

Channel Migration Assessment

Clallam County: Puget Sound WRIAs 18 - 19

December 2011

Final Version April 2018



DEPARTMENT OF
ECOLOGY
State of Washington

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Chapter 1 Introduction

1.1 Channel Migration Zones

Dynamic physical processes in rivers can cause channels in some areas to move or "migrate" over time. The natural meander patterns of stream channels are the result of the dissipation of energy of flowing water and the transportation of sediment. The area within which a river channel is likely to move over a period of time is referred to as the channel migration zone (CMZ). Since the ground within a CMZ is subject to erosion, it represents a hazardous area for development. Roads, pipelines, buildings, and other property are all at risk within a CMZ. Protecting development within a CMZ can alter natural processes and adversely impact critical salmon habitat. Delineation of CMZs allows landowners, planners and other entities to determine if they have facilities or property that could be subject to erosion, plan for future development that safeguards human welfare and critical habitat and identify sites that may need erosion protection or habitat restoration opportunities.

Channel migration can occur **gradually**, as a river erodes one bank and deposits sediment along the other. Erosion occurs when the stream has sufficient energy to cut into a bank, so it is dependent on both flow conditions and the resistance of the bank material. Channel migration also can occur **abruptly**, such as cases of channel widening associated with large floods or channel downcutting ("incision") that over steepens and destabilizes stream banks. Channel incision is a common occurrence in urbanizing basins due to changes in amount and timing of runoff due to increases in impervious surfaces in a basin. Abrupt migration also occurs when stream takes another path within its floodplain, typically because it offers less resistance (for example, a more direct path or a way around an obstruction). This circumstance is referred to as an 'avulsion'. While areas susceptible to avulsions can be identified, the timing of an avulsion depends on flood events and debris accumulations that are less predictable.

Channel migration can occur in streams of all sizes. The highest rates of channel migration generally occur along large channels with erodible banks, particularly where the original forest was removed. The other areas prone to rapid channel migration are areas where steep tributaries enter larger, flatter valleys. Frequent channel migration in these sites forms an alluvial fan, thus fans are considered high risk areas for erosion and are included in the maps. Both gradual and abrupt channel changes are natural processes important in sustaining critical habitat for aquatic species, while also posing risks to property and infrastructure, and thus are important to consider in land-use planning within Clallam County.

A CMZ as defined in Rapp and Abbe (2003) consists of several distinct zones. The area where the stream has been in the past as recorded in old maps and photos is referred to as the "historical migration zone" and clearly an area susceptible to future channel migration. This zone may also include pre-historic channels evident in site topography. The CMZ also includes "avulsion hazard areas" such as low-lying floodplain or cleared areas between large bends in the stream. The CMZ also includes an "erosion hazard area" that represents areas where the channel may not have been historically but may move in the future based on ground erodibility, evidence of

migration in similar areas, and rates of historic migration. The erosion hazard zone includes valley hillslopes in valleys that are actively forming, which are common in the young landscape of Western Washington. Where a channel cuts into a valley margin it will tend to over-steepen the hillslope and create an increased risk of a landslide, referred to as a “geotechnical hazard”, that can pose a significant threat to areas that may be situated outside CMZ or flood hazard zone. Therefore, it is important to remember that CMZs may affect higher ground susceptible to erosion driven by the stream. Therefore, it is important to remember that CMZs may affect higher ground susceptible to erosion driven by the stream. In such circumstances, the CMZ may extend beyond the established floodplain. In other cases, such as heavily vegetated small channels, the CMZ may be considerably smaller than the floodplain or the FEMA delineated special flood hazard zone.

In the Puget Sound ecoregion, channel migration is the primary floodplain geomorphic process that creates a shifting mosaic of habitat patches of different ages within the river corridor, by re-setting vegetation communities and aquatic habitats. This mosaic provides highly productive ecological areas for aquatic organisms as well as terrestrial species. The channel migration processes occur on a variety of spatial and temporal scales from local bank erosion to avulsions that create many kilometers of new channel to entire reworking of floodplains. Rivers erode some patches each year while other patches accrete sediment and gradually rise in elevation above the river bed (Nanson and Beach, 1977; Abbe and Montgomery 1996; Brummer, Abbe and others 2006). The high density of complex boundaries between ecotones (Ward et al 1999) creates more environmental complexity, maintained by interactions between river channels and floodplain forests.

Channel migration commonly threatens infrastructure like roads, levees, and private property. Actions to protect property are expensive and have historically had a severe impact on aquatic habitat and, potentially, other property. In cases where channel migration rates have been affected by land development such as forest clearing, land tilling, and increased runoff from development, it can have negative impacts on water quality, delivering un-naturally high sediment and pollutant loads to downstream water bodies like Puget Sound. Where rapid migration occurs, risk to people and infrastructure often is much greater than flooding alone. Channel migration can also include channel widening associated with major flood events or increases in discharge resulting from urbanization common throughout Western Washington. Figure 1.1 shows a residential development with homes built next to a stream that has changed considerably between 1990 and 2009. The 2009 image shows that the stream in this residential development moved, eroded banks, deposited sediment, and removed trees and vegetation along the banks. The loss of vegetation along the stream banks increases the likelihood that the channel will continue to migrate and cause further bank erosion.



Figure 1.1 Mission Creek near Belfair, WA. Note the change in width of the channel and additional deposition between 1990 (upper photo) and 2009 (lower photo) in this residential neighborhood.

