

**Assessment of Stream Restoration Efforts and Development of  
Effectiveness Monitoring Protocol  
Ohop Creek, Pierce County, Washington**

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## **Executive Summary**

Between 2008 and 2015, the Nisqually Indian Tribe, Nisqually Land Trust, and South Puget Sound Salmon Enhancement Group conducted a multiphase restoration project on a two-km section of Ohop Creek, located west of the town of Eatonville, WA. The creek had been channelized in the early part of the 19<sup>th</sup> century to develop Ohop Valley for agriculture. The restoration focused on constructing a new channel to provide improved aquatic and riparian habitat. Restoration on the upstream section, Phase I, occurred between 2008 and 2010 and the downstream section, Phase II, between 2014 and 2015. A key element of the restoration was the use of engineered wood structures (LWM) to create flow complexity and provide cover for anadromous fish. To evaluate the success of the restoration project in meeting objectives, I assessed how the channel morphology and aquatic habitat distribution have evolved since completion. The assessment focused on four key components: the stability of the channel dimensions, the amount and distribution of in-channel habitat, the physical effects on the channel from the engineered wood structures, and the frequency of floodplain inundation.

From observations and analysis, I developed a protocol to monitor habitat and to help land owners and future researchers continue to assess the effectiveness of the restoration treatment. The purpose of the monitoring protocol is to inform stakeholders in future restoration on other sections of Ohop Creek. The protocol implements benchmarked cross-sections, longitudinal profile and pool survey, discharge measurements, and an extensive photo survey that documents LWM and channel bank interaction.

I measured channel widening from aerial photos and orthographic images between 2011 and 2017 using transects oriented perpendicular to the channel centerline. Greatest average annual rate of widening occurred in areas with engineered wood structures in Phase I, with a consistent average rate of 0.3 m/yr from 2011 to 2017. Widening in the Phase II reach was also greatest for transects located in areas containing engineered wood structures, with an annual average rate of 0.2 m/yr from 2015-2017. Channel incision was determined from comparing 25 surveyed cross-sections with design cross-sections derived from as-built drawings and construction plans. Deepening from LWM-induced bed scour is relatively active throughout most of the project reach, averaging 0.2 m/yr in the Phase II reach from 2015 to 2017. The magnitude of deepening

in the Phase I channel could not be confidently quantified because it was not possible to verify if the Phase I reach had been constructed according to design plans.

Channel habitat was investigated by conducting a pool survey using a survey-grade GPS with real time kinematic (RTK) corrections, recording the depth, location, and type of each pool.

Pools formed from scour around LWM and free-form pools augmented by nearby LWM structures constituted 51% of the pools in the Project reach. LWM scour pools were on average deeper than other pool types, with an average residual depth of 0.4 m.

LWM-induced bank scour was surveyed and measured from orthographic images. Forty percent of the structures were observed to be inducing lateral bank scour. LWM structures composed of several vertical log piles interwoven with horizontal logs and rootwads (referred to as “complex” or “type 6” structures) positioned at the inflection point between meanders were associated with the highest frequency and magnitude of bank scour, averaging 25 m<sup>2</sup> of lateral scour per structure between 2015 and 2017.

Discharge measurements made in the restoration area were on average 6.5% higher than discharge measurements recorded six kilometers upstream at USGS gage #12088000 “Ohop Creek near Eatonville, WA”, which is 9% lower than the increase in flow derived by engineers by using a regional scaling relationship between drainage area and discharge.

During a site visit in February of 2018 I observed the Phase II reach to be at or just above bankfull flow at 9.1 m<sup>3</sup>/s. Using reach average cross-sectional bankfull area and water-surface slope, I calculated a bankfull discharge of 12.4 m<sup>3</sup>/s for the Phase I reach from application of Manning’s equation. Flood duration analysis of USGS mean daily discharge records from 1994 to 2010 indicate that the Phase I and II bankfull flows are expected to inundate the floodplain an average of 2.2 and 5.4 days per year, respectively, which is 50-60% less than predicted by Project engineers.

Based on the findings presented in the current study, the LWM structures are providing bed scour for fish habitat in the Project reach. In addition, channel widening was shown to be strongly correlated with lateral bank scour induced by LWM-structures, indicating that the engineered wood structures are providing both in-channel habitat and flow complexity necessary for achieving the Project objective of enhancing aquatic habitat for rearing fish. However, initial

channel widening from LWM-induced bank scour has decreased the frequency of floodplain inundation predicted by Project engineers, which negatively impacts the Project goal of riparian zone rehabilitation at least in the short-term. Monitoring the LWM structures is a key component of the protocol developed from this study and will help to resolve this issue in the future.

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## 1.0 Introduction

Between 2008 and 2015, the Nisqually Indian Tribe, Nisqually Land Trust, and South Puget Sound Salmon Enhancement Group conducted a restoration project on Ohop Creek, located west of the town of Eatonville in Pierce County, Washington (Figure 1). During the 1930s, the lower section of Ohop Creek had been channelized for agricultural purposes (Watershed Professionals Network, LLC & GeoEngineers, Inc., hereafter referred to simply as WPN, 2006). The channelized creek incised into its bed, lowering the groundwater table, separating the stream from the riparian zone, and diminishing the creek's ability to provide quality aquatic habitat. The overall goal of the Ohop Valley Restoration Project (Project) was to rehabilitate channel and riparian habitat along Ohop Creek by constructing a new channel that had the size, cross-sectional form, and sinuosity of a natural channel (Cardno ENTRIX, hereafter referred to as Cardno, 2011).

A key component of the new channel was the inclusion of large woody material (LWM), which research has shown to influence the formation and maintenance of deep scour pools that provide refugia and rearing habitat to anadromous fish (Abbe and Brooks, 2011). Project managers designed and installed over 90 LWM structures in the study reach to achieve the Project goal of enhancing aquatic habitat and to provide stability to the channel banks. The LWM structures used in the Project reach were designed to form deep scour pools and bed complexity away from the core of the structures, thus serving to minimize the amount of bank erosion and to decrease the likelihood of channel avulsions. The LWM structures were redesigned between the Phase I and Phase II channels to more closely mimic their patterns found in free-flowing lowland streams (Cardno, 2014).

The objective of the present study is to characterize how the morphology and aquatic habitat distribution of the channel has evolved following restoration to evaluate the success of the treatment in achieving Project goals. To accomplish this objective, I integrate field measurements with aerial and orthographic image review in order to answer the following questions:

- How has the channel planform evolved since completion with regards to centerline migration and channel widening?

- How has the channel cross-sectional area evolved with regards to channel width and mean depth?
- Do in-stream LWM structures installed during restoration produce scour pools for aquatic habitat?
- Do in-stream LWM structures provide the expected stability with regards to lateral bank erosion?
- What is the current bankfull discharge in the Project reach and is it providing the expected frequency of flooding to the riparian zone?

A critical missing component of the restoration design was a specific monitoring and evaluation protocol to assess the Project effectiveness. This oversight is common in restoration projects; although the number of stream restorations is increasing, research shows only a small fraction of projects in any country or watershed is adequately monitored (Roni et al., 2013). Nevertheless, a comprehensive monitoring and evaluation protocol can help land managers assess whether the restoration treatment was effective in meeting objectives. Here I use an analytical approach to design a monitoring protocol that is informed by the research conducted in this report. The protocol implements channel planform surveys, permanently benchmarked cross-sections, discharge measurements, and an extensive photo survey that documents LWM structures in order to inform stakeholders considering future restoration on other sections of Ohop Creek.

## **2.0 Background**

### ***2.1 Anthropogenic Disturbances and Channel Response***

Historically Ohop Valley was home to a swampy cedar thicket (*Thuja plicata*) (Homza et al., 2002). By the middle of the 19<sup>th</sup> century, the valley was settled by European homesteaders who converted the densely forested wetland into pastures and agriculture land. In order to reduce flow into the lower Ohop Valley, the upper quarter of the watershed was diverted into Lake Kapowsin and the Puyallup River Basin in the latter part of the 1800s (WPN, 2006). By the middle of the 1900s much of the valley's forests had been logged and over four miles of the lower reach of Ohop Creek had been channelized and moved to the eastern side of the valley. The former

channel was almost completely filled in using excavated material to provide more level ground for farming and grazing.

Ohop Creek was channelized in the 1930s and the new channel was dug deeper than the former natural channel, in order to decrease flooding during peak winter flows (WPN, 2006).

Downcutting into the sandy bed followed as a result of shortening the channel, resulting in a channel that was entrenched as much as 3.5 m below the floodplain. Typically, a channelized stream will form new meanders as sediment eroded from upstream headcuts is deposited downstream (Simon 1995). Eventually a new inset floodplain will form as the channel meanders. Since the straightening in the 1930s, however, no new meander bends had developed in the channelized section of Ohop Creek. The combined effects of low sediment load, low gradient and low discharge have hindered the straightened sections of Ohop Creek from developing natural meanders and establishing a new floodplain (WPN, 2006).

## ***2.2 Ohop Valley Restoration Project***

Straightening Ohop Creek and removing the forest cover in the surrounding valley greatly reduced the creek's ability to provide quality habitat for anadromous fish. In 2001 the Nisqually Indian Tribe published the Nisqually Chinook Recovery Plan, identifying Ohop Creek as a high-priority area for restoration to restore the channel's ability to support juvenile Chinook (*Oncorhynchus tshawytscha*) rearing habitat (NCRT, 2001). In 2002, a comprehensive restoration plan was developed for the Ohop Valley (Homza et al., 2002). In August of 2006, WPN and GeoEngineers conducted preliminary site investigation, analysis, and conceptual design for Ohop Creek. A phased approach to restoration was adopted in which construction would be implemented as funding became available and land ownership issues were resolved (Cardno, 2011). Construction of the Phase I channel, located between Peterson Road and 400 m below State Route 7, began in 2008 and was completed in 2010. Construction on Phase II, which continued the valley restoration downstream to 800 m above of the confluence with the Nisqually River, began in 2014 and was completed in September of 2015.

Engineers used reference reach cross-sections and hydraulic modeling to determine bankfull flow at USGS gage #12088000. Using a regional power-law relationship between increasing watershed area and discharge, the bankfull flow at the gage was then scaled up by 15.5% to select a design flow for the new channel. A channel-capacity discharge of 10.7 cubic meters per

second ( $\text{m}^3/\text{s}$ ), which has a peak recurrence interval of 1.07 years, was used to design the Phase I reach (WPN, 2006). After performing a flow duration analysis of mean daily discharge records at USGS gage #12088000 for water years 1994-2010, Cardno decided to reduce the design discharge for the Phase II reach by 26%, to  $7.9 \text{ m}^3/\text{s}$  (1.02-year peak recurrence interval), in order to increase the frequency of flooding with the goal of establishing healthy riparian vegetation. The bankfull flow was estimated to exceed the top of the constructed channel an average of 13.4 days/year, an increase of 8.8 additional days from the Phase I design discharge.

### ***2.3 Study Site***

Ohop Creek drains approximately 110 square kilometers ( $\text{km}^2$ ) of land ranging in elevation from 900 to 137 meters ( $\text{m}$ ) as it flows southwest into the Nisqually River (Cardno, 2011). The USGS has operated streamflow gage #12088000 intermittently since 1927 on Ohop Creek at a site 6 km upstream from the Project reach and 320 m below Ohop Lake (USGS, 2017). Average annual flow measured at the gage for the 59 years of record is  $1.89 \text{ m}^3/\text{s}$ . The datum at the gage is 158.86 m (NAVD 1988). The Project area is located in the lowermost two km of Ohop Valley. The valley through the Project area has a very low gradient, decreasing only 2 m in 2.4 km.

Ohop Creek is an underfit stream; the erosional processes associated with the modern stream are not sufficient to have shaped the landscape of the wide valley in which the creek flows (Cardno, 2011). The valley was formed approximately 16,000 years ago by at least one glacial outburst flood along the southern margin of the Puget lobe of the Vashon ice sheet (Bretz, 1913). The 10 km wide flood spillway drained a glacial lake while the Puget lobe blocked the northern and western drainage courses (Pringle, 2008).

The oldest geologic unit present in the study area is the Mid-upper Miocene Mashel Formation, which is predominantly clay, fine-grained sand, and lignite (Walters and Kimmel, 1968; Figure 1). Quaternary alluvium overlies the Mashel Formation in the Project reach. Deposits of blue clay underlie the floodplain alluvium in the upper reaches of the Project area, indicating that the valley was once a lake bottom (WPN, 2006). Lynch Creek, which joins Ohop Creek 250 m below Ohop Lake, delivers an unknown quantity of gravel and cobbles to the upper reaches of Ohop Creek. The channel substrate through the Project area is dominated by fine-grained sand.

Ohop Creek is the second-largest salmon-producing tributary in the Nisqually River Watershed (NCRT, 2001). Ohop Creek hosts several salmonid species: Chinook salmon (*Oncorhynchus tshawytscha*), Coho salmon (*Oncorhynchus kisutch*), pink salmon (*Oncorhynchus gorbuscha*), winter chum salmon (*Oncorhynchus keta*), rainbow trout (*Oncorhynchus mykiss*), and cutthroat trout (*Oncorhynchus clarkia*) (Brian Combs, South Puget Sound Salmon Enhancement Group, written communication, 2018).

### **3.0 Investigation Methods**

To create current high-resolution (< 1.0 m) images of the study area, I flew photogrammetry surveys with a DJI Phantom 3 Professional UAV on July 29-30<sup>th</sup> and August 10<sup>th</sup> of 2017 and used the aerial photos to create 0.05-m resolution orthographic images (also referred to as orthoimages in this report) in Structure from Motion (SfM) software. The orthoimages were used in several of the investigation methods where high resolution was needed to verify field observations, identify LWM structures and pool boundaries, and measure bank erosion. The aerial photos used to create the orthoimage for the section of the Project reach between Peterson Road and State Route 7 were collected on a day where there was smoke from a nearby forest fire, which resulted in a hazy image relative to the other orthoimages. Nevertheless, the orthoimage is clear enough to serve the purposes of this investigation.

#### ***3.1 Channel Migration and Widening***

Within the study area, I used 1.0-m resolution NAIP aerial images from 2011, 2013, 2015, and 2017 to digitize the active channel boundaries and centerlines into a GIS. In addition to NAIP images I used the 0.05-m orthoimage of the Project area to verify channel boundaries for 2017, because dense bank vegetation in the Phase I reach between Peterson Rd and State Route 7 made locating the channel banks difficult. Channel boundaries were defined by transitions from vegetated banks to wetted channel and prominent topographic breaks on point bars. Channel centerlines were drawn as continuous lines by estimating the halfway distance between the left and right bank. Both boundaries and centerlines were digitized at 1:500 scale.

Using the Washington State DOE Channel Migration Toolbox (Legg et al., 2014) I constructed transects perpendicular to the channel centerline and then calculated migration rates and width

changes between 2011 and 2017 for the Phase I channel, and between 2015 and 2017 for the Phase II channel (Figure 2). An interval spacing of 10 m between transects was chosen in order to ensure that enough transects intersected LWM structures, making it possible to determine the magnitude of widening provided by in-channel wood.

### ***3.2 Channel Cross-section***

During August and September of 2017, I installed permanent benchmarks and surveyed 25 cross-sections in the Project reach (Figure 3; Appendix A1). The benchmark locations were recorded using a Trimble Geo7X GPS unit connected to the Washington State Reference Network (WSRN) to achieve real-time field corrections. I used the North American Datum (NAD) 1983 as the horizontal datum and NAVD 1988 as the vertical datum. The horizontal and vertical accuracies of the coordinates was 0.02 m and 0.03 m, respectively.

Following sampling methodology from the Environmental Protection Agency's Environmental Monitoring and Assessment Program (Peck et al., 2006), 20 of the cross-sections (identified by OCXS 0X designation) were equally spaced through the Project area, while the other 5 (OCXS 0X.X designation) were located at either upstream or downstream ends of the same meander to investigate how the shape of the channel changed through a meander. No cross-sections were located in the upper section of Phase I between Peterson Road and State Route 7 because the channel was too deep to be safely waded. A 1.0-m interval between measurement points was used for the floodplain. No set interval was used in the channel; instead, emphasis was placed on capturing all salient features such as significant changes to slope, edge of water on both left and right bank, benches or inset stream terraces, and woody debris. The depth of the water was measured, and the local water surface slope was calculated between each cross-section. Channel depth was calculated by averaging the difference between the channel bed elevation and the bankfull elevation (typically the elevation of the floodplain). Top width was calculated as the difference between the distance to the bankfull edge of the right bank and the left bank from the left bank benchmark. Using the top width and mean channel depth, w/d ratios were calculated for each cross-section.

