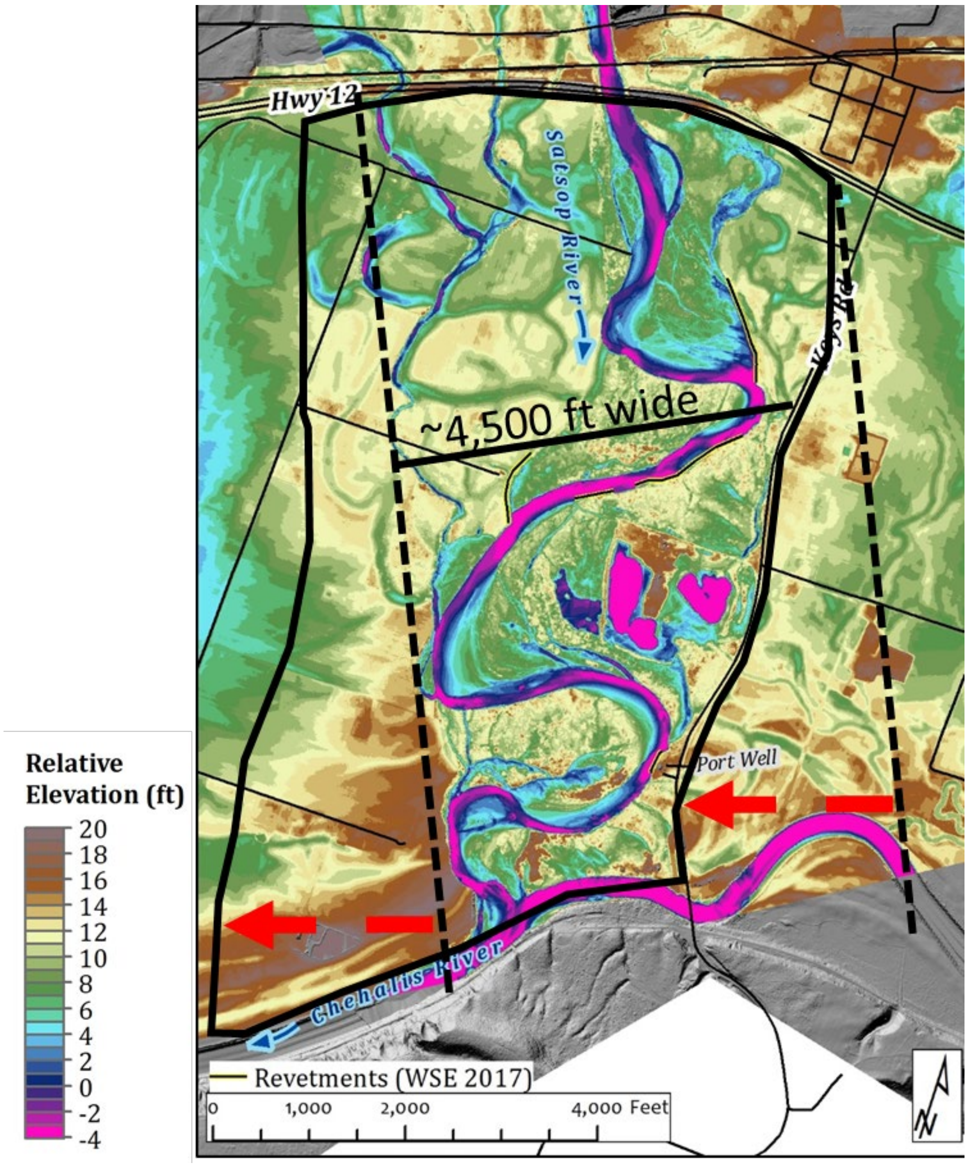

Figure 6. Shift in meander belt and occupation zone of the Lower Satsop River. Keys Road cuts off a portion of the river's meander belt – necessitating a shift to the west as the river attempts to maintain its historical planform geometry.

3.3 Recent Migration Patterns and Future Trends

Channel migration in the project area is driven by lateral migration of meander bends and channel avulsions, or cutoffs. It is these processes that establishes the river's "meander belt" where meander bends expand in both directions around a central axis until they are cutoff by a channel avulsion when the slope of the bend gets too low-. The lower meander sequence in the project reach between RM 0-1 experienced this expansion/cutoff process between ~1990 until November 2018 (Figure 7). Prior to 2006, the meander sequence eroded outward from a central axis in both eastward and westward directions. However, when the eastern portion of the sequence met resistance with riprap protecting the port well, the bend between RM 0.2-0.6 began migrating towards itself from both ends because the stream's energy could no longer move eastward. The bends continued to migrate closer towards each other until they eventually cutoff in November 2018. This cutoff however, shifted the central axis of the meander belt towards the west where it is likely to remain until the river expands in both directions and another bend eventually cuts off (Figure 7). Because of this, both right bank outer bends are likely to migrate into existing farmland (Figure 8).

