East Fork Lewis River Ridgefield Pits Restoration

Geomorphology Report

SUBMITTED TO
Lower Columbia Estuary Partnership

January 2020

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Ridgefield Pits Restoration

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SUBMITTED TO
Lower Columbia Estuary Partnership
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1. Introduction

1.1 BACKGROUND AND OBJECTIVES

Inter-Fluve is assisting the Lower Columbia Estuary Partnership (EP) in assessing restoration feasibility of approximately two miles of the lower East Fork Lewis River near La Center, WA. The study area extends from approximately river mile (RM) 7.0 (just downstream of the Ridgefield Pits) to RM 10 (near Daybreak Bridge). The project, in part, seeks to address impacts associated with the avulsion of the river into the Ridgefield Pits gravel mining area in the mid-1990s and the associated impacts to habitat at the avulsion site and in the upstream channel and floodplain. It also seeks to identify and evaluate other potential aquatic habitat enhancement opportunities in the study area.

This report supports the restoration planning effort by characterizing the fluvial geomorphologic processes operating in the project area. It is based partly on previous studies and partly on new work performed as part of this effort. The primary objectives of this study can be summarized by the following:

1. Characterize fluvial geomorphologic processes and trends in the study area – this evaluation supports the identification of habitat restoration actions that are set within the appropriate geomorphic context of the study area. It also helps to understand how future river dynamics may affect or interact with restoration actions.
2. Update estimates of system recovery from the1995-1996 Ridgefield Pits avulsion – recovery of the avulsion area is assumed to occur once the avulsed pit area fills with sediment over time, as it has been doing since the initial avulsion. Previous estimates for recovery time have been made. This effort evaluates the current status of the natural recovery process and provides an updated estimate of pit recovery time. This information is helpful for determining if restoration of the avulsed reach is warranted, and how it might be performed.
3. Provide recommendations for modeling analysis scenarios – the EP is performing the hydraulic and sediment modeling for potential restoration scenarios. Based on the findings of this geomorphology study, recommendations for modeling scenarios are provided.

1.2 PRIOR STUDIES

The following previous studies have evaluated habitat, land use impacts, and/or restoration opportunities in the study area and have been reviewed as part of this effort.

- Daybreak Mine Expansion Habitat Conservation Plan (HCP) (Storedahl & Sons 2003). Includes the main HCP document as well as the following attachments or follow-up work that are relevant to this effort:
    - Conceptual Restoration Plan for Ridgefield Pits (R2 Resource Consultants 1999) – Appendix B of HCP
    - Geomorphic Analysis of the East Fork Lewis River (WEST Consultants 2001) – Appendix C of HCP

  - Daybreak Ponds Avulsion Mitigation (WEST Consultants 2001 and Ecological Land Services) – Addendum 1 to Appendix C of HCP
  - CM-10 Monitoring Report-Ridgefield Pits Bathymetric Survey (Tech Memo by WEST Consultants 2013) – monitoring requirement of HCP
- Assessment and Strategic Plan for East Fork Lewis River (Dover Habitat Restoration for Friends of the East Fork 2003)
- East Fork Lewis River (RM 13 to RM 6), Including West Daybreak Park Project Reach – Fluvial Geomorphology and Erosion and Sediment Evaluation (Frank Reckendorf 2010).
- The Lower East Fork Lewis River Subbasin: A Summary of Habitat Conditions, Salmonid Distribution, and Smolt Production (WDFW 2001)
- East Fork Lewis River Basin – Habitat Assessment (SP Cramer & Associates 2005)
- Lower East Fork Lewis River Habitat Restoration Plan (Inter-Fluve and Cramer Fish Sciences, for LCFRB 2009)

2. River Segment Delineations

The study area, and adjacent upstream and downstream areas, have been split out into 5 segments for the purposes of this evaluation. The locations of the segments are displayed in the map in Figure 1.

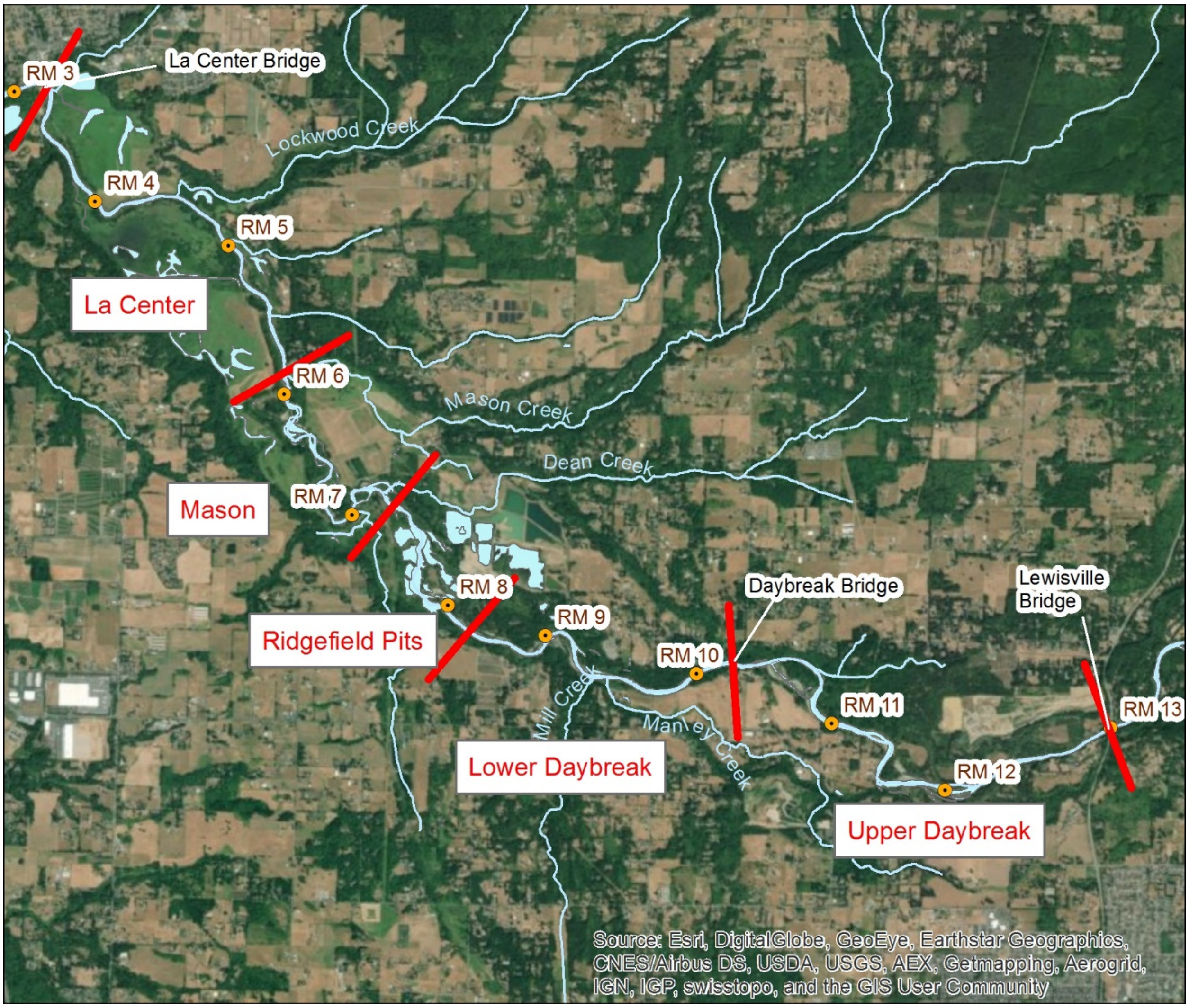


Figure 1. Location of segments used in the geomorphology assessment.

3. River Hydrology and Flood History

A brief description of basin hydrology and flood history is included here as it provides important context for understanding geomorphic changes in the system and can inform stream restoration planning. The EF Lewis has a rainfall-dominated hydrograph typical of western Cascades streams. An exceedance plot showing the median and the 10 and 90 percent exceedance flows from the past 30 years for the USGS gage at Heisson (RM 20) are included in Figure 2. The Heisson Gage is approximately 10 miles upstream of the study area, with Lower Rock Creek (RM 16.2) being the primary tributary that enters between the site and the gage, so flows at the study area would be slightly greater, but seasonal patterns would be generally the same. Note the relatively steady median winter flow of around 1,000 cfs but the wide daily range. This demonstrates the high variation in winter flows, and therefore the unpredictability of occurrence of channel forming flows. Some years may have multiple high flows that can mobilize sediment and cause adjustments in channel form, whereas other years may see no bed mobilizing events. In contrast, summer base flows are very consistent, with an average median daily flow of 69 cfs in August.

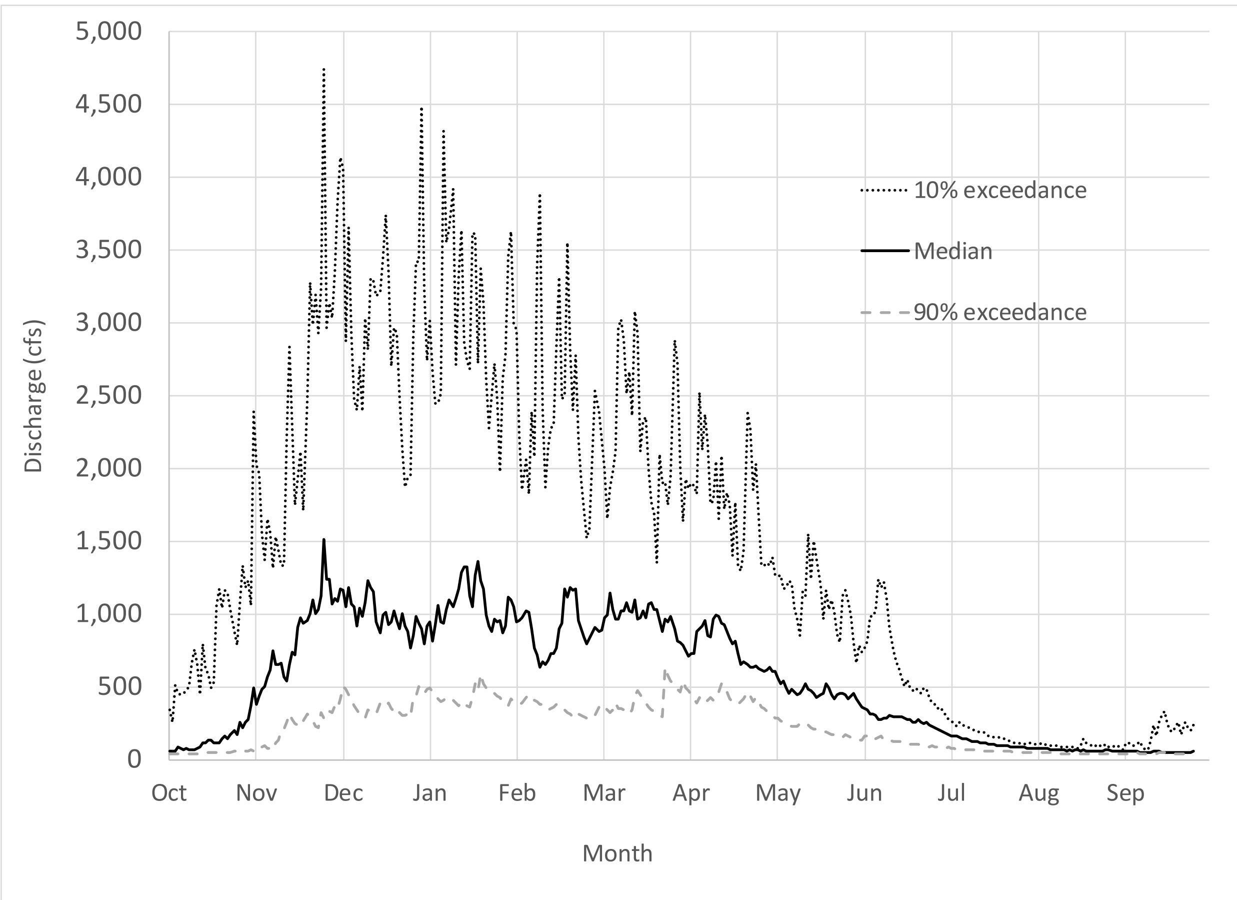


Figure 2. Daily flow exceedance chart from the Heisson Gage (USGS # 14222500) for the past 30 years (normals) – water years 1989-2018.

The flood recurrence intervals from the Heisson Gage are provided in Table 1, and a graphical display of annual peaks since the 1930s is provided in Figure 3. As can be seen, three flood events in the past 25 years have met or exceeded the 50-year event; and the February 1996 event, which is the flood of record, is near the 500-year event. From Figure 3, it also appears that since the 1970s, there has been greater variation in the size of peak flows, which is possibly related to basin land use such as increases in the road drainage network, timber harvest, and conversion of forest to other uses.

Table 1. Flood recurrence intervals from Mastin et al. (2016) for the Heisson Gage (USGS #14222500), using 82 years of record.

Flood Recurrence Interval	Discharge (cfs)
2-Year	9,160
5-Year	12,900
10-Year	15,400
25-Year	18,500
50-Year	20,800
100-Year	23,100
200-Year	25,300
500-Year	28,300

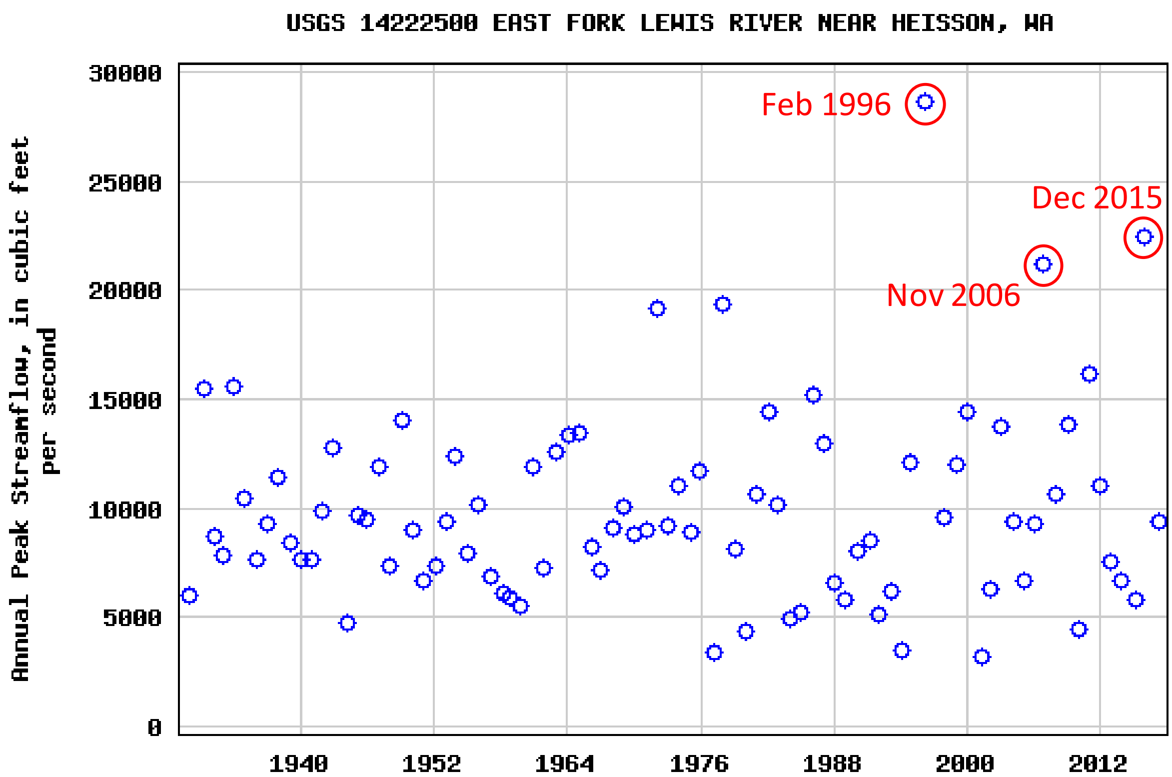


Figure 3. Annual peak flows for the period of record from the Heisson Gage (USGS #14222500). Recent and prominent flood events over the past 25 years are highlighted.