Areas that have not experienced channel migration in historic times can still be at significant risk, particularly in areas that have experienced upstream land development or are responding to sediment and wood accumulation. Historic actions to limit channel migration not only had severe impacts on salmon habitat and floodplain ecosystems but are extremely expensive and still susceptible to future erosion. These historic actions included excavating straight channels ('channelization'), dredging or gravel mining in existing channels and floodplains, construction of revetments (i.e., bank hardening), levees/dikes, and riparian and channel clearing (i.e., tree and wood removal) and contributed to cumulative impacts that reduced the geomorphic and ecologic complexity of streams and contributed to the listing of salmon under the Endangered Species Act (NMFS 2008). Delineating CMZs helps municipalities and private landowners avoid developing in hazardous areas, manage property or infrastructure currently at risk, and identify potential restoration opportunities.

1.2 CMZs developed by Department of Ecology for the Shoreline Master Program

The Washington Department of Ecology (Ecology), Shorelines and Environmental Assistance Program (SEA) is responsible for managing Shoreline Master Program (SMP) updates and providing technical and policy assistance to local communities.

Since many local communities do not have the resources (staff with necessary expertise in fluvial geomorphology or budgets to conduct channel migration assessments), Ecology applied for grants to provide technical assistance for channel migration mapping. Ecology received a scientific and technical investigations grant from the Environmental Protection Agency (EPA), Region X. One objective of the grant is to identify and map the general location of channel migration zones for Puget Sound communities that do not have existing CMZ assessments and are updating their SMPs. Identification of channel migration zones under SMP criteria may support community efforts at complying with new FEMA regulations related to endangered species (See Chapter 2, Regulatory Context, for more details).

This report was prepared by Ecology and the consultants working on the project and provides information, methods, and maps of areas in Clallam County with a high probability of being subject to channel movement based on the historic record, geologic character and evidence of past migration (WAC 173-26-221(3)). The delineations included in this report represent the "general location" because they relied on GIS data and did not include a detailed analysis of historic migration rates, nor did they include field verification or geotechnical assessments done as part of delineating a CMZ using the more detailed method described in Rapp and Abbe (2003). These general CMZs are intended to provide preliminary maps that comply with SMP guidelines, assist with planning, and indicate areas where additional data and analysis should be conducted to complete a more detailed delineation. The methods used to complete the general CMZ delineations are summarized here and described in detail in Chapter 4.

The SMP guidelines specify that, during the watershed characterization and inventory phase of their SMP update, local communities will identify the general location of channel migration zones using information that is relevant and reasonably available WAC 173-26-201(3) (c) (vii).

Relevant and reasonably available information for general mapping of channel migration zones includes geologic maps and studies, soil data, bank alteration or hardening locations, flood control structures including public roads and railroads, historic aerial photos and maps for identifying evidence of past migration, Light Detection and Ranging (LiDAR) maps, and other

information providing evidence of past and present migration. In addition to the information described above, detailed assessments would also include field data collection, mapping channel locations from archival maps and aerial photographs, calculating channel migration rates, and hydrologic and hydraulic analyses. Detailed assessments are not required under the SMP regulations.

Detailed channel migration assessment and mapping methods are well described in the scientific and grey literature, and in Ecology publications (Rapp and Abbe 2003, Olson 2008). However, a method for determining the general location of channel migration zones as required in the SMP regulations had not been developed by 2004 when the new rule took effect. The SMP guidelines do not provide guidance on mapping the general location of the channel migration zone beyond what is described in WAC 173-26-221(3)(b) (see Regulatory Context section or Appendix A for more detail on regulatory requirements).

Lack of specific guidance in the regulations as well as in the scientific literature required that a streamlined method be developed for this project to identify the general location of channel migration zones. The streamlined method needed to include the following characteristics:

- Relies on existing data to identify the general location of the CMZ.
- Incorporates geomorphic and hydrologic knowledge and experience relevant to assessment area.
- Enabled the rapid assessment of 550 stream miles to meet the fast-tracked schedule for the Puget Sound communities to complete their SMP updates.

The term “streamlined method” describes the mapping method developed for this project to meet the above needs; this method results in planning-level channel migration zones (pCMZs).

The streamlined method did not include field verification or detailed analysis of channel migration rates. Although historic aerial imagery dating back to the 1930’s was reviewed in areas where it was available, analysis focused on imagery available since 1990 due to its widespread availability. Key to most of the delineations was the information found in high resolution (2m pixel) LiDAR DEMs that provided analysts with detailed information on alluvial landforms within project stream valleys. Using the stream water surface profile as the datum, maps illustrating the “Relative Water Surface Elevation” (RWSE) were developed for all sites where LiDAR was available (See Section 4.3 for details). These RWSE maps offered an accurate means of assessing relic channels, valley widening, and landsliding, and provide important evidence of potential channel migration. Although the streamlined method was designed to be consistent and repeatable, professional judgment was an important part of the process and required experienced practitioners.

This document is not intended as a primer on geomorphology, nor is it intended to be used as guide for delineating channel migration zones. The ‘streamlined’ method used to identify areas of potential channel migration in this report differs from the more detailed method described on the Ecology website and in A Framework for Delineating Channel Migration Zones (Rapp and Abbe 2003) and should only be used as a guideline for identifying areas where more detailed channel migration zone studies should be conducted.

As of 2011, draft web guidance for identifying CMZs is available on the Ecology website (Olson 2008) with a final published version and related documents pending release in 2014/15. The web guidance provides instructions and references related to channel migration zones, a glossary, a

more detailed description of the regulatory framework, and example CMZ delineation reports (using more detailed methods).