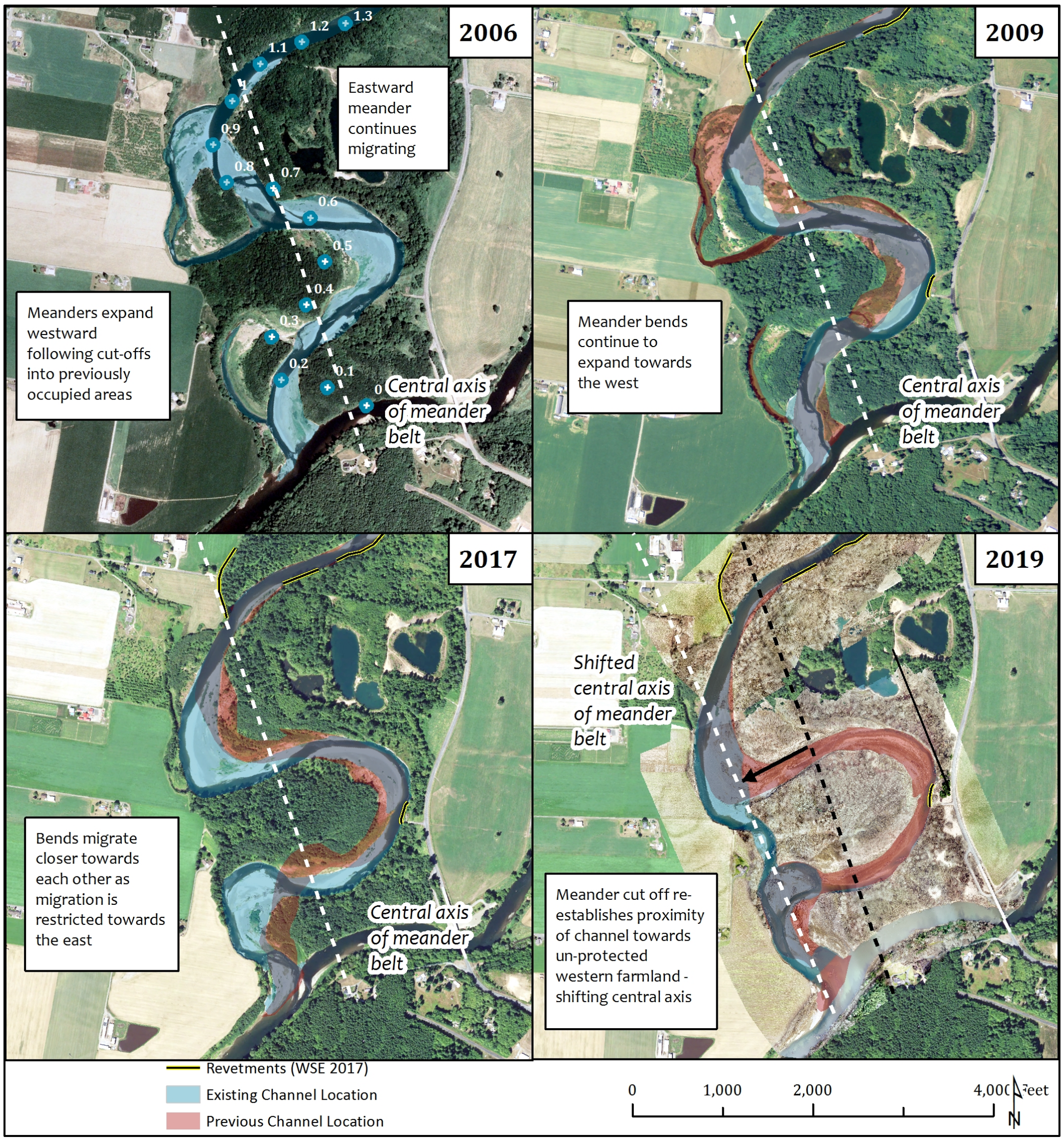

Figure 7. Recent channel migration patterns within the Lower Satsop River.

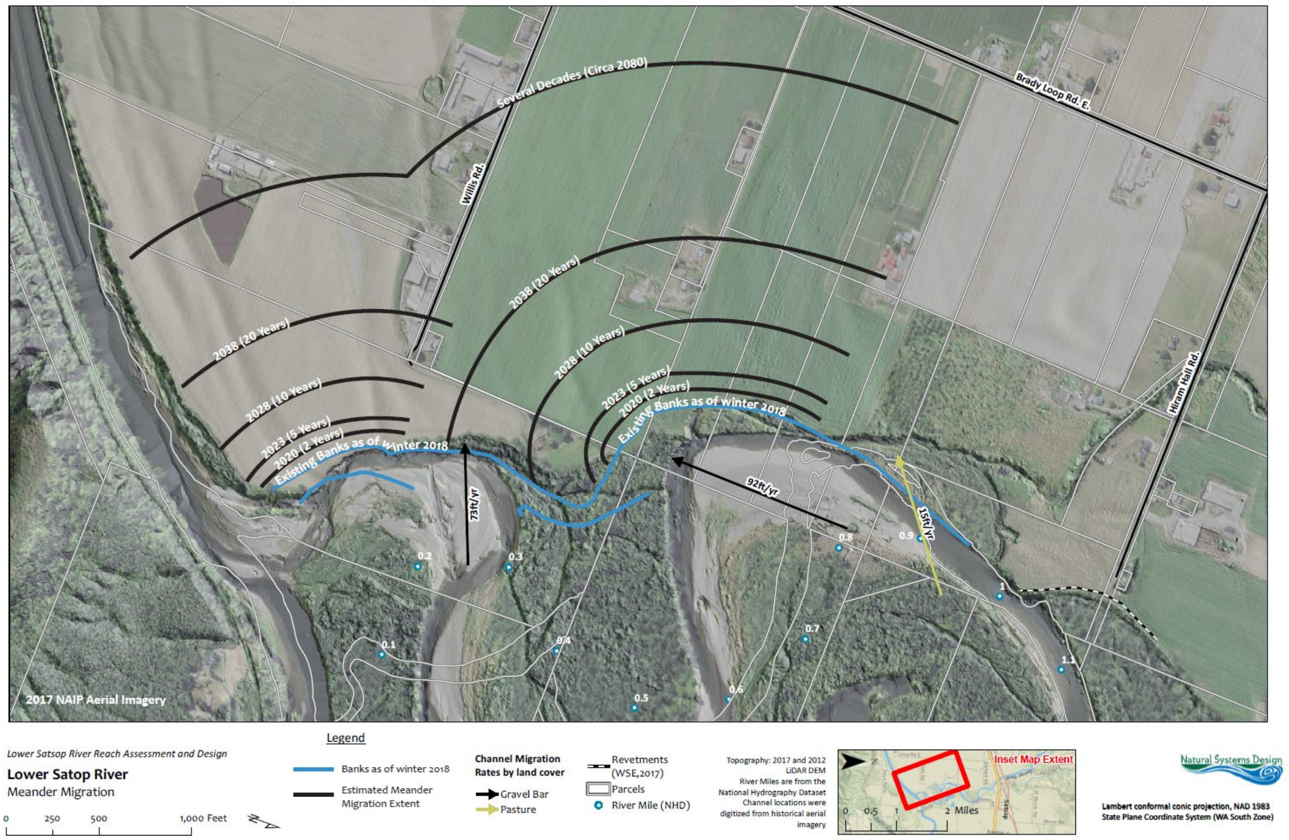

Figure 8. Projected channel migration trajectory for the Lower Satsop River. Future river locations estimated using historical erosion rates of each specific bank.

Figure 8 presents the projected channel migration trajectory for the project area based on measured historical erosion rates of 92 ft/yr for the upstream bank and 73 ft/yr for the downstream bank. Because of the shift in the meander belt axis, both meander bends are expected to expand towards the west and erode ~30 acres of land over 10 years if erosion continues at historical rates. This poses a risk to valley landowners and farmers who could lose significant quantities of land and soil. Additionally, the projected migration trajectory poses a risk to habitat conditions because of the high input of fine sediment to downstream ecosystems.

3.4 Summary

The channel migration assessment illustrates the risk that the current river migration trajectory is putting on valley landowners and habitat conditions. The primary findings of the assessment are:

- The Lower Satsop River likely occupied a river corridor ~4,500 feet wide prior to the settlement of Europeans in the 1800’s. The river likely migrated across the confluence ridge formed as the Satsop river enters the over-widened Chehalis River valley.
- Infrastructure such as Keys Road, the Port of Grays Harbor well and the revetment located on WDFW property have contributed in shrinking the available occupation area for the river and re-directing channel migration towards the west.

- The channel avulsion that occurred in November 2018 shifted the central axis of the meander belt towards the west. Because of this, right bank farmland is at risk of erosion as a new meander sequence develops.
- Continued erosion of farmland silts poses a direct risk to habitat due to an increase in fine sediment loads and a lack of wood recruitment.

Restoration designs developed by NSD as part of this project are intended to help address the direct risks to valley landowners and habitat conditions.

4 HABITAT CHARACTERIZATION

NSD staff conducted a site assessment on March 12-14, 2019, on the Lower Satsop River to quantify baseline conditions and identify restorative actions to improve habitat conditions within the study reaches. The project reach begins at RM 2.2 immediately downstream of the Highway 12 bridge and extends to the confluence with the Chehalis River. The primary focus was the 2018 November-December avulsion channel and abandoned meander, but the mainstem Satsop River, its floodplain areas, and Chehalis River confluence were included in the site assessment. Additional desktop-based work was conducted to supplement the field observations.