The surveyed cross-sections were compared to design cross-sections, constructed using 0.3-m interval topographic contours from the Phase II as-built drawings (Appendix A2). A 2010 LiDAR digital elevation model (DEM) of Pierce County (PSLC, 2010), and RTK GPS

elevations collected by Cardno in November of 2015 were used to verify elevations extracted from the as-built drawings. RTK data was not available for all cross-sections. Channel width, mean depth, and w/d ratios were calculated for the design cross-sections and compared to the 2017 surveyed cross-sections to determine if, where, and how much incision had occurred in the Phase II channel.

No as-built drawings were created for the Phase I construction. The thalweg elevations for the constructed channel for cross-sections located in the Phase I reach (OCXS 19-21) were determined from signed construction plans produced by Cardno in 2009. However, it was not possible to determine if the Phase I channel was built to the specifications of the construction plans, and so incision values in this reach may have more associated uncertainty than in the Phase II reach.

### ***3.3 Large Woody Material and Bank Stability***

During the spring and summer of 2017 and winter of 2018, I conducted a survey of the in-channel LWM structures in the Project area. I identified six types of LWM structures used in the Project channel (Figure 4, Table 1). Four of the structure types were used in both the Phase I and Phase II channels, although Project engineers redesigned several of the structures to interact more with the low-flow water surface, providing cover without inducing much flow complexity (Cardno, 2014). Construction plans for the Phase I channel were used to help identify structure types in the Phase I channel. No plans were provided for the Phase II channel and confidence in identifying the structure type is lower in this reach. In addition to the six types of engineered LWM structures, four large channel plugs were also installed to prevent the new channel from flowing back into the old channel. Also, two natural log jams were observed in a section of the old channel in the Phase II reach.

The surface area of each structure was measured in a GIS using 0.05-m orthoimages. The protrusion distance, defined here as the distance an LWM structure protrudes into the channel, was measured at a right angle from the bank to the end of the farthest log or rootwad. Thirteen of the forty-two structures located in the Phase I reach were heavily covered in vegetation, making it difficult to accurately measure the surface area and protrusion distance, and were not included in the final tally.

The geomorphic location in the meander was noted for each structure. I defined four distinct geomorphic locations: the upstream and/or downstream end of a point bar, the apex of the outside of the meander, the downstream end of the outside of the meander, and the inflection point between two meanders just above the upstream head of a point bar. The latter category is exclusive to the Phase II reach.

LWM structures associated with bank scour (also referred to in this document as bank erosion) were identified both in the field and from 0.05-m orthoimages. Amount of scour was quantified in a GIS for each structure and delineated by structure type and geomorphic location in the meander.

**Table 1. Summary of LWM structures in Project reach**

Type	Tot. #	Phase	Typ. Location	Description
1 (A-frame)	22	I & II	Outside of meander (apex or downstream end)	Composed of 4 logs embedded into bank at 60 degree angle to flow and 1 log installed with rootwad orthogonal to flow to intercept flow and provide fish habitat. Slash material installed in between logs.
2 (Fence)	17	I & II	Outside of meander (apex or downstream end)	Composed of 3-4 logs embedded in bank with rootwads orthogonal to flow and 3-4 wracked members angled into the flow. Woody slash installed in voids between logs and bank.
3 (Wall)	8	I & II	Outside of meander (typically at apex)	Composed of 5-6 logs embedded in bank with rootwads orthogonal to flow, locked into place by system of vertical log piles and "footer" logs without rootwads placed parallel to flow.
4 (Tight A-frame)	9	I only	Inside of meander at point bar	Similar to type 1 (A-frame) structures but composed of only 2-3 logs and key members embedded into bank at 30 degree angle to flow.
5 (V-frame)	23	I & II	Outside of meander (apex or downstream end)	Composed of 1-2 logs embedded into bank with top branches extending into flow and 1 log installed with rootwad orthogonal to flow. Installed for flow complexity and to induce bed scour.
6 (Complex)	4	II only	Outside of meander (downstream end)	Composed of 6-7 vertical log piles with layers of woven horizontal logs, rootwads, and slash material extending into the flow to provide physical and hydraulic refugia for fish.

### ***3.4 Pool Survey***

I conducted a pool survey between September and early October of 2017, recording residual depth, location, and pool type. The survey covered a section of the Project reach from 380 m below State Route 7 extending downstream another 2000 m. The survey was not extended upstream into the upper Phase I reach due to the water being too deep to safely wade at the time. A Trimble Geo 7X GPS unit, receiving RTK corrections from the WSRN, was used to measure the upstream elevation, the maximum depth, and the elevation of the downstream riffle at each pool. The horizontal and vertical accuracies of the measurements were 0.02 m and 0.03 m, respectively. Pool types were divided into LWM scour, beaver pools, and free-formed pools, which were further divided into free-formed pools augmented by LWM, those associated with slumped bank material, and those associated with the confluence of the new channel and the old channel that had been preserved as alcove habitats for rearing juvenile fish (referred to as confluence pools). Average pool spacing was calculated and expressed in units of distance per average bankfull channel widths.

### ***3.5 Bankfull Discharge***

I measured discharge in the Project reach using a SonTek/YSI FlowTracker Handheld Acoustic Doppler Velocimeter (ADV) on four different site visits between May 6<sup>th</sup> and 25<sup>th</sup> of 2017, using standard methodology developed by the USGS (Turnipseed and Sauer, 2010). I selected a site free from upstream obstructions that had reasonably uniform bed surface conditions. The reach was a section of the channel located between two meanders and had relatively parallel streamlines making it an ideal location for measuring discharge (Figure 5). Each discharge measurement was also correlated with stage height measured from a staff gage (referred to as DGN, following naming established by the Nisqually Indian Tribe) that had been installed onto an LWM structure located 300 m downstream of State Route 7 (Figure 1). The stage and discharge at the DGN site were used to develop a rating curve for the Project monitoring protocol.

Bankfull discharge for the Phase II reach was determined from field observations made during a site visit while the Phase II channel was at or slightly above bankfull. The Phase II reach-average bankfull area and water-surface slope were used to back-calculate an average Manning's roughness coefficient ( $n$ ) from the Phase II bankfull flow using Manning's equation. The average

Manning's n value was then used with the Phase I reach-average cross-sectional bankfull area and water-surface slope to calculate the bankfull discharge in the Phase I channel.

Following techniques outlined in Knighton (1998) I plotted w/d ratios against channel depth from field measurements reported on the USGS website from 1993-2018 in order to determine the bankfull depth at the USGS gage. I then plotted the streamflow against the depth for each field measurement and used a best-fit regression to determine the bankfull discharge at the USGS gage, which I then related to the stage height using the current rating curve. During a site visit to the gage in late spring of 2017, I used topographic bankfull indicators to verify the bankfull stage.

To determine the recurrence interval for the annual maximum series, I used USGS's PeakFQ tool to fit the annual maximum series from 1994-2010 to a log-Pearson Type III frequency distribution following standards described in USGS Bulletin 17B (Flynn et al., 2006). Following methods used by Cardno (2011), I conducted flow duration calculations on mean daily discharge records from USGS gage #12088000 for water years 1994-2010 to determine the number of days per year the current bankfull flow in the Project reach was expected to overtop the channel assuming future hydrology is similar to the 1994-2010 record.

## **4.0 Results of Investigation**

### ***4.1 Channel Widening and Migration***

The NAIP image analysis indicates that the Phase I reach widened by an average of 1.3 m from 2011-2017 (Figure 6). Paired t-Test analysis shows widening in the Phase I reach to be statically distinguishable from no change over the 6-year record ( $p < 0.05$ ). The greatest magnitude of widening occurred around wood structures, with an average widening of 1.9 m (N = 60, SD = 1.5) from 2011-2017. Areas where no wood was located only widened by an average of 0.7 m (N = 72, SD = 1.7) over the same time period. Widening at wood structures appears to have progressed at a consistent rate of 0.3 m/yr from 2011 to 2017, whereas widening in areas without wood was initially high between 2011 and 2013, but has steadily decreased since.

The Phase II reach widened by an average of 0.3 m from 2015-2017. Paired t-Test analysis shows average widening in the Phase II reach to be indistinguishable from no change for this time period ( $p > 0.05$ ). However, widening in areas of the reach where wood structures were located was found to be distinguishable from no change over the 2-year record ( $p < 0.05$ ).

Widening at wood structures in the Phase II reach was on average 0.4 m (N = 43, SD = 1.7) from 2015-2017, and only 0.2 m (N = 136, SD = 1.9) for areas with no wood.

Channel widening measured from comparing the 2017 surveyed cross-sections with the as-built and design cross-sections is similar in magnitude to the NAIP image analysis and also indicates that widening is greatest for cross-sections located at or near LWM structures (Figure 7). Phase I widening averaged 1.2 m (N = 3, SD = 0.5) around wood structures from 2010 to 2017. Of the four cross-sections in the Phase I reach, OCXS 19 was the only one not located near an LWM structure. Widening at this location was measured at 0.5 m. Widening in the Phase II reach between 2015 and 2017 averaged 0.6 m (N = 10, SD = 0.4) at or near wood structures and 0.2 m (N = 11, SD = 0.1) for other cross-sections.

Migration rates for both the Phase I and Phase II reach were less than half of the magnitude of rates for channel widening, making it difficult to determine if any appreciable migration had occurred in the Project channel. Due to this uncertainty, migration rates are not reported here.

#### ***4.2 Channel Incision***

Comparison of the surveyed and the design cross-sections show that the Phase I average channel depth increased from 1.2 m (N = 4, SD = 0.1) to 1.9 m (N = 4, SD = 0.2) and the average cross-sectional w/d ratio decreased by 29% since 2010 (Figures 8 and 9). However, this magnitude of incision seems unreasonable when considering that the channel bed in this section is firm, cohesive material. Only four cross-sections are located in the Phase I reach and three of them are located in deep LWM scour pools. It is likely that the large magnitude of incision is biased because of the scour pools and does not reflect reach-wide channel incision so much as localized deepening from wood-induced bed scour.

The Phase II reach increased in depth from 1.0 m (N = 21, SD = 0.1) to 1.2 m (N = 21, SD = 0.2) since 2015, with a resulting 15% decrease in average w/d ratio. The 0.2 m of deepening falls within the range of uncertainty from the as-built contours (+/- 0.3 m), so it is difficult to

definitively determine if the channel has incised. However, the magnitude of deepening in the Phase II reach can be explained as localized scour associated with LWM structures. Average depth change for cross-sections located around LWM in the Phase II reach is 0.4 m (N = 10, SD = 0.1). The magnitude of deepening from LWM provides a realistic estimation of actual deepening in the Phase I reach. From this analysis I conclude that the observed increase in average depth of ~ 0.2 m for the Phase II reach is provided by localized scour from LWM structures.

### ***4.3 Pool Survey***

Pools formed from LWM scour constituted 44% of the pools in the Project reach (Figure 10). Free-form pools that were augmented by nearby LWM structures constituted another 7% of all pools surveyed, bringing the total number of pools associated with in-channel wood up to 51%. At the time of the survey, several small beaver dams were observed in the new Phase II channel at locations where the stream approached the southern valley wall. None of the beaver dams remained in February of 2018. Average pool spacing in the Project reach is 2.5 mean channel widths, which is consistent with pool average spacing for forced pool-riffle channels with high wood loading (Montgomery et al., 1995).

Average residual depth for LWM scour pools was higher (0.44 m, N = 31, SD = 0.17) and showed more variability than most other pool types (Figure 11). The average depths of confluence pools were as high as that of LWM scour pools. Several factors may be contributing to the depth of the confluence pools: (1) accretion of water behind back-channel beaver dams that causes localized downstream incision, or (2) artifacts of the old entrenched channel. Average residual depths for other free-form pool categories were between 0.31-0.34 m.

### ***4.4 Bank Scour from LWM***

Of the 89 LWM structures identified in this study, 40% were observed to be inducing lateral bank scour (Table 2). Certain combinations of structure type and location in the meander were associated with high frequency and magnitude of bank scour (Figure 12 and 13). The highest occurrence and magnitude of bank scour was attributed to complex structures located at the inflection point between two meanders. Of the three complex structures at this location in the meander, all were contributing to large amounts of bank scour, with an average of 24 m<sup>2</sup> of scour

per structure. Complex structures are also typically the largest structures in the Project reach and tend to protrude into the channel more than other structure types, which could be contributing factors to the frequency and magnitude of scour. A-frame, fence, and V-frame type structures are also located at inflection points but were associated with much less scour at this location (8.9, 7.2, and 4.1 m<sup>2</sup> respectively).

A-frame and fence structures located at the cut bank apex of meanders in the Phase I reach were associated with high frequency and magnitude of bank scour. In the Phase II reach, both of these structure types were largely positioned at the downstream end of meanders where they tended to cause less bank scour, indicating that the redesign of LWM structures between Phase I and Phase II was at least partly successful in curbing wood-induced bank erosion.

**Table 2. Summary of LWM-induced bank scour and geometry in Project reach. PB = Point Bar; OM-A, OM-D, OM-I = Outside of Meander (apex, downstream, inflection point). “% Total” represents the percentage of structure type associated with bank scour.**

Type	Count	% Total	Location	Mean scour (m <sup>2</sup> )	Range (m <sup>2</sup> )	SD
1 (A-frame)	3	50	PB	5.8	1.9-9.4	3.1
	2	28	OM-A	16	NA	NA
	5	71	OM-D	12	1.8-26	8.9
	2	100	OM-I	8.9	6.6-11	8.9
2 (Fence)	6	75	OM-A	14	10-21	3.8
	2	33	OM-D	7.8	3.4-12	4.5
	2	66	OM-I	7.2	1.5-13	5.7
3 (Wall)	2	40	OM-A	8.7	3.3-14	5.4
	1	33	OM-D	8.1	NA	NA
4 (Tight A-frame)	2	80	OM-A	8	NA	NA
5 (V-frame)	1	11	PB	9.5	NA	NA
	1	12	OM-A	3.9	NA	NA
	2	100	OM-I	4.1	3.4-5.0	0.8
6 (Complex)	1	100	OM-D	23	NA	NA
	3	100	OM-I	24	15-39	11
<b>Geometry</b>	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Mean Surface Area (m <sup>2</sup> )	15	20	19	6.7	4.8	36
Mean Protrusion Dist. (m)	2.6	2.9	1.2	1.9	1.8	3.9

#### ***4.5 Bankfull Discharge and Flood Frequency***

On the four occasions that I measured discharge in the Project reach the discharge was on average 6.5% higher than instantaneous discharge measurements recorded at USGS gage #12088000, which is 9% lower than estimated by project engineers (Table 3). On April 6<sup>th</sup> the water was too deep to safely wade and so discharge was measured from a kayak. Only velocity at the 0.6-depth was measured on that occasion.

**Table 3. Discharge measurements at Ohop Creek DGN gage site.**

Date	5/6/2017	5/11/2017	5/14/2017	5/25/2017
Width (m)	9.2	9.0	9.0	8.9
Mean depth (m)	1.3	0.62	0.6	0.57
Mean velocity (m/s)	0.39	0.34	0.33	0.25
Area (m <sup>2</sup> )	11.9	5.6	5.4	5.1
Q (m <sup>3</sup> /s)	4.72	1.89	1.78	1.28
DGN gage hgt. (m)	0.75	0.10	0.09	-0.09*
Slope	0.0005	0.0005	0.0005	0.0005
Manning's n	0.052	0.044	0.044	0.050
USGS Q (m <sup>3</sup> /s)	4.39	1.78	1.65	1.21
Q diff %	+7.0	+5.8	+7.3	+5.5

\*Depth below bottom of staff gage

The rating curve constructed from the above discharge measurements (Figure 14) was used to successfully predict within 0.02 m the DGN stage during a site visit on February 10, 2018 by prorating the USGS reported discharge at gage #12088000 by a factor of 6.5%. The discharge that day was 2.4 m<sup>3</sup>/s at the USGS gage and a predicted 2.6 m<sup>3</sup>/s in the Project reach, indicating that the DGN rating curve is useful within the range of measured flows used to construct the curve.

From the analysis of USGS field data described in the methods section, I determined the bankfull discharge at the USGS gage to be 11.0 m<sup>3</sup>/s, which corresponds with the 1.2-year peak recurrence interval. The peak return period for the gage is consistent with average discharge recurrence intervals determined from stream gages for Pacific Maritime Mountain streams (Castro and Jackson, 2001).