As of 2018, the information and materials noted above are available via Ecology's new webpage: <https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Hazards/Stream-channel-migration-zones>.

This report was completed as a Draft document in 2011 under an EPA grant to help Clallam County comply with a required Shoreline Master Program (SMP) comprehensive update. The analyses summarized in this report were conducted jointly by Ecology and their consultants and describes "general channel migration zones" as determined using a "streamlined method" that relies on LiDAR Digital Elevation Maps (DEMs) and "Relative Water Surface Elevation" (RWSE) maps generated by the team to identify planning-level channel migration zones (pCMZs). No field work was completed as part of the delineations, and no detailed analysis of historical channel migration rates or geotechnical analyses were completed. Please refer to Section 1.2 for more details on the methodology used for this study.

At the time this report was generated it was intended to provide a guideline for identifying areas where more detailed channel migration zone studies might be needed. No additional work has been completed since the report was generated as a Draft document in 2011. The report is being finalized in 2018 with minor edits to correct typos and provide clarification. Physical conditions along the streams and rivers evaluated may have changed substantially in places since 2011; therefore, appropriate judgment should be applied to the use of the conclusions, recommendations, and opinions presented in this report.

Chapter 2 Regulatory Context

The Shoreline Master Program (SMP) Guidelines are state standards that local governments must follow in drafting their shoreline master programs (See Appendix B for regulations relating to CMZs). The Guidelines translate the broad policies of the Shoreline Management Act (RCW 90.58.020) into standards for regulation of shoreline uses.

The Shoreline Management Act (SMA) provides for the protection of ecological functions while allowing for reasonable and appropriate uses (RCW 90.58.020). It also describes the responsibilities and relationship between local and state government.

The SMA “establishes a cooperative program of shoreline management between local government and the state. Local government shall have the primary responsibility for initiating the planning required by this chapter and administering the regulatory program consistent with the policy and provisions of this chapter. The department shall act primarily in a supportive and review capacity with an emphasis on providing assistance to local government and on insuring compliance with the policy and provisions of this chapter” (RCW 90.58.05).

The Washington State Shoreline Master Program guidelines, administered through the Washington Department of Ecology (Ecology), identify channel migration zones as critical freshwater habitats. Guidelines for Shoreline Master Program updates requires that local jurisdictions identify potential conflicts along shorelines based on current and projected use (WAC 173-26-201(3)(d)(ii)). Specifically, channel migration zones are to be identified as part of an inventory of shoreline conditions (WAC 173-26-201(3) (c) (vii)).

The purpose for identifying Channel Migration Zones is described in the rules governing flood hazard reduction in the general master program provisions (WAC 173-26-221):

“Over the long term, the most effective means of flood hazard reduction is to prevent or remove development in flood-prone areas, to manage storm water within the flood plain, and to maintain or restore river and stream system's natural hydrological and geomorphological processes...

The dynamic physical processes of rivers, including the movement of water, sediment and wood, cause the river channel in some areas to move laterally, or "migrate," over time. This is a natural process in response to gravity and topography and allows the river to release energy and distribute its sediment load. The area within which a river channel is likely to move over a period of time is referred to as the channel migration zone (CMZ) or the meander belt. Scientific examination as well as experience has demonstrated that interference with this natural process often has unintended consequences for human users of the river and its valley such as increased or changed flood, sedimentation and erosion patterns. It also has adverse effects on fish and wildlife through loss of critical habitat for river and riparian dependent species. Failing to recognize the process often leads to damage to, or loss of, structures and threats to life safety.

Applicable shoreline master programs should include provisions to limit development and shoreline modifications that would result in interference with the process of channel migration that may cause significant adverse impacts to property or public improvements

and/or result in a net loss of ecological functions associated with the rivers and streams.”
WAC 173-26-221(3).

WAC 173-26-201(3) (c) (vii) states that local government shall, at a minimum, and to the extent such information is relevant and reasonably available, collect the following information: General location of channel migration zones, and flood plains. Ecology interprets this requirement to mean that a channel migration map will be developed. The guidelines only require that the general location be identified based on existing data rather than identifying channel migration zones based on detailed channel migration assessment.

The regulations provide limited guidance for collecting information on the general location of channel migration zones:

“The channel migration zone should be established to identify those areas with a *high probability* of being subject to channel movement *based on the historic record, geologic character and evidence of past migration*. It should also be recognized that past action is not a perfect predictor of the future and that human and natural changes may alter migration patterns. Consideration should be given to such changes that may have occurred and their effect on future migration patterns.

For management purposes, the extent of likely migration along a stream reach can be identified using evidence of active stream channel movement over the past one hundred years. Evidence of active movement can be provided from historic and current aerial photos and maps and may require field analysis of specific channel and valley bottom characteristics in some cases. A time frame of one hundred years was chosen because aerial photos, maps and field evidence can be used to evaluate movement in this time frame.” WAC 173-26-221(3).

The federal regulatory and legal environment also recognizes the importance of channel migration areas and their relationship to critical habitat in the Puget Sound. The Washington Forest Practices Habitat Conservation Plan, authorized under the Endangered Species Act, provides authorization for incidental take of listed fish species provided that authorized forest practices are followed. Forest practices regulations define the channel migration zone as an area where the active channel of a stream or river is prone to move and the movement results in a potential near-term loss of riparian function and associated habitat adjacent to the stream (WAC 222-16-010). Although the definition of the CMZ used in the forest practices regulation is similar to the definition used in the SMP, the forest practice rules include the near-term loss of riparian function and habitat as part of the definition. Under the Forest Practices regulations, no timber harvest, road construction or salvage is permitted within CMZs except for the except for the construction and maintenance of road crossings and the creation and use of yarding corridors in accordance with applicable rules (WAC 222-30-020(12)).