NSD collected a wide suite of data sources to document existing conditions and to analyze geomorphic, hydraulic, and habitat conditions within the project reach to inform the design. Field data collection included:

- Riparian vegetation classes
- Large wood classes
- Pools
- Side channels
- Sediment grain size
- Stream bank materials

This assessment builds on existing studies of the Satsop River and previous work by NSD for the Aquatic Species Restoration Plan (ASRP), which is one of the pillars of the Chehalis Basin Strategy by the State of Washington. NSD characterized reach-scale geomorphic and habitat conditions within two priority reaches; Satsop River RM 3.7 to 6.0, and the East Fork Satsop River RM 7.8 to 10.0. Figure 9 shows the location of the Lower Satsop project reach. Note that river miles shown are based on the National Hydrography Dataset (NHD) channel alignment prior to the 2018 avulsion.

Figure 9. Habitat characterization survey, performed by NSD (March 2019).

Five native anadromous salmonid populations utilize the Satsop River for all or large portions of their freshwater life-history stages. The Satsop River provides juvenile summer and over-winter rearing habitat for Chinook, Steelhead, Coho, and Chum. Alcoves, side channels, deep pools, and ponded portions of riverine wetlands provide this critically important habitat, particularly in areas that maintain consistent inundation, cool water temperatures, and abundant vegetation and corresponding zooplankton and benthic invertebrates for foraging. None of the salmonid species in the Satsop Basin are listed under the Endangered Species Act, so a Recovery Plan has not been written for the basin. However, average runs are declining, resulting in limitations on tribal and non-tribal harvests (Aquatic Species Restoration Plan Steering Committee, 2017).

Several other species of native salmonids have been described as present in the Satsop River and its tributaries including mountain whitefish, rainbow trout, cutthroat trout, dolly varden, and bull trout (Wydoski and Whitney 2003).

Current conditions of habitat quality, at the time of field survey, are summarized in part by the quantity of wood, pools and side channels in Table 1. Quantities of key habitat parameters are compared to reference conditions from empirical data from similar sites in western Washington State. The amount of large wood and pools is well below reference conditions. Detailed descriptions of individual habitat parameters are provided in subsequent sections.

Table 1. Summary of habitat characterizing parameters from the March 2019 field survey.

Existing Large Wood Density (key pieces/mi)	Reference Large Wood Density (key pieces/mi)[1]	Existing Log Jams (stable jams/mi)	Reference Log Jams (stable jams/mi)[2]	Existing Pool Density (pools/mi)	Reference Pool Density (pools/mi)[3]	Existing Side Channel Length (length/mi)
6	> 64	1.4	10	6	>18	0.8

Table footnotes

[1] Wood loading per Fox and Bolton (2001), 75% value for applicable channel width

[2] Stable log jam density per Abbe and Montgomery (2003), based on drainage area and mean annual discharge compared to Queets River

[3] NOAA (1996), based on channel width > 100 ft

4.1 Riparian Conditions

The riparian areas within the Lower Satsop River reach (RM 2.2 – 0.0) contain roughly an equal distribution of farmland and deciduous forest with very few conifers. NSD used field reconnaissance observations to note the species and condition of riparian vegetation in the modern floodplain areas. Tree heights are inferred from the 2017 highest-hit LiDAR dataset. Between RM 2.2-1.7 there is a ~300 ft wide deciduous forest on the right bank, and ~500 ft wide young deciduous forest containing primarily alder on the left bank. From RM 1.6-1.0, the right bank floodplain contains a forest which is dominated by alder and black cottonwood, with tree heights >100 ft and a predominantly salmonberry understory. The left bank from RM 1.6-0.6 is also deciduous forest with large sections of trees >100 ft tall, but very few conifers. The 2018-19 avulsion channel begins at RM 0.6, which flows directly through established deciduous forest. Tree heights in this section are nearly all >50 ft. Along the left bank of the abandoned meander, deciduous forest covers the floodplain area to the confluence with the Chehalis River. Evidence from the field survey, such as flotsam and the presence of fine alluvial material, indicate recent engagement between floodplains and the mainstem channel. There are notably few conifers in the riparian areas. Figure 10 shows typical riparian conditions along the Lower Satsop River reach.

Figure 10. Riparian conditions along the Satsop River near RM 1.7 (NSD, March 2019). Active erosion of outside meander bank with young alder recruitment (left), and view of cultivated area looking downstream (right).

In powerful dynamic rivers such as the Satsop, only coniferous species such as Sitka spruce, western red cedar, and Douglas fir, as well as some very large black cottonwoods, can grow large enough to resist the forces of the river and remain stable enough to hold banks and form logjams. There are very few conifers, or trees large enough, to provide long-term structure for the Lower Satsop River or act as key pieces in the formation of logjams. Smaller species, such as red alder or cottonwood, which are the dominant species in the project area, are typically not large enough to provide these functions. Farmed lands provide almost no structural or habitat functions to river systems as grass roots are not deep enough to stabilize banks, they provide no shade, and cannot act as a source of large wood to the stream. Re-establishment of mature mixed coniferous and deciduous forests within the floodplain is an essential element necessary to reducing channel erosion rates, increasing the age, size, and effectiveness of recruited wood, and improving existing floodplain aquatic habitats (i.e. wetlands and side channels).

Riparian forests add physical structure to river systems by stabilizing banks, slowing flood waters, and providing a source of large wood when trees are recruited to the stream channel from erosion. Riparian forests also provide numerous habitat functions to river ecosystems including reducing water temperatures by shading the stream, providing cover to aquatic species, contributing carbon and other nutrients to the ecosystem food web, housing birds and other wildlife, and providing forage for insects and herbivorous animals. The degradation of riparian forests has a direct impact on habitat quality, and secondly, limiting the supply of large wood available for sustaining habitat-forming processes.

4.2 Large Wood

NSD used 2018 and 2019 aerial photographs and a field survey conducted in March 2019 to count, measure (through visual estimation) and geo-locate functional wood, stable log jams, and key pieces within the project reach. Baseline large wood distributions were compared to reference conditions presented in Fox and Bolton (2007) for unmanaged forested basins in Washington State and in Abbe and Montgomery (2003) for the nearby Queets River basin (Abbe and Montgomery, 2003; Fox and Bolton, 2007). Since the landscape has been significantly altered from historical conditions, it is important to compare baseline data to multiple reference condition sources. Table 2 and Table 3 summarize the field counts of large wood in the Lower Satsop River in comparison to reference conditions.

Table 2. Wood count summary for Lower Satsop River (RM 2.2 - 0.0), excluding wood from log jams.

Existing Functional Wood (total count)	**Existing Key Pieces** (total count)	**Existing Key Piece Frequency** (key pieces/mi)	**Reference Key Piece Frequency** (key pieces/mi)*
39	1	0.5	>64

Table footnotes
* Wood loading per Fox and Bolton (2001), 75% value for applicable channel width

Table 3. Log jam count summary for Lower Satsop River (RM 2.2 - 0.0).

Existing Log Jams (total count)	**Existing Stable Log Jams** (total count)	**Existing Stable Log Jams** (stable jams/mi)	**Reference Stable Log Jams** (stable jams/mi)*
4	3	1.4	10

Table footnotes
* Stable log jam density per Abbe and Montgomery (2003)

Functional wood is defined as pieces that exert an influence on bed topography and sediment distributions, but are not necessarily stable during high flows. Examples of functional wood include bank-recruited red alders and black cottonwood that form a scour pool beneath them, but lack the volume and weight to resist mobilizing forces from a bankfull discharge (Figure 11). Measurements of functional wood length and diameter at breast height (DBH) visually estimated in the field for pieces greater than 12 inches DBH. Wood outside of the channel margin was not included in the count.