The Phase II reach was observed at or just above the bankfull flow at 9.1 m<sup>3</sup>/s. I calculated a Phase II reach-average bankfull velocity of 0.60 m/s and an average bankfull Manning's n of 0.045, which was consistent with the average roughness coefficient calculated from discharge measurements at the DGN gaging site (0.048). The reach-average Manning's n value resulted in an estimated average bankfull discharge of 12.4 m<sup>3</sup>/s in the Phase I reach (see Appendix A3 for calculations). The corresponding discharges at USGS gage #12088000 for the Phase I and Phase II bankfull flows were determined from applying the 6.5% scaling factor.

The peak recurrence intervals determined from the USGS annual maximum series records from 1994 to 2010 show that the Phase I and II channels are expected to overtop 83% and 93% of the years, respectively (Table 4). These values are lower by 10% for the Phase I channel and 5% for the Phase II channel than design expectations. The flood duration estimates from mean daily discharge calculations indicate that the Phase I and Phase II channels are expected to overtop an average of 50% and 60% less days per year than predicted, respectively.

**Table 4. Peak flood recurrence intervals and flood duration estimates for bankfull discharge in the Project reach.**

Phase	Bankfull Q (m <sup>3</sup> /s)	Corresponding flow at USGS gage	Peak Recurrence Interval	Flood Duration (days/yr)	Max Duration (days/yr)	Change from Predicted (days/yr)
I	12.4	11.6	1.21	2.4	8	-2.2
II	9.1	8.5	1.07	5.3	17	-8.1

## **5.0 Assessment of Ohop Valley Restoration Project**

The results provide the means to answer the questions presented in the introduction of this study. Section 5.1 addresses the questions of how the channel planform and cross-sectional area have evolved. Section 5.2 considers the effects of LWM structures on scour pool formation and bank scour. Section 5.3 addresses the question of bankfull discharge and the frequency of floodplain inundation.

### ***5.1 Channel Widening and Deepening***

Channel widening has occurred throughout the Project area as a result of lateral bank scour at LWM structures. In the Phase I reach widening from wood-induced bank erosion has continued at a relatively constant rate since 2011 while widening at areas of the reach without wood has decreased in recent years. Field observations suggest that the decrease in the widening rate at areas without wood is a result of vegetated sod failure blocks that appeared to be deflecting flow away from the channel banks. The presence of these blocks suggests that the riparian root mass in the Phase I reach is now sufficient to provide enough cohesion to failed bank blocks such that the blocks remain as stable features and buffer the bank toe from additional erosion. These blocks were observed throughout the Phase I reach but only in a few locations in the Phase II reach. The Phase II reach did not see as much widening as Phase I in the first few years after restoration was completed, which suggests that the redesigned LWM structures in the Phase II reach limit bank erosion more than the structures in the upstream reach.

Localized channel deepening is relatively active throughout most of the Project channel as a result of LWM-induced bed scour. Much of the LWM scour is localized to areas next to the wood, although there are sections of the Project reach where LWM scour pools overlap and create a continuously deep channel. Magnitude of deepening in the Phase I reach is difficult to quantify without as-built drawings. It is possible that the Phase I channel was dug deeper than designed, but without being able to verify this possibility we must dismiss the 0.7 m of incision as being unrepresentative for average increase in channel depth for the entire Phase I reach. The comparison of surveyed and as-built cross-sections in the Phase II reach, however, provides a reasonable magnitude of deepening from LWM scour and is consistent with average residual

depth of LWM scour pools throughout the Project area, which gives confidence that the measurements of deepening in the Phase II reach are meaningful.

## ***5.2 Effects of LWM Structures***

In general, the LWM structures observed during this investigation are providing bed scour for fish habitat in the Project reach. Because of the low-energy environment of Ohop Valley, LWM in the Project reach was not expected to influence the formation of channel-spanning pools, but instead to create smaller lateral pools (WPN, 2006). Yet, channel-spanning pools were observed in several locations of both the Phase I and Phase II reaches, suggesting that LWM bed scour is greater than expected.

Channel widening was shown to be strongly correlated with lateral bank scour induced by LWM-structures, especially for structures positioned in the downstream reach of a meander. The complex (type 6) structures were shown to initiate the highest frequency and magnitude of bank erosion. During site visits at high-flow conditions, streamflow flanking was observed at all complex structures located at inflection points between meanders (Figure 14). Flanking, where the channel has gone behind the structure and begun to erode the bank from slower, more turbulent currents, suggests that the structure protruded too far into the channel to maintain the bend. Complex structures regularly contain several logs oriented perpendicular to the flow that protruded into the channel more than 4 m, or about one-third of the average channel width. Fence (type 2) LWM structures, which rarely protruded one-third of the channel width, also showed evidence of streamflow flanking when located at inflection points, but to a lesser degree.

The high occurrence of flanking at inflection points coupled with the high magnitude of erosion attributed to structure type indicates that both position in the channel and structure form are critical components when designing woody structures for use in restoration projects. Because buffering the banks from erosion was a LWM design element, future design should consider using LWM structures with logs parallel to streamflow, such as wall (type 3) structures, in zones of high shear stress. Wall structures placed at the cut bank apex of a meander tend to produce only small amounts of lateral bank scour while still providing scour pools, thus meeting Project goals of providing both aquatic habitat and bank stability.

Despite areas where large amounts of LWM-induced bank have resulted in streamflow flanking and widening, much of the observed bank scour in the Phase II reach was limited to localized areas of the bank immediately upstream and/or downstream of the wood. Areas where greater amounts of scour and flanking were observed are not inherently problematic and can potentially pose benefit to Project success. Flanking of the LWM structures increases flow complexity by creating new channels and/or backwater alcoves that are beneficial to rearing salmon. Extensive bank scour could decrease the stability and life expectancy of the wood, which could result in rapid channel migration away from the constructed channel. Yet, we would expect this to be a self-limiting process. As the channel moves away from the wood structure, bank erosion would decrease. Because the LWM structures installed in the Project reach were ballasted to prevent them from being removed during high-flow events, it is likely that detached LWM structures would become stream hard points where newly recruited wood would be retained, again serving to increase in-channel habitat and complexity. However, initial channel widening from LWM-induced bank scour does negatively impact the frequency of floodplain inundation, as discussed in Section 5.3 below. Monitoring the LWM structures is a key component of the protocol developed from this study and should be used to inform future restoration in Ohop Valley.

### ***5.3 Bankfull Discharge and Flood Duration***

Bankfull discharge values for both the Phase I and Phase II reach indicate that the frequency of floodplain inundation is lower than Project engineers expected. Part of the decrease in expected flooding can be explained by the widening of the channel from LWM structures. Widening from wood alone has increased the cross-sectional area by 21.5% in the Phase I reach since 2011 and 4.5% in the Phase II reach since 2015. The increase to the cross-sectional area will require a higher discharge in order to overtop the banks. Because the Phase II reach was built to a smaller bank-filling capacity than the Phase I reach the expected days/year of overtopping is more sensitive to changes to the cross-sectional area. For example, assuming no change to reach average roughness or slope, a 5% change in cross-sectional area results in a change of 1.4 days/year of expected flooding in the Phase I reach but only 0.3 days/year in the Phase II reach. Another explanation for the lower annual flood duration comes from the expected 15.5% increase in flow from the USGS gage to the restored area. My discharge measurements indicate that the increase in flow from the USGS gage is only 6.5%. This predicts a higher flow at the

USGS gage based on flows in the restored area. Because the mean daily discharge is based on flow conditions at the USGS gage, it follows that a higher discharge at the gage will result in a lower probability of overtopping the channel throughout the year.

The 1.2-year annual series bankfull discharge recurrence interval at the USGS gage is consistent with the regional average Castro and Jackson (2001) determined by analyzing USGS gage data for several streams in the Pacific Northwest. This value is slightly higher than the 1.02-year peak recurrence interval of the Phase II reach. I recognize that the regional average was determined from mostly gravel-bed streams with gradients typically higher than Ohop Creek. Yet, it is possible that long-term channel enlargement may result as the constructed channel resizes in order to accommodate a larger peak recurrence interval. Current bankfull capacity of the Phase I reach determined during this study indicates that it can sufficiently accommodate the 1.2-yr peak flow. However, the Phase II reach would require a 28% increase in the current bankfull area (15.2 m<sup>2</sup>) to sufficiently pass the same flow. Continued monitoring will help to resolve this issue in the future.

## 6.0 Recommendations

I recommend stakeholders and future researchers employ the effectiveness monitoring protocol developed as part of this investigation to address the following questions:

- Are the LWM structures continuing to provide deep scour pools for aquatic habitat?
- Is streamflow flanking at LWM structures continuing to cause large amounts of erosion to the channel banks and, if so, what implications does this have on bank stability and channel complexity?
- Is the channel continuing to widen and, if so, what implications does this have on frequency of floodplain inundation?

In addition, I recommend that cross-sections be installed and surveyed between Peterson Road and State Route 7 to better characterize the observed incision in the Phase I reach, although this may prove difficult due to the depth of the channel in this location.

The monitoring protocol included with this document (Appendix B) should be employed every odd year to coincide with new NAIP imagery. In this way, overall reach characteristics such as sinuosity, migration, and widening can be readily measured without the need to construct new orthographic images from photogrammetry surveys. I recommend that monitoring last for at least 5 cycles (10 years) in order to adequately track trends through time.

It will be particularly useful to continue to further develop the DGN rating curve for the Project reach. The DGN rating curve is important in that it gives stakeholders and practitioners a means to determine discharge and river stage remotely in the Project reach by relating to discharge measurements reported at USGS gage #12088000. A robust rating curve requires large inputs of data collected at a wide range of stream flows over several years. The DGN rating curve has been calibrated to date using mostly low-flow discharge measurements taken in one month. I recommend future investigators conduct discharge measurements at various flows in the Project reach to make the curve useful at a wider range of discharge-stage values.

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## Ohop Valley Restoration Project Area

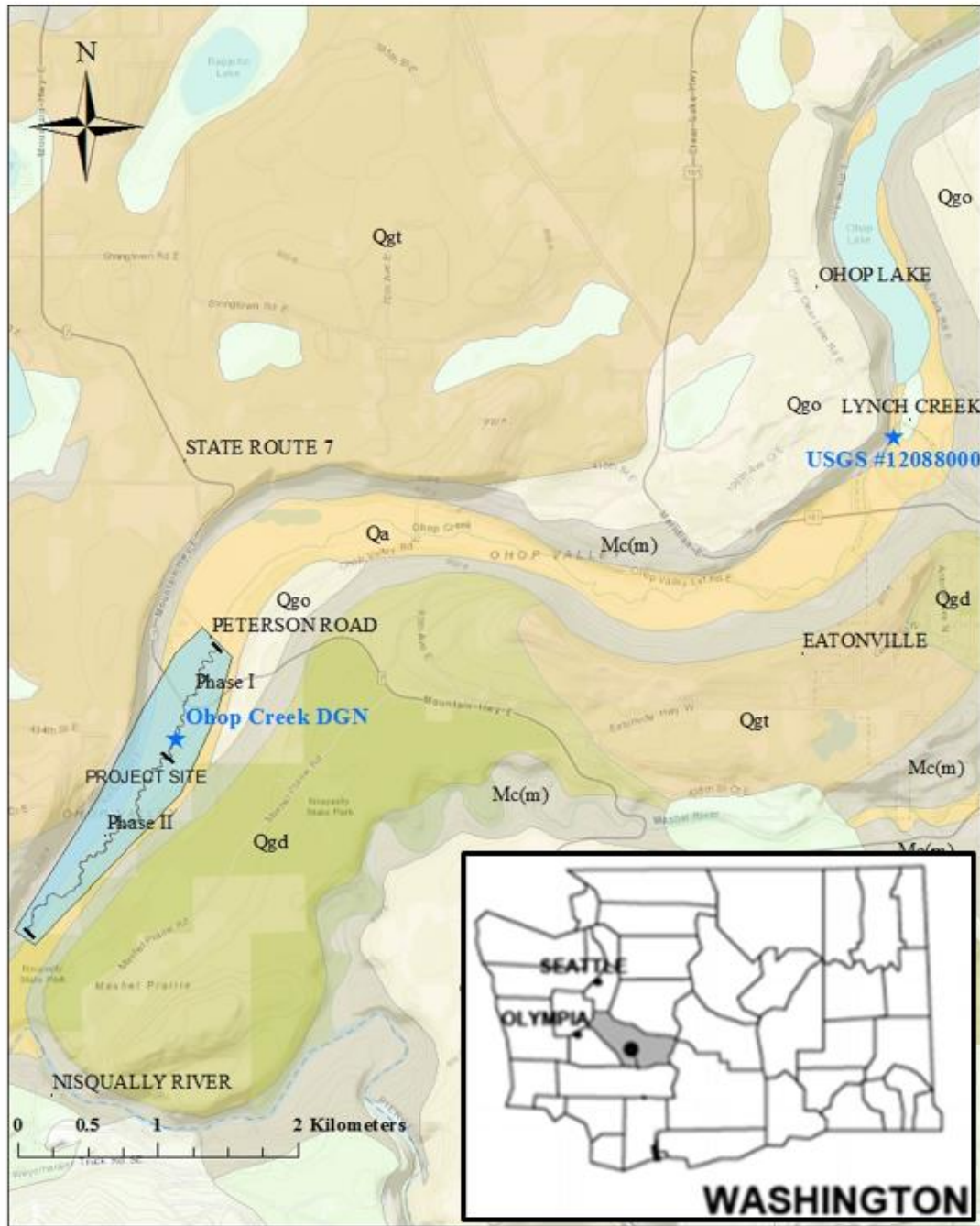


Figure 1. Overview map of Ohop Creek Restoration Project area. Qa – Quaternary alluvium. Qgd - Quaternary glacial drift. Qgo – Quaternary glacial outwash. Mc(m) – Miocene Mashel Formation. Source for geologic units: 1:100,000 surface geology dataset from Washington Department of Natural Resources ([www.dnr.wa.gov/programs-and-services/geology](http://www.dnr.wa.gov/programs-and-services/geology)).

## Ohop Valley Restoration Project Area

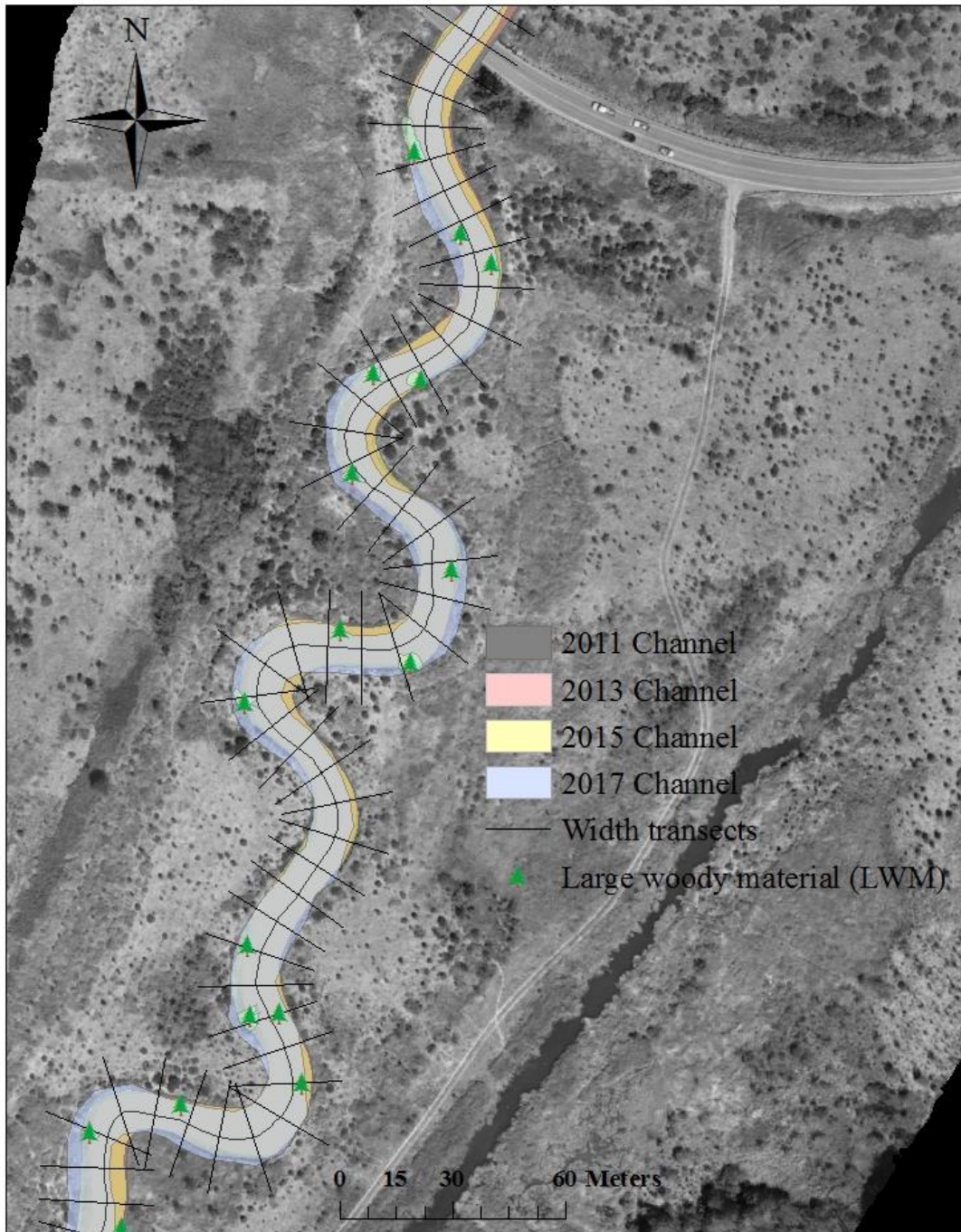


Figure 2. Channel widening in the Project reach was measured from active channel polygons, digitized at 1:500 scale, and width transects created using the Channel Migration Toolbox. Pictured is a section of the Phase I reach.