More recently, the National Marine Fisheries Service (NMFS) Biological Opinion declared the Federal Emergency Management Agency (FEMA) floodplain management program results in a “take” of Puget Sound Chinook salmon, steelhead and Orca whales (NMFS 2008). NMFS opinion allows for reasonable and prudent alternatives to be implemented that would avoid the likelihood of jeopardizing the continued existence of listed species or result in destruction or adverse modification of critical habitat. NMFS discussed with FEMA the availability of a reasonable and prudent alternative that FEMA can take to avoid violation of the Endangered

Species Act section 7(a)(2) responsibilities (50 CFR 402.14(g)(5)). FEMA lists the Washington State Shoreline Master Program updates as a reasonable and prudent alternative to implementing the channel migration requirements of the biological opinion.

Chapter 3 Landscape Context

The topography, geology, climate, soils, vegetation, and land use characteristics for an area collectively describe the landscape context for hydrologic and geomorphic processes. These basin-scale conditions exert physical controls on characteristics such as valley slope, stream discharge, sediment load input, and bank material composition. This section presents the generalized landscape context for the study area to provide background information on the basin-scale conditions and processes affecting channel migration.

3.1 Topography

The area of Clallam County evaluated in this study includes three distinct physiographic zones located in water resource inventory areas (WRIAs) 18 and 19, with a single outlier in WRIA 20. The first two zones are on the northern slope of the Olympic Peninsula and the third is in the interior lowland and western coastal area. See inset map in Figure 3.1 showing the locations of these physiographic zones. The Olympic Mountains and streams flowing into the Pacific Ocean lie outside of the area evaluated in the EPA funded study.

WRIA 18 – 19: The first physiographic zone is situated along the eastern lowland plain. Streams in this area flow northward across a broad low relief area and into the Strait of Juan De Fuca. The coastal plain that defines this area begins with an abrupt cliff along the Strait of Juan de Fuca and increases gradually to an elevation of about 500 feet. Streams in this area occupy valleys incised into the lowland plain. The headwaters of these streams are located in the higher elevations (Morse Creek) or lower foothills (Lyre R., E. and W. Twin R., and Deep Creek) of the Olympic Mountains.

WRIA 19: The second physiographic zone occupies the western portion of the north slope of the Olympic Peninsula. Streams in this area (the Pysht, Clallam, Hoko, Little Hoko and Seiku Rivers) also drain to the Strait of Juan de Fuca. These streams flow through narrow valleys cut into high-relief uplands and then onto broad alluvial plains adjacent to the Strait of Juan de Fuca. Maximum elevations of peaks in this zone are around 1300 feet and valleys grade to sea level.

WRIA 19 – 20: The third physiographic zone in the study area is the northwest interior and western coast, the area that lies southwest of the Crescent formation (see figure 3.1). Streams in this zone either flow north through deep canyons into the western foothills zone (The upper part of Hoko River and Herman Creek in WRIA 19) or west directly into the Pacific Ocean (Sooes River in WRIA 20). This area has modest relief. Highlands reach elevations of nearly 1000 feet and valley bottoms are around 500 feet. Valleys are typically broad and most were glacially formed.

3.2 Geology

Three principle types of bedrock underlie the study area: highly deformed marine sedimentary rocks of the Olympic Subduction Complex, basalts of the Crescent Formation, and marine sedimentary rocks of the Crescent Group (Figure 3.1).

The highly deformed marine sedimentary rocks of the Olympic Subduction Complex consist of sediment that was deposited on the Juan de Fuca plate and accreted to the base of the North American Plate during subduction of the Juan de Fuca plate (Brandon and Vance 1992). Because

they are highly deformed and often much fractured, these rocks have moderate to high fluvial erosion potential and may be prone to landslides.

The basalt unit of the Crescent formation formed from lava flows in a rift zone on the seafloor during the Eocene epoch (between 34 and 55 Million years ago). Subsequent tectonic processes have uplifted and tilted the Crescent Formation to its current position. The Crescent Formation separates the highly deformed marine sedimentary rocks of the Olympic Subduction Complex from the tilted marine sedimentary rocks of the Crescent Group (Figure 3.1). The basalt is a very hard and dense rock type, and therefore has low fluvial erosion potential. Streams that flow through it occupy steep-walled narrow valleys.

Marine sedimentary rocks of the Crescent Group were deposited during the upper Eocene to Pliocene (55 to 3 million years ago). They are composed of siliciclastic (quartz-based) sediments ranging from mudstones to conglomerate. These sedimentary rocks are typically layered, and oriented in the northwest-southeast direction. (Babcock et al. 1994). Overall this bedrock type has moderate and moderate-high fluvial erosion potential.