4. Analysis of Geomorphic Changes in the Study Area

4.1 TIMELINE OF LAND USE AND CHANNEL CHANGES

A chronology of land use and river changes in the study area was put together using available aerial photos and maps. The oldest maps are the Government Land Office (GLO) survey maps, obtained on-line from the US BLM general land office on-line maps database (US BLM 2019, www.glorecords.blm.gov). These are the oldest known maps of the study area and date back to 1854. A US Army Corps of Engineers map based on surveys from 1910 was also obtained, as well as a topographic map from 1935 presumably created as part of the evaluation of the once-proposed Eddy Rock Dam site on the EF Lewis near Paradise Point. Beginning in 1939 there are regular, at least decadal, aerial photos that were obtained for the study area. Sources include Earth Explorer (https://earthexplorer.usgs.gov), Clark County maps online (https://gis.clark.wa.gov/mapsonline/index.cfm), and Google Earth. These maps and photos were georeferenced in a GIS and used to understand the land use history of the study area and to take measurements of channel form and position to assess geomorphic trends. Since the late 1990s, aerial photos are available for almost every year, providing a relatively thorough chronology of river planform changes since the 1996 Ridgefield Pit avulsion.

A timeline of land uses and channel conditions within the river corridor is provided in Table 2. A brief summary of the geomorphic history of each segment is included below:

Upper Daybreak. There were split flow conditions with large forested islands until the 1970s, then a single thread channel the last 5 years. It has recently returned to two primary split flow segments. Early instream mining (1930s) has had a large impact on channel dynamics. Artificial confinement at Daybreak Bridge has likely affected sediment transport processes. Channel migration has been halted at the Daybreak Bridge crossing, which has been in place since at least the 1930s; the bridge also constrains flood flows, contributes to channel incision, and affects floodplain inundation patterns. The river segment between Manley Creek and Lewisville Bridge has lost approximately 50% of its historical channel migration zone (CMZ, SP Cramer & Associates 2005). Very little wood was visible in old photos, and it is assumed that wood has been regularly removed from the channel in the past. New wood accumulations are present, particularly at the downstream end where the channel has newly avulsed upstream of the park; but few large key pieces exist and jams are transient. There has been some restoration work including large wood placements in off-channel areas.

Lower Daybreak. The downstream portion changed from complex multi-thread to single-thread from 1910-1940. The channel has shifted and avulsed regularly throughout the photo record, including rapid southward scrolling at Lower Daybreak bank due at least in part to vegetation removal, avulsion into the RM 9 pit, and impacts of extensive instream gravel mining in the 1950s. The CMZ has been constrained by at least 50% compared to historical conditions (SP Cramer & Associates 2005). Very little wood was visible in old photos except for at the downstream end in 1939. It is assumed that wood was regularly removed from the channel in subsequent years. New wood accumulations are present, particularly at the deposition zone near RM 9.1; but few large key pieces exist and jams are transient. Some restoration work has been conducted, including bank work that was altered by flows river-left RM 8.8 and removal of a spur dike river-right near RM 9.5.

Ridgefield Pits. There was gradual conversion from multi-thread to single thread in the Pits reach and just upstream and downstream from 1910 to 1950. The 1939 photos show flood overflow channels leaving the channel and entering the floodplain, with some appearing to not return at all, or appearing to flow into Dean or Mason Creeks. Throughout the photo record, there can be seen a gradual increase in clearing for agriculture and mining. Since the 1950s, there has been extensive instream and floodplain gravel mining with large impacts to channel and habitat complexity. The 1996 gravel pit avulsion severely impacted the reach, abandoning 4,300 feet of former pool-riffle channel in exchange for slow deep pools through the pits. For the foreseeable future, the channel is likely to be contained within the pits, significantly constraining the CMZ. The 1939 photos show relatively abundant large wood jams on bars, in side-channels, and in the floodplain. It is assumed that wood was regularly removed from the channel in subsequent years. New wood accumulations are present on the delta forming in the pits; but few large key pieces exist and jams are transient. There has been some restoration work, including large wood jams at the downstream end of the pits and invasive species control.

Mason. There was early (1930-1950) simplification and reduction in channel sinuosity, possibly related to mining and downstream channel dredging for steamship traffic (discussed in SP Cramer 2005), then increased scrolling and sinuosity from the 1950s to 1980s, and then armoring to stop scrolling in multiple locations. Approximately 64% of the historical CMZ has been lost (SP Cramer & Associates 2005). Only a few jams were visible in the 1939 photos, and it is assumed that wood has been regularly removed from the channel in the past. New wood accumulations are present, particularly at the upstream end along the bank near RM 7-7.1; but few large key pieces exist and jams are transient. There has been some recent restoration work including backwater channels, chum spawning channels, and instream large wood placements.

La Center. Floodplain clearing, levee construction, and armoring have been the primary impacts. Channel planform has remained relatively unchanged but channel incision and floodplain disconnection has occurred, which is likely related to early dredging and stream cleanouts to facilitate steamship traffic (late 1800s/early 1900s; SP Cramer & Associates 2005). Floodplain and off-channel connections have been improved with restoration projects over the last 10 years. Very little wood is visible in the photo record, although sunken wood is known to be present in small quantities throughout the reach currently. Recent restoration work includes levee removal, levee breaching, and enhancement of off-channel and lower tributary habitats.

Table 2. Timeline of land use and channel changes.

Source	Year	Description of key conditions by Segment				
		La Center	Mason	Ridgefield Pits	Lower Daybreak	Upper Daybreak
GLO Maps	1854-1858	Single-thread channel with floodplain wetlands. For the valley bottom, map notes "Low rich bottom subject to inundation"	Upstream portion shows a complex multi-thread channel network. For the valley bottom, map notes "Low rich bottom subject to inundation"	Complex multi-thread channel network. For the valley bottom, map notes "Low rich bottom subject to inundation"	Downstream portion shows a complex multi-thread channel network. For the valley bottom, map notes "Low rich bottom subject to inundation"	Mostly single thread with one long side channel.
USACE topo Map	1910	Mostly single-thread. Appears to be a bridge at La Center	For Ridgefield Pits segment and a portion of Mason and Lower Daybreak, shows a complex multi-thread channel network. No bridge at Daybreak.			Shows a crossing (not necessarily a bridge) at Lewisville
USACE topo Map	1935	Single thread with extensive floodplain wetlands	Extensive floodplain wetlands near mouth of Mason Creek	Mostly single-thread with some small side channels and backwater areas	Mostly single-thread, with some backwaters. A bridge crossing shown at Daybreak.	Multiple split flow sections and one long smaller side channel. A bridge crossing shown at Lewisville
Air photo	1939	Single thread with extensive scrub-shrub wetlands and abandoned oxbows throughout the floodplain. Instream gravel bars visible. Very little wood visible.	Mostly single thread channel with some remaining split flow at upstream end. Beginning of extensive agricultural development in floodplains. Floodplain overflow channel network in far river-right floodplain. Only small gravel bars. A few large wood jams visible.	Two or three prominent side channels and evidence of old channel scars. Significant agricultural production and possible grading activity in former channel locations. Extensive gravel bars and scour features. Abundant large wood jams as margin jams, apex jams, and rafted jams on floodplain surfaces.	Mostly single thread with evidence of side channels and abandoned oxbows in downstream portion. Downstream portion mostly still forested. Lower Daybreak site is cleared of floodplain and riparian vegetation. Original Daybreak Bridge is in place. Extensive gravel bars and scour features. Several large wood jams visible.	Two major split flow areas around forested islands (RM 10.5-12). Extensive instream gravel mining (gravel bar scalping) in lower portion near current Daybreak Park and just upstream. River-left floodplain at downstream end in agricultural fields. Beginning agricultural development upstream river-right. Extensive gravel bars and scour features, especially at downstream end. Bridge crossing at Lewisville. Only a few large wood jams visible.
Air photo	1951	Single thread. Clearing of floodplain vegetation both sides. Perpendicular levee in river-left floodplain at RM 5.1 is in place. There is a narrow bridge crossing at RM 5.1. La Center Levee is in place. Very little wood visible.	Multiple avulsions have reduced sinuosity. Mostly single thread, except for some split flow at upstream end. Extensive gravel bars. Near total clearing of floodplain on river-left and additional clearing on river-right. Very little wood visible.	Only one remaining split flow area, from RM 7.5-7.2. Some re-growth of previously cleared riparian/floodplain forests. Extensive scoured bars. A couple of large wood jams visible. Old channel scars continue to disappear. Very little wood visible.	Mostly single-thread with short split flow segments. Instream gravel mining near RM 9.4 from north side. Upstream left-bank (Lower Daybreak area) cleared. Very little wood visible.	Extensive instream gravel mining with many mining scars around RM 11. Previous flow splits still present RM 10.5-12. Less extensive gravel bars compared to 1939. Very little wood visible.
Air photo	1955	La Center Wetlands outlet channel has been ditched. Ford crossing river-left floodplain outlet channel near RM 4. No other significant changes since 1951. Very little wood visible.	Mostly single thread, except for some split flow at upstream end. Continued disconnection of former channel scars. Meander scrolling into cleared riparian/floodplain both sides RM 6.6-6.8. Extensive gravel bars. Very little wood visible.	Large open-water area RM 7.6-8, assumed to be from instream gravel mining. Split flow downstream. Appears heavily manipulated (grading). Very little wood visible.	Recent channel changes initiating split flow conditions. Intensive gravel mining river-right RM 9.4. Very little wood visible.	Mining activity may have ceased, vegetation is colonizing previous mining scars. Secondary channels beginning to cut off. Expansion of agricultural clearing. Very little wood visible.
Air photo	1960	Bridge gone at RM 5.1. No other significant changes since 1955. Very little wood visible.	Single thread except for upstream end. Continued meander scrolling into cleared riparian/floodplain both	Open-water area still present. Split flow upstream, single-thread downstream (old split flow cut off). Additional floodplain clearing river-	RM 9.4 mining scars still visible but might have ceased instream mining. Mostly single-thread. Long small	No evidence of mining. Gravel mining area near RM 11 becoming more single thread and vegetated.

Source	Year	Description of key conditions by Segment				
		La Center	Mason	Ridgefield Pits	Lower Daybreak	Upper Daybreak
			sides RM 6.6-6.8. Extensive gravel bars. Very little wood visible.	left has occurred. Very little wood visible.	side-channel RM 8.7-8.2. Very little wood visible.	Secondary channels continuing to cut off. Very little wood visible.
Air photo	1970	No significant changes since 1960.	Continued meander scrolling into cleared riparian/floodplain both sides RM 6.6-6.8, as well as at other bends. Increased overall sinuosity. Small split flow RM 6.8. Extensive gravel bars. Some re-growth of floodplain forest river-left but more clearing in river-right floodplain. Very little wood visible.	Mostly single-thread except for split flow within active channel at upstream end near RM 8.1. Signs of active floodplain gravel mining river-left at upstream end. Open-water area from previous photos is gone. Former downstream side-channel is fully cut off. Very little wood visible.	Channel avulsed into RM 8.7 side-channel. Floodplain gravel pits at RM 9 and near County yard river-right near RM 9.3. Beginning erosion of Lower Daybreak bank. New bridge at Daybreak. Very little wood visible.	Continued cut off of side-channels. No mining. Beginning of Daybreak Park. New bridge at Lewisville. Very little wood visible.
Air photo	1975	No significant changes since 1970.	Continued meander scrolling, some development of short split flow sections, increasing sinuosity. Very little wood visible.	Beginning of more mining activities river-left. Possibly some new instream mining near RM 7.7. Establishment of new roads along in floodplain. Very little wood visible.	Single-thread, except for significant scaring (from instream gravel mining?) near RM 9.4. More erosion at Lower Daybreak bank. Very little wood visible.	Continued cut off of side-channels. Mostly single-thread. No mining. Very little wood visible.
Air photo	1990	Culvert crossing in place on river-left floodplain outlet channel near RM 4. No other significant changes since 1975. Very little wood visible.	Some short sections of split flow remaining. Airstrip in place river-right floodplain. More clearing downstream end of river-right floodplain towards Mason Cr. Meander scrolling has been halted at multiple locations via riprap, including river-left RM 6.9 & 6.7 and river-right along the airstrip. Very little wood visible.	Ridgefield Pits fully present and maybe still actively being mined. River entering upstream end of Pit 7 (at least at high flows). Mainstem is fully single-thread. Very little wood visible.	Single-thread. Erosion and meander development at Lower Daybreak. No active mining at floodplain pits, which are isolated from river. Recovered river channel near RM 9.4. Significant rural residential development in riparian and floodplain areas. Very little wood visible.	Single-thread except for small split flow near RM 12. New rural residential development in riparian areas and throughout floodplain. New bank armoring work river-left RM 11.6. Very little wood visible.
Air photo	2005	Fish ladder in place at La Center Wetlands outlet channel. No other significant changes since 1990. Very little wood visible.	Some channel changes at up- and downstream ends but a general reduction in sinuosity and simplification. Less extensive gravel bars. Very little wood visible.	Mainstem avulsed through Ridgefield Pits. Delta growth at head of pits. Former channel becoming revegetated. Some pits remain isolated from mainstem. Very little wood visible.	Single-thread. Avulsion has occurred through RM 9 pit (1995). Significant meander scrolling to north at RM 9.1. Continued erosion and scrolling south at Lower Daybreak. Very little wood visible.	Mostly single-thread with new side channel forming at RM 10.5 in former main channel alignment. Additional clearing for residential development. Further bank armoring work river-left RM 11.6. Very little wood visible.
Air photo	2018	Restoration work in place including re-meandering of La Center Wetlands outlet ditch, removal of fish ladder at outlet, breaching La Center Levee, new bridge at culvert crossing of outlet channel near RM 4, and removing cross-levee at RM 5.1.	Greatest change is scrolling to the north at RM 7.2. Otherwise minor changes. Less extensive gravel bars. A few large wood jams visible.	Continued delta growth and channel changes at upstream end of pits. Filling and vegetation re-growth in other areas of pit margins. Abundant large wood jams and pieces deposited on new delta.	Mostly single-thread except for new split flow near RM 9.1 due to partial avulsion (chute cut-off) across bar in 2009. Continued erosion and scrolling south at Lower Daybreak. Several wood and jams, particularly abundant wood at RM 9.1 avulsion area.	Re-development of split flow conditions RM 10.5-12. Extensive gravel bar scour. Several large wood jams, especially at newly avulsed channel just upstream of Daybreak Park.

4.2 GRAVEL PIT AVULSIONS

Gravel pit avulsions can have a strong influence on river processes and habitat. In the case of the EF Lewis River avulsions, the past pit captures, particularly the Ridgefield Pit avulsion, have major implications to floodplain connectivity, degree of side-channel activation, sediment transport, and sediment storage. These changes, and the past and potential future trends in profile adjustment, can have an important influence on restoration planning, particularly when restoration objectives include side-channel activation, floodplain reconnection, and construction of features that may be affected by changes to the sediment transport regime. For these reasons, the pit captures on the lower river are described here and are further evaluated as an integral part of the geomorphology analysis.

4.2.1 Overview of Effects of Gravel Pit Captures

Gravel pit captures have occurred throughout modern history and their effects to river functions and aquatic habitat have been well-documented in the literature (e.g. Kondolf et al. 2002, Norman et al. 1998, Reclamation 2005). A gravel pit capture is when a river's path enters a floodplain gravel pit or series of pits. Pit captures occur either through lateral migration of the river into the pits or from overflowing floodwaters that results in a shift of the river into the pits. This later mechanism is frequently termed a gravel pit avulsion and is what occurred at the Ridgefield Pits in the fall of 1996, transforming the former floodplain pits into instream pits.

Pit captures also initiate upstream and downstream channel incision (lowering) (Kondolf et al. 2002). Upstream incision is caused by the upstream propagation of a knickpoint, sometimes referred to as headcutting. A knickpoint is a point along the longitudinal profile of the stream where the slope increases abruptly (Brush and Wolman 1960). Where the river enters the deep pits, a knickpoint is created. The knickpoint then propagates upstream over time, lowering the elevation of the bed as it goes. This process, and its occurrence in the EF Lewis, is described further in Section 4.3.2. Downstream incision is caused by a disruption in the bedload transport regime of the river. The slow deep pools become a sink for coarse bedload because they no longer have the available energy to transport the material. The downstream reach then becomes starved of bedload, resulting in "hungry water" downstream that results in erosion of the channel bed and banks (Kondolf 1997) (see diagram in Figure 4).