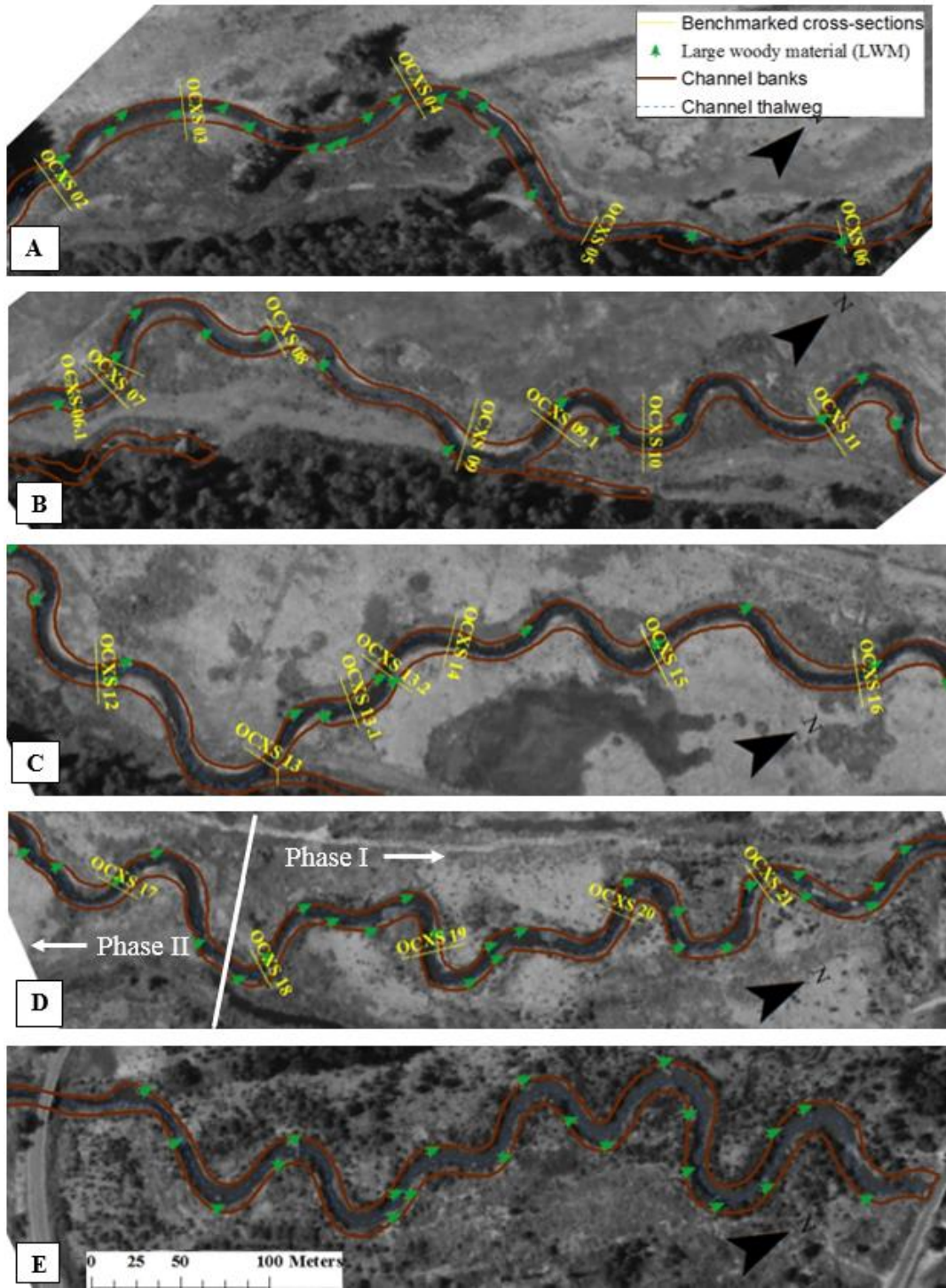


Figure 3. Five-cm orthographic images created in Agisoft Photoscan showing location of permanently benchmarked cross-sections and LWM structures in the Project reach. Images are oriented from downstream (A) to upstream (E). Transition between Phase I and II is shown in image D.



Figure 4. Six different LWM structure types identified in the Project reach. Flow direction for the first four images (types 1-4) is from top to bottom and from right to left for the latter two images (types 5 & 6).



Figure 5. Reach used for discharge measurements in the Project area in spring of 2017. Streamflow is from left to right in this image. The DGN staff gage is located approximately 20 meters downstream (to the right) from this location.

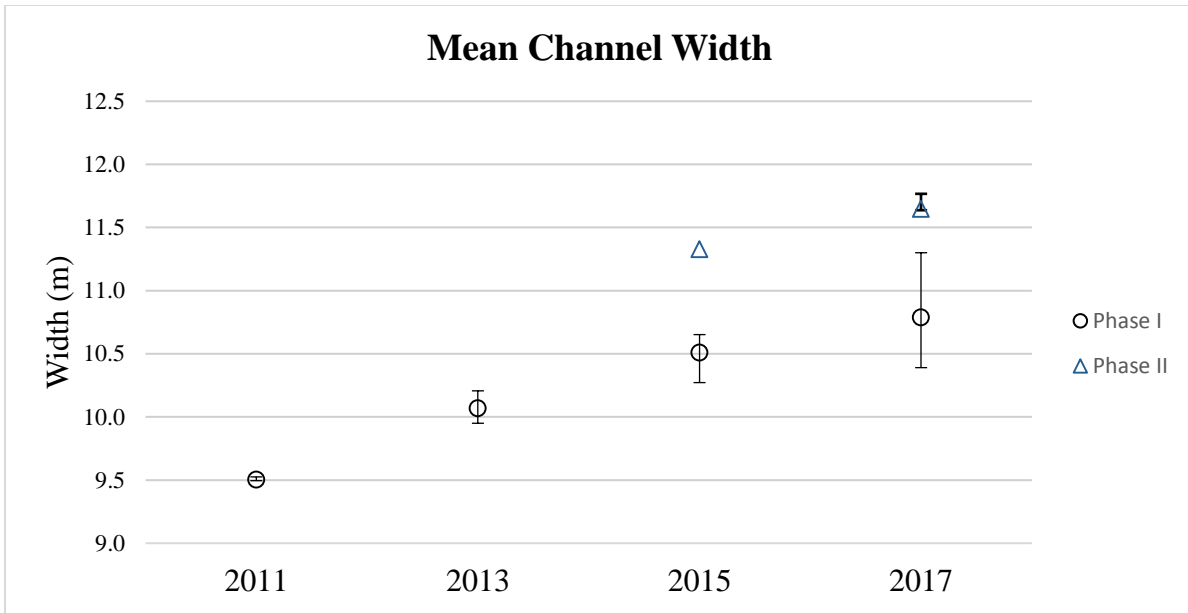


Figure 6. Average channel widening for the Phase I and Phase II reaches. Top and bottom whisker bars indicate the average magnitude of widening associated with transects that intersected LWM structures and those that did not, respectively.

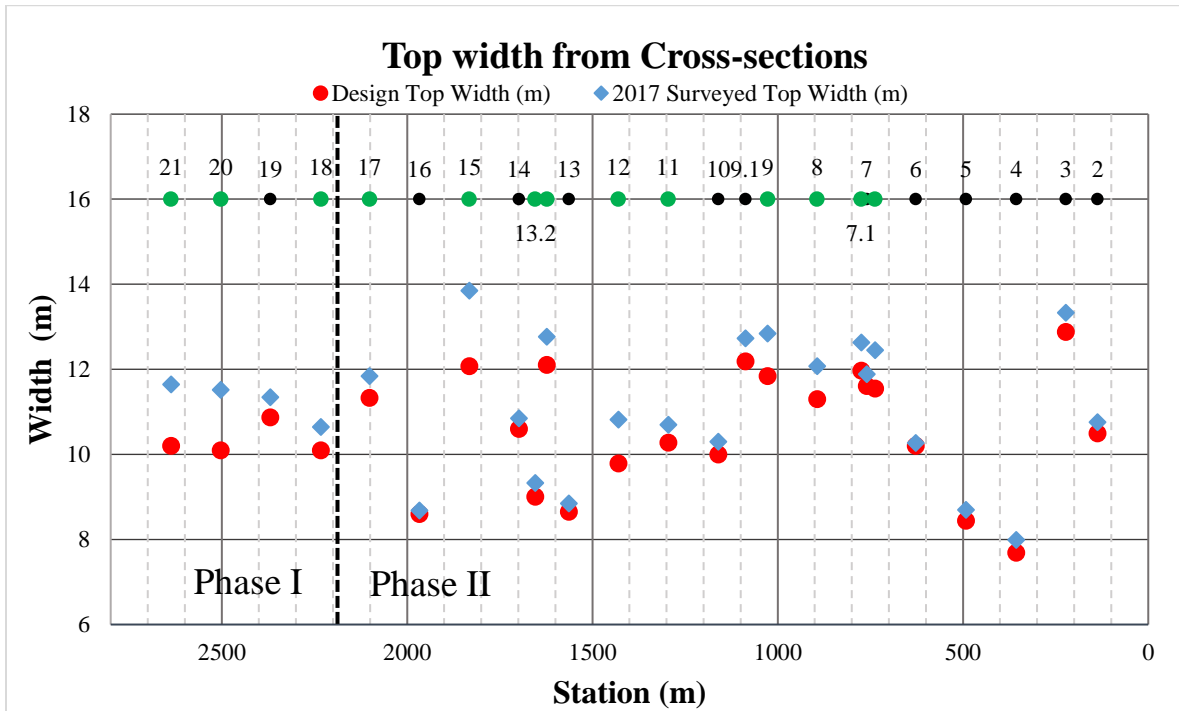


Figure 7. Summary of top width comparisons from design and 2017 surveyed cross-sections. Cross-section locations and numbers are shown at the top of plot for reference. Cross-sections located at or near LWM structures are marked in bright green.

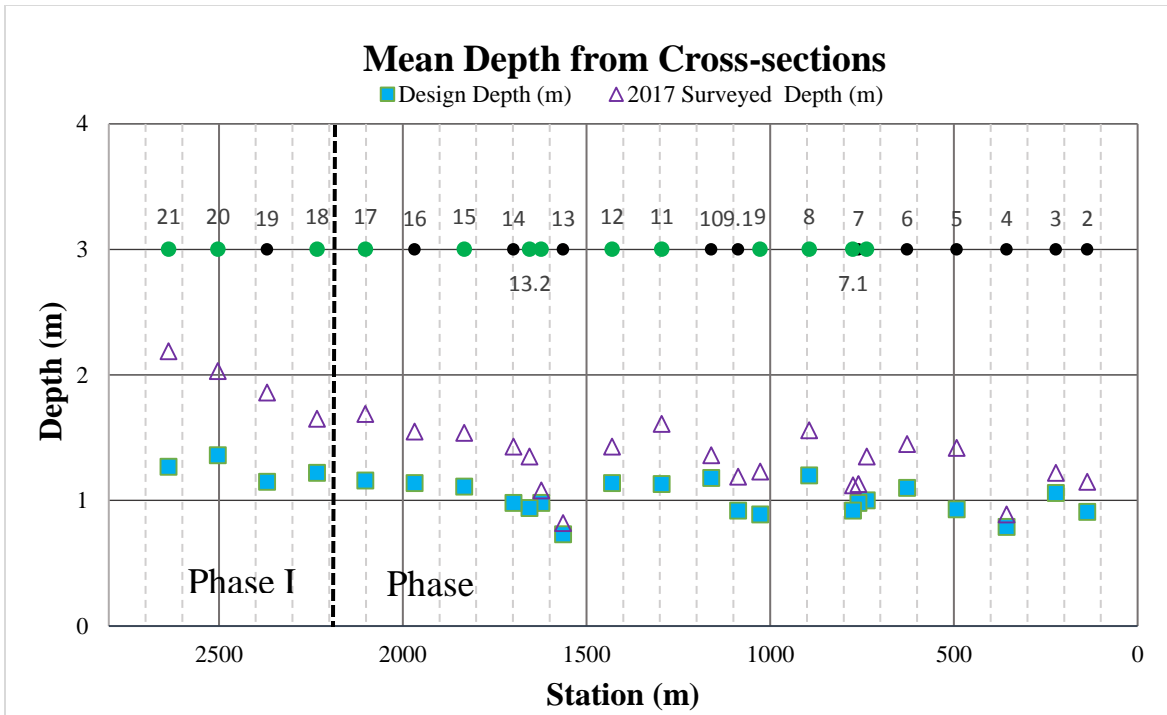


Figure 8. Summary of mean depth comparisons from design and 2017 surveyed cross-sections. Cross-section locations and numbers are shown at the top of plot for reference. Cross-sections located at or near LWM structures are marked in bright green.

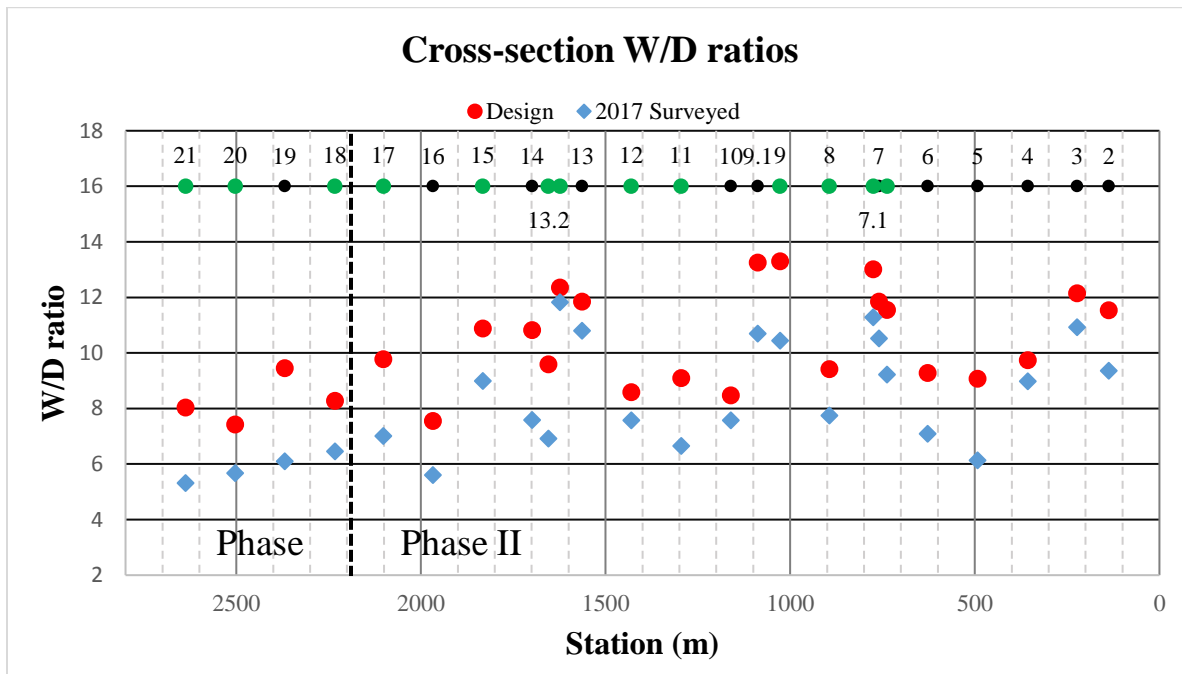


Figure 9. Summary of width/ depth ratios from design and 2017 surveyed cross-sections. Cross-section locations and numbers are shown at the top of plot for reference. Cross-sections located at or near LWM structures are marked in bright green.