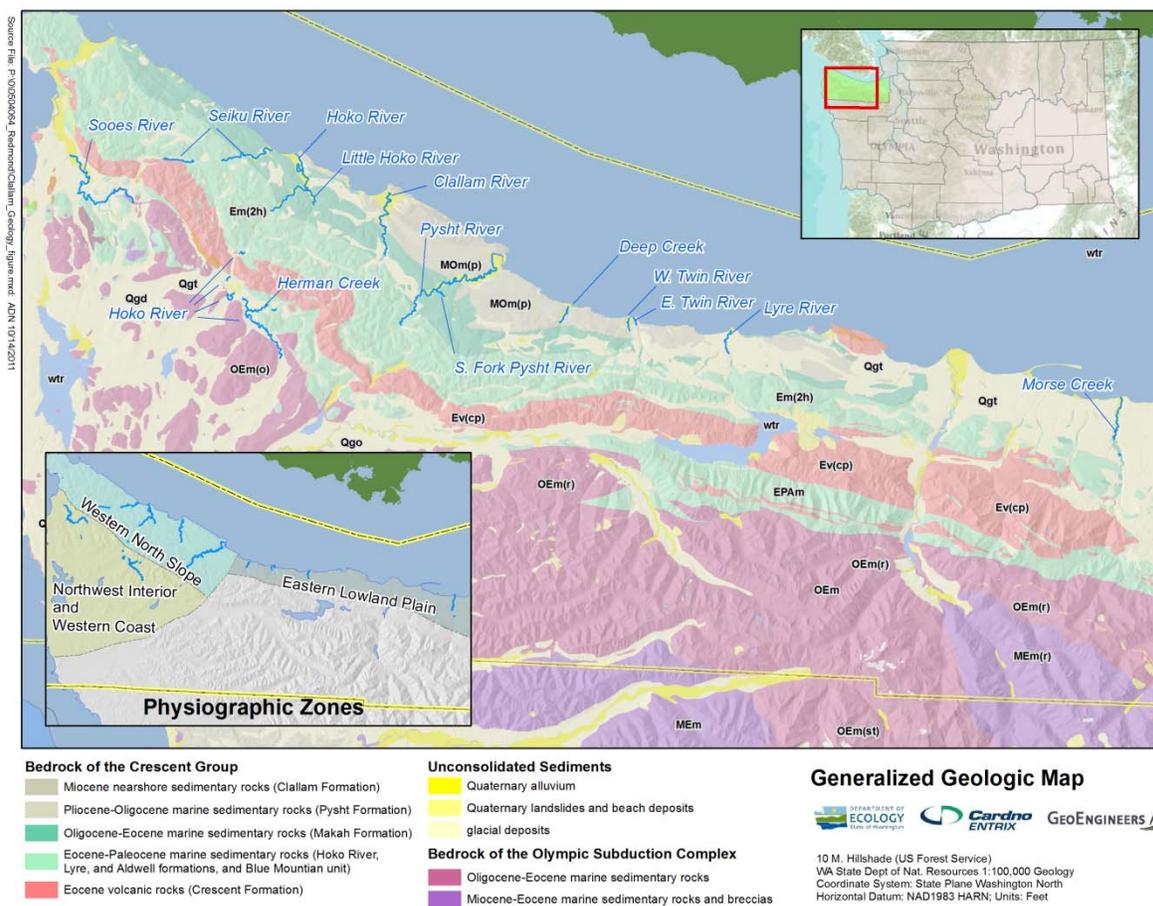


Figure 3.1 General geology and physiographic zones of the Clallam County assessment area.

The modern landscape of Clallam County was primarily formed by glaciation, periglacial processes, and large changes in relative sea level. Continental glaciers advanced and retreated from the study area numerous times during the Quaternary period (approximately the last two

million years). The most recent advance of the continental ice sheet overrode low elevations approximately 15,000 years ago. Extensive glacial deposits cover the lowland parts of Clallam County (Figure 3.1). The Juan de Fuca Lobe of the continental ice sheet filled what is now the Strait of Juan de Fuca. It influenced the landscape to elevations of up to 3000 feet along the north coast of the Olympic Peninsula (Polenz et al. 2004) and flowed over the foothills in the northwest part of the peninsula to the Pacific Ocean. Alpine Glaciers occupied mountain valleys of the Olympic peninsula. With the exception of the glacier that occupied the Elwha R. valley, these alpine glaciers were not connected to the Juan De Fuca Lobe but flowed either west into the Pacific Ocean, or east to merge with the Puget Lobe. Most of the alpine glaciers did not significantly influence streams and stream valleys included in this study.

Glacial deposits in the study area include outwash, drift, and till. Glacial outwash is generally well-sorted sand and gravel deposited by meltwater draining off the glacier. As is described in Table 4.2 glacial outwash deposits have moderate to high fluvial erosion potential. Glacial drift was deposited directly from floating ice masses and has moderate fluvial erosion potential. Glacial till is unsorted sand, gravel, silt, and clay deposited beneath the base of a glacier. Unfractured basal till has low fluvial erosion potential and fractured till has high fluvial erosion potential.

Dramatic changes in relative sea-level elevation from the time of deglaciation to the present have had important effects on stream valleys in the study area. These changes in relative sea level were caused both by fluctuations in the absolute (global) sea level and in the absolute elevation of the local land surface. The weight of the large continental glacier depressed the absolute elevation of the land surface. Following the retreat of the continental glaciers about 13,000 years ago the local land surface was still depressed and the relative sea level along the Strait of Juan de Fuca was 230 feet, or more, higher than present relative sea level. During this period of high relative sea level, streams graded to this higher sea level migrated across the low gradient plain depositing thick alluvial sediment deposits. As the land surface rebounded after the weight of glacial ice was removed, relative sea level dropped to a minimum of about 200 feet below modern sea level (about 11,000 years ago). During this sea level minimum, streams incised deep valleys into the eastern lowland plain zone and western foothills zones. A series of alluvial terraces on valley walls record stream incision as river valley elevations graded to this sea level minimum. After about 11,000 years ago crustal rebound slowed but absolute global sea level continued to rise. This caused the relative sea level along the Olympic Peninsula to rise until it reached current sea level elevation about 6,000 years ago. The valleys that had graded to a much lower relative sea level then filled with alluvial sediment to form the current delta plains along the Strait of Juan de Fuca (Schasse et al. 2004, Polenz et al. 2004, and citations therein). This alluvial valley fill is highly erodible and forms a very low relief surface. Streams therefore may readily migrate across the whole valley bottom. Stream reaches up gradient from the effects of sea level fluctuation, are largely controlled by bedrock; these reaches have slowly incised since retreat of the glaciers and continue to degrade to the present day (Polenz et al. 2004).