Figure reproduced from Norman et al. 1998

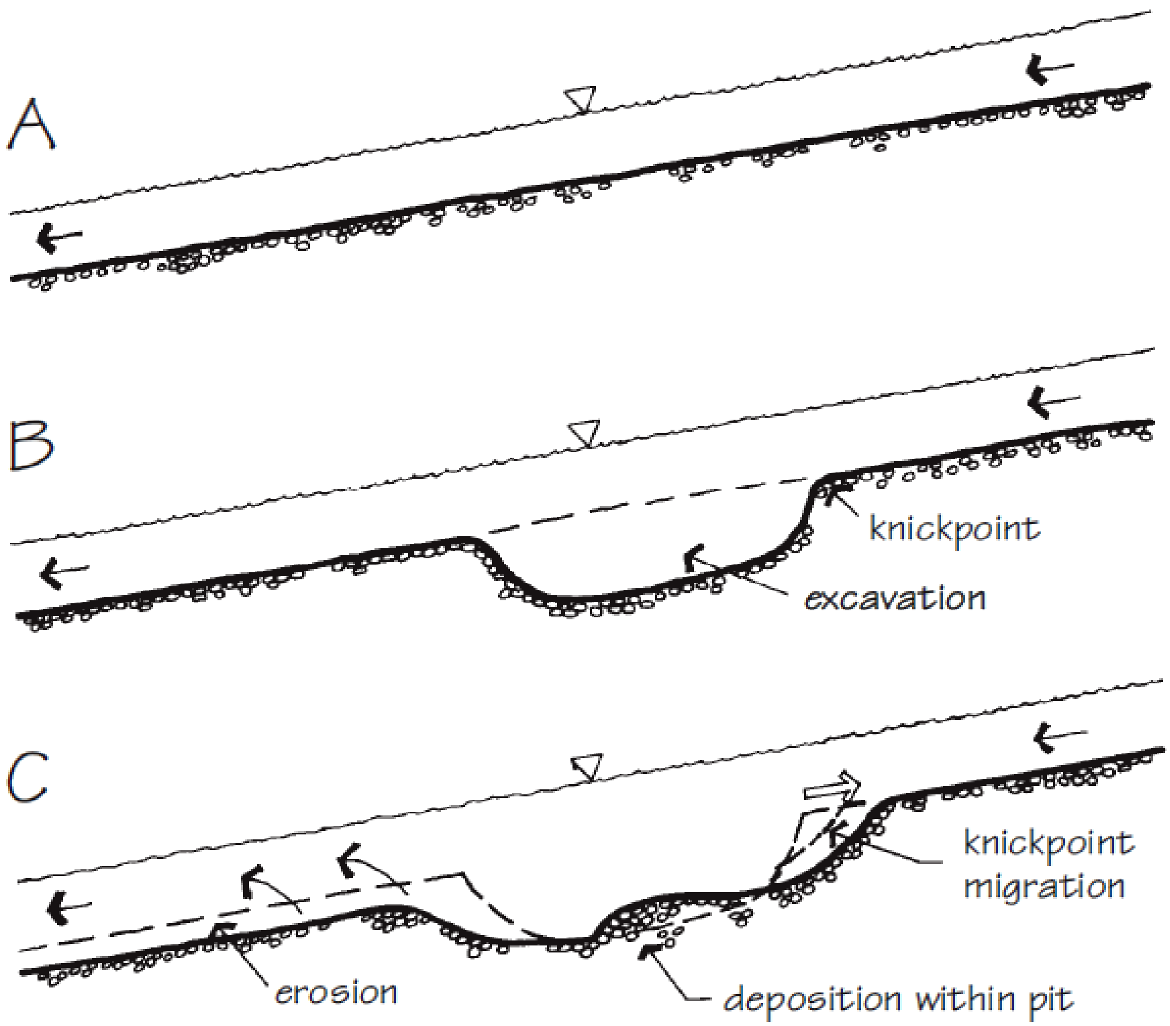


Figure 4. A. Hypothetical pre-pit capture longitudinal profile. B. Longitudinal profile showing the river flowing through a gravel pit (noted "excavation"). The location of the knickpoint is identified. C. Following avulsion, the knickpoint moves upstream and the eroded material deposits in the pit. The lack of bedload transport to the downstream reach causes erosion of the channel downstream due to the disruption in the sediment balance (Figure reproduced from Norman et al. 1998, which had been modified from Kondolf, 1993.)

Pit captures affect river processes and habitat. The transformation of the river from a formerly lotic (flowing) environment into a lentic (pond-like) environment can have negative impacts to channel migration, substrate/spawning conditions, vegetation, water quality, aquatic habitat complexity, and presence of invasive species (Kondolf et al. 1997, Kondolf et al. 2002, Norman et al. 1998, Clark 2003). The upstream and downstream incision can also cause channel instability, which can affect habitat and put infrastructure at risk (Kondolf et al. 1997).

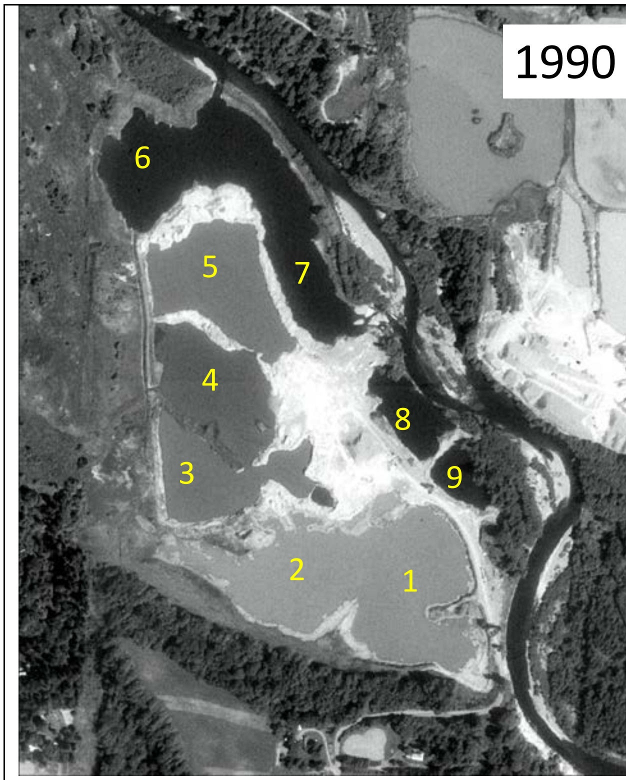
4.2.2 Description of 1990s Pit Avulsions

During flooding in the 1990s, the EF Lewis avulsed into two separate floodplain gravel pits, the Mile 9 Pit and the Ridgefield Pits. These events had a strong effect on channel and floodplain processes and are important context for restoration planning. The following discussion describes these avulsion events.

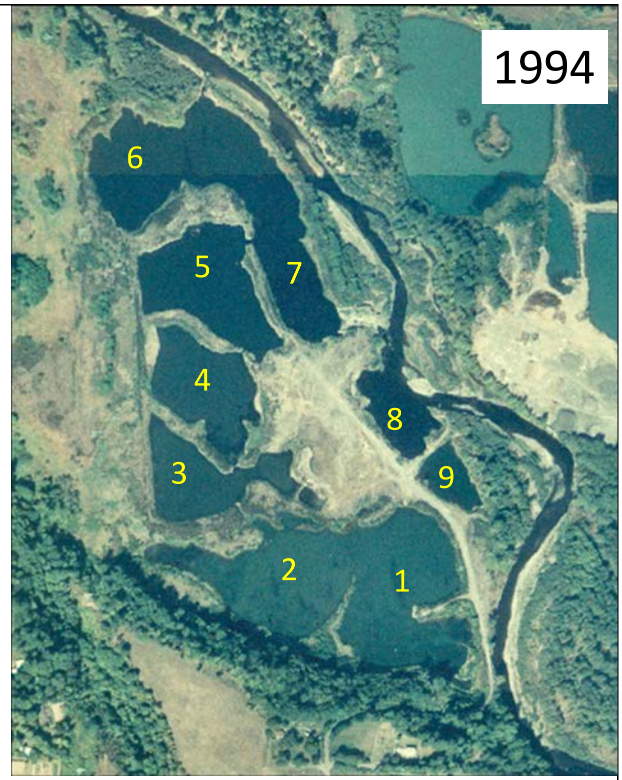
In November of 1995, the river avulsed through a floodplain gravel pit near RM 9. This is just upstream of the Ridgefield Pits. The location of the former pit is shown in the aerial photos in Figure 5.

Figure 5. Location of the Mile 9 Pit avulsion, which occurred in November 1995.

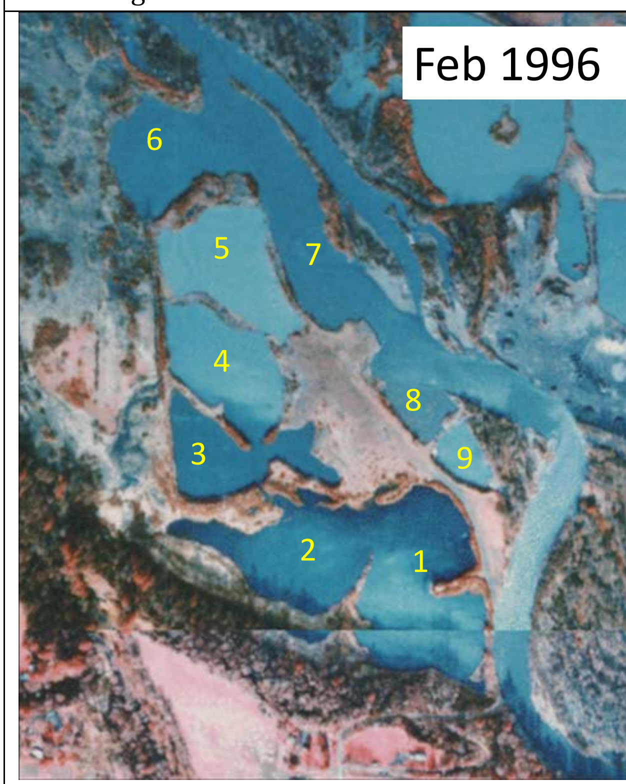
The Ridgefield Pits avulsion occurred over a longer period of time, with initial pit breaching occurring at least by 1990 and full avulsion through multiple pits in 1996. A sequence of the Ridgefield Pits breaching and avulsion is shown in Figure 6. Following full avulsion of the pits, 4,300 feet of former channel, which once contained high quality salmonid spawning and rearing habitat, was abandoned, and the channel then flowed through a series of slow-moving pools up to 30 feet deep.



Breaching into Pits 7 and 8.

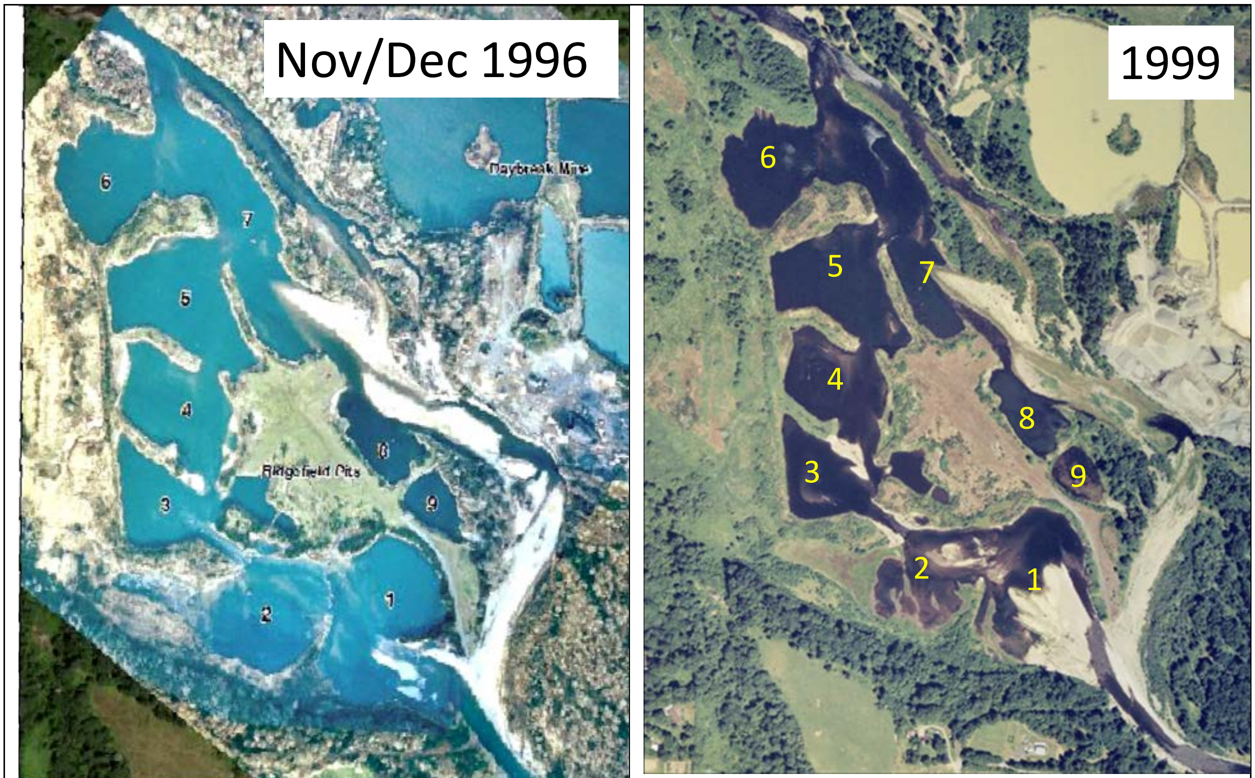


Channel connected to Pit 8.



Flood of February 1996 showing avulsion through Pits 8, 7, and 6.

Following flood, channel is established in new avulsion path through Pits 8, 7, and 6.



In November 1996 flood, channel avulses through Pits 1-7.

River becomes established through Pits 1-7, fully abandoning former channel.

Figure 6. Breaching and avulsion sequence at the Ridgefield Pits.

4.2.3 Initial Observed Channel Response to Ridgefield Pit Avulsion

Aside from the abandonment of the former channel and conversion of the reach to a series of deep-water pits, there is little information from prior studies on the initial response of the upstream or downstream channel as a result of the pit avulsions. To our knowledge, there are only two measurements that were taken following the Ridgefield Pits avulsion that attempted to quantify the amount of change in channel elevation caused by the avulsion. One of these was 5 ft of channel bed degradation (i.e. lowering) that was measured immediately upstream of the pit entrance one month following the full Ridgefield Pit avulsion (WEST 1996 as cited in WEST 2001). It was also observed at this time that there was a slight increase in slope upstream of the pits (WEST 2001). This may have been the knickpoint moving upstream. The other measurement was 10 ft of channel bed lowering that was observed in approximately the same location (at upstream end of the abandoned channel) in 1998, approximately two years following the avulsion (Norman et al. 1998. See Figure 7). These are expected responses of the channel profile following gravel pit capture that have been noted in numerous other circumstances (Norman et al. 1998, Kondolf et al. 2002), and suggest that there were significant changes to the channel profile in response to the avulsion. Given the low overall slope of the channel (<0.3%), it would be expected that those changes likely propagated a considerable distance upstream. The following sections describe evaluations that were conducted in order to better understand changes to the channel profile and to understand current trends.