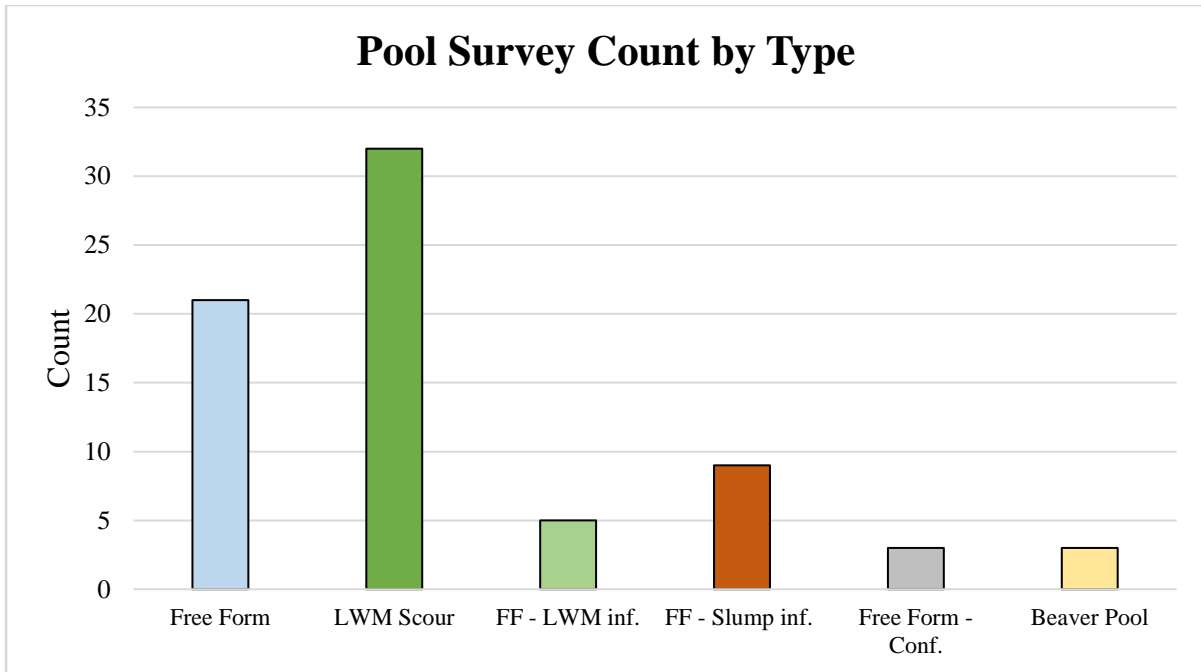


Figure 10. Pool survey count by type identified in the Project reach during the summer of 2017. By February of 2018 the beaver pools no longer remained in the Project area.

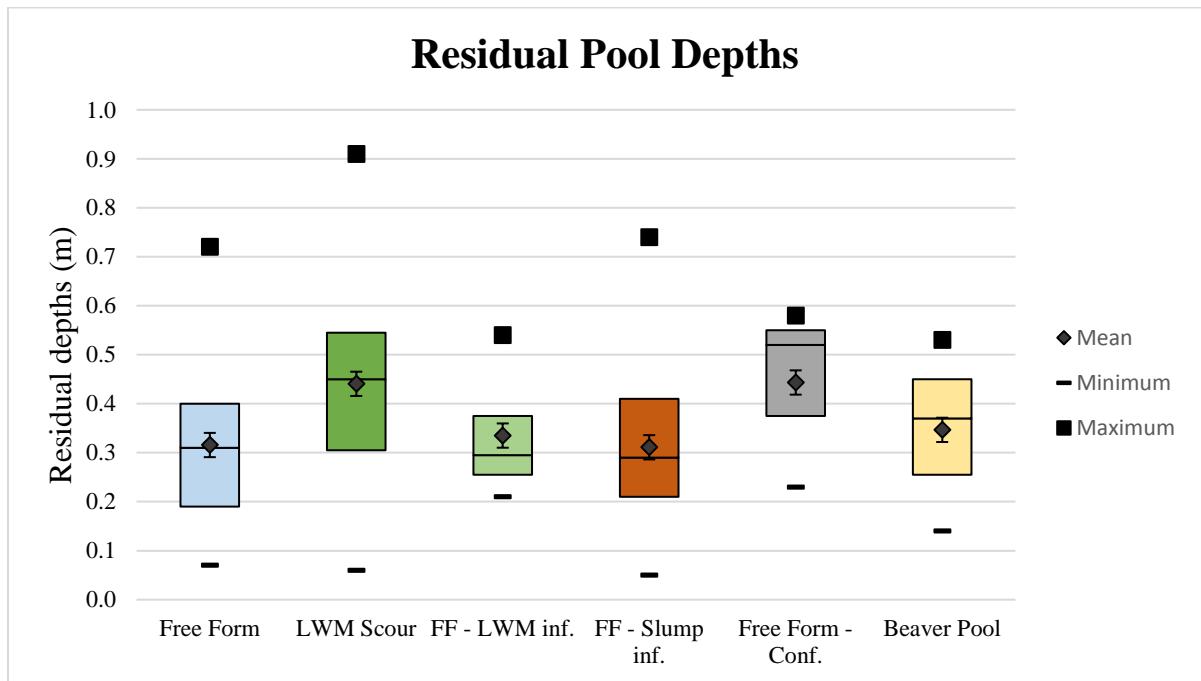


Figure 11. Residual depths of surveyed pools in the Project reach. Upper and lower boxes show 75% and 25% quartile, respectively, separated by median value. Whisker bars show standard error of the mean.

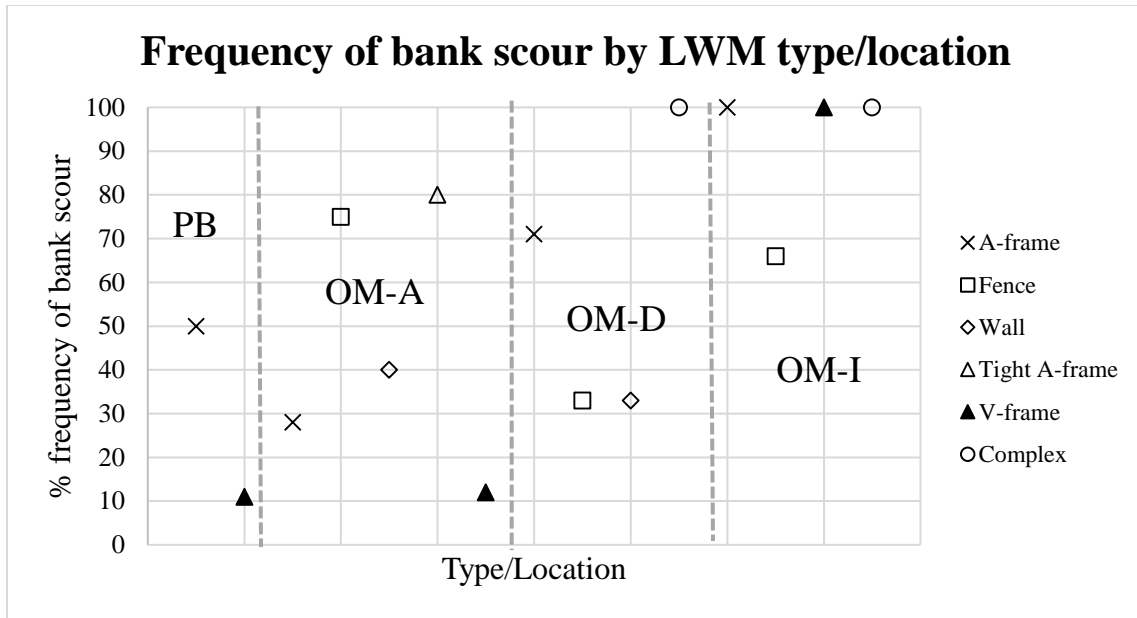


Figure 12. Frequency of bank scour expressed at % of total occurring structures by LWM type and location in the meander. Dashed vertical lines separate locations in the meander. PB = point bars, OM-A = apex of the outside of a meander, OM-D = downstream outside of a meander, OM-I = inflection point between meanders.

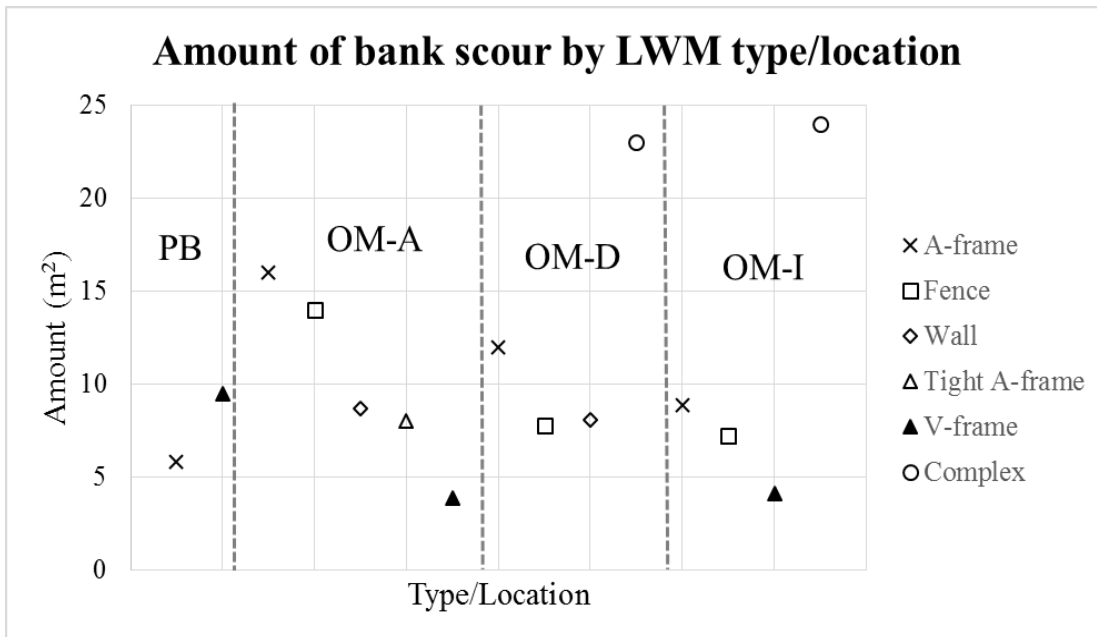


Figure 13. Amount of bank scour by LWM type and location in the meander. Dashed vertical lines separate locations in the meander. PB = point bars, OM-A = apex of the outside of a meander, OM-D = downstream outside of a meander, OM-I = inflection point between meanders.

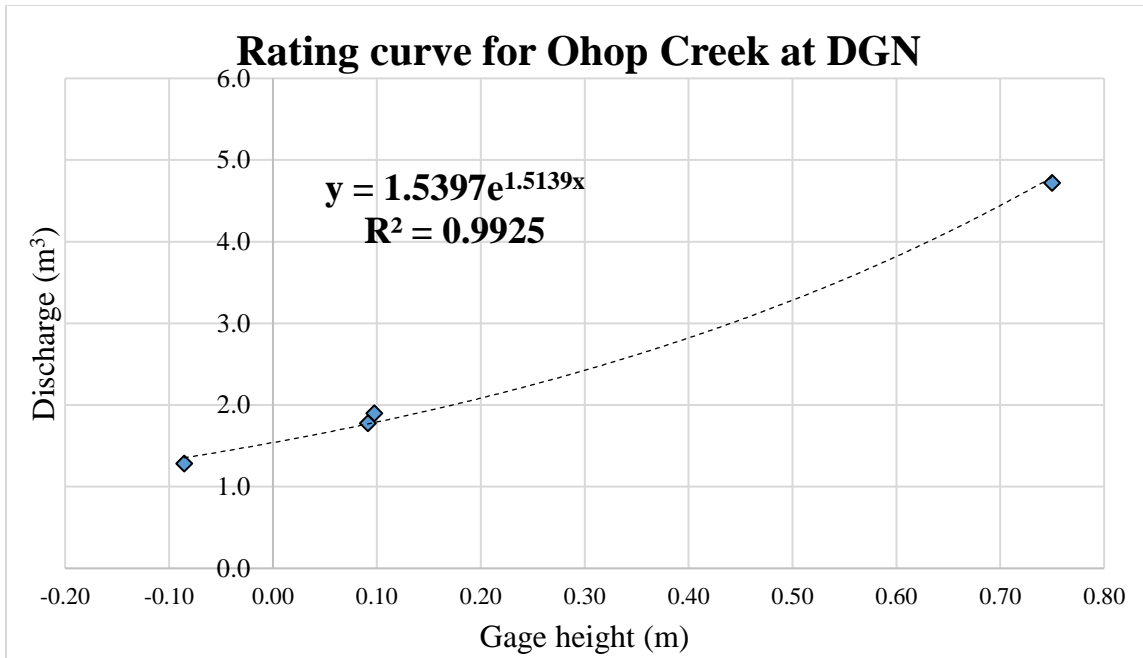


Figure 14. Rating curve from constructed from discharge measurements made during spring of 2017. Negative numbers are measured from the bottom of the DGN gage, which does not extend into the summer low flow

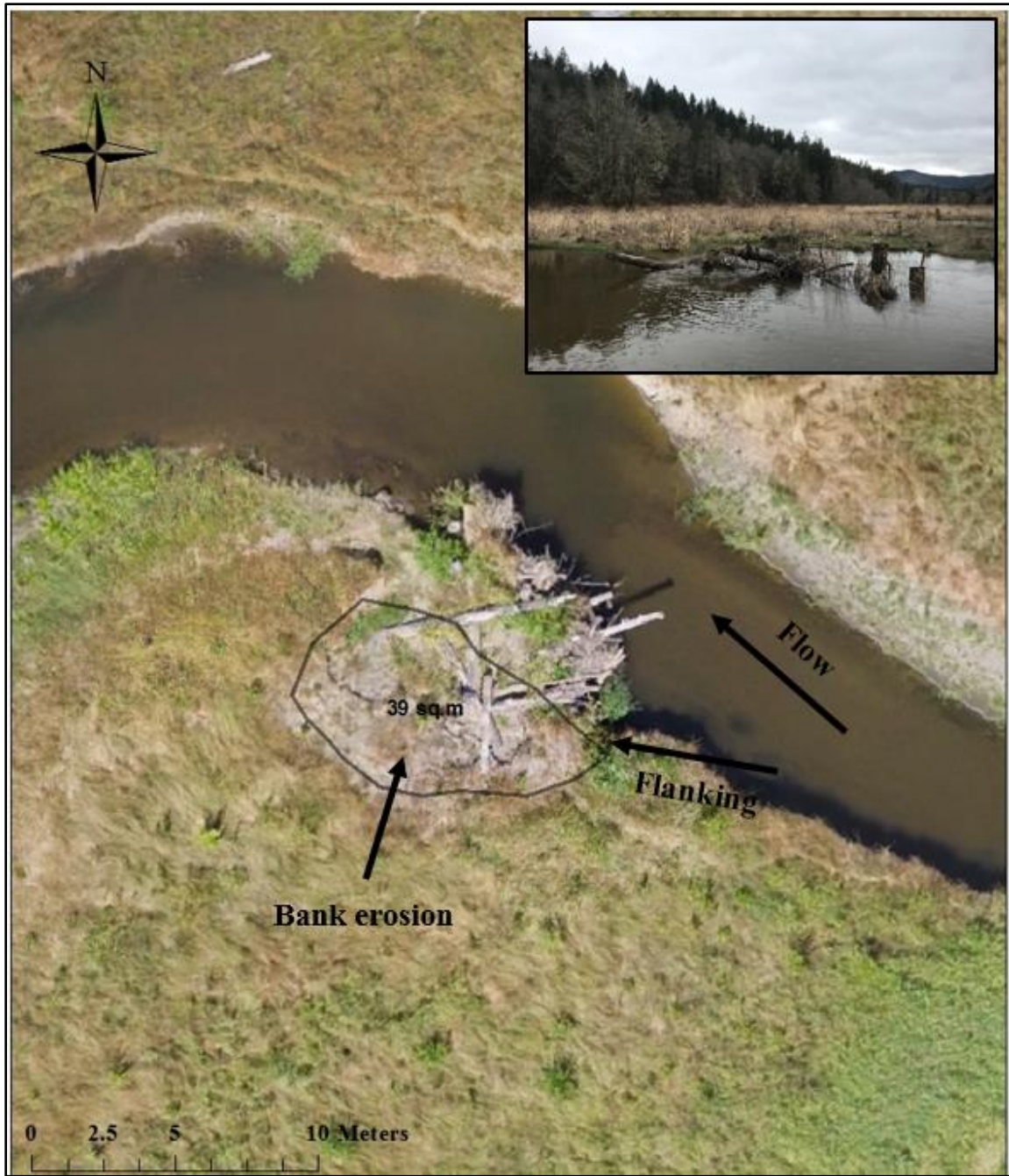


Figure 15. Type 6 (complex) LWM structure in Phase II reach where the channel has gone behind the structure and caused erosion to the bank. Flanking suggests that the structure protrudes too far into the channel to maintain the meander bend. Inset photo was taken on February 3, 2017 at a discharge of  $\sim 9 \text{ m}^3/\text{s}$ .