Although the extent of alluvial valleys near the Strait of Juan De Fuca was largely defined by the relative sea level minimum approximately 11,000 years ago, considerable erosion of valley walls may still be possible when streams meandering across the valley bottom come into contact with valley walls, especially where those walls are composed of weak bedrock or unconsolidated glacial sediments.

3.3 Precipitation and Runoff

Climatic conditions in Clallam County are characterized by seasonal variations with cool, wet winters and generally dry summers. There is a very strong precipitation gradient across the county. Rainfall in the northwestern foothills along the Pacific coast averages up to 140 inches per year while rainfall in the extreme northeast part of the county averages as little as 15 inches per year (Daly 2000).

Rainfall is the dominant form of precipitation affecting surface runoff and streamflow characteristics. High flows typically persist through the winter and peak flows are generated by winter storms. Snowfall is uncommon in the lowland areas but accumulates in the mountains during winter. Snowmelt contributes to spring runoff volumes for streams draining the Olympic Mountains but does not raise flows to flood stages.

Extreme flood events occur in response to episodic events known as atmospheric rivers or “the pineapple express”. These narrow plumes transport large amounts of moisture directly from the subtropics and produce large amounts of precipitation. Recent studies indicate that extreme flood events in Western Washington have increased in frequency and magnitude during recent decades and suggest a likelihood that this trend will continue under projected climate change scenarios (e.g., Abbe et al., 2008; Tohver and Hamlet, 2010). Increased storm frequency and magnitude may increase high flows that may in turn increase frequency and extent of channel migration.

Chapter 4 Streamlined Method

This chapter describes the streamlined method developed for determining general or ‘planning-level’ CMZs for the SMP update process. This section is not intended to be used as guidance for delineating CMZs, but rather to describe the methods used in estimating the general pCMZs mapped in this report. The delineations were conducted by trained geomorphologists, reviewed by three licensed geologists each with over 25 years of geomorphology expertise, and approved by the Department of Ecology consistent with the QAPP developed for the EPA grant (Appendix D).

4.1 Definitions

This report uses language specific to the field of geomorphology as well as terms and acronyms specific to the streamlined method developed for this investigation. To provide context for the reader, this section will define some of the terms specific to this report. For definitions of other technical terms, refer to the glossary of terms and acronyms in Appendix A.

As explained in Chapter 1, the streamlined method developed for the general pCMZ delineations included in this report differs from the more detailed method described in Rapp and Abbe (2003) and by the Department of Ecology. The streamlined method only uses available remote-sensed data, is less quantitative, does not rely on field-verified data, and is therefore much less specific than the other more detailed methods. In order to avoid confusion with the terms used in Rapp and Abbe (2003), this report used different terms to describe similar phenomena. Table 4.1 lists the terms used in this report as well as the similar terms from Rapp and Abbe (2003).

Table 4.1 Terms used in this report and similar terms used in Rapp and Abbe (2003).

Term used in this report	Definition	Similar term used in Rapp and Abbe (2003)
Active channel corridor	The active channel corridor, as defined for this method, generally corresponds to the meander belt of the active channel (unvegetated area) and has a width approximating the meander amplitude of the analysis reach (See Figure 4.4)	Historical Migration Zone (HMZ)
Avulsion Hazard Areas	The area in the floodplain at risk of avulsion	Avulsion Hazard Zone (AHZ)
Erosion Hazard Buffer	The area added to the active channel corridor as a basis for the CMZ. It is based on ½ to 1 width of the active channel corridor and adjusted based on local conditions including geology, soils, geomorphology, vegetation, etc. See Figure 4.4 for an illustration.	Erosion Hazard Area (EHA)
Disconnected Channel Migration Zone (DCMZ)	The area located in CMZ where publicly maintained man-made structures restrict channel migration. The specifics are outlined in WAC 173-26-221(3)(b).	Disconnected migration area (DMA)

<p>General Channel Migration Zone (CMZ)</p>	<p>The result of the streamlined process described in Chapter 5 includes the erosion hazard buffer and the avulsion hazard buffer. Based on the SMP definition: Channel migration zone (CMZ) means the area along a river within which the channel(s) can be reasonably predicted to migrate over time as a result of natural and normally occurring hydrological and related processes when considered with the characteristics of the river and its surroundings.” (WAC 173-26-020(6)). Also referred to as pCMZs.</p>	<p>CMZ=HMZ+AHZ+EHA-DMA</p>
<p>Geotechnical setback buffer</p>	<p>Channel and terrace banks at risk of mass wasting due to erosion of the toe were assigned a geotechnical setback buffer. For this study, geotechnical buffers were applied to the channel migration zone delineation where there was an elevation difference of 25 feet between the water surface as designated in the RWSE and the elevation of the delineation. Geotechnical buffers indicate where additional geotechnical review should be conducted in the field to determine the width of the geotechnical buffer.</p>	<p>Geotechnical Setback (GS)</p>
<p>Alluvial Fan</p>	<p>A low, outspread mass of loose materials (sand, cobbles, boulders), with variable slope, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain or upland valley; or where a tributary stream is near or at its junction with the main stream. Alluvial fans were delineated from LiDAR and DEM maps for this project (See Section 4.4 (6) below).</p>	<p>Not part of Rapp and Abbe (2003)</p>
<p>Potential Inundation Zone (PIZ)</p>	<p>Areas of the valley bottom that are at or below the approximate water surface elevation as indicated on the RSWE map. These areas are likely subject to inundation when there is an over-bank flood.</p>	<p>Not part of Rapp and Abbe (2003)</p>