Figure 11. Example of functional, non-stable large woody debris (LWD) on the Satsop River near RM 0.4. 2019 aerial image (left) and ground-based photo (NSD, March 2019). Pictured are bank-recruited alders approximately 60 ft in length and DBH of 14 inches with rootwads 10 ft in diameter.

Key pieces are defined as pieces of wood estimated to be stable during flood events. Key pieces are capable of recruiting additional wood and serve as the forming members of log jams. A general rule for key piece sizing is the length equal to ½ bankfull width and the DBH equal to ½ bankfull depth (Abbe and Montgomery, 2003). Figure 12 is an example of a stable key piece that is accumulating additional debris and sediment. Note that this is the only conifer identified from the field survey.

Figure 12. Example of stable key piece on the Satsop River near RM 0.25. 2019 aerial image (left) and ground-based photo looking downstream (NSD, March 2019). The conifer marked in the photo (red arrow) is approximately 60 ft in length and has three separate trunks with DBH of 20 inches.

Log jams were defined as wood accumulations that showed evidence of remaining stable under high flow conditions based on review of past aerial photographs. Field evidence included:

- Presence of multiple piece wood accumulations in the river,
- Sediment accumulation behind the jam,
- Vegetation establishment within the jam,
- A variety of decomposition stages of wood composing the jam (i.e. wood transported from different floods), and;
- The presence of stabilizing key pieces.

Figure 13. Example of stable log jam on the Satsop River near RM 0.5. 2019 aerial image (left) and ground-based photo (NSD, March 2019). The log jam pictured is located at the apex of the channel split between the avulsion and abandoned meander, near RM 0.5. Aerial imagery shows wood accumulation at this location as early as 2013. The majority of wood accumulation is composed of alder and cottonwood species.

Table 2 provides a summary of functional and key piece wood counts in the Lower Satsop River. Thirty-nine functional pieces and only one key piece was counted. Comparing the existing density of key pieces, 0.5 per mile, to the reference value of at least 64 key pieces per mile, the volume of stable wood in the system is low. Nearly all wood is located on the channel margins which provides minimal structure to the channel bed and offers little hydraulic complexity. Table 3 summarizes the number and density of logjams in the project reach. Stable logjams in the Lower Satsop River are 14% of reference conditions. Furthermore, deciduous species (particularly alder) comprise the majority of functional wood and logjams. Deciduous species are less decay-resistant than coniferous species and are being recruited primarily from immature, early successional riparian forests.

Stable large wood provides critical functions for sustaining river systems with low rates of channel migration and a diversity of high-quality habitat for aquatic species. Stable log jams and other large wood material act to partition shear stress (i.e. stream energy) across the channel bed and banks – thus lowering the available energy for channel migration (Manga and Kirchner, 2000). This same process can help reverse channel incision by trapping sediment (May and Gresswell, 2003). The deficiency of stable large wood and logjams, and the conifer species that have historically been present in the system, is a direct contributor to degraded habitat conditions in the Lower Satsop River. Addressing the depletion of large wood with both instream structures to provide immediate habitat and stability and replanting of conifers are necessary to restore the large wood process into the future.

4.3 Pools

The quantity, size and location of pools is generally reflective of the hydraulic conditions within the project reach. NSD recorded the number of pools in the Satsop River along with their formative mechanism. Pool depths were not directly measured. Figure 9 shows the location of pools surveyed in March 2019. Of the 13 pools identified in the field survey, 9 are formed by the presence of wood, 2 formed by rock or revetment scour, and 2 pools formed by meander bends. Eight of the pools formed by wood are from functional pieces, but are not considered stable features. For comparative stream widths, the reference density is at least 18 pools per mile (NOAA, 1996), where the project reach has a surveyed density of 6 pools per mile.

The overall frequency of pools in the project reach is low compared to reference values. The highest density of pools occurs in the avulsion reach, which is consistent with the higher degree of wood loading compared to the rest of the reach. Pools provide refuge from high flows during over-wintering and thermal refuge during summer months. Deep pools are also important holding habitat for adults migrating upstream to spawn, particularly populations that spend longer durations migrating, such as Spring Chinook and Winter Steelhead. Given the lack of large stable wood in the river system and availability for recruitment from riparian forests, the quality (frequency and depth) of pools in the Lower Satsop are consequently degraded. It is therefore crucial for the improvement of instream habitat, that instream structure from large stable wood is addressed.

4.4 Side Channels

Side channels are formed by channel migration, avulsion, and frequent flooding that creates channel scars and other low-lying depressions in the floodplain. Within the Lower Satsop River, these features mostly occur in the form of overflow and backwater connections to the mainstem channel. A total of 6 side channels were identified through topographical analysis of landforms and also confirmed during the field survey (Table 4). Preliminary two-dimensional hydraulic modeling by NSD provided additional insight into side channel connections with the mainstem Lower Satsop River (NSD, 2019b). Side channels are mapped in Figure 9.

The side channel at RM 1.6 is supplied by Henson Creek, which approaches from upstream of Highway 12, and forms an alcove feature at its outlet. Multiple beaver dams were observed in the lower section of the RM 1.6 side channel. The side channels at RM 1.5 and 1.15 are the second and third longest, and serve as overflow pathways through the WDFW parcel on the Satsop River. It should be noted that these become engaged at nearly the 2-yr flow (26,260cfs) and are otherwise dry. The two downstream-most side channels are less than 1,000 ft in length and are connected only by backwater from the mainstem Satsop River.

Table 4. Satsop River side channels, from RM 2.2 to 0.

SIDE CHANNEL	RIVER MILE CONNECTION (RM)	LENGTH (FT)	PRIMARY CONNECTION
1	2.15	973	Overflow
2	1.6	3,276	Backwater Trib.
3	1.5	1,513	Overflow
4	1.15	2,069	Overflow
5	0.55	925	Backwater
6	0.5	849	Backwater

Side channel habitats are important aquatic habitats for juvenile salmonids, amphibians, and mammals that depend on slow velocity wetted habitats outside of the main river channel. The highest quality habitats are associated with the perennially inundated downstream alcove habitat (RM 1.6) that is fed by tributary and hyporheic flow. The side channels connected as overflow pathways are located on low-lying gravel bars, some of which are sparsely vegetated, but able to support young to mature deciduous riparian vegetation. Flows through these channels recede rapidly with the descending limb of the seasonal hydrograph. Side channels connected through backwatering of the mainstem channel occur only during elevated flows (2-yr flow and above). This means that 5 of the 6 side channels are able to provide habitat for aquatic species at relatively infrequent discharges and for short durations.