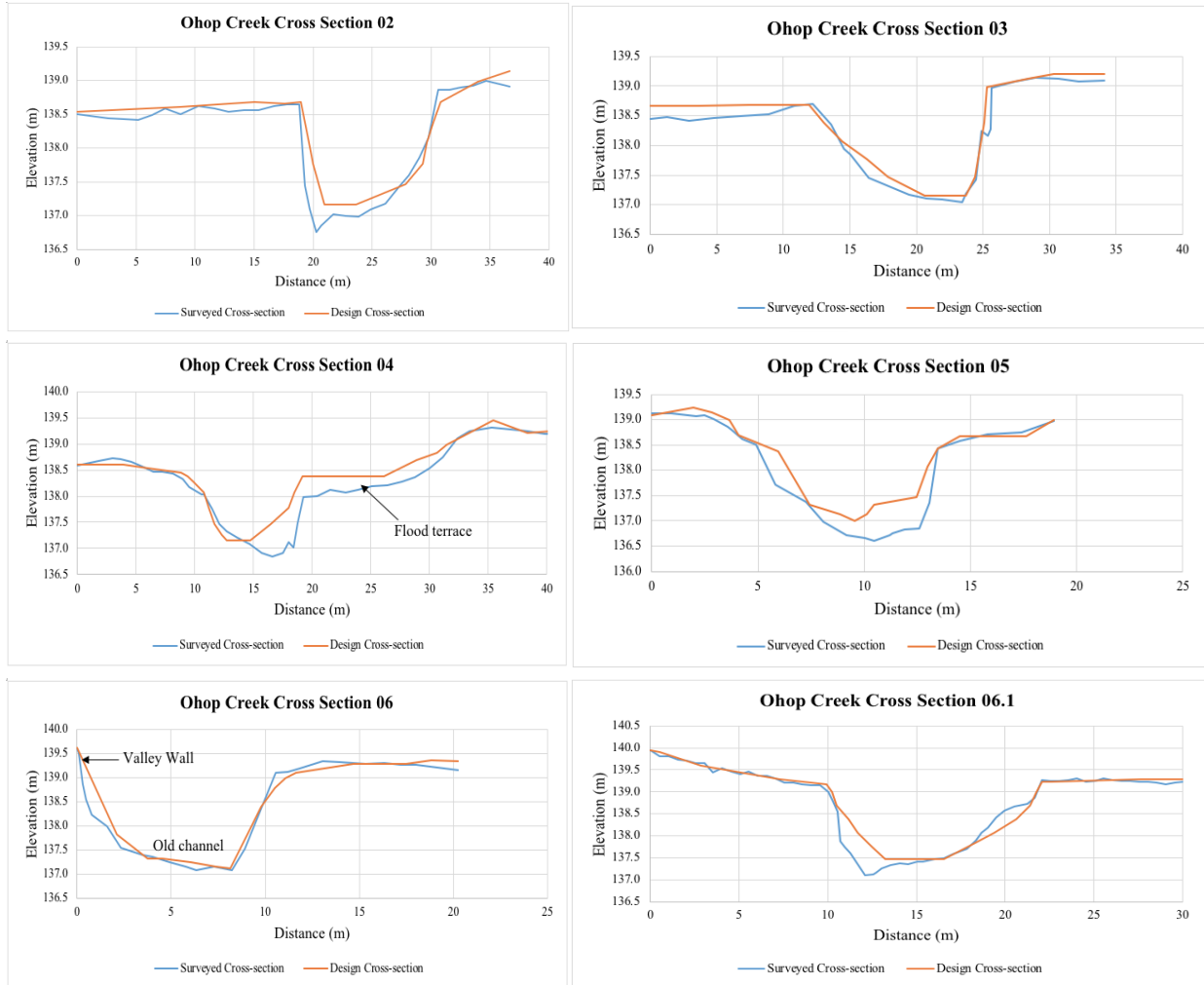
## Appendix A

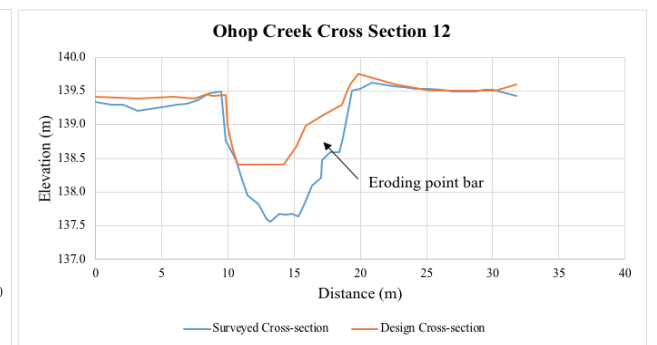
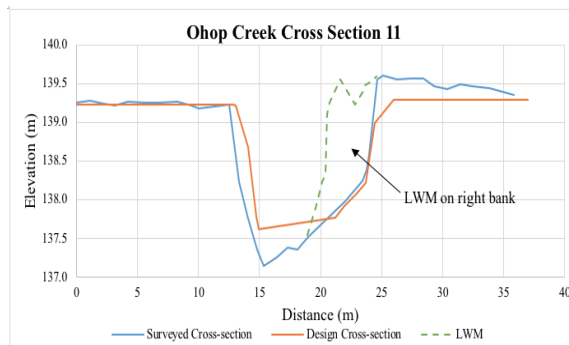
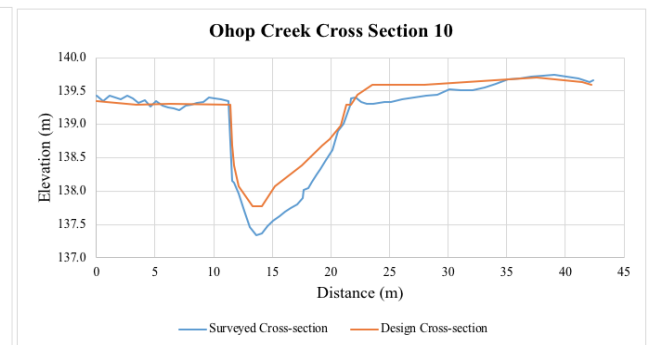
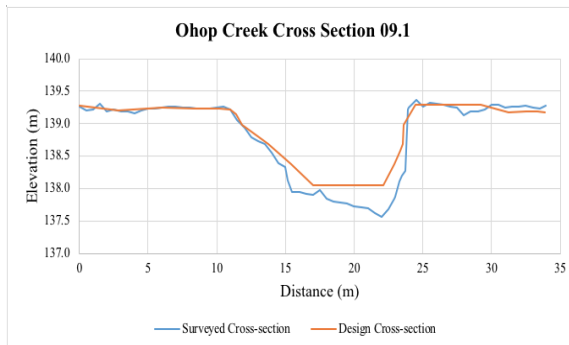
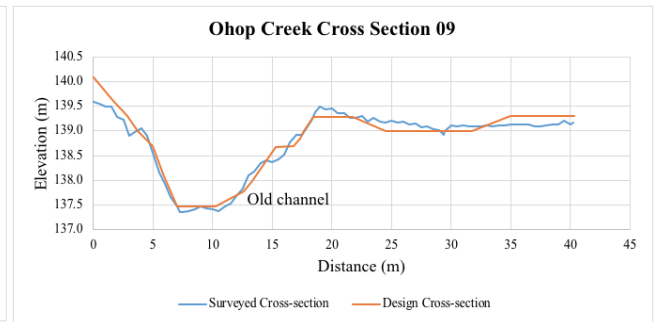
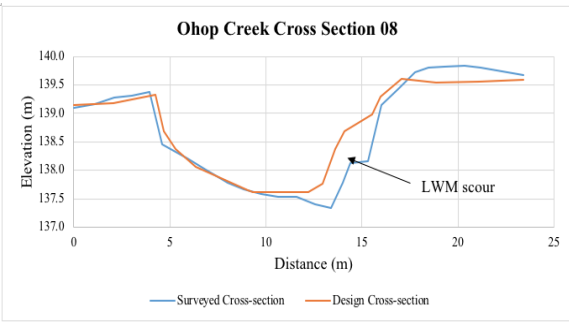
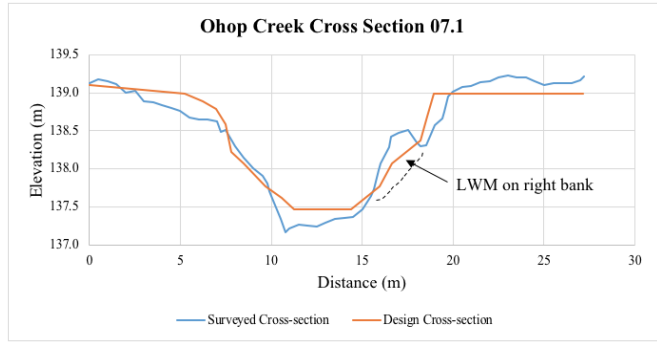
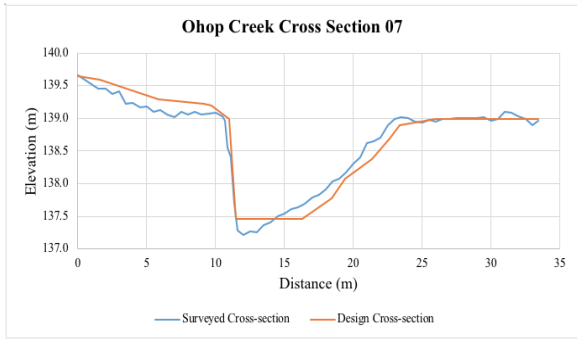
**A1.** Benchmarked monuments for Ohop Creek Restoration Area cross-section. Coordinate system- UTM Z10 N, horizontal datum - NAD 1983 (Conus), vertical datum – NAVD88.

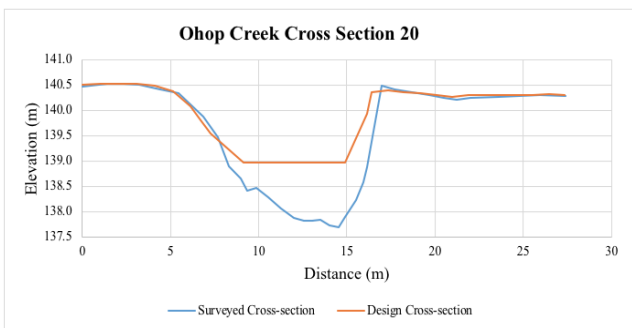
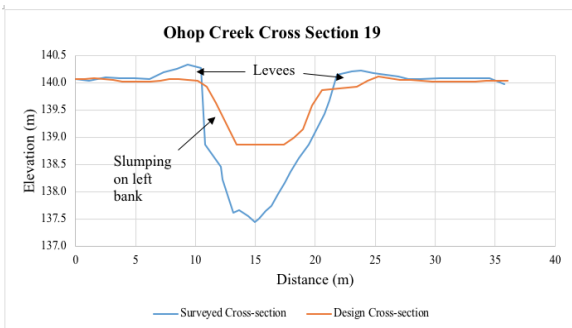
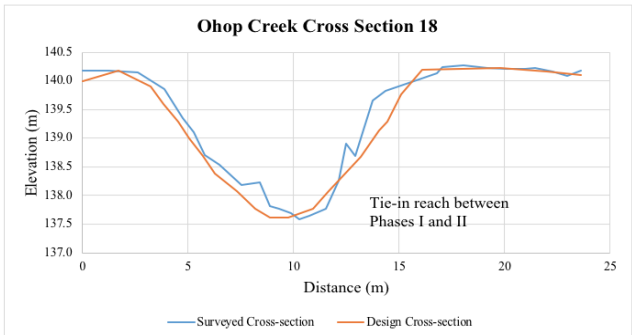
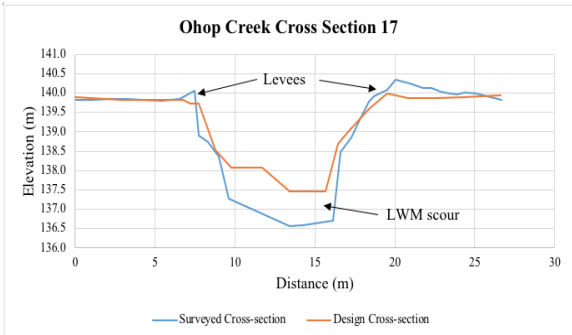
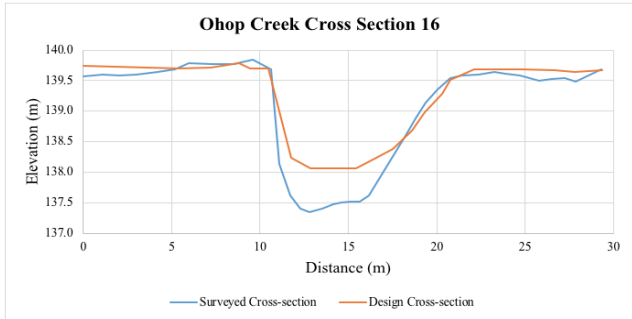
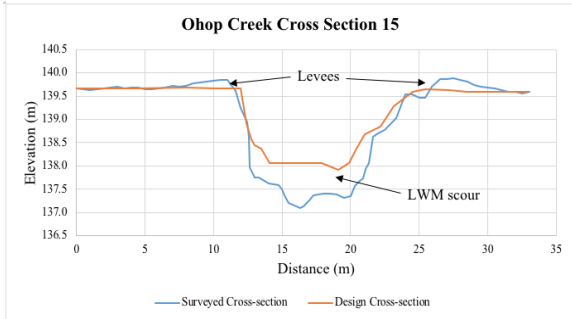
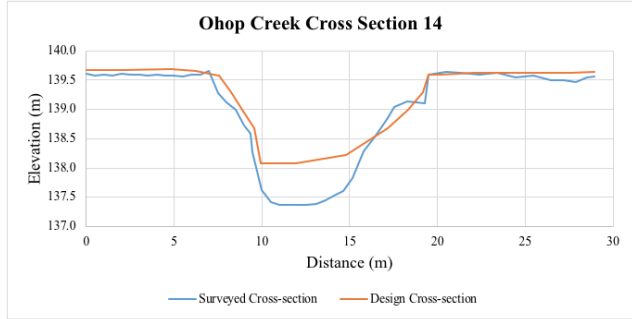
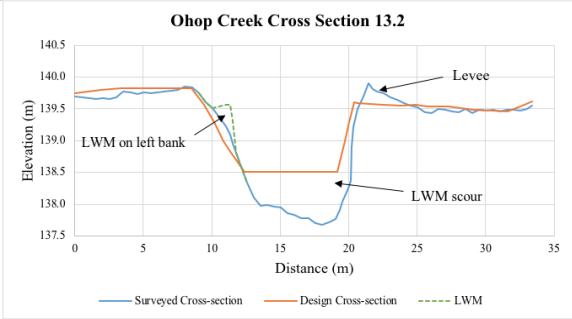
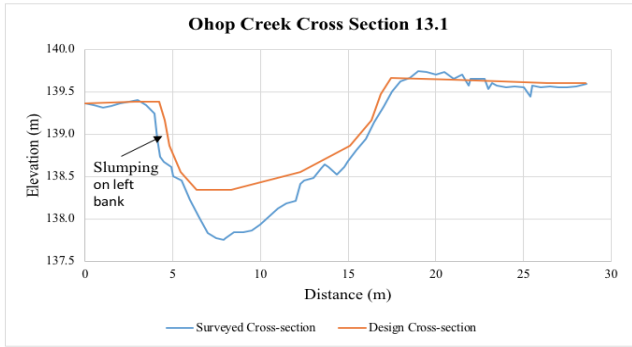
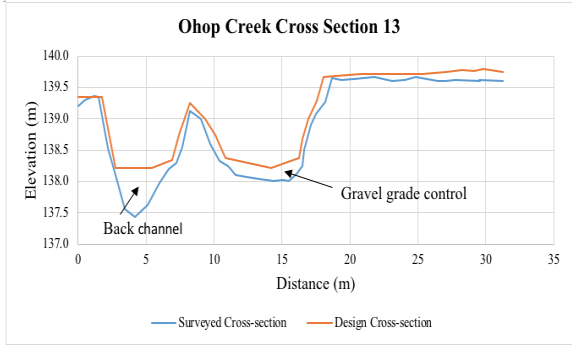
Benchmark ID	Bank	Northing (m)	Easting (m)	Elevation (m)
OCXS_02	Left	5188775.52	548779.19	138.50
	Right <sup>i</sup>	5188786.98	548744.38	138.91
OCXS_03	Left	5188845.34	548795.47	138.44
	Right	5188868.16	548770.35	139.10
OCXS_04	Left <sup>i</sup>	5188933.68	548876.79	138.60
	Right	5188949.98	548838.81	139.19
OCXS_05	Left	5188928.53	548984.92	139.04
	Right	5188946.64	548979.43	138.98
OCXS_06	Left*	No benchmark	No benchmark	No benchmark
	Right	5189023.54	549071.77	139.16
OCXS_06.1	Left	5189101.23	549123.07	139.95
	Right	5189116.70	549093.72	138.95
OCXS_07	Left	5189128.80	549130.70	139.66
	Right	5189125.44	549097.42	138.97
OCXS_07.1	Left	5189145.95	549122.02	139.12
	Right	5189133.75	549097.76	139.21
OCXS_08	Left	5189211.68	549160.60	139.10
	Right	5189216.16	549137.64	139.68
OCXS_09	Left	5189245.69	549263.98	139.59
	Right	5189278.46	549240.52	139.14
OCXS_09.1	Left	5189304.99	549294.95	139.26
	Right	5189296.55	549262.12	139.28
OCXS_10	Left	5189322.82	549325.76	139.43
	Right	5189348.99	549292.60	139.66
OCXS_11	Left	5189412.83	549385.23	139.28
	Right	5189416.13	549348.41	139.36
OCXS_12	Left	5189449.52	549451.12	139.38
	Right	5189462.08	549421.95	139.43
OCXS_13	Left	5189518.02	549523.12	139.05
	Right	5189507.53	549505.11	139.60
OCXS_13.1	Left	5189564.95	549522.30	139.36
	Right	5189568.46	549493.96	139.60
OCXS_13.2	Left	5189597.74	549518.60	139.69
	Right	5189583.16	549488.57	139.55
OCXS_14	Left	5189618.48	549513.86	139.61
	Right	5189637.57	549492.10	139.56
OCXS_15	Left <sup>i</sup>	5189719.22	549574.55	139.67
	Right	5189719.12	549541.60	139.60