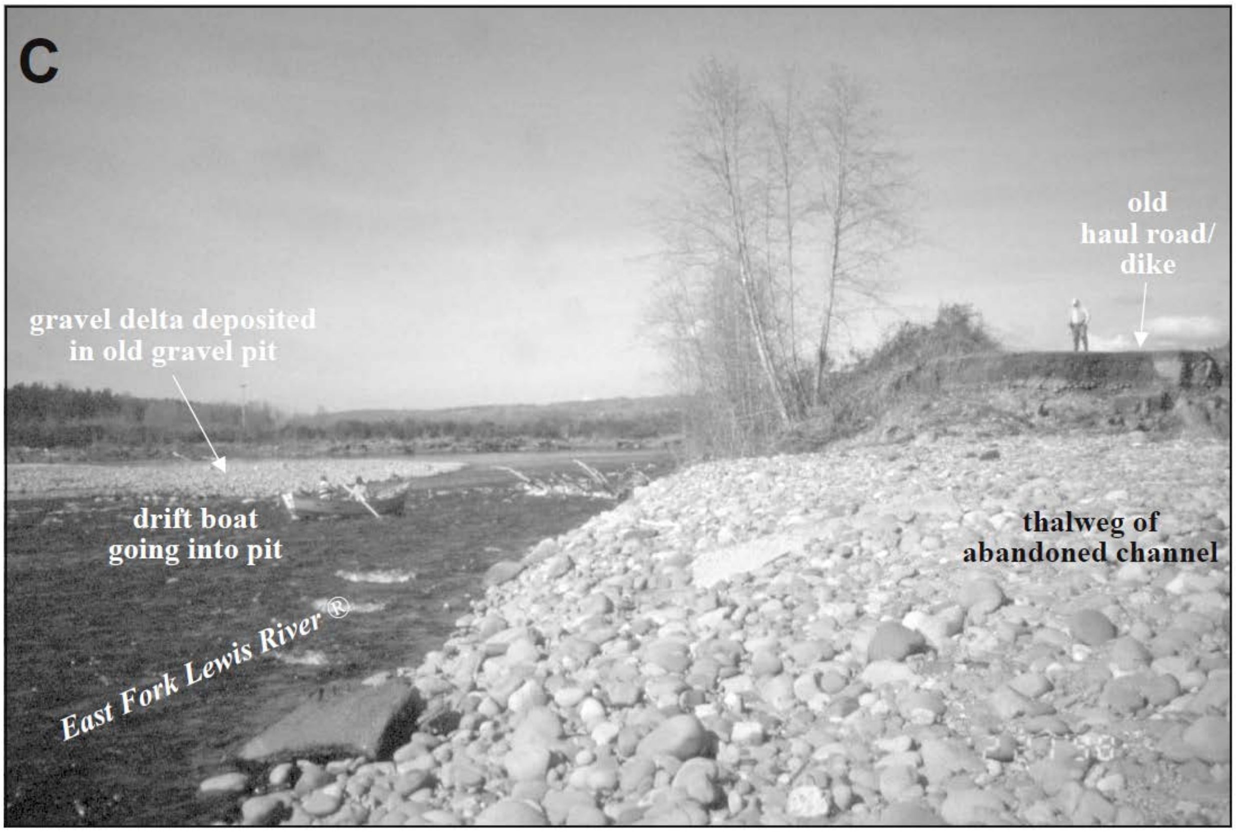


Figure 7. Re-print of Figure 20-C from Norman et al. 1998. This 1998 photo shows the elevation difference between the abandoned channel and the new avulsion channel just upstream of the entrance to Pit 1. This distance was estimated by the authors (Norman et al. 1998) as approximately 10 vertical feet.

4.3 LONGITIDUNAL PROFILE ANALYSIS

4.3.1 Available Profile Data

In order to document changes in channel profile in the study area, we compared past and current (2018) channel profile surveys. There was relatively little historical profile information available for this analysis, particularly data that spanned a sufficient length of channel to make adequate comparisons. We ended up relying mainly on the two datasets presented in WEST (2001), which included data from a 1977 FEMA study (FEMA 1991 as cited in WEST 2001) and a survey performed in December 1996 shortly after the full Ridgefield Pits avulsion (WEST 2001). These historical data were compared with the 2018 topographic and bathymetry survey performed by Inter-Fluve as part of the current effort. This comparison allows for an evaluation of how conditions have evolved in the years following the avulsion.

The original survey data from the two older surveys were not available for analysis. Station and elevation data were therefore taken from Figure 6-5 in West (2001) using AutoCAD to scale the axes. West (2001) had normalized profile length in their comparison, adjusting 1977 data to the 1996 profile. These data were then matched to the 2018 profile data using common points such as the pit entrance and Daybreak Bridge. All elevation data were adjusted to the NAVD88 vertical datum. The 1977, 1996, and 2018 channel paths were very different. These changes in channel length and thalweg location between survey periods poses practical challenges in matching the profiles from different time periods. For this reason, specific changes at any given point may not be accurate, and so we rely primarily on broader interpretations of the profile data.

4.3.2 Evaluation of Profile Changes

The profiles are depicted in Figure 8. Daybreak Bridge is just upstream of RM 10. There is a large wood accumulation zone at RM 9 (discussed later in Section 4.6), which may be causing a rise in the profile upstream to closer match the 1977 and 1996 profiles. The location of the Ridgefield Pits is identified for reference. The lower bed elevation in the pits is evident in the post-avulsion profiles, with the new delta forming in the pits evident in the 2018 profile between RMs 7.8 and 8.1. Additional accumulated sediments (fines) are evident in the more downstream portion of the pits. The 1977 profile, which represents the pre-avulsion condition, has an average overall slope of approximately 0.28%, which matches the slope upstream of the pits in 1996 (0.30%) and 2018 (0.27%), even though there is smaller-scale variation in these profiles. The slope within the pits is essentially flat for 1996, and also for 2018 (0.05%) for the portion downstream of the new delta. The slope downstream of the pits in 2018 is slightly flatter than the upstream segment, at 0.17%.

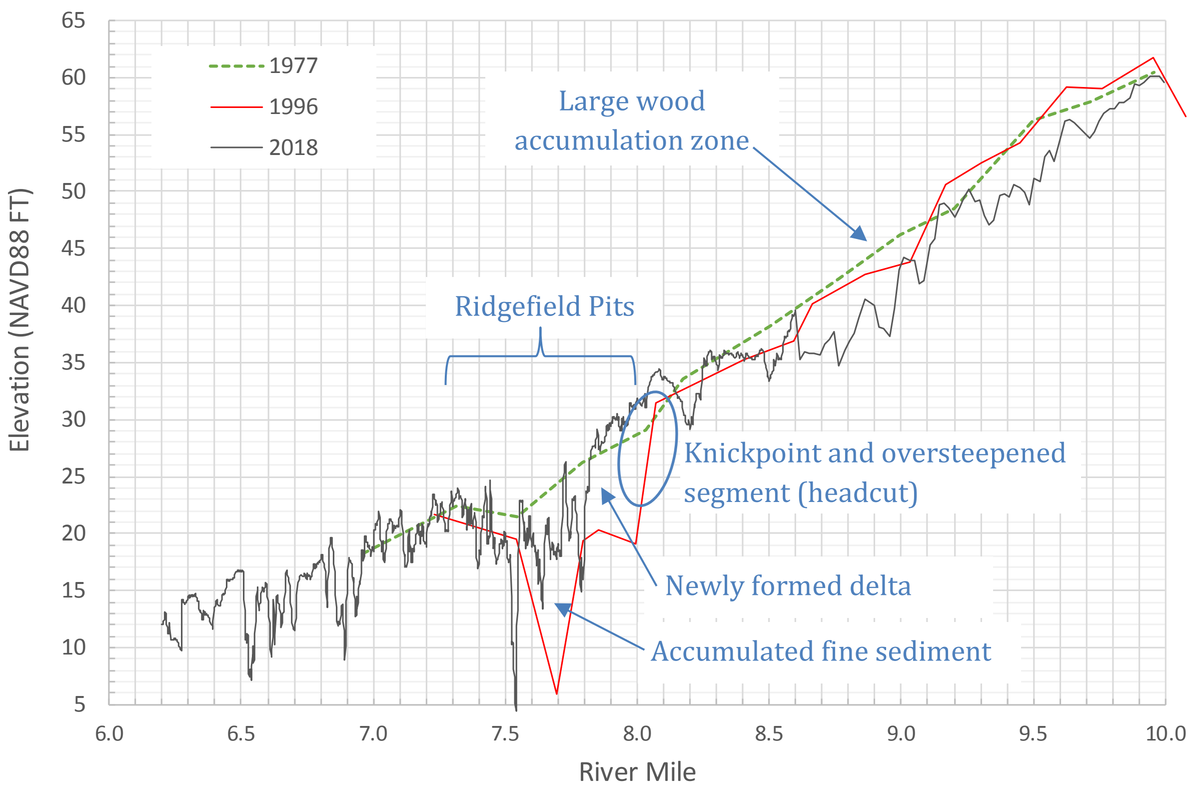


Figure 8. Longitudinal profiles from 1977, 1996 and 2018, with relevant features noted.

A longitudinal profile comparison was also made between the abandoned channel and the newly formed channel through the upper end of the pits. This comparison allows for another way to look at changes in the bed profile from the pre-avulsion condition and provides some insight into future trends. The locations of the profiles are shown in Figure 9 and the profiles themselves are shown in

Figure 10. This simple analysis shows that the new channel bed that has formed through the upstream end of the pits is 3-4 feet lower on average than the pre-avulsion channel. The newly formed section of channel has a slope of 0.26%, which matches the reach-average slope upstream and the slope of the pre-avulsion channel from 1977.

Figure 9. Location of profiles through upstream end of pits.

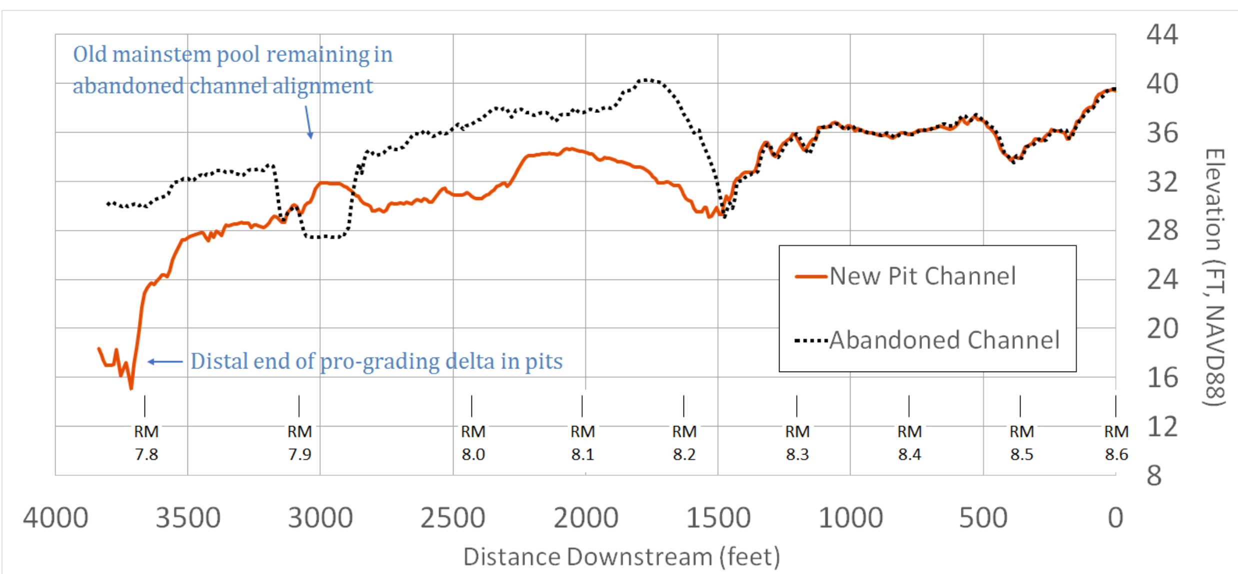


Figure 10. Profiles through upstream end of pits. Based on 2018 topographic/bathymetric data.

The immediate post-avulsion knickpoint and corresponding oversteepened segment can be clearly seen at the upstream end of the pits (RM 8.0-8.1) in the 1996 profile (Figure 8). This segment had a local slope of approximately 2.63% (over nearly 400 ft of channel); this is over 8 times that of the former reach-average slope. Observations described in Norman et al. (1998) indicated that this knickpoint moved upstream in the years following the avulsion.

In a flume study of knickpoint migration, Brush and Wolman (1960) investigated the rates and means by which knickpoints migrated upstream in non-cohesive bed materials, and the corresponding effects to the upstream and downstream reaches. They explain that the greatest amount of channel bed erosion occurs at the knickpoint location itself, where the slope steepens but depth remains high. This can be explained by the bed shear stress equation:

$$\tau = \gamma RS$$

Where τ is bed shear stress (the stress applied to the bed and banks and available to transport sediment), γ is the specific weight of water, R is hydraulic radius (approximates depth in large shallow channels), and S is channel slope. Therefore, all other things being equal, an increase in slope results in an increase in shear stress.

Reaches both downstream and upstream of the knickpoint have less erosive energy due to lesser depths (downstream reach) and lesser slopes (upstream reach) than the knickpoint location itself. Continued erosion at the knickpoint, and deposition downstream, causes the knickpoint to move upstream. As it moves, the knickpoint migration causes the longitudinal growth of the downstream oversteepened reach. This is due not only to the upstream movement of the knickpoint but also the downstream movement of the toe (downstream end of the oversteepened reach) as the newly eroded material is deposited downstream. In the case of the EF Lewis, the new toe is the distal end of the pro-grading delta of deposited material in the pits. As the length of the oversteepened reach increases, the slope decreases and slowly begins to rebound towards the reach average slope.

Although the specific upstream extent of knickpoint migration is unknown, evaluations of gravel pit captures and instream mining on other rivers have shown that channel incision can propagate considerable distances upstream, even on the order of miles, and can cause significant erosion and instability that can put habitat and infrastructure at risk (Kondolf et al. 2002). The upstream extent of knickpoint migration can be challenging to identify for low gradient channels with high natural profile complexity such as the lower EF Lewis. Brush and Wolman (1960) reasoned that once the profile has regained a slope to within 20% of the average slope of the channel, then the knickpoint can no longer be identified. If we were to apply this reasoning to the EF Lewis, we can then make estimates as to the upstream extent of knickpoint migration as a result of the Ridgefield Pit avulsion. Using the original reach average slope of 0.0027, once the oversteepened reach flattens to 0.0032 (within 20% of the average), we can assume the knickpoint has essentially disappeared. Assuming the avulsion lowered the base level of the channel at the pit entrance on the order of 5 to 10 feet (see Section 4.2.3), this equates to an upstream travel distance of 1.75 to 3.5 miles, or up to somewhere between RM 10 (near Daybreak Bridge) and RM 11.75. The travel distance may be somewhat less given the downstream movement and raising of the toe elevation of the oversteepened reach as the delta has grown within the pits.

During the period of knickpoint migration, bed material is eroded and then re-deposited downstream. Brush and Wolman's (1960) experiments showed that the re-deposition of material can also induce channel widening, which generates an additional source of material. This can lead to a complex erosion and depositional process, particularly in natural channels. The current profile and planform complexity of the Lower Daybreak Reach (and possibly the downstream portion of the Upper Daybreak Reach), as well as observations of significant channel adjustments in the reach in recent history, may be related to the instability caused by the knickpoint migration and channel steepening. The overall increase in channel slope increases the energy available to do work on (i.e. erode) the channel bed and banks. This can be explained by the Stream Power relationship:

$$\Omega = QS$$

Where Ω is Stream Power (the energy of the flowing water, which can be used as an indicator of the available stream energy to transport sediment), Q is the river discharge, and S is channel slope. Therefore, assuming no change in discharge, an increase in slope results in an increase in stream power.

This increase in stream energy would be expected to cause chaotic and dynamic patterns of erosion, deposition, and river planform changes as the river profile adjusts to its new equilibrium. It is therefore assumed that for a period of years following the avulsion, the upstream contributing reach was more efficient at eroding local bed and bank material and transporting that material (and any material entering the reach from upstream) down into the pits. The rapid extension of the delta in the pits observed in the years following the avulsion (and described further in Section 5.4) is the result of the erosion, transport, and deposition of this material. The chute cut-off at RM 9 in 2009, avulsions and channel changes upstream of Daybreak Bridge, and on-going bank erosion in numerous areas including lower Daybreak, are also possible sources of this material.