4.2 Stream Selection

Puget Sound streams within Mason, Skagit, and Clallam Counties were selected for streamlined channel migration assessments based on several criteria including:

- Puget Sound SMP update schedule
- Channel confinement, gradient, and floodplain
- Erosion potential of stream banks and floodplains
- Evidence of channel movement
- Land Ownership

- No existing CMZ delineations

A report describing the method used by the Department of Ecology (Ecology) to select streams for channel migration assessment is attached as Appendix C and includes more detail on the selection criteria for segments analyzed. Figure 4.1 shows the streams assessed for Clallam County along with their associated basins. Approximately 40 miles of streams in Clallam County WRIAs 18 – 20 were assessed. This assessment is not intended to cover all streams that may have channel migration zones, thus streams not included may still be subject to channel migration. Most of the streams on federal lands (primarily Olympic National Park) were not included, and many of those certainly experience channel migration. The EPA grant only covers streams flowing into the Puget Sound region. With the exception of Sooes Creek (WRIA 20), the maps and report does not cover the Clallam County streams that flow into the Pacific Ocean. Those will be assessed separately.

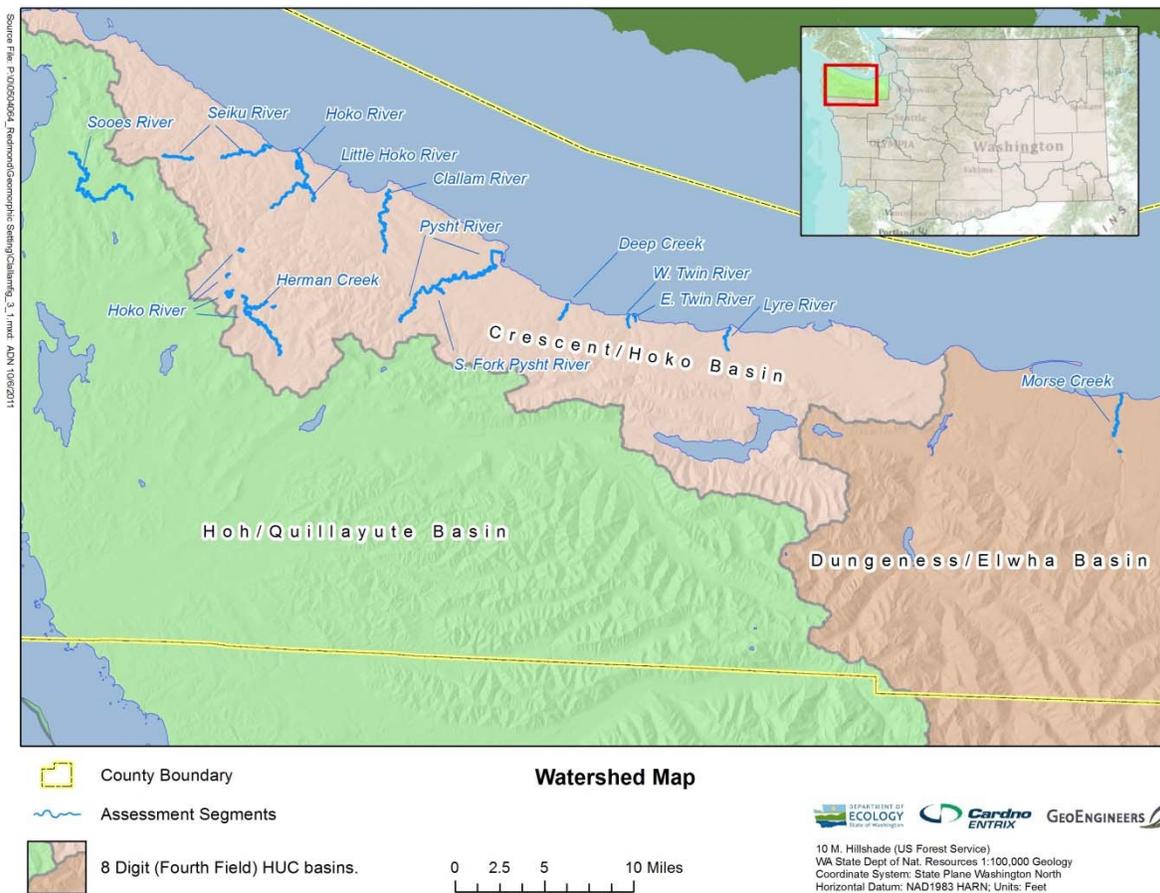


Figure 4.1. Streams selected for assessment in Clallam County. Some streams on federal lands were not assessed.