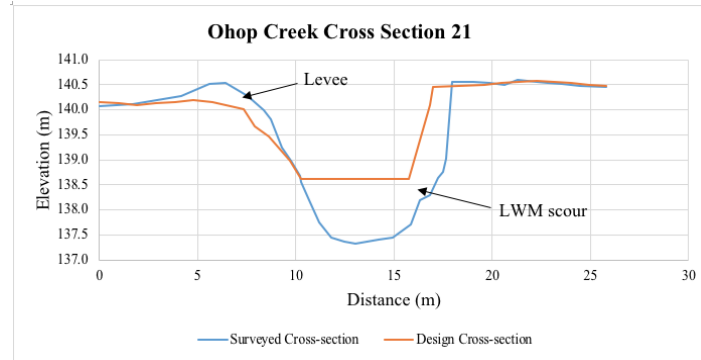
OCXS_16	Left	5189804.45	549629.30	139.57
	Right	5189813.10	549601.23	139.68
OCXS_17	Left	5189898.09	549686.94	139.82
	Right	5189881.56	549666.04	140.00
OCXS_18	Left	5189944.36	549760.26	140.17
	Right	5189942.29	549736.75	140.14
OCXS_19	Left	5190016.47	549774.92	140.07
	Right	5190051.53	549781.42	139.94
OCXS_20	Left	5190143.70	549809.88	140.46
	Right	5190125.32	549789.56	140.22
OCXS_21	Left	5190214.60	549828.74	140.08
	Right	5190208.77	549803.63	140.46

## A2. Comparison of surveyed and design cross-sections









### A3. Calculations

#### Manning's Equation

For a uniform flow in open channels the channel slope  $S_c$  equals the water surface slope  $S_w$

$$Q_b = V_b A_b = (1.00/n) A_b R_h^{2/3} \sqrt{S_w}$$

Where:

$Q_b$  = Discharge ( $\text{m}^3/\text{s}$ ) at bankfull

$V_b$  = Velocity ( $\text{m}/\text{s}$ ) at bankfull

$A_b$  = Reach-average area ( $\text{m}^2$ ) at bankfull

$n$  = Manning's Roughness Coefficient

$R_h$  = Hydraulic Radius (m)

#### Phase II calculations

Given:  $Q_b = 9.1 \text{ m}^3/\text{s}$

$A_b = 15.2 \text{ m}^2$

$R_h = 1.07 \text{ m}$

$S_w = 0.00065$

Calculate:  $V_b = 9.1 \text{ m}^3/\text{s} \div 15.2 \text{ m}^2 = 0.60 \text{ m}/\text{s}$

$$n = (1.00 \div 0.60 \text{ m}/\text{s}) \times (1.07 \text{ m})^{2/3} \times \sqrt{(0.00065)} = 0.045$$

#### Phase I calculations

Given:  $A_b = 20.2 \text{ m}^2$

$R_h = 1.39 \text{ m}$

$S_w = 0.0005$

Calculate:  $V_b = (1.00 \div 0.045) \times (1.39 \text{ m})^{2/3} \times \sqrt{(0.0005)} = 0.61 \text{ m}/\text{s}$

$$Q_b = 0.61 \text{ m}/\text{s} \times 20.2 \text{ m}^2 = 12.4 \text{ m}^3/\text{s}$$

# Appendix B – Ohop Valley Restoration Monitoring Protocol

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## **B1. Objective**

The objective of the Ohop Valley Restoration Project Monitoring Protocol (Protocol) is to evaluate the success of the Ohop Valley Restoration Project in restoring and maintaining aquatic habitat. It is intended to relate current stream characteristics to past conditions to track trends in watershed conditions through time. The Protocol is designed to help stakeholders and future researchers determine cause-and-effect relationships between measured stream properties and watershed processes that influence stream form and function. The Protocol integrates methods and assessments from this study, fieldwork, and desk review in order to monitor:

- Overall reach characteristics (meander geometry, sinuosity, gradient)
- Channel cross-section characteristics (bankfull width and mean depth)
- Channel discharge and stage
- Habitat composition (pool distribution, percent pools, pools/ km , residual pool depth)

In addition to these four categories, a photoset of cross-sections and LWM structures has been developed to provide monitoring practitioners with visual references in order to track changes to cross-sectional characteristics and bank stability around LWM structures.

The methods are informed in part by monitoring programs developed by the United States (U.S.) Department of Agriculture Forest Service (Reeves et al., 2003) and by the U.S. Environmental Protection Agency (Peck et al., 2001).

The methods in this document are supported by ready-to-use spreadsheets for analyzing and comparing collected data from year to year. The spreadsheets were designed to facilitate ease of data input and analysis and do not require an extensive background in surveying or fluvial sciences to operate. The spreadsheets can be found at <http://hrrngtn.com/ohop/> along with the photo survey images, GIS layers, and the main body of this document.

Ideal time for surveying both longitudinal and cross-sectional surveys is during the late summer/early fall low-flow period when discharge conditions are typically stable. Surveying should be conducted at low-flow so that future surveys can be conducted at similar discharge conditions and data can be used to compare channel conditions to determine trends over time. Sampling at low-flow also has the benefit of decreasing variability added by factors such as turbidity and increasing the likelihood that the channel can be safely waded.

## **B2. Methods**

### ***B2.1 Overall Reach***

A simple remote-sensing approach that utilizes maps and orthographic images can be implemented to characterize overall reach characteristics. This protocol focuses on how to measure channel sinuosity, migration and width, meander geometry, and slope in a GIS or Google Earth from 1.0 m resolution National Agriculture Imagery Program (NAIP) images that are published in the fall of every odd year for Washington State. LiDAR digital elevation models (DEM) should also be implemented as new data sets are made available.

#### **Channel Sinuosity**

Channel sinuosity is defined as the ratio between the channel length measured as the centerline of the low-flow channel) and the valley length (Figure 1). To measure the sinuosity of Ohop Creek, digitize the channel centerline in a GIS for the latest NAIP image (available at [www.fsa.usda.gov/programs-and-services/aerial-photography](http://www.fsa.usda.gov/programs-and-services/aerial-photography)) and divide the shape length by the valley length. Alternatively, the same methodology can be conducted using Google Earth by simply using the path tool.

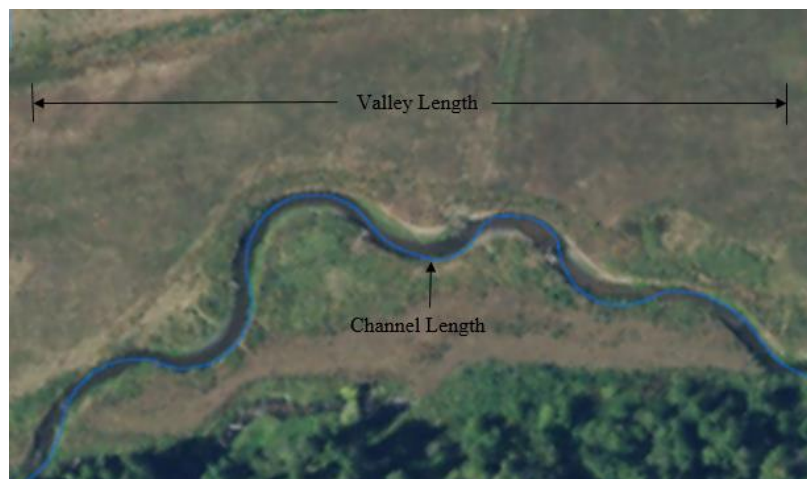


Figure 1. Sinuosity is defined as the channel length (shown in blue) divided by the valley length.

#### **Channel Migration and Width**

Channel migration and widening can be readily measured in a GIS using the latest NAIP image. Measure lateral migration along the axis of several meander bends and determine the mean

migration rate. Width should be measured by determining the distance between active channel boundaries at equal intervals throughout the channel reach. Alternatively, you can use the Washington State DOE Channel Migration Toolbox (Legg et al., 2014) to calculate migration and widening. The directions for the tool are simple to use and the accompanying document (downloadable from the website listed in the references) will walk you through the process. In addition to quantifying migration and widening, note any avulsions that may have occurred in the Project reach.

### Meander Geometry

The wavelength, amplitude, and radius of curvature are commonly used metrics to characterize the geometry of channel meanders that can readily be measured in a GIS or in Google Earth. Wavelength should be measured from the upstream inflection point to the downstream inflection point of each full meander (Figure 3). Amplitude should be measured from outer bank to outer bank. Radius of curvature is measured by superimposing circles over the channel centerline and then using the area of the circle to calculate the radius ( $A=\pi r^2$ ).

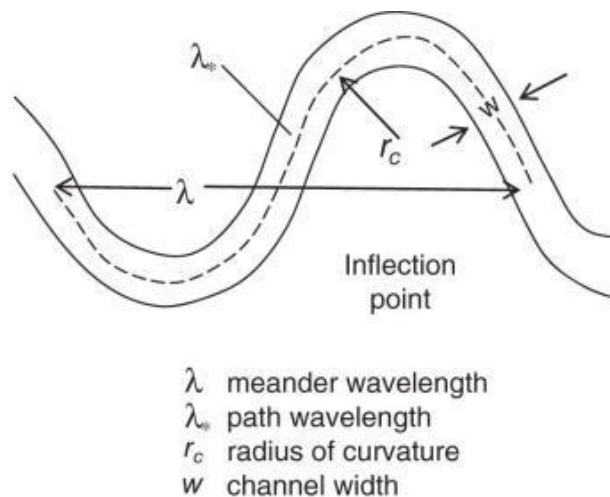


Figure 3. Parameters used to characterize bend geometry. Source: Wohl, 2014.

### Channel Slope

To determine slope in the Project channel, a longitudinal profile should be conducted. This profile should be conducted at the same time as the pool survey described in section B2.4. The slope is determined by taking the difference in the water surface elevation at a downstream control structure (i.e., bar, riffle) and the water surface elevation at the upstream control structure

for each reach, and then dividing by the length of the reach. Alternatively, the change in water surface elevation and distance between surveyed cross-sections (described in section B2.2) can be used to calculate slope. If new LiDAR DEMs of the Project reach become available, slope can be determined by querying the DEM for the elevation value at an upstream and downstream point, taking the difference in those two elevations, and dividing by the channel length between the two points. However, caution should be used while using LiDAR derived in-channel elevations because most LiDAR cannot penetrate more than a few centimeters into water.

## ***B2.2 Cross-section Characteristics***

25 permanently benchmarked cross-sections were established and measured at the Ohop Creek Restoration Area to determine how the cross-sectional form is evolving over time. For the monuments, we drove 0.6 m - long lengths of 0.9 cm diameter pieces of rebar into the ground and capped them with orange plastic caps and then geospatially located the benchmarks using the Trimble Geo7X GNSS system with Real Time Kinematics (RTK) enabled. Locations of the benchmarks are contained in Appendix A in this document.

### **General Approach**

Cross-sections can be surveyed by conventional surveying tools such as a tripod-mounted auto level and stadia rod or a total station and prism. Begin and end the cross-sections at the benchmark monuments. Incorporating the benchmarks into the survey will allow you to plot the survey relative to elevation (not just change in depth from floodplain to thalweg), which will make it possible to compare your cross-section to previously surveyed cross-sections. An interval of 1.0 m should be used between measurement points in the flood plain. Because the purpose is to capture all salient features of the channel (slope breaks, edge of water, thalweg, etc.), no set interval should be used in the channel itself. In the wetted part of the channel, measure the bed by placing the rod firmly on the bottom but not digging the rod or prism into the substrate. Record the depth of the water while in the channel so that you can use the water surface elevation between cross-sections to calculate the water surface slope.

While at the cross-section take a set of photos with a camera or a cell phone to document the cross-section (Figure 4). Record where along the cross-section the photos were taken (distance relative to one of the benchmarks). Also, take photos from about 10 paces upstream and

downstream of the cross-section. Try to include the entire cross-section in the photos. When re-surveying cross-sections, include photos taken from the same view points as previous photos.



Figure 4. Cross-section from right bank looking toward left bank (left image) and cross-section view looking upstream (right image).

### **Analysis**

The “Ohop Creek Benchmarked Cross-section” spreadsheet found at the website provided above can be used to enter and plot your cross-section data. Calculate the top width as the difference between the bankfull edge of the left bank and the right bank. Determine the mean channel depth as the average of the difference between the bankfull elevation and the elevation of the channel bottom for all survey points. Calculate the cross-sectional bankfull area as the product of the bankfull width and mean depth. Additionally, the “Ohop Creek Cross-section Comparison” spreadsheet can be used to compare your cross-section to previously surveyed cross-sections. Visually inspect the shape of the channel cross-sections and consider how it has changed since the last survey. Note any observations made while in the field that could help explain changes to the form or area of the cross-section.

### ***B2.3 Discharge***

At the Ohop Creek Project area, discharge was measured to determine the percentage increase in flow in the Project area from the USGS gage (12088000 “Ohop Creek near Eatonville, WA”). Discharge measurements were also correlated to stream stage measured at a staff gage installed during restoration in order to create a rating curve for the Project area.

## General Approach

Discharge should be measured with a velocimeter, a wading rod, and a tape measure using a standard methodology like the one employed by the USGS (Turnipseed and Sauer, 2010). Select a site to measure discharge that is free from both upstream and downstream obstructions, and has a reasonably uniform bottom condition. Straight sections of channels with parallel streamlines are ideal locations to measure discharge (Figure 5). Avoid areas of the channel that cannot be safely navigated or are too deep to measure. In sand-bottom streams like Ohop Creek, it is sometimes difficult to keep the wading rod from sinking into the streambed. Practitioners need to be careful that the measured water depth, as well as the depth of the probe placement, are based on the surface of the streambed.



Figure 5. Select a cross-section site that is straight, has minimal upstream and downstream obstructions, and reasonably uniform bottom conditions.

After measuring the velocity and calculating the discharge, note the stage of the water indicated on the DGN staff gage. The DGN gage is located on the right bank of the channel, 260 m downstream of State Route 7. Note the gage does not extend into the summer low flow. Measurements to the water surface need to be made from the bottom of the gage.