Although the original, pre-avulsion profile elevation will not fully recover unless and until the pits fully fill with sediment, the filling that has occurred to date has raised the toe of the upstream oversteepened reach and has moved it downstream, therefore reducing the overall slope of the oversteepened reach. This is evidenced by only a 3- to 4-foot difference in bed elevation seen now between the newly formed channel through the pits and the head of the abandoned channel (Figure 10). This is compared to a 5-10 ft difference shortly after the avulsion (Section 4.2.3). This has reduced the energy that was responsible for delivering abundant material to the pits in the early years following the 1996 avulsion. This early delivery of sediment following initial knickpoint migration was also observed by Brush and Wolman (1960) in their flume studies. This may explain the lower rates of delta growth and pit filling in recent years that is described later in Section 5.4.

However, without more profile data, it is difficult to determine the rates and the specific degree of profile adjustment that has occurred. There may be additional channel elevation data available from 1999 and 2013 that could further help fill in the intervening years between December 1996 and 2018 to better understand these dynamics – efforts are currently being made to obtain these datasets.

For the reach downstream of the pits, there is even less available data to evaluate profile adjustment. However, based on other studies of gravel pit captures, and sediment transport processes (see review in Kondolf 2002), one would expect an increase in channel size downstream given that the pits capture much of the coarse bedload. Channel expansion is the result of continued erosion of bed and bank material but without the replenishment of material from upstream. This expansion can result in widening and/or vertical incision and can lead to channel instability with effects on habitat and infrastructure. The specific effects on the downstream reach of the EF Lewis due to the avulsion is unknown as there is a lack of sufficient before and after data to evaluate it, but based on other studies of similar events, one would expect that channel expansion and an increase in bed instability has occurred in the downstream reach.

Although the above discussions focus almost solely on the effects of the pit avulsion, it is difficult to distinguish the observed channel dynamics in the reach from those caused by the various other human pressures acting within the system or from natural riverine processes. Other driving factors for channel change within the study area include the scour caused by the constriction at Daybreak Bridge (near RM 10), rapid erosion of the unvegetated Lower Daybreak cut-bank (RM 9.8), erosion of the large bluffs on the south bank, the chute cut-off near RM 9 in 2009, rapid erosion of the unvegetated river-right bank near RM 7.2, and riprap banks on both sides of the channel from RM 6.6 to 7.0. These factors and others have combined with the effects of the pit avulsion to result in the complex channel patterns and processes we have observed over the past two plus decades.

4.4 PLANFORM CHANGE ANALYSIS

A planform change analysis was performed to help understand past channel changes and potential future trends. The aerial photo and map analysis provided previously in Section 4.1 qualitatively described past planform changes in the study area. One of the most notable changes observed in the photo/map record was a change from a complex multi-thread channel system (anabranching) to primarily a single-thread system prior to the 1930s. Changes since then have been more subtle and less obvious, except for what appears to be a recent transition to more multi-thread conditions in the Upper Daybreak segment. The 2005 habitat assessment (SP Cramer & Associates)

In order to better understand planform changes, we used the aerial photo and map records to quantify planform changes using two simple metrics: 1) sinuosity, and 2) proportion of multi-thread channel segments. Sinuosity was calculated as the channel length measured from the maps or air photos divided by the down-valley length of the segment. The proportion of multi-thread channel was calculated by measuring the portion of the segment length that was comprised of more than one active channel. Due to poor photo quality of the older photos and unknown accuracy of the historical maps, this analysis required some judgment calls with respect to what constituted an active channel. Scour features (e.g. gravel bars, opening in vegetation) were used as the primary indicators of active channels where surface water could not be seen directly.

The sinuosity results are included in Table 3. The La Center segment was not included in this analysis because of the lack of channel changes in the historical record. The Mason segment has the greatest overall sinuosity compared to the other segments, with an average of 1.6 compared to an average of 1.2 for the others. The Mason segment also exhibits the greatest fluctuation in sinuosity over the years. The segment with the second greatest fluctuation is the Ridgefield segment. Upper Daybreak has the least fluctuation. Currently (2018), Mason and Lower Daybreak have sinuosity's that are intermediate within their past ranges; whereas Ridgefield is on the high end of its historical range (same as 1854) and Upper Daybreak is on the low end of its range (also same as 1854). In general, there are not obvious trends in the sinuosity data, at least at the time steps analyzed. We can assume that various human perturbations, such as gravel pit captures and bank armoring, have affected localized sinuosity, but these may be off-set by upstream and downstream channel responses, which would tend to dilute the signal at the reach scale.

Table 3. Sinuosity results.

Year	Mason	Ridgefield	Lower Daybreak	Upper Daybreak	Total
1854	1.5	1.4	1.1	1.1	1.2
1910	1.4	1.3	1.0	1.3	1.2
1939	1.8	1.2	1.2	1.2	1.3
1951	1.4	1.1	1.4	1.2	1.3
1960	1.6	1.1	1.2	1.2	1.2
1975	1.8	1.1	1.2	1.2	1.3
1990	1.7	1.2	1.2	1.2	1.3
2005	1.6	1.3	1.2	1.2	1.3
2018	1.6	1.4	1.2	1.1	1.2
Averages	1.6	1.2	1.2	1.2	1.3

The results of the split flow analysis are shown by segment in Figure 11. Except for the La Center segment, which has remained single-thread throughout the historical record, all of the segments have shown a decrease in the amount of multi-thread channel segments. This decrease is most pronounced in the Ridgefield Pits segment, which is to be expected given the historical multi-thread pattern observed in the historical maps. Most of the segments show a decrease in multi-thread in the early years, variability from the 1930s until about 1980, and then a modest increase in the last 10-20 years. As expected, the greatest increase is in Upper Daybreak, where two prominent recent avulsions have created split flow conditions.

There is good evidence that the Ridgefield Pits segment, and possibly much of the lower river, had an anabranching channel pattern historically, consisting of a multi-thread channel network, abundant vegetation with a range of species and age-classes, and a well-connected valley bottom floodplain that is inundated frequently. This was believed to be a common channel type for many rivers in the region prior to river manipulations by Euro-American settlers (Cluer and Thorne 2013). An historically anabranching channel pattern is supported by the 1854-6 and 1910 maps for the Ridgefield Pits segments and just upstream and downstream. The historical presence of this channel type is further supported for much of the lower river by a regional (Columbia River Basin) channel typing analysis conducted by Beechie and Imaki (2014), whose model predicts an anabranching channel type throughout the study area, except for a significant portion of the La Center segment, which they classify as meandering.

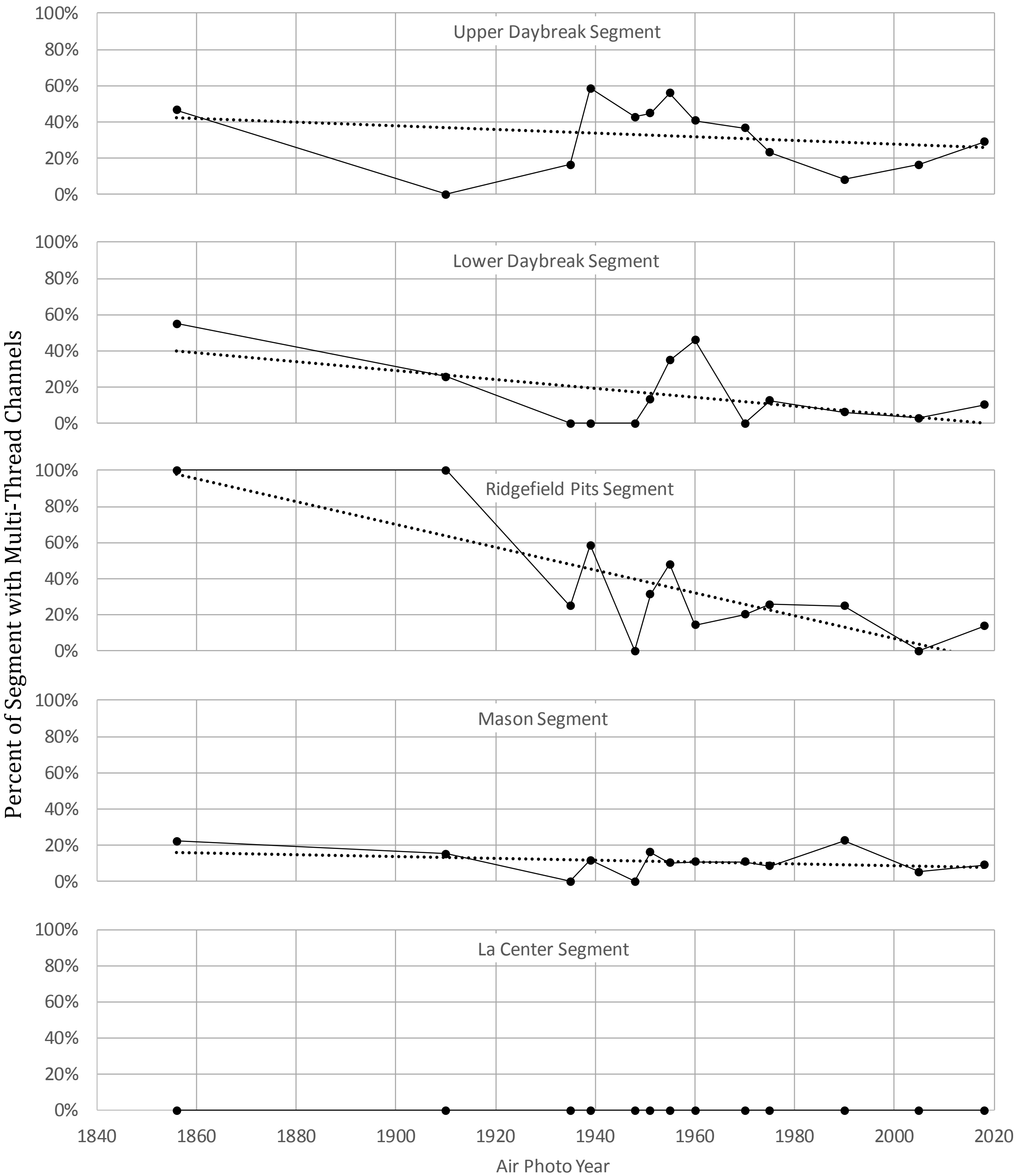


Figure 11. Time series of percentage of river segment with multi-thread channels or prominent flow-through side-channels. Dotted line is a linear trendline fit to the data.

4.5 SIDE CHANNEL CONNECTIVITY

Side-channel connectivity will be evaluated in further detail using the hydraulic modeling results, but some observations are made here based on the field surveys and geomorphic evaluations.

There are two prominent side-channel alignments that are being considered for enhancement. These are located in the Lower Daybreak reach and include the right bank side-channel from RM 9.45 to 9.1 and the right bank side channel from RM 9.0 to the pits (see Figure 12). Both of these side-channels have existing surface flow during high flows, with the upstream side-channel having greater surface water connectivity to the mainstem; however, both side-channels disconnect from surface flow during base flows in the summer.

The upstream side-channel was flowing with surface flows from the mainstem during surveys on April 26, 2018 (see Figure 13) and was still barely connected during surveys on May 22, 2018. The downstream side-channel was dry on May 22 (see Figure 14). Based on vegetation and scour features, it is assumed that the downstream side-channel flows during annual high flows and the upstream side-channel flows for much of the year but becomes disconnected from surface flows typically in late spring.

Figure 12. Location of side-channels being evaluated for enhancement.

Figure 13. View from top end of upstream side-channel, looking upstream towards inlet. Near RM 9.45. April 26, 2018.

Figure 14. View of downstream side-channel near its upstream end, May 22, 2018.

Site observations (Estuary Partnership and Inter-Fluve 2018/19) revealed that the connectivity of the upstream side-channel may have increased in recent years. The enhanced connectivity could be due to a number of factors: 1) aggradation of the riffle immediately downstream of the side-channel inlet, which is assumed to be the re-deposited material that has eroded from the Lower Daybreak bank just upstream. Erosion rates of up to 7-8 ft/year (since 1990) at the long lower Daybreak cut-bank and associated growth of the river-left point bar (15 ft/yr since 1990) at RM 9.4-9.5 supports this interpretation; 2) the northward migration of the meander bend at RM 9.4-9.5 towards and into the lower floodplain where the side-channel is located. Gravel mining from the 1950s to early 1970s in this floodplain area (see photos in Appendix A) would have lowered the floodplain elevation; and 3) A cross levee and rock barb on river-right at RM 9.5 were removed circa 2006, which has helped allow this meander migration to occur.

The downstream side-channel is located in a former main channel alignment from the 1960s, prior to a major avulsion to the south, possibly during the 1964 flood. The side-channel alignment is visible in the aerial photo series since then. The 1996 Ridgefield Pits avulsion and related profile adjustment (lowering) likely reduced the connectivity of this side-channel to the mainstem. Since the avulsion, connectivity has likely gradually increased as the longitudinal profile has recovered (Section 4.3.2) and as the deposition zone near RM 9.0 has grown.

4.6 LARGE WOOD PROCESSES

Instream large wood is an important part of channel and habitat form and function in the lower EF Lewis. In this section, we first discuss large wood numbers and describe how wood is distributed in the study area. We then discuss large wood conditions according to the three primary large wood processes; sources, recruitment, and retention. 'Sources' describes the wood that is available to the system. 'Recruitment' describes the processes required for the river to recruit wood into the channel. And 'retention' describes the ability of the channel to retain the wood.

4.6.1 Large wood counts and accumulation patterns

For the western Cascades, for target instream large wood numbers, the National Marine Fisheries Service (NMFS) defines "properly functioning" as wood counts (at least 50-ft long and 2-ft diameter) exceeding 80 pieces/mi. Although wood was not measured and counted in the field as part of this effort, observations during field surveys and coarse-scale counts from air photos show that this threshold is not met in any of the segments in the study area. However, Upper Daybreak, Lower Daybreak, and the Ridgefield Pits segments have in the range of 30-50 qualifying pieces per mile. Many more pieces of wood exist in these segments, but the vast majority of the wood does not meet the NMFS length or diameter criteria. In general, compared to historical conditions where much older forests would have been present in the valley bottom, the instream wood is smaller and more transient now.

Although wood quantities and sizes are low compared to index conditions, the air photo analysis suggests that there is likely more wood now than there was for much of the past several decades. The 1939 photos show some large jams, particularly in the highly depositional Pits Reach (Figure 15), but the photos since then show very little wood in the channel. This is assumed to be the result of wood removal activities, which were common throughout the region only until the last couple of decades.

Figure 15. Large wood accumulations in the Pits segment (near RM 7.4) in 1939.

We are now seeing some of the large wood numbers return, and along with it, some of the natural dynamic channel adjustments associated with wood. The current wood numbers are considerably greater than what was measured in the 2004 (SP Cramer & Associates 2005) and 2010 (R2 Resource Consultants 2011) habitat surveys (Table 4), indicating that wood numbers have risen in recent years. This is due to some of the recent (last 8 years) channel changes in the lower river where channel migration and avulsions have recruited large wood from riparian zones.

Table 4. Large wood counts from the 2004 SP Cramer & Associates (2005) and 2010 R2 Resource Consultants (2011) habitat surveys.

Segment	2004 total large[1] pieces (Cramer survey)	2004 large[1] pieces/mi (Cramer survey)	2010 total large[1] pieces (R2 survey)	2010 large[1] pieces/mi (R2 survey)
La Center	50	19	NA	NA
Mason	10	6	3	2
Ridgefield	7	8	4	5
Lower Daybreak[2]	19	10	24	5
Upper Daybreak[2]	9	3		

[1] Large pieces in the Cramer and R2 surveys used the WA TFW criteria, which is 50 cm (1.64 ft) diameter and 2 meters (6.56 ft) length.

[2] The reach break between Lower and Upper Daybreak in the Cramer study is Manley Creek, which is approximately a half-mile downstream of the segment break we use for this report (Daybreak Bridge). Lower and Upper Daybreak were considered as one reach in the R2 study.

The wood that is present today is primarily concentrated in a few prominent deposition zones that contain high densities of wood. These include above Daybreak Bridge where the channel has recently avulsed near RM 10.5, at the deposition zone near the 2007-8 avulsion near RM 9.1, and at the delta forming in the pits near RM 8.0. These are shown in the map in Figure 16 and in the images in Figure 17 – Figure 19. These are all areas of instability, in various measures affected by human stressors, yet they also exhibit some of the greatest habitat complexity in the lower river.