4.5 Summary

Based on evidence provided by aerial imagery, topographic datasets, and field survey, the habitat conditions are currently degraded below reference conditions within the project reach. The current riparian vegetation conditions within the project reaches do not appear to be capable of providing structural functions to the river system. There is a lack of mature vegetation and large trees capable of providing adequately sized large wood to the stream, resisting the river's forces during floods and maintaining integrity of the banks. Moreover, there is a lack of conifer species in the existing riparian forests. The high percentage of cultivated lands within the project reaches are further contributing to the deficit of mature riparian vegetation. The degradation of riparian forests within the project reach has also impacted in-channel habitat conditions through reductions in stable large wood, log jams, and pools. The impacts of the degraded riparian forest on river system elements such as in-channel large wood, channel migration/erosion, flooding, and aquatic species habitat development are also described in the upper reaches of the Satsop River (NSD, 2019).

Based on the results of the habitat assessment, we recommend the following restorative actions be taken in order to improve habitat conditions:

- Increase frequency of stable large wood and log jams in order to:
  - Provide immediate in-channel cover for aquatic species
  - Form deep pools
  - Reduce channel migration rates
  - Store sediment
  - Protect riparian forests and allow them to reach maturity
  - Increase floodplain connectivity
- Plant riparian buffers and restore existing riparian forests in order to:
  - Eventually provide source of stable large wood for channel
  - Reduce channel migration rates
  - Increase shade of channel
  - Provide habitat for wildlife
  - Improve floodplain habitat

4.6 Hydrology and Hydraulics

4.6.1 Hydrology

NSD conducted a Log Pearson III analysis following the USGS Bulletin 17C methodology to determine the magnitude of the 1-, 2-, 5-, 10-, 25, 50-, and 100-year return interval events at the USGS gage 12035000, Table 5. The gage is located at the Monte Elma bridge crossing the Satsop River mainstem approximately 600 feet upstream of the project reach.

Table 5. Recurrence events calculated using peak flows from the period of record, USGS Gage 12035000.

RECCURRENCE FLOW EVENT	SATSROP RIVER (CFS)
1-yr Flow (Q1)	10,000
2-yr Flow (Q2)	26,260
5-yr Flow (Q5)	35,820
10-yr Flow (Q10)	40,970
25-yr Flow (Q25)	46,370
50-yr Flow (Q50)	49,720
100-yr Flow (Q100)	52,610

4.6.2 Hydraulic Model Development

In 2018, NSD developed a two-dimensional (2D) hydraulic model which includes the project reach as part of the East Fork Satsop Aquatic Species Restoration Plan Early Action Project. The model utilized 2017 topobathymetric LiDAR data to represent ground surfaces. In March of 2019, NSD collected bathymetric survey data from the recent channel avulsion, as well as land based topographic survey of the abandoned meander. The computational mesh for 2D hydraulic model was subsequently updated with this new dataset. Reach hydraulics were analyzed using a 2D RiverFlo-2D computer model. The model was used to evaluate existing hydraulic and floodplain processes, risks to private property, and to evaluate the restoration concepts developed in the preliminary design.

Table 6. Mesh spacing applied to model breakline categories.

SURFACE TYPE	MESH SPACING (FT)
Thalweg	10
Bank Top and Toe	15
Gravel Bar	15
Floodplain Channel	30
Valley Grade Break	50
Outer Boundary	50

In order to accurately capture the topography and yield results with fine enough detail in areas of interest, the model mesh was refined in the main and floodplain channels, with expanded mesh spacing in less topographically complex areas farther from the stream. Table 6 presents the mesh spacing used in the model. Hydraulic resistance is characterized in the model by polygons representing differing surface roughness types such as channel, vegetated bar, forest, or pasture. Table 7 includes the Manning's n value associated with each category.

Table 7. Model roughness values.

SURFACE TYPE	MANNING'S n COEFFICIENT
Logjam	0.15
Forest - Mature	0.08
Forest - Young	0.10
Scrub/Shrub	0.05
Standing Water	0.035
Pasture/Agriculture	0.03
Gravel bar	0.045
Channel	0.035
Road, gravel	0.025
Road, paved	0.02

NSD calibrated the existing conditions hydraulic model to USGS gage 12035000 for the November 2017 high flow event, approximately 33,500 cubic feet per second (cfs). To best match the rating curve across the full range of discharge, Manning's n-values are reduced according to computed depth. Figure 14 shows the calibrated model results compared to the published rating curve for USGS gage 12035000. Hysteresis in the computed water surface elevations is noted, but differences between the USGS 12035000 rating curve are within 0.25 feet.

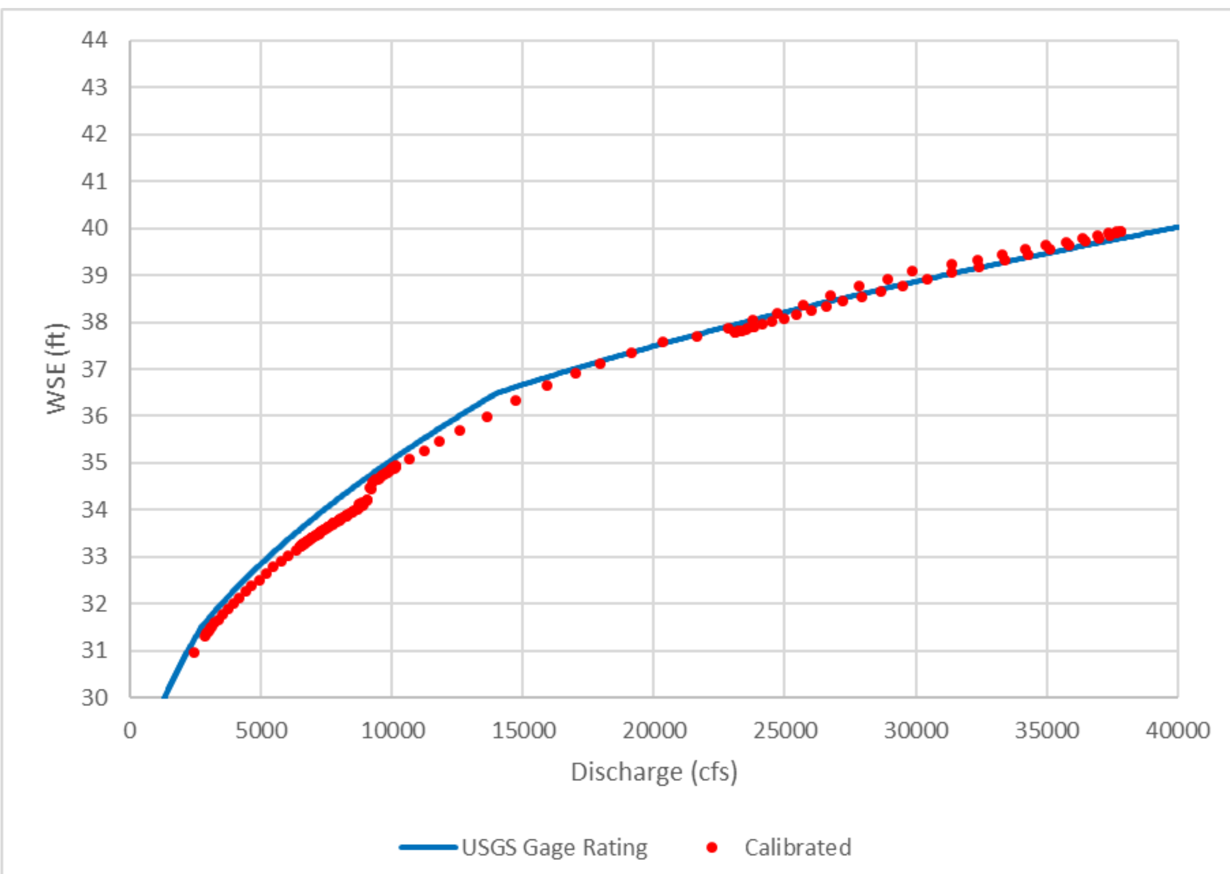

Figure 14. Calibration of Manning's n-values, computed versus USGS 12035000 rating.