## **Analysis**

Enter the discharge data in the “Discharge and DGN Rating Curve” spreadsheet and plot the discharge and corresponding stream stage on the current rating curve. Determine if your discharge measurement are within 5% of discharge predicted from the rating curve for the stage. If not, the rating curve may need to be corrected, or shifted, to better reflect current stage-discharge relations. To determine if a shift is warranted, follow USGS standards like those described in Rantz et al. (1982).

Finally, go the USGS gage 12088000 “Ohop Creek near Eatonville, WA” web page (USGS, 2017) and note the discharge and gage height reported at the stream gage at the time of your discharge measurement in the Project reach. Calculate the percent difference between the two discharges and note it on the discharge spreadsheet.

### ***B2.4 Habitat Composition (Pool Survey)***

A pool survey is should be conducted to record the depth, surface area, and type (large woody material (LWM) scour, free from, slumped bank material influenced, etc.) of pools. The depth of the pool is measured by its residual depth, which is the difference in the bed elevation of the pool and the downstream riffle crest (Lisle, 1986). Pool surveys may be conducted with basic surveying equipment such as a tripod-mounted auto level, stadia rod, and measuring tape.

## **Analysis**

In the spreadsheet provided, enter the distribution of pool types, and the mean residual depth for each pool type. Also enter the percent pools and pools/average channel width into the spreadsheet in the designated spaces.

### ***B2.5 Photo Survey***

A standardized photo survey provides a snapshot of current stream characteristics. Having a standardized protocol for viewing angles and locations is of great benefit as it allows practitioners to reoccupy photo points and capture new images year after year. At the Ohop Valley Restoration Project area, over 160 photos were taken from spring of 2017 to winter of 2018 (Appendix C). These photographs should be used in tandem with other field monitoring

efforts to identify areas that need more intensive study, such as LWM structures that are causing increasingly large amount of bank erosion and may lead to a channel cutoff.

For the surveyed cross-sections, photographs were taken from the banks standing on transect and from approximately 10 paces upstream and downstream of the cross-sections. Channel conditions were not always amenable for capturing photographs. For instance, a deep LWM scour pool below OCXS 13.1 made photographing the cross-section from 10 paces downstream challenging and so a shorter distance (approximately 5 paces) was chosen. Nearly every LWM structure between State Route 7 and the bottom of the reach was photographed, with nearly every photo being captured from the right bank (due to ease of access). No standard distance was used for these photos, but GPS coordinates were measured for the majority of the photos using a Trimble Geo 7X while RTK corrections from the Washington State Reference Network (estimated field accuracy of +/- 2 cm).

### **B3. References**

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- Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 pgs.
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- Wohl, E., 2014. *Rivers in the landscape: Science and management*. Wiley Blackwell, 318 pgs.

## Appendix C

Ohop Creek Photo Survey Points 2017-2018 (see file Ohop\_Creek\_Photo\_Survey for actual photos)

Photo ID	Date	Discharge* (cfs)	Lat/Long	Description
01(1)	7/20/2017	8.21	46.850874,	Downstream at OCXS_02
01(2)	2/3/2018	288	-122.360513	Downstream at OCXS_02
02(1)	2/3/2018	288	46.850942, -122.360496	Wood on left bank at OCXS_02
02(2)	2/3/2018	288		Wood on right bank above OCXS_02
02(3)	2/3/2018	288		Upstream above OCXS_02
03(1)	7/29/2017	7.27	46.851684, -122.359673	Downstream toward OCXS_03
03(2)	7/29/2017	7.27		Wood in channel on left bank
03(3)	2/3/2018	258		LWD structure on left bank
04(1)	2/3/2018	258	46.852287, -122.359298	Flooded bank downstream of OCXS_04
04(2)	2/3/2018	258		Along transect at OCXS_04
04(3)	2/3/2018	258		Upstream at OCXS_04
04(4)	2/3/2018	258		Along transect and right bank at OCXS_04
05(1)	7/20/2017	8.21	46.852524, -122.356935	Natural log jam
05(2)	2/3/2018	258		Downstream of natural log jam
05(3)	2/3/2018	258		Downstream of natural log jam
05(4)	7/20/2017	8.21		Natural log jam
05(5)	2/3/2018	258		Natural log jam
06(1)	7/20/2017	8.21	46.853193, -122.356064	Confluence of new and back channel
07(1)	9/13/2017	5.12	46.853737, -122.355910	Along transect OCXS_06.1
08(1)	9/13/2017	5.12	46.853764, -122.355724	Upstream toward OCXS_07
09(1)	7/29/2017	7.27	46.853859,	Downstream on point bar at OCXS_07
09(2)	7/29/2017	7.27	-122.355764	Upstream on point bar at OCXS_07
10(1)	9/13/2017	4.81	46.853950, -122.355738	Upstream toward OCXS_07.1
11(1)	2/3/2018	282	46.853954,	Flooded LWD on right bank at OCXS_07.1
11(2)	2/3/2018	282	-122.355871	Flooded LWD on right bank at OCXS_07.1
12(1)	9/13/2017	4.81	46.854030, -122.355833	Downstream toward OCXS_07.1
13(1)	2/3/2018	270	46.854499, -122.355582	LWD on left bank and bank retreat
14(1)	9/13/2017	5.12	46.854582, -122.355260	Upstream toward OCXS_08
15(1)	2/3/2018	270	46.854657, -122.355359	LWD downstream of OCXS_08
15(2)	2/3/2018	270		LWD on transect at OCXS_08
15(3)	2/3/2018	270		Upstream toward LWD at OCXS_08
15(4)	2/3/2018	270		Upstream toward LWD at OCXS_08

16(1)	9/13/2017	5.12	46.854628, -122.355110	Along transect from left bank OCXS_08
17(1)	9/13/2017	5.12	46.854702, -122.355203	Downstream toward OCXS_08
18(1)	5/11/2017	57.5	46.854839, -122.354905	LWD on left bank and bank retreat
19(1)	9/13/2017	4.81	46.855003, -122.353861	Upstream from OCXS_09
20(1)	2/3/2018	273	46.855224, -122.353668	Confluence of new and back channel
21(1)	9/13/2017	4.81	46.855360, -122.353501	Downstream from below OCXS_09.1
22(1)	2/3/2018	267	46.855590, -122.353675	Downstream towards LWD above OCXS_09.1
23(1)	2/3/2018	267	46.855713, -122.353311	LWD on left bank and bank retreat
23(2)	2/3/2018	267		LWD on left bank and bank retreat
24(1)	9/13/2017	5.12	46.855672, -122.353190	Upstream toward OCXS_10
25(1)	9/13/2017	5.12	46.855776, -122.353005	Downstream toward OCXS_10
26(1)	7/29/2017	6.90	46.855798, -122.353053	Downstream on point bar above OCXS_10
26(2)	7/29/2017	6.90		Upstream on point bar above OCXS_10
27(1)	2/3/2018	267	46.855963, -122.353121	Downstream from LWD on right bank
27(2)	2/3/2018	267		Across channel at LWD on right bank
27(3)	2/3/2018	267		Upstream from LWD on right bank
28(1)	5/11/2017	57.5	46.856684, -122.352520	LWD on right bank above OCXS_11
28(2)	2/3/2018	247		LWD on right bank above OCXS_11
28(3)	2/3/2018	247		LWD on right bank above OCXS_11
29(1)	2/3/2018	247	46.856852, -122.352161	LWD on left bank and bank retreat
29(2)	2/3/2018	247		LWD on left bank and bank retreat
30(1)	5/11/2017	58.8	46.856961, -122.351487	Downstream at LWD above OCXS_12
30(2)	5/11/2017	58.8		Downstream at LWD above OCXS_12
30(3)	2/3/2018	247		Downstream at LWD above OCXS_12
30(4)	2/3/2018	247		Across channel at LWD above OCXS_12
30(5)	2/3/2018	247		Across channel at LWD above OCXS_12
31(1)	5/11/2017	58.8	46.856992, -122.351435	Looking upstream from LWD on right bank
31(2)	2/3/2018	247		Downstream at LWD above OCXS_12
31(3)	2/3/2018	247		Upstream at LWD above OCXS_12
32(1)	2/3/2018	247	46.857333, -122.350450	Confluence of new and back channel
33(1)	2/3/2018	267	46.857607, -122.350636	Downstream at LWD on right bank
33(2)	2/3/2018	267		LWD on left bank below OCXS_13.1
33(3)	2/3/2018	267		LWD on left bank below OCXS_13.1
33(4)	2/3/2018	267		Upstream toward OCXS_13.1
34(1)	9/13/2017	5.12	46.857738, -122.350483	Upstream from OCXS_13.1

35(1)	9/13/2017	5.12	46.857874, -122.350445	Downstream towards OCXS_13.1
36(1)	9/13/2017	5.12	46.857990, -122.350475	Upstream towards OCXS_13.2
37(1)	9/13/2017	5.12	46.858078, -122.350616	Downstream towards OCXS_13.2
38(1)	9/13/2017	5.12	46.858388, -122.350639	Downstream from OCXS_14
38(2)	9/13/2017	5.12		Upstream from OCXS_14
39(1)	2/3/2018	264	46.858673, -122.350422	LWD on right bank
40(1)	2/3/2018	264	46.858742, -122.350452	Downstream toward LWD on right bank
41(1)	9/13/2017	5.12	46.859036, -122.349842	Upstream towards OCXS_15
42(1)	2/3/2018	264	46.859206, -122.349981	LWD on right bank at OCXS_15 transect
43(1)	9/13/2017	5.12	46.859215, -122.349909	Downstream toward OCXS_15
44(1)	2/3/2018	264	46.859254, -122.349967	Downstream toward LWD at OCXS_15
44(2)	2/3/2018	264		Upstream from above LWD at OCXS_15
45(1)	7/30/2017	6.17	46.859833, -122.349225	Downstream on point bar below OCXS_16
45(2)	7/30/2017	6.17		Upstream on point bar below OCXS_16
46(1)	2/10/2018	87.6	46.859987, -122.349170	Downstream from OCXS_16
46(2)	2/10/2018	87.6		Upstream from OCXS_16
46(3)	2/10/2018	87.6		Along transect at OCXS_16
47(1)	2/10/2018	87.6	46.860088, -122.349147	Downstream at LWD at OCXS_16
47(2)	2/10/2018	87.6		Across channel from LWD at OCXS_16
47(3)	2/10/2018	87.6		Upstream from LWD at OCXS_16
47(4)	2/10/2018	87.6		LWD on right bank at OCXS_16
47(5)	2/10/2018	87.6		LWD on right bank at OCXS_16
48(1)	2/10/2018	92.8	46.860481, -122.348519	LWD on right bank below OCXS_17
48(2)	2/10/2018	92.8		LWD on right bank below OCXS_17
49(1)	2/10/2018	92.8	46.860665, -122.348333	Right bank monument for OCXS_17
49(2)	2/10/2018	92.8		Downstream from OCXS_17
49(3)	2/10/2018	92.8		Upstream from OCXS_17
49(4)	2/10/2018	92.8		Across channel at LWD at OCXS_17
49(5)	2/10/2018	92.8		Across channel at LWD at OCXS_17
50(1)	2/10/2018	89.3	46.860712, -122.348360	LWD on right bank from above OCXS_17
50(2)	2/10/2018	89.3		LWD on right bank from above OCXS_17
51(1)	2/10/2018	89.3	46.860948, -122.348413	LWD on right bank above OCXS_17
51(2)	2/10/2018	89.3		LWD on right bank above OCXS_17
51(3)	2/10/2018	89.3		LWD on right bank above OCXS_17
52(1)	2/10/2018	89.3	46.861003, -122.347672	Wood on left bank at tie-in point
52(2)	2/10/2018	89.3		Wood on left bank at tie-in point
52(3)	2/10/2018	89.3		Old channel confluence on left bank
52(4)	2/10/2018	89.3		Old channel and riprap on left bank

53(1)	2/10/2018	89.3	46.861167, -122.347366	Downstream from OCXS_18
53(2)	2/10/2018	89.3		Upstream from OCXS_18
53(3)	2/10/2018	89.3		Across channel at OCXS_18
54(1)	2/10/2018	89.3	46.861247, -122.347440	Downstream at LWD above OCXS_18
54(2)	2/10/2018	89.3		Downstream at LWD above OCXS_18
55(1)	2/10/2018	89.3	46.861492, -122.347597	Downstream from wood on right bank
55(2)	2/10/2018	89.3		Across channel from wood on right bank
55(3)	2/10/2018	89.3		Upstream from wood on right bank
56(1)	2/10/2018	89.3	46.861993, -122.347382	Downstream toward erosion on right bank
56(2)	2/10/2018	89.3		Across channel at LWD on right bank
56(3)	2/10/2018	89.3		Upstream with LWD and right bank
56(4)	2/10/2018	89.3		Slump block and LWD on right bank
57(1)	2/10/2018	84.2	46.862018, -122.346913	Right bank monument at OCXS_19
57(2)	2/10/2018	84.2		Downstream from OCXS_19
57(3)	2/10/2018	84.2		Upstream from OCXS_19
57(4)	2/10/2018	84.2		Across channel at OCXS_19
58(1)	5/11/2017	57.5	46.862205, -122.346822	Upstream from LWD above OCXS_19
58(2)	2/10/2018	84.2		LWD on right bank and bank retreat
58(3)	2/10/2018	84.2		Upstream toward LWD and bank retreat
58(4)	2/10/2018	84.2		Upstream toward LWD and bank retreat
58(5)	2/10/2018	84.2		Across channel toward LWD with staff gage
59(1)	5/6/2017	181	46.862280, -122.346847	Downstream toward LWD and bank retreat
59(2)	5/6/2017	181		Downstream toward LWD and bank retreat
59(3)	5/6/2017	181		Downstream toward LWD and bank retreat
59(4)	5/6/2017	181		Across channel above LWD bank retreat
59(5)	5/6/2017	181		Across channel above LWD bank retreat
59(6)	2/10/2018	84.2		Downstream toward LWD and bank retreat
59(7)	2/10/2018	84.2		Downstream toward LWD and bank retreat
59(8)	2/10/2018	84.2		Across channel above LWD bank retreat
60(1)	5/11/2017	57.5	46.862531, -122.346763	Downstream from narrow point in channel
60(2)	5/11/2017	57.5		Across channel at narrow point
60(3)	2/10/2018	87.6		Across channel at narrow point
60(4)	2/10/2018	87.6		Across channel at narrow point
60(5)	2/10/2018	87.6		Across channel at narrow point
60(6)	2/10/2018	87.6		Across channel at narrow point
60(7)	2/10/2018	87.6		Downstream from narrow point in channel
61(1)	2/10/2018	87.6	46.862864, -122.346657	Right bank monument at OCXS_20
61(2)	2/10/2018	87.6		Downstream from OCXS_20
61(3)	2/10/2018	87.6		Upstream from OCXS_20
61(4)	2/10/2018	87.6		Across channel at OCXS_20
62(1)	2/10/2018	89.3	46.862952, -122.346803	Upstream towards LWD above OCXS_20
63(1)	2/10/2018	89.3	46.863066, -122.346821	Downstream towards LWD above OCXS_20
64(1)	2/10/2018	89.3	46.863170, -122.346435	LWD on right bank between OCXS_20 and 21
64(2)	2/10/2018	89.3		Slumping on left bank

64(3)	2/10/2018	89.3		LWD on right bank between OCXS_20 and 21
65(1)	2/10/2018	89.3	46.863182, -122.346249	LWD on left bank with bank retreat
65(2)	2/10/2018	89.3		LWD on left bank with bank retreat
66(1)	2/10/2018	80.8	46.863578, -122.346486	Right bank monument at OCXS_21
66(2)	8/27/2017	6.12		Downstream at LWD below OCXS_21
66(3)	8/27/2017	6.12		Downstream at LWD below OCXS_21
66(4)	2/10/2018	80.8		Downstream at LWD below OCXS_21
66(5)	2/10/2018	80.8		Downstream at LWD below OCXS_21
66(6)	2/10/2018	80.8		Downstream at LWD below OCXS_21
66(7)	2/10/2018	80.8		Upstream from OCXS_21
66(8)	2/10/2018	80.8		Across channel at OCXS_21
66(9)	2/10/2018	80.8		Right bank downstream from OCXS_21
66(10)	2/10/2018	80.8		Slump block on right bank at OCXS_21
67(1)	2/10/2018	87.6	46.864267, -122.346189	Looking upstream at wood on right bank
68(1)	2/10/2018	87.6	46.864377, -122.346205	Downstream toward wood below Hwy 7
68(2)	2/10/2018	87.6		Downstream toward wood below Hwy 7
68(3)	2/10/2018	87.6		Hwy 7 bridge over Ohop Creek