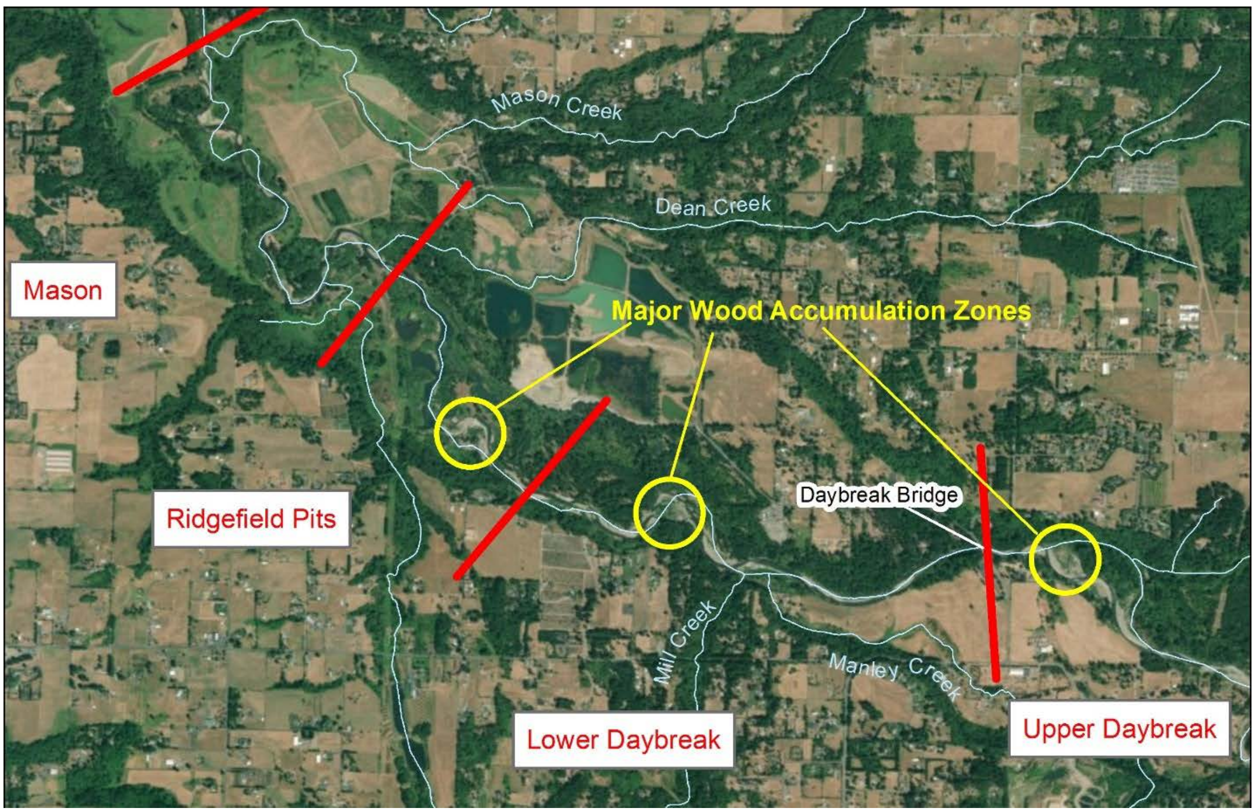


Figure 16. Map showing the three prominent wood accumulation zones.

Figure 17. Wood accumulation zone near RM 10.5 upstream of Daybreak Bridge. Gardner Johnston photo June 2019.

Figure 18. Wood accumulation zone near RM 9.1. Gardner Johnston photo June 2019.

Figure 19. Wood accumulation in the upstream end of the Ridgefield Pits. Gardner Johnston photo June 2019.

4.6.2 Sources

There are two primary sources of wood to the lower river. These include upstream fluvially-derived wood and local riparian/floodplain sources. Although the specific relative contributions of these sources to instream wood in the study area is unknown, it is clear that most of the current wood, particularly the larger pieces, has come from local sources and is related to relatively recent channel avulsions and bank erosion. The lack of wood upstream of the upstream avulsion in the Upper Daybreak segment, located near RM 11.5, suggests there may not be a significant contribution of wood from upstream in recent years. Upstream of Lewisville Park (RM 13 to 14.3), natural channel confinement increases and extends for many miles upstream, limiting the recruitment potential for wood. There is likely wood contributed from the upper watershed and tributaries; however, the wood that does make it to the lower river may be small and deteriorated due to the long travel distance.

Local riparian and floodplain sources have been heavily impacted by clearing of valley-bottom forests that began prior to 1900 and have continued to today. There are several areas where cleared riparian and floodplain conditions have been maintained. The most notable areas are the left bank near RM 10.9 in Upper Daybreak, the lower Daybreak cut-bank field (~RM 9.7) (Figure 20), throughout the Pits segment, and at the BPA transmission line crossing and along the airstrip on river right in the Mason segment. The La Center segment also has considerable past floodplain clearing that has been mitigated by the creation of new forested riparian buffers by the County and Clark Public Utilities. Even where there are forested riparian and floodplain areas, the timber is second growth and not as large as what would have been present historically.

Figure 20. Cleared riparian zone and floodplain at the Lower Daybreak cut-bank near RM 9.7. View looking downstream. Gardner Johnston photo June 2019.

4.6.3 Recruitment

The processes of wood recruitment have been altered in the study area. As described previously, most of the wood in the lower river is recruited from local riparian or floodplain sources. This occurs either through lateral bank erosion or from abrupt changes in the course of the channel (channel avulsions). Although recruitment processes are occurring in several areas as already mentioned, there are several areas where recruitment processes have essentially been stopped for the foreseeable future. These are areas where channel migration has been halted and include the Daybreak Bridge crossing, the portion of the channel flowing through the deep Ridgefield Pits, bank armoring river-right near the powerline crossing at RM 7.2, the riprap banks on river-left from RM 6.6 – 6.9, and the riprap banks on river-right along the airstrip (RM 6.5).

4.6.4 Retention

Although wood numbers have increased in recent years, the ability of wood to remain stable within the active channel has been reduced compared to historical conditions. The current wood is transient and highly mobile and shifts frequently with high flows. There are also few pieces of wood or jams that span the channel or even interact with the low-flow channel since much of the wood is located atop gravel bars. This reduction in the ability for the channel to retain wood is due to a couple of primary factors. For one, the size of wood available to the system is smaller than what would have been expected historically where very large trees, cottonwoods and conifers, would have been available. Clearing of valley bottom forests since Euro-American settlement is the primary cause for the reduction in tree sizes. There is now a lack of functional "key pieces" of a size large enough to remain self-stabilized in the active channel. For low gradient alluvial systems like the lower EF Lewis, the availability of key pieces is necessary to initiate log jam formation.

The second factor affecting retention are the numerous modifications to the channel that have reduced complexity or affected natural river dynamics. These include artificial confinement such as that caused by the Daybreak Bridge crossing. Confinement increases stream energy and scour, and reduces channel complexity, thus reducing the ability of wood to remain in the channel.

4.7 SUMMARY OF GEOMORPHIC CHANGES AND TRENDS

Key pieces from the information in the sections above are summarized below.

4.7.1 Historical Conditions

- Portions of the lower river, particularly the area now occupied by the Ridgefield Pits avulsion, historically exhibited a complex, anabranching channel pattern. The Mason segment and Daybreak segments were highly sinuous meandering reaches with occasional side channels. The La Center segment was single-thread but with abundant abandoned oxbows. All of the lower valley bottom was a well-connected floodplain wetland system with large extents of annual inundation by high flows.
- There was historically abundant side-channel habitat, especially in the naturally laterally active segments including Mason, Ridgefield, and Lower and Upper Daybreak.
- There was likely abundant instream large wood creating stable jams and forested island features. Abundant large wood was present in the Ridgefield Pits segment, with lesser amounts in Mason and Lower Daybreak in the 1939 photos.
- The large wood in the channel, and large and robust riparian and floodplain vegetation, likely resulted in relative stability of the channel during regularly recurring floods (i.e. annual to 5-year event); with channel adjustments via scrolling and avulsions occurring during the larger, less common events (> ~5-year event). These disturbance events would create a complex patchwork mosaic of instream and floodplain aquatic habitats, with high productivity of fish and other aquatic species in the intervening years.

4.7.2 Land Use Impacts

- Conversion of valley bottom forests to agriculture and rural residential development began prior to 1900 and has continued to today. Recent trends show agricultural land being converted to residential uses.
- Instream mining occurred in the study area from the 1930s to at least 1975.
- Floodplain gravel mining has occurred throughout the photo record (since 1939) and continues today.
- Mainstem channel avulsions into gravel pits has occurred on multiple occasions.
- There was dredging in the lower reaches (mainly downstream of La Center but also up to Mason Creek) from the late 1800s to the 1920s.

- Roads and bridges, including the Lewisville Bridge, Daybreak Bridge, and La Center Bridge all constrict the channel and floodplain.
- There are multiple locations where bank armoring, primarily riprap, halts channel migration processes.
- There are levees in several areas, most notably in the La Center segment. These levees affect channel migration and floodplain inundation rates and patterns.
- There has been floodplain fill associated with roads and development. This has affected floodplain connectivity in some areas.
- Wood was assumed to have been regularly cleared from the channel in the mid-1900s.

4.7.3 Current Conditions

- Previous complex anabranching channel types have been replaced with meandering or confined reaches with none or only occasional side-channels.
- The once highly connected floodplain is now partially-to-fully disconnected, with less frequent inundation and less floodplain wetlands.
- There is a narrower channel migration zone compared to historical conditions, with much of the wide, formerly available CMZ now eliminated or significantly constrained.
- There is less large forest structure and less instream large wood and log jams compared to historical conditions.
- The reduction in structure and hydraulic roughness results in channel changes in some areas that occurs very frequently (~annually). These areas have relatively high habitat complexity but are also possibly more at risk of redd scour and burial issues.
- In other areas, artificial confinement or flow through former gravel pits results in channel changes that occur seldomly or not at all. These areas lack habitat complexity and have poor water quality. In areas with bridges or armoring, the confinement leads to high stream energy and a more erosive environment. Sediment is readily scoured and transported through these segments, depositing downstream in lower energy areas where it causes channel instability.
- There has been a moderate increase in channel dynamics and associated split flows and large wood recruitment over the last 5-8 years, particularly in the Upper Daybreak segment.
- There is currently a moderate amount of large wood in certain active deposition zones including the delta forming in the pits, at the bend at RM 9.1, and at the newly formed avulsion channel upstream of Daybreak Park (RM 10.5). But there are very few large enough pieces to serve as key pieces in the mainstem and jams are therefore transient.
- There is the potential for continued recruitment of wood from riparian zones within the study area as the channel continues to laterally migrate; however, the size of the available riparian trees are typically not big enough to serve as key pieces that would self-stabilize in the main channel and be able to rack additional wood and form large jams.
- The knickpoint from the 1996 Ridgefield Pits avulsion has traveled far enough and flattened out enough to have blended into the average channel slope, and can no longer be reasonably identified. There is, however, a slightly steeper slope in the Lower Daybreak Reach that may be causing greater instability in the reach. This slope will continue to flatten as the delta

continues to pro-grade into the pits, but it may take a very long time, if ever, for the slope to fully return to the pre-avulsion slope.
- The instability in the Lower Daybreak segment created by the pit avulsion has not been all negative with respect to habitat conditions. Although there have been dramatic channel changes as a result, and likely redd scour and burial that have impacted fish, there is also recruitment of riparian trees and new accumulations of large wood. The wood is providing habitat that did not exist previously, and it has increased dynamic channel processes in some areas, such as creating split flow conditions, which has further increased habitat quantity and quality.

5. Pit Filling Trends & Estimates of Recovery Time

5.1 BACKGROUND

Understanding the timeline for geomorphic recovery of this reach is important for determining how long and to what degree the reach will recover on its own without intervention. This information can form the basis of decisions for restoration planning, including whether or not active restoration is warranted and the types of approaches that would be appropriate. To that end, this section describes prior estimates of pit filling rates and then provides new and updated evaluations of pit filling rates, including new predictions for the timeline for the passive recovery of the reach. A multiple lines of evidence approach was used to evaluate pit filling rates. This includes three methods: 1) update to the volumetric filling analysis performed by WEST (2001 & 2013) (Section 5.3), 2) planview analysis of pit filling using the air photo record (Section 5.4), and 3) depth of refusal measurements of fine sediment accumulation (Section 5.5).

For the Ridgefield Pits reach to be considered geomorphically recovered from the impacts of the 1995-1996 avulsions, it is assumed that all the pits would need to fill with bedload/sediment and that the river channel and active floodplain longitudinal profile would need to return to a similar slope and elevation as the pre-avulsion profile. Previous estimates of recovery time defined geomorphic recovery as "when the channel has returned to an elevation similar to the pre-1996 avulsion channel" (West 2001). However, past estimates did not include the filling of all the pits in this definition; Pits 8 and 9 were excluded, even though current channel dynamics suggest that erosion of the main channel into these pits at some point in the future is likely. For the purposes of this assessment, we consider the filling of all the pits critical to full geomorphic recovery since future channel migration into non-filled pits would result in similar (albeit smaller) pit captures that would have detrimental impacts to river geomorphic function and would result in impaired habitat conditions similar to what is found in the existing pit reach.

Figure 21. Aerial oblique view looking downstream from near the upstream end of the Ridgefield Pits reach.

5.2 PRIOR STUDIES

Original estimates of pit filling rates were provided by WEST (2001) as part of the Daybreak Mine Expansion HCP studies. These estimates were then updated by WEST in 2013 (WEST 2013). The primary reasons for estimating pit filling rates were twofold: 1) to understand recovery times as an example of what might be expected if the river were to avulse into the Daybreak Pits, and 2) to understand recovery time with respect to risk to the Daybreak Pits, with the assumption that once the Ridgefield Pit reach recovers, lateral channel migration into the Daybreak Pits would be more likely to occur.

WEST (2001) originally estimated the timeline for recovery via 2 primary methods. The first involved calculating the volume of sediment that had filled the pits since the 1996 avulsion and then using that data, along with some assumptions of watershed sediment supply, coarse bedload supply, sediment transport capacity, sediment trapping efficiency, and volume of pits remaining to be filled, to make a filling rate prediction. This resulted in an estimate of 25 years (since the 1996 avulsion), or recovery by Year 2021, for the pit reach to recover. This analysis had inherent uncertainty for a number of reasons, including the need to rely on recollections of pit depths from workers at the mine to estimate the pre-avulsion pit volumes. This analysis also disregarded Pits 8 and 9, assuming that because they were not connected to the mainstem, they were not necessary for reach recovery.

The second method described in the WEST (2001) report for estimating recovery time involved calculating the growth rate of the gravel/cobble delta forming at the upstream end of the pits. Based on a delta growth rate of approximately 100 ft/year, they estimated it would take 30 years (by Year 2026) for the delta to reach the downstream end of the pits.

As part of their requirements under the HCP, Storedahl commissioned an analysis in 2013 to evaluate the status of pit filling and to update the recovery rate estimate. This analysis was described in a tech memo from WEST to Storedahl (WEST 2013). The method relied on a volumetric analysis of pit filling and built off of the previous pit volume calculations used for the pit filling predictions in the HCP described previously (WEST 2001). The results of this evaluation resulted in a geomorphic recovery prediction of 30 years, which was said to match the 25-30 year prediction from the HCP (WEST 2001), and meaning the reach was still on track to be recovered by 2026.

5.3 UPDATED PIT FILLING ESTIMATE BASED ON PIT VOLUME MEASUREMENTS

As part of this study, we compare 2018 pit volumes to past volume data in order to check the status of pit filling and to update the predictions for timeline to recovery. The pit volumes from prior studies and from this current study are presented in Table 5. The pre-avulsion data and 1999 data were presented in Appendix C of the HCP (WEST 2001). Note that Pits 8 and 9 were not included in this study, as mentioned previously. The pre-avulsion volumes are based on estimates of pit depths from a worker at the mine. The 1999 and 2013 data are based on surveys by WEST consultants. This study adds 2018 pit volume estimates to the time series based on 2018 bathymetric and ground survey data by Inter-Fluve and the Estuary Partnership (Inter-Fluve 2018) combined with the 2010 LiDAR (USACE 2010) to make a composite digital elevation model.