4.6.3 Hydraulic Model Existing Conditions

To evaluate conditions, a transient model simulation of the following flow events was run:

- 100-year flood discharge without backwater effect from the Chehalis River
- 100-year flood discharge with backwater effect from the Chehalis River
- 10-year flood discharge
- 2-year flood discharge without backwater effect from the Chehalis River
- 2-year flood discharge with backwater effect from the Chehalis River
- Habitat flow, overwintering habitat flow

Map outputs of flow depth, velocity and shear stress are included in Appendix D. Summary statistics compiled for the 2-year and 100-year recurrence flow are presented in Table 8; values were sampled from 2-D hydraulic model output at a cross-section across the main conveyance area of the channel near RM 0.7. The Q100 recurrence flow sets the conditions over which the design stability is evaluated.

Table 8. Summary of Q2 and Q100 hydraulic parameters under existing conditions.

FLOW	*DEPTH (FT)				*VELOCITY (FT/S)				*SHEAR STRESS (LB/SQFT)	
	MIN	MAX	MEAN	SD	MIN	MAX	MEAN	SD	MEAN	SD
Q2: 26,260 cfs	6.40	13.56	10.31	2.43	6.41	14.64	11.13	2.63	1.37	0.43
Q100: 52,610 cfs	10.22	16.64	13.88	2.15	1.52	13.16	8.94	3.94	0.52	0.43

4.7 Landownership and Site Infrastructure

Within the reach, most land is owned privately with a few key properties owned by the State and County. Most land owners live within or adjacent to the project reach, except for the WDFW property near RM 1 and the Port of Grays Harbor property, where a drinking water supply well is located near RM 0.4. The River left floodplain is in close proximity to Keys Road and there are some bank hardening treatments adjacent to the WDFW property and also near the Port of Grays Harbor well. Open agricultural lands used for farming characterize the majority of the River right floodplain through the project reach. These lands are at high risk of future erosion (NSD 2018a). Restoration efforts within the project reach need to consider potential effects to bank erosion in these areas and methods to reduce the rapid erosion rates through private agricultural lands. See Figure 15 for a map of land ownership within the reach.

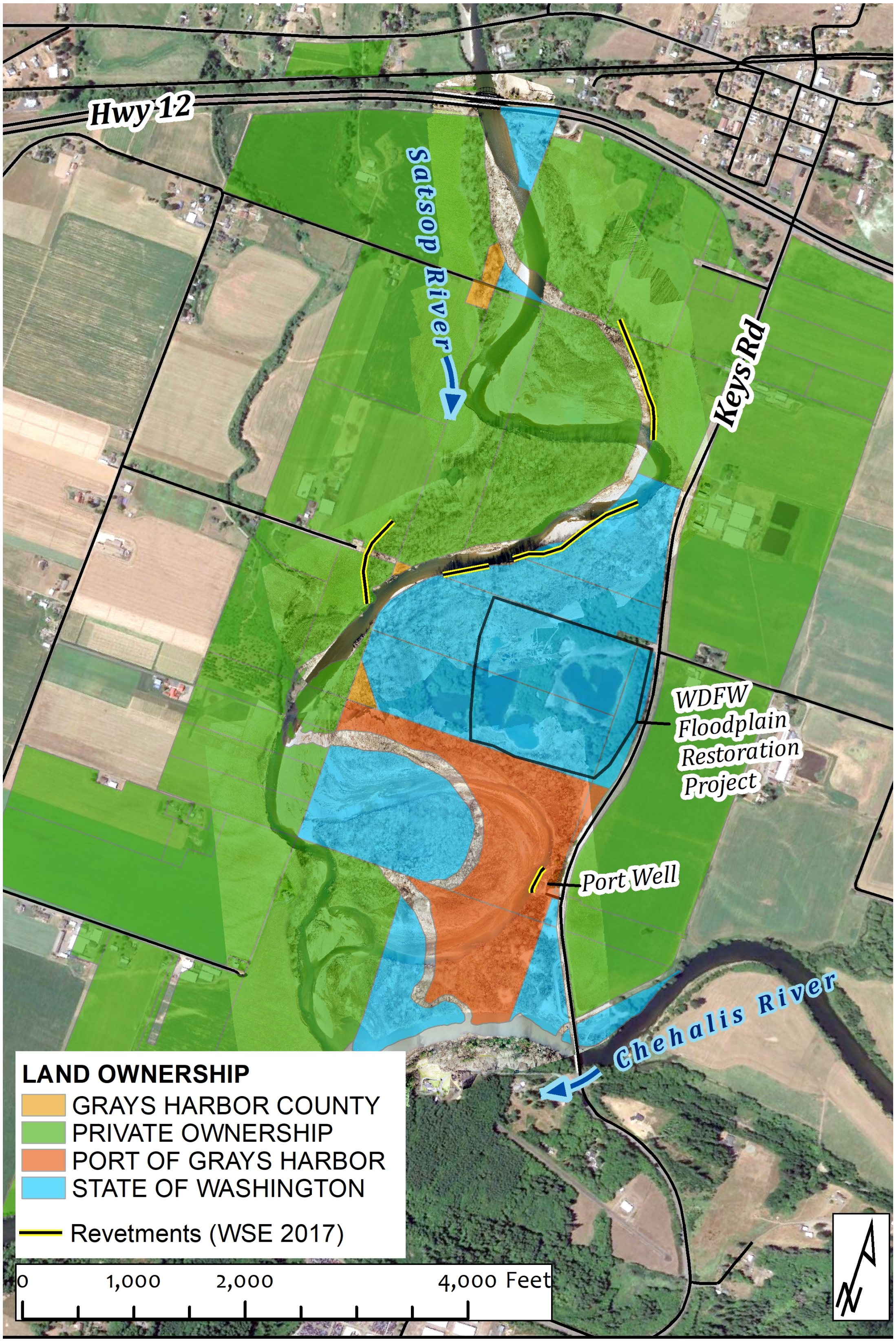

Figure 15. Land ownership within the project reach.

5 CONCEPTUAL DESIGN DEVELOPMENT

The purpose of the conceptual design was to develop a reach scale plan to address channel migration and the associated erosion of agricultural lands while identifying areas where restoration actions could increase floodplain connectivity and improve the quality of instream and off channel habitat. The reach scale conceptual plan was developed with data collected as part of the geomorphic assessment and prioritized restoration actions based on rate of erosion, location of floodplain channel, channel migration trends and causal factors, and existing habitat features. Concept design elements include installing bank and in-stream wood structures, salvaging existing wood accumulations, removing bank hardening treatments, installing floodplain roughness features, riparian forest enhancement and conifer underplanting, and removing or relocating floodplain infrastructure. The reach scale concept design was submitted for a round of review by stakeholders and agencies at a Lower Satsop Advisory Group meeting. Reviewer comments were incorporated into the conceptual design subsequently; the conceptual design is included as Appendix A.

6 PRELIMINARY DESIGN DEVELOPMENT

The preliminary design includes priority actions identified in the reach scale conceptual design.

6.1 Engineered Log Jam Structures

Engineered Log Jams (ELJ) structures (i.e. in-stream and channel margin) will increase habitat complexity, improve connectivity to existing side channels, wetlands, and floodplain features, promote natural channel processes, such as lateral channel migration, and create stream bank stability where desired. All structures are designed to meet site-specific conditions as evaluated through buoyancy and stability calculations, and hydraulic responses based on water depth and velocity utilizing topographic data and output from the 2D modeling effort.

Each ELJ structure is designed to create a desired hydraulic response in the river or floodplain, provide habitat, create complexity, and in some cases create stability over time. ELJ features are designed to mimic structures that would have naturally occurred if anthropogenic actions had not altered the geomorphology of the river course and reduced the natural inputs of wood material to the system.

NSD developed the following large wood structure types to achieve the project goals:

- Apex
- Deflector
- Floodplain Roughness, Triangle elements

All of these wood structure types are pile supported with key member logs interlaced to provide structural stability. The specific design criteria associated with structural stability are adopted from the US Bureau of Reclamation's 2014 *Large Woody Material – Risk Based Design Guidelines* (RBDG). Although the minimum stability design flow criteria for the Satsop River LWM structures is the 50-year flow, the design engineers applied the 100-year design flow in order to meet recent legislation in Washington exempting landowners from liability for the LWM structures on their property, if the structures are designed for the 100-year event. The ratings for risk are shown in Table 9.

Table 9. Risk based design criteria for the Lower Satsop River.

PUBLIC SAFETY RISK	PROPERTY DAMAGE RISK	STABILITY DESIGN FLOW CRITERIA	FOS SLIDING	FOS BUOYANCY	FOS ROTATION FOS OVERTURNING
High	Moderate	100-year	1.5	1.75	1.5

6.2 Design Elements

6.2.1 Relief Channel

A temporary relief channel is proposed to be graded through the gravel bar on the left bank starting at RM 0.9 with a planform that curves to the east and reconnects with the main channel at RM 0.4. The main purpose of the temporary relief channel will be to reduce dewatering and isolation challenges within the low flow channel during construction. The temporary relief channel will also reduce hydraulic pressures along the eroding bank near RM 0.7 by diverting water into the pre-avulsion channel during normal to high flows. However, due the channel bend morphology and sediment transport dynamics, the temporary relief may fill in with sediment over time and is not expected to provide long-term hydraulic relief to the eroding bank near RM 0.7. The temporary relief channel will be approximately 1,250 feet long with a top width of 50 feet, 2:1 side slopes and depths ranging from 3-5 feet to maintain a grade of 0.3 percent. The hydraulic conveyance of the relief channel will be roughly 700 cubic feet per second (cfs).

Approximately 10,000 cubic yards of material will be excavated from the relief channel during construction. It is estimated that 3,800 cubic yards can be incorporated into ELJ's as backfill leaving 6,200 cubic yards to be placed on the floodplain. Options for placement of this alluvium include: 1) building out the bank in the meander at the Port of Grays Harbor well; 2) stockpiling the material for WDFW to use as part of the Phase II floodplain restoration project; 3) spreading the alluvium out on the existing gravel bar; 4) a combination of Options 1-3, as needed. Option 1 would require the material to be placed behind the bank structures proposed at the meander, as well as a revegetation component to stabilize the material. Option 2 would require intra-agency coordination and interest in the material by WDFW. It is not clear at this time if such a quantity of material is desired for Phase II of the floodplain restoration design. Option 3 would raise the elevation of the gravel bar by 0.75 feet and would have to be completed prior to placement of ELJ's.

6.2.2 Apex ELJs

Apex ELJ's act as hard points to split flow as mid-channel jams, at the head of gravel bars, and in association with side channel and alcove elements. They increase channel length by splitting flow and locally raise water surface elevation increasing floodplain inundation and side channel utilization. Apex structures increase bend hydraulics to induce scour and lateral migration. Their primary hydraulic influence is local, creating velocity and shear stress gradients which result in pool habitat and adjacent sediment sorting.

Five (5) Apex structures are to be located in the main channel near the relief channel inlet. This placement will increase the water surface elevation and deflect flows into the proposed relief channel. Structure spacing, orientation and quantity were determined by evaluating hydraulic effects including backwater, velocity gradients and channel obstruction. An additional ten (10) Apex structures will be located in the abandoned meander. These structures will provide aquatic habitat by creating deep pools, sorting sediment, and providing cover.

6.2.3 Deflector ELJs

Deflector ELJ's act as hard points along the bank to stabilize and slow unnaturally high erosion rates and allow for riparian vegetation to mature without restricting lateral migration beyond the natural long-term migration rate. Deflector structures interact with all flows maximizing interstitial space, as well as velocity gradients, without creating undue safety hazards. Deflector structures form pools through local scour with the potential to induce lateral channel migration and improve hydraulic connectivity with proposed or existing side channel elements.

Two (2) deflector structures will be placed just upstream of the inlet to the proposed relief channel. This placement will control any potential for bank erosion as a result of flows turning into the relief channel. Structure spacing and quantity were determined by applying methods presented in the literature on spur dikes and groin research, (1984, Klingeman, Peter et.al.) (2005, Abbe, Timothy et.al.). An additional four (4) deflector structures will be placed on the right bank in the abandoned meander just upstream of the Port's well. This structure placement will provide protection to Keys Road and the Port's well, in addition to providing aquatic habitat by creating deep pools, sorting sediment, and providing cover.

6.2.4 Floodplain Roughness, Triangle Elements

Floodplain roughness structures add roughness to the floodplain and rack material and debris that is carried over the floodplain at higher flows; directing flow into preferential flow paths and helping to establish secondary channel networks. The racking and slash that integrates into the structure can provide local cover when inundated. Floodplain roughness structures achieve habitat uplift through increased floodplain utilization and increase in channel length through creation of secondary channel network. They typically interact with higher flows which reach and inundate gravel bars. For this site, they are designed to potentially interact with the main channel under future conditions.

Fourteen (14) floodplain roughness triangles are to be installed on the floodplain on the western side of the relief channel. These are positioned to provide resistance to flow across the gravel bar and to keep flows in the relief channel so that they discharge into the abandoned meander downstream of the avulsion.

6.3 Hydraulic Model Proposed Conditions

Modeling of proposed conditions is directly informed by the existing conditions analysis described in Section 4.6.2. In an iterative process, design elements were incorporated into the model and subsequently evaluated for their effectiveness in achieving the project goals. Output parameters such as depth, velocity and shear stress provide the basis for designing structure location, type, size and component details, and also allow the Design Team to quantify changes to location-specific hydraulic conditions (e.g. backwater, side channel connectivity, floodplain inundation). Combined with field reconnaissance and landowner feedback, two iterations of proposed conditions hydraulic modeling were completed to refine concept designs.