The pit volumes are in reference to an "average water surface elevation", which WEST (2001) defined based on a groundwater contour map; those elevations are listed as the 'Pit Top Elevation' in Table 5. Although one would expect a reduction in the volume of the pits as they fill with sediment, this is not always the case, especially when considering changes in individual pits. For the pre-1996 to 1999 data, WEST (2013) attributes this to several factors, including lateral channel migration moving material out of the pits, using pit boundaries that may have been different from the original study, and potential under-estimation of the original pre-1996 volumes. When looking at the total volume changes with all pits combined, there is a 12% reduction in volume from pre-1996 to 1999 and a 57% reduction from pre-1996 to 2013. These data were used in 2013 to develop the 30-year estimate for pit filling (i.e. pit filling by 2026, WEST 2013). The 2018 data, however, show a reversal in trends in pit volumes for the pits, with an overall increase in total volume from 2013 to 2018. The reason for the increase in volume is unknown. The 1999 and 2013 topographic data were not available for this analysis, although efforts are being made to obtain it, which may help clarify the reason behind the differences. Some of the increase in volume in some pits could be due to lateral channel migration moving material out of the pit area; however, this would not apply to most of the pits and would not account for the increase in pit volume for the reach as a whole. In total, the 2018 data suggest a total decrease in pit volumes of 36% from pre-1996 to 2018, which is substantially less change in volume suggested by the 2013 data (57% decrease) and has different implications for timeline for reach recovery. The total changes in pit volumes from these various time periods/studies are plotted in Figure 22. Linear trendlines show that without the 2018 data, the pits could be on a trajectory to fill by 2026, which was the conclusion from the WEST (2013) study. However, without the 2013 data, the trend suggests the pits may be on a longer trajectory to fill, by 2068. Both of these trendlines assume linear relationships using the 1999 data, when in reality, the rate of pit filling may not be linear, which is discussed further in Section 5.4.

Table 5. Pit volume estimates.

	Values previously reported in Storedahl HCP Appendix C (WEST 2001) and 2013 Tech Memo (WEST 2013)							**Values based on 2018 survey**	
Pit	Pre-1996 Pit Volume (2001 study)	Pre-1996 Pit Depth (2001 study)	Pit Top Elevation (2001 study)	1999		2013		2018	
				Volume	Volume Change	Volume	Volume Change	Volume	Volume Change
	(cy)	(ft)	(ft)	(cy)	(%)	(cy)	(%)	(cy)	(%)
1	157,700	12	35	118,583	-25%	21,958	-86%	69,777	-56%
2	102,900	12	34	130,131	26%	54,185	-47%	103,409	0%
3	108,500	20	33	124,203	14%	76,290	-30%	92,798	-14%
4	143,500	20	32	105,176	-27%	51,000	-64%	81,192	-43%
5	164,800	20	31	160,661	-3%	88,955	-46%	116,640	-29%
6	204,900	30	31	128,119	-37%	66,211	-68%	87,233	-57%
7	186,900	20	30	178,981	-4%	96,299	-48%	135,951	-27%
TOTAL	**1,069,200**			**945,854**	**-12%**	**454,897**	**-57%**	**687,000**	**-36%**

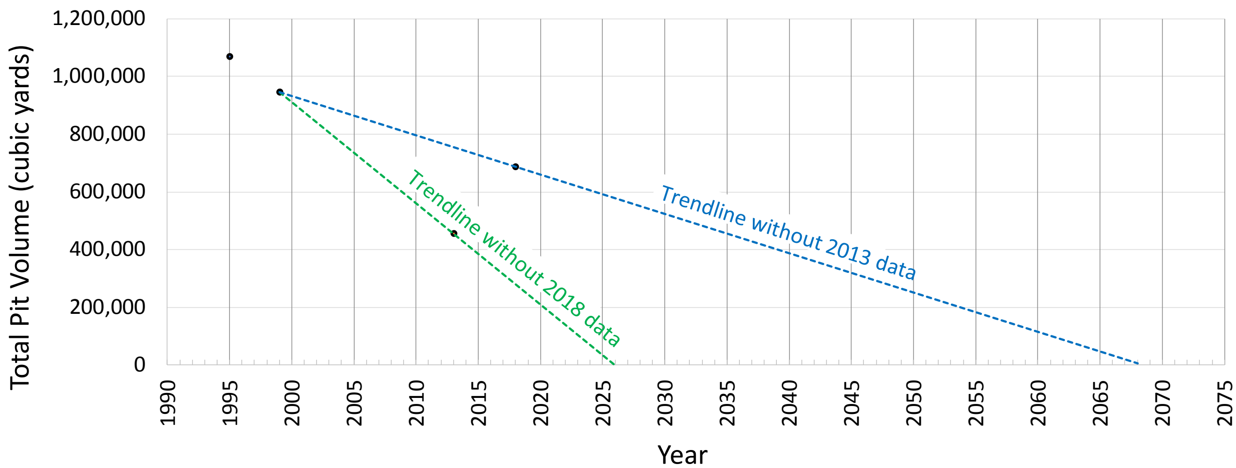


Figure 22. Pit volume estimates.

It should also be noted that this analysis does not include pits 8 and 9. If pits 8 and 9 were included, the total pit volume would be greater and the timeline to recovery would be even longer. Considering that lateral migration is likely to occur into these pits at some point in the future, it would seem reasonable to include these when making predictions for reach recovery.

5.4 PLANVIEW AREA ANALYSIS OF PIT FILLING

Due to uncertainties associated with the three-dimensional data required to compare changes in pit *volumes* over time, we also performed a two-dimensional "planview" analysis of pit filling using the historical photo record since just prior to the 1996 avulsion. For this 23-year period, we were able to obtain aerial photographs for 18 years, a nearly annual record. These photos were obtained from Clark County, Google Earth, and past reports. Although this analysis provides less detail than a 3D volumetric analysis, it avoids the uncertainty associated with the 3D survey data and also provides a nearly complete annual record to evaluate trends in pit filling rates since the avulsion.

A 1994 (pre-avulsion) air photo was used to draw initial pit boundaries for this analysis in a GIS, based on extent of open-water within the pits. For each photo set/year following the avulsion, polygons were then drawn around areas within the initial pit polygons that appeared to be above water. These represented areas considered "filled" with sediment within the pits. Although nearly all of the photos were taken during low water periods in the summer, the timing varies and so does river discharge, which affects the apparent amount of pit filling year-to-year. For this reason, there are some years where filling appears to decrease from a previous year or years, which would not be expected; but this is assumed to be related simply to higher water in the photo compared to previous years.

For each photo set/year, the area of pit filling was calculated and was compared to the initial pre-avulsion pit boundaries. These data are presented in Table 6. The chart in Figure 23 displays the annual trend in the data. The trendline that is fit to the data is a 4th order polynomial trendline, and does not include data from the 6 years where pit filling appears to decrease from a prior year. The table and chart also include the annual peak flow events during this period, from the USGS Heisson Gage (#14222500). These are included to evaluate wh ether or not pit filling rates appear to be correlated with flood events. Appendix B shows all of the photo years and delineated fill polygons generated for this analysis.

Table 6. Pit filling calculations by photo year with peak flow information.

Air Photo Year	Pit Fill Area (acres)	Percent Fill (of pre-avulsion pit acreage)	Intervening annual peak flow events	
			Flow (cfs)	Date
**pre-avulsion total pit acreage = 49.1*				
Summer 1996	0.3	1%	28,600	8-Feb-96
Late Fall 1996	3.1	6%	6,000	19-Nov-96
1998	9.3	19%	9,580	30-Oct-97
2000	17.6	36%	12,000 14,400	27-Dec-98 25-Nov-99
2002	19.0	39%	3,170 6,330	30-Apr-01 25-Jan-02
2003	22.2	45%	13,700	31-Jan-03
2005	21.1	43%	9,420 6,690	29-Jan-04 18-Jan-05
2006	22.1	45%	9,270	10-Jan-06
2007	21.1	43%	21,200	7-Nov-06
2009	26.8	55%	10,700 13,800	3-Dec-07 8-Jan-09
2010	26.4	54%	4,470	1-Jan-10
2011	27.2	56%	16,200	16-Jan-11
2012	27.7	56%	11,000	22-Nov-11
2013	28.0	57%	7,570	19-Nov-12
2014	27.7	57%	6,660	2-Dec-13
2015	26.0	53%	5,850	10-Feb-15
2016	28.3	58%	22,400	9-Dec-15
2017	27.2	55%	9,360	15-Mar-17
2018	29.8	61%	6,540	29-Dec-17

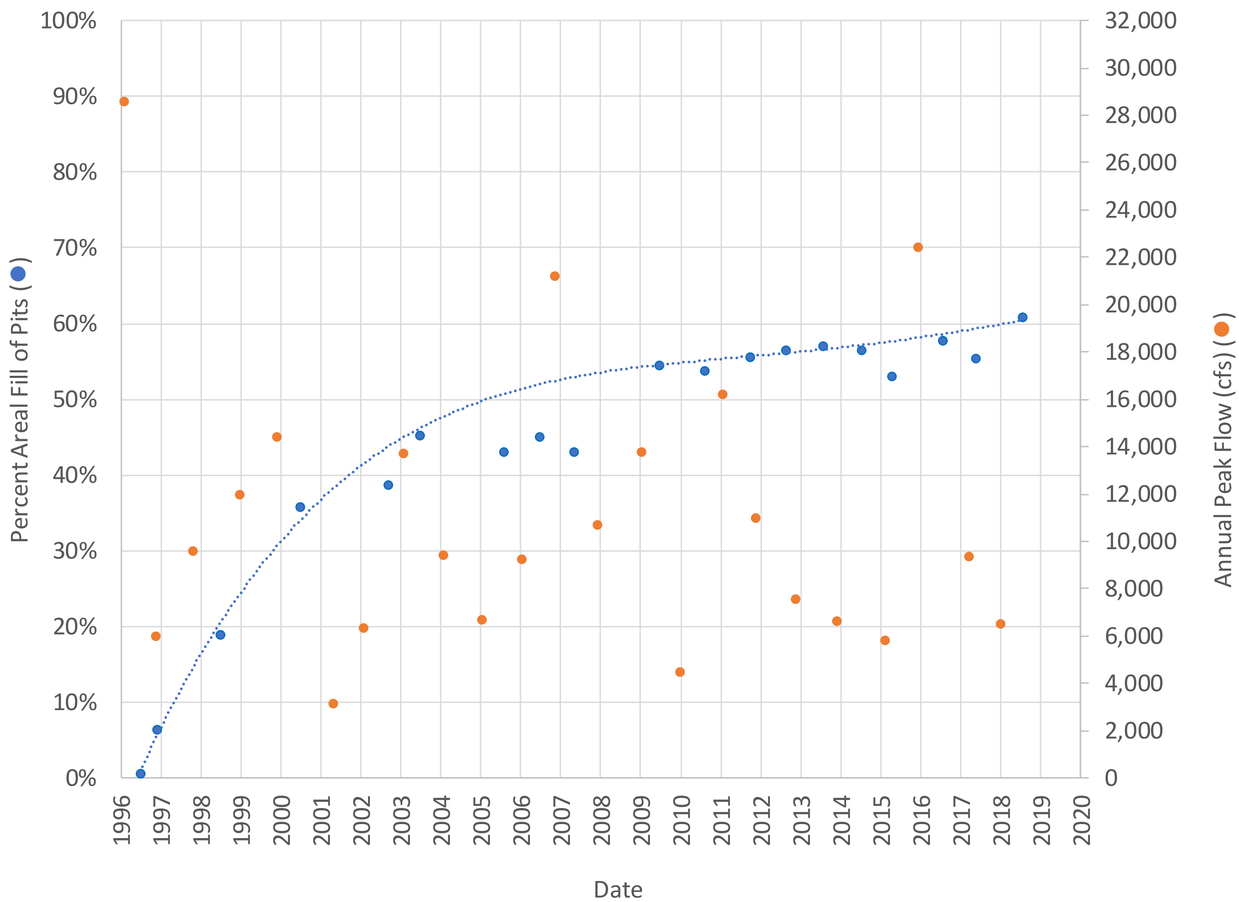


Figure 23. Trend in pit filling rates compared to peak flow data from the USGS Heisson Gage (#14222500).

This pit filling analysis indicates that the rate of pit filling has slowed and has become more consistent over the past 10 years. Whereas the average pit filling rate for the first 11 years post-avulsion was 1.9 acres/year, the average rate for the past 9 years has been 0.34 acres/year. One might expect that the reduction in pit filling rates could be a result of smaller floods in recent years; however, the peak flow data actually show that the largest post-avulsion peaks occurred after the pit filling rates slowed. It is assumed that the reduction in pit filling rates is instead due to cessation of the initial knickpoint migration following the 1996 avulsion and the subsequent recovery (rebound) of the longitudinal profile and thus a reduction in the contribution of bedload from upstream, as described previously in Section 4.3.2.

In Figure 24, the trend in pit filling rates is expressed as the amount of pits remaining 'unfilled' over time. If we assume that the recent (i.e. past 10 years) trend in filling rates continues (0.34 acres per year), then according to this analysis, the pits will fill by the year 2075. This is based on 19.3 acres remaining to be filled, at a rate of 0.34 acres/year, resulting in approximately 57 years. This "filling", however, only constitutes sediment that is above water during the low water period, and may be a lower threshold than the filling that was described as necessary to achieve pit "recovery" by WEST (2001), specifically: "when the channel has returned to an elevation similar to the pre-1996 avulsion channel". If this criterion were used, the timeline for recovery may be longer.

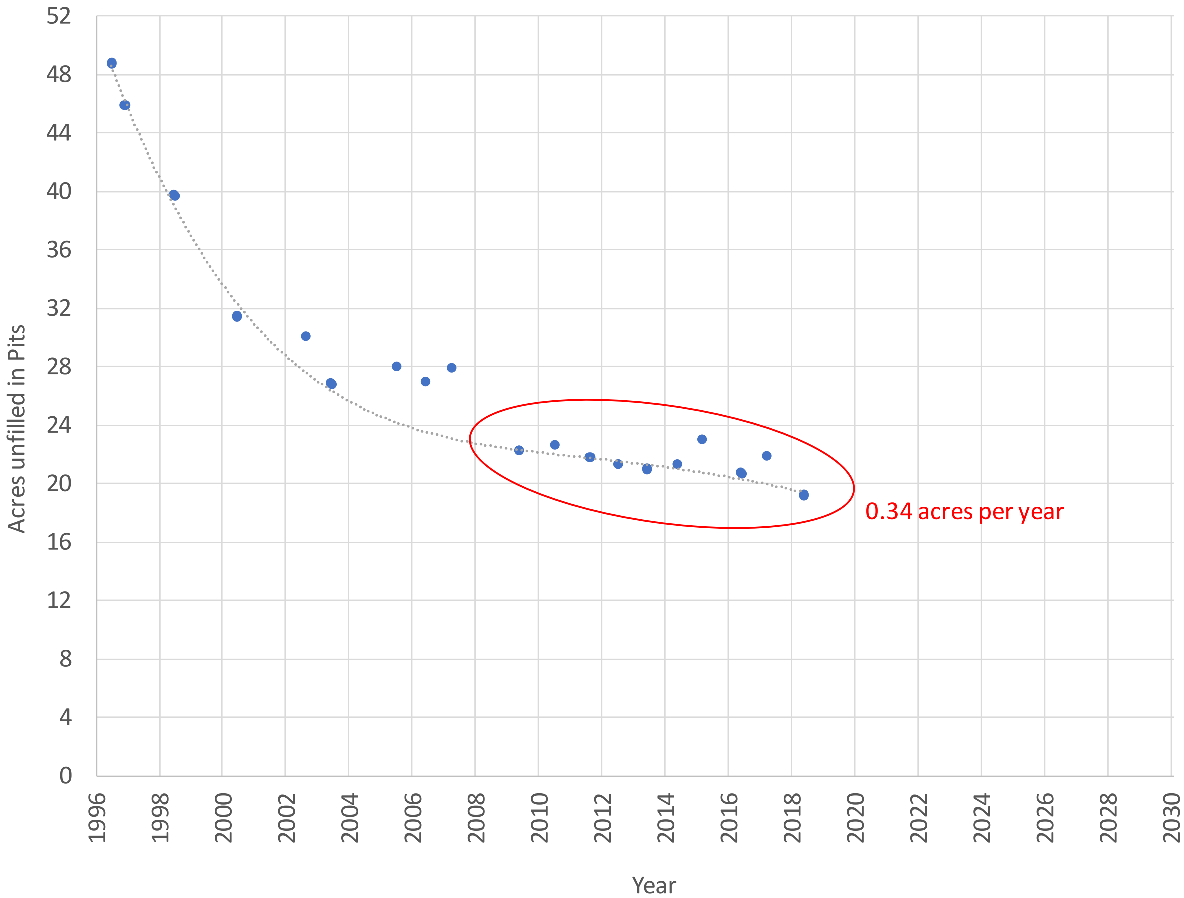


Figure 24. Area (acres) unfilled in pits by year since the avulsion. For the past 10 years, the pits have filled at an average rate of 0.34 acres per year, based on the two-dimensional "planview" anaylsis of filling.

This analysis revealed two primary modes of pit filling: 1) gravel-dominated bedload forming the delta at the upstream end of the pits, and 2) fine silts and sands filling the remainder of the pits. The delta has formed via bedload transport from upstream that is pro-grading into the pits. As the new channel aggrades, it has initiated meander migration that has eroded the former pit walls. The new material generated from this erosion has further contributed to pit filling. The areas downstream of the coarse delta, and the pits that are not directly in-line with the main channel, are comprised of fines (sands and silts). Similar to West (2001), we assume that this material is primarily contributed from upstream watershed areas. However, it is possible that this fine material could be re-suspended as the newly-forming main channel continues to pro-grade into the pits and shifts laterally into off-line pond areas. These dynamics could extend the timeline for reach recovery.

The growth of the delta is fairly easy to measure from the air photo series; however, the amount of accumulation of fines in the pits, and how long that would take to fully fill the pits, is more uncertain. This is further evaluated in Section 5.5.

5.5 DEPTH OF REFUSAL MEASUREMENTS OF ACCUMULATED SEDIMENTS

In order to better understand the rate of pit filling downstream of the coarse gravel delta, we performed a series of depth-of-refusal (DOR) measurements. We selected a sample area for these measurements in Pit #7, which was believed to be sufficiently downstream of the delta to avoid coarse sediment and to have a range of channel conditions and depths. A total of 17 samples were taken, including areas within the main channel through the pits, channel margins, and off-line pit areas (Figure 25). The DOR measurements were performed using a smooth metal rod pushed through the fine sediments until refusal depth was reached. This refusal depth is assumed to be the original bed of the pits prior to accumulation of fines following the avulsion. The refusal depth and the depth to the top of the sediment deposit were recorded in order to calculate the sediment thickness at each sample point. These data are presented in Table 7.

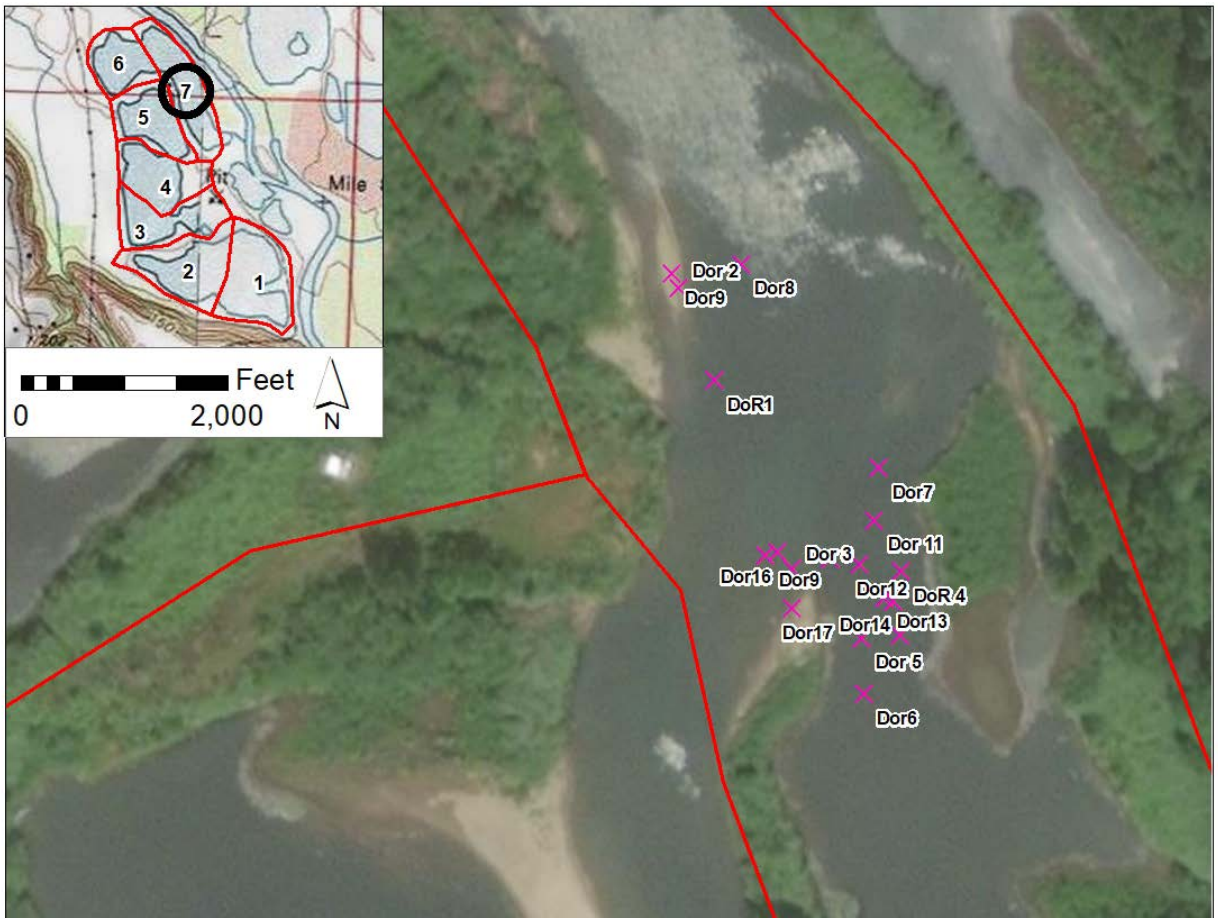


Figure 25. Location of depth-of-refusal measurements.

Table 7. Depth-of-refusal data.

Sample Location	Depth to top of sediment (ft)	Depth to Refusal (ft)	Sediment thickness (ft)
1	2.3	4.8	2.5
2	3.5	9.5	6.0
3	4.6	8.0	3.4
4	8.5	10.0	1.5
5	6.5	8.6	2.1
6	6.4	11.3	4.9
7	3.5	10.2	6.7
8	9.5	14.0	4.5
9	3.5	5.5	2.0
10	6.3	10.0	3.8
11	11.6	13.0	1.4
12	9.0	12.2	3.2
13	7.9	9.3	1.4
14	7.8	12.5	4.7
15	7.8	11.7	3.9
16	5.0	7.0	2.0
17	1.7	4.2	2.5
Averages	**6.2**	**9.5**	**3.3**

Sediment thickness ranged from 1.4 to 6.7 feet with an average of 3.3 feet. This equates to an average of 0.14 feet (1.7 inches) of sediment deposition per year for the 23 years since the 1996 avulsion. For each sample location, the estimated time for the site to fill was calculated by dividing the depth to the top of the sediment layer by the average feet/year of sediment accumulation for the sample location. The average of all of these estimates was approximately 58 years, or filling by 2076. This can be considered a low estimate since it assumes that filling is achieved when the sediment layer reaches the water level at the time of the survey, which was during a very low water period (Oct 18, 2018). It also only looks at filling via fine sediment deposition, and disregards the growth of the coarse gravel delta. However, it is reasonable to assume that in the downstream portion of the pits and in some of the off-line pits (or off-line areas of connected pits), filling is likely to occur via fine sediment accumulation only, since the delta may never reach these areas. It is also reasonable to assume that the fully disconnected Pit 9 and the mostly disconnected Pit 8 would have far less sediment deposition than the sample sites would suggest; and if these remain disconnected, they may take a much longer time to fill passively since they would not receive the same amount of fine sediment as those connected to the main channel.

5.6 SUMMARY

A multiple lines of evidence approach was taken to evaluate pit filling rates and to estimate the timeline to pit filling and reach recovery. Three methods were used, including evaluating trends in pit volumes, trends in the spatial area of pit filling, and DOR measurements of fine sediment accumulations. The results of these methods are included in Table 8.

These results indicate that the timeline for the recovery of the pit reach may be considerably longer than the previous estimate of recovery by Year 2026 (WEST 2001 and 2013). Based on the analyses presented in this report, and in consideration of the notes in Table 8, pit recovery is likely to take until at least Year 2075, and possibly considerably longer.

Table 8. Estimates of the timeline to pit recovery from the methods presented in this report.

Method	Estimate of years to recovery (from 2018)	Notes
Pit volume changes based on topo-bathy surveys	50 (filled by 2068)	• Disregards 2013 data from WEST (2013) for the reasons described in Section 5.3. • Doesn't include Pits 8 and 9, so estimate is likely low.
Planview area analysis of pit filling	57 (by 2075)	• Estimate may be low because measures are based on visible land at low flow, which would be less deposition than recovery of elevations that match the pre-avulsion channel.
DOR measurements of accumulated sediments	58 (by 2076)	• Estimate may be low because measures are based on recovery to a low water level during the survey, which would be less deposition than recovery of elevations that match the pre-avulsion channel.

6. Implications for Restoration

The geomorphology and pit filling evaluations have several implications for habitat restoration planning in the study area. These are listed below.

- Dynamic channel changes have always occurred throughout the study area and should be expected to continue. However, the rates of change and potential future changes have been affected by human actions, which has resulted in some areas with more frequent channel changes and other areas with less frequent channel changes.
- Restoration actions should assume that dynamic changes, especially planform (lateral) dynamics, will continue and that these dynamics are important for the recovery of habitat complexity and native vegetation.
- A sinuous and complex planform with occasional meander cut-offs and abundant former channel scars will increase aquatic habitat complexity. These conditions will also support temperature refugia by creating hyporheic flow paths with strong head gradients, such as subsurface flow across point bars that contribute cool water to back-bar channels.
- In some areas, restoration actions may be beneficial that add structure to mimic the historical structure of large standing trees and large instream log jams – elements that would have resisted annual adjustment but would have been deformable at 5-10 year flood recurrence events. Other areas may benefit from removing structures, such as artificial bank armoring, fill, or levees that limit the degree of dynamic change and adjustment.
- Projects should be designed for resiliency and deformation, with channel alterations that retain quality habitat with fluctuating sediment supplies. Adding new permanent structures that constrain floodplain or channel migration zone processes should be avoided unless they are part of a plan to improve overall river corridor function (e.g. set-back levees around critical infrastructure).
- The Ridgefield Pits are unlikely to fill for at least another 50-60 years, and it could possibly take considerably longer. Habitat conditions in the pits reach will slowly improve over time but the reach will remain significantly impaired until the pits fill. Continued impairment of pits over several more decades may bolster the need for active, as opposed to passive, restoration at the site. Alternatives should be considered for speeding the recovery process in the pits reach.
- Pit avulsion into the Daybreak Pits would cause significant impairment and it is paramount to prevent this in the future or to restore and reconnect a portion of those pits in a deliberate fashion.

- There will be continued, albeit subtle, longitudinal profile 'rebound' in the Lower Daybreak segment. This should work in concert with any side-channel reconnections that are considered.
- Relatively rapid erosion of the Lower Daybreak cut-bank is expected to continue. This has pros and cons with respect to restoration. Cons include the potential for redd scour and burial on an on-going basis, delivery of fines to the channel, and lack of large wood recruitment due to the cleared field. There is also very poor channel margin and riparian function in this area. Pros include the colonization of the opposite point bar with native vegetation and creation of more highly connected floodplain in this area. The rapid erosion of bedload also helps speed the longitudinal profile rebound and provides material to help fill the Ridgefield Pits. The re-deposition of this material just downstream also helps to keep the right-bank side-channel active. At the least, this site would benefit from revegetation throughout the floodplain. Of greater benefit would be a more targeted effort to slow (but not permanently stop) erosion, giving planted vegetation a chance to mature, and also increasing instream and channel margin habitat complexity.
- Restoration actions that work to further increase connectivity of the river-right side-channel across and downstream from the Lower Daybreak cut-bank, and work near the Manley/Mill confluence area, will need to take into account what future projects (if any) are likely to occur at the lower Daybreak cut-bank, since actions or the lack of actions at the cut-bank could affect channel dynamics and sediment/bedload sources that might impact those efforts. Ideally these various efforts would be considered as one cohesive group of actions.
- Although there is a lack of data to fully assess it, there has likely been incision in the Mason segment due to the bedload trapping of the pits. This will continue until the pits fill. This could affect projects including side-channel reconnections and large wood placements. Actions that help contribute or recruit bedload to the Mason segment would help to mitigate the effects of the pit capture. This could include removing any bank armoring in this segment.
- Wood delivery to the channel will continue. Wood numbers may continue to be high in localized depositional areas, but there is an overall lack of large key pieces that can remain stable in the main channel, so wood is expected to continue to be transient. Projects that create conditions for more stable wood structures and the ability to trap and retain mobile wood will create conditions that are more in line with historical wood jams that had greater retention time in the system.
- Areas of high channel complexity have less invasive plant species. Restoring complexity to some areas may be the best way to address invasive vegetation.
- The existing degree of connectivity of the upstream right bank side-channel is likely related to erosion at the Lower Daybreak cut-bank and subsequent re-deposition of this material at the riffle downstream. This process will likely continue if conditions remain the same at the cut-bank, at least until continued meander scrolling results in an avulsion.

7. Recommended Modeling Scenarios

Based on the site investigations and project objectives, recommendations for initial modeling scenarios are provided. This includes hydraulic and sediment transport modeling. The results of these model runs can be used to evaluate preliminary potential benefits, risks, costs, and constraints of key restoration alternatives.

No action/passive recovery of pits – This would include modeling existing hydraulic and sediment transport conditions. Sediment modeling could be used as another line of evidence to help understand potential rates and means of pit filling over time.

Relocate main channel back into pre-1996 avulsion channel – This scenario would use select grading and log jams to relocate the main channel into the former, abandoned channel alignment. Iterative modeling of proposed grading scenarios would help to understand the level of grading that would be necessary and the feasibility of this approach given the current elevation difference between the main channel and abandoned channel. If initial analysis shows this is likely to be infeasible without new levees and armoring, then full hydraulic modeling of this scenario may not be necessary.

Full pits reach re-grade – This scenario would include grading and filling to re-contour the pits reach into a multi-thread connected channel and floodplain wetland system. The elevation of the new channel/floodplain system would be lower than the pre-avulsion elevation given the amount of material removed by past mining. The objective would be to determine the amount of fill and grading necessary to achieve meaningful habitat improvement, and to determine whether there is enough material available on or near the site. The lateral extents of grading will also need to be determined, including interface with the BPA powerline towers. Sediment transport modeling could be used to help understand the effects of this alternative on sediment transport and aggradation within the pits reach compared to the No Action (existing conditions) alternative.

Side-channel re-connections –This scenario would include increasing flows in the two prominent right bank side-channel alignments in the Lower Daybreak reach. This would be accomplished using select excavation in the side-channel alignments as well as mainstem log jams to raise/divert water into the side-channels. The objective would be to understand the amount of grading and log jam work that would be necessary to achieve perennial connectivity.

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9. Appendices

APPENDIX A – HISTORICAL MAPS AND PHOTOS

APPENDIX B – PIT FILLING PHOTO ANALYSIS