Proposed conditions designs are incorporated into the hydraulic model by 1) modifying topography, 2) adjusting roughness, and 3) refining the computational mesh. NSD followed this process for ELJs and other structures. ELJs are represented by a series of elevated "pillars" at the face of the structure with their crest height being consistent with the design detail. Using this method, flow is obstructed around the upstream face of the structure but still allowed to pass through in a limited capacity. The increase in roughness accounts for energy dissipation created by the flow obstruction. Finally, maximum mesh cell size is reduced to 2 feet in order to capture these effects in the model. A schematic of this arrangement is shown in Figure 16.

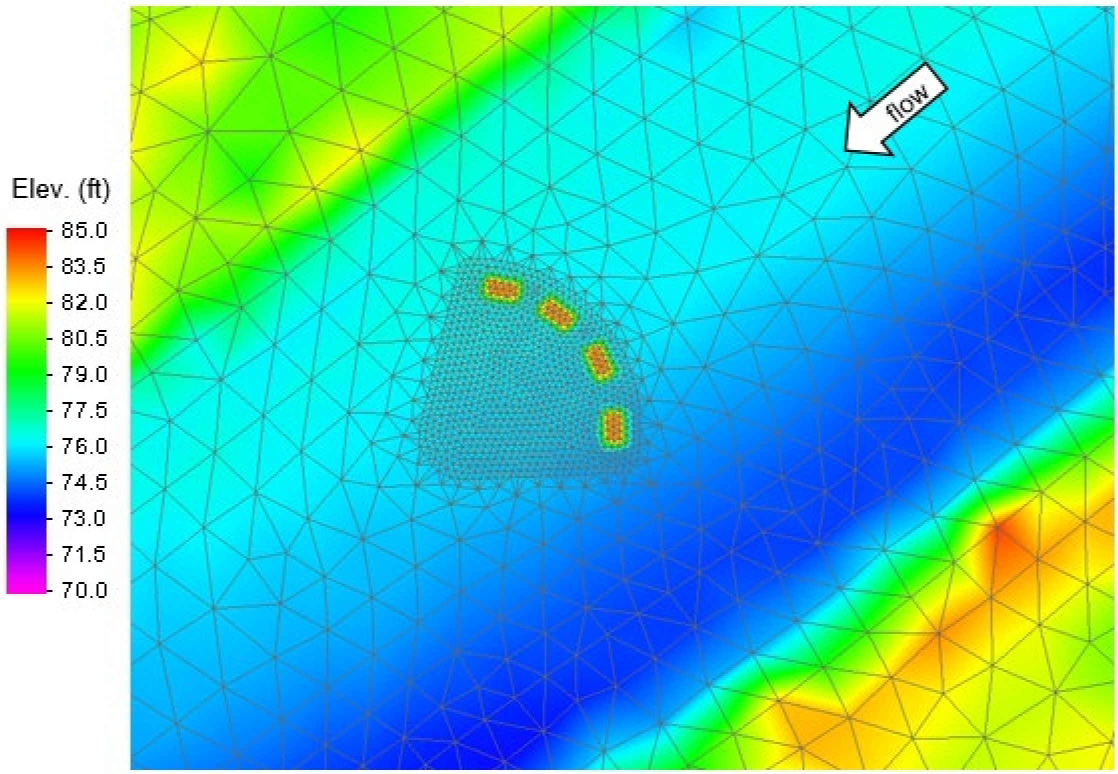

Figure 16. Schematic of ELJ structure in Riverflow 2D.

The proposed conditions topography is created by imposing structure dimensions onto the existing conditions dataset. Pillar dimensions are set proportional to ELJ size, with smaller structures containing fewer pillars. A minimum of 2 to 3 cells is required between each pillar. This approach was validated through a series of independent model simulations to ensure that both local and reach-scale hydraulic conditions are sufficiently represented. Defining ELJs as pillars with increased roughness produces hydraulic effects as expected from traditional methods, but furthers the representation as a porous structure.

Map outputs of flow depth and velocity are included in Appendix D. The most pronounced effects from the first iteration of proposed conditions modeling includes reduction of mainstem channel velocity, increase in mainstem depth and wetted floodplain areas and reduction in mainstem shear stress. During the second iteration, design elements were adjusted to promote these conditions further. Adjustments include repositioning, adding or removing structures and modifying structure crest elevations.

6.4 Permitting Considerations

Based on input received during conceptual design development and the preliminary design, the following authorizations and approvals are anticipated to be required.

- Clean Water Act Section 404 authorization from U.S. Army Corps of Engineers (USACE) and Section 401 Water Quality Certification from Washington State Department of Ecology
- National Historic Preservation Act, Section 106 Cultural and Historic Resources consultation (component of authorization from USACE)

- Endangered Species Act Section 7 consultation (tentative); No Effect Letter for NOAA Fisheries regulated species; Biological Evaluation form for USFWS regulated species (component of authorization from USACE)
- Magnuson-Stevens Fisheries Conservation and Management Act, Essential Fish Habitat (EFH) consultation on salmonids with NOAA Fisheries
- Hydraulic Project Approval, WDFW, Fish Enhancement Streamlined Process
- Washington Department of Natural Resources, WDNR, Aquatic Use Authorization
- Grays Harbor County, Shoreline Substantial Development Permit
- Grays Harbor County Floodplain Impact Assessment
- Grays Harbor County Critical Areas Review
- State Environmental Policy Act (SEPA) compliance

6.5 Construction Considerations

The anticipated in-water work window for the Lower Satsop River is very short, August 1 to August 31 to avoid and minimize impacts to juvenile and adult salmonids (2018, WDFW). Construction is anticipated to span 2 years. Riparian plant procurement (e.g. contract growing) will likely need to occur the year or more prior to installation due to the number of plants required. Invasive species management actions (e.g. knotweed control; blackberry clearing) would likely occur prior to ELJ placement and riparian plant installation. Riparian plantings would likely be installed in the fall and/or spring following each in-water construction season; supplemental plantings may be installed in the years following initial construction to ensure sufficient survival and potentially to add shade-tolerant plants over time.

Key construction issues investigated and resolved during the preliminary design include:

- Field verify hydrologic conditions in potential wetland creation and rehabilitation areas
- Identify potential large wood sources
- Confirm feasibility of driving timber piles to design depths with commercially available equipment
- Investigate feasibility of producing the large stock of plant materials required for riparian plantings
- Invasive species management areas, techniques, and timing

6.6 Quantities and Cost

NSD determined the quantities of materials presented in Table 10 using the design details shown in the September 2019 preliminary design plans, Appendix B. NSD also prepared a construction cost estimate for the draft preliminary design, Appendix C. ELJ costs were estimated per structure by applying a unit price to the building materials and adding equipment and labor rates from the 2019 edition of RSMeans data. Unit costs were based on costs incurred implementing other restoration projects in Whatcom and Clallam counties and through internet research. Due to the preliminary nature of the designs, an allowance of 15 percent for indeterminates was added to the total cost, inclusive of an assumed construction date. The sales tax rate of 8.8 percent for Grays Harbor County was also applied to the sub-total.

Table 10. Construction quantities.

ITEM	QUANITY	UNIT
Mobilization	1	LS
Erosion/Water Pollution Control Measures	1	LS
Access and Staging	1	LS
Site Isolation	1	LS
Type 1 Apex ELJ	12	EA
Type 2 Apex ELJ	3	EA
Type 1 Deflector ELJ	6	EA
Floodplain Roughness Triangular ELJ	14	EA

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