4.3 Data Sources and Processing

The method developed for this report is a streamlined approach that primarily relies on recent air photos and LiDAR ‘bare earth’ digital elevation models (DEMs) to estimate the area where stream channels have a high probability of moving given current hydrologic and geomorphic conditions. LiDAR DEMs typically have a horizontal resolution of 2 m (pixel size) and sub-

meter vertical accuracy, although in heavily vegetated areas vertical accuracy can be in error by over a meter. LiDAR accuracy is more than sufficient for purposes of this analysis. LiDAR-based DEMs show much more detail than USGS 10m DEMs; geomorphic features such as channels, alluvial fans, landslides scarps, and infrastructure such as roads and railroad beds are clearly displayed even for smaller streams that are obscured by vegetation (Figure 4.2).



4.2. Example of LiDAR map with geologic map overlay (above) and aerial imagery (below) from Clallam River showing

Figure

features visible on a high-resolution DEM including stream channels, roads, and development. Note that the topography and stream channel are clearly visible on the LiDAR map.

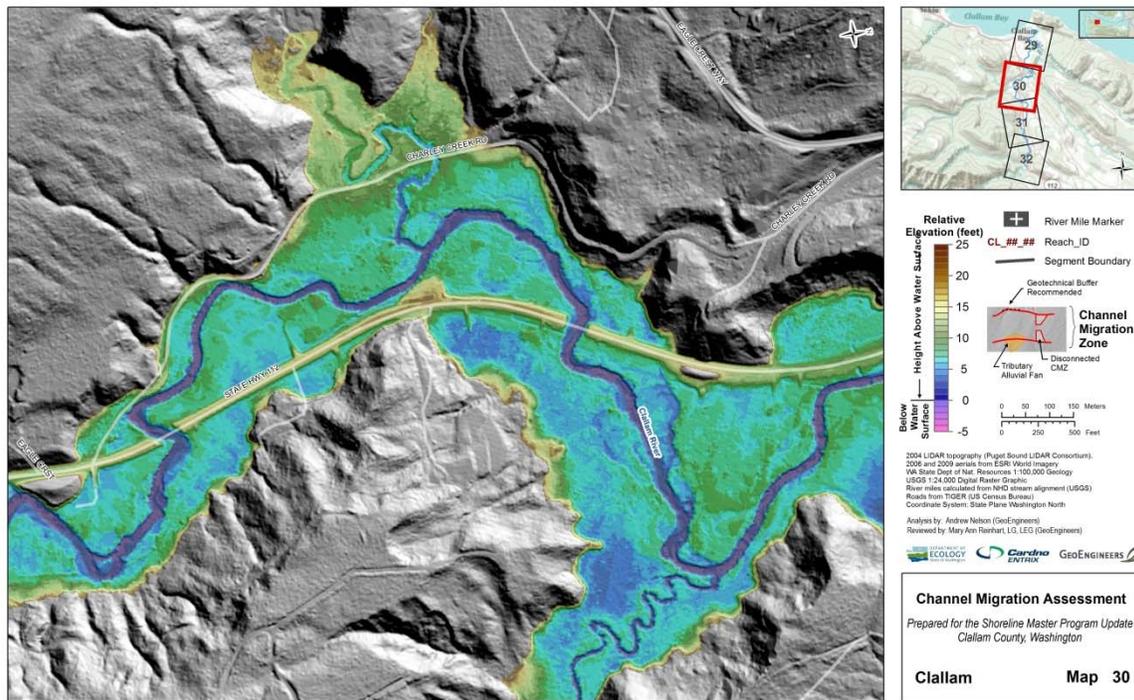


Figure 4.3. Relative Water Surface Elevation (RWSE) map for the same section of Clallam River as Figure 4.2.

The high resolution (2m) LiDAR DEMs were further processed to create a derived product used to determine the elevation of the floodplain relative to the water surface elevation in the channel. This map product is referred to as a detrended DEM, height above water surface (HAWS), relative water surface elevation (RWSE), and relative surface elevation (RSE) model, and was described by Jones (2006) for its utility in identifying side channels and other alluvial landforms along a stream corridor. This report will refer to the results as RWSE maps. RWSE maps were developed by Ecology by a methodology described in Appendix D. Figure 4.3 is the RSWE map for the same section of Clallam River shown in Figure 4.2.

Multiple geomorphic features can be distinguished on the RWSE map including relic or pre-historic channels, alluvial fans, floodplains and terraces, wetlands, infrastructure such as road beds, fill, and drainage ditches in relation to the stream profile. Low lying areas that lie close to or below the stream’s water surface can be quickly called out to identify potential areas of flooding or future channel pathways (locations of potential avulsions). These high resolution DEMs provide an accurate means of identifying alluvial landforms that were created since the Puget Lowland glaciation ended 10,000 years ago. The maps also provide a means of determining if a stream valley is still actively widening erosional arcs in valley hillslopes are visible that have similar radii of curvature as the current stream. These features are particularly obvious in cases where the stream is up against the valley hillslope (See Figure 4.6). Sites with active valley widening means the pCMZ not only includes the entire valley but extends into the

valley hillslopes. In such cases, the streamlined assessment calls out the need for additional geotechnical investigation to determine the extent of a geotechnical setback buffer, which describes the extent to which river erosion affects landslide hazards (by eroding the toe of the slope). Although geotechnical buffers are not described in the regulations for CMZs, they were included because they indicate where potential hazards associated with CMZs extend beyond the boundary of the general delineation.

Aerial imagery shows features such as vegetation, development, land-use, landslides, unvegetated banks (possibly eroding), large woody material in the channel, sediment bars, oxbow lakes, and stream location relative to other features (Figure 4.2). Sequential photos can reveal erosion rates. The streamlined assessment utilized aerial imagery available on the internet (Google Earth and Bing) that generally dates back approximately 20 years. Additional older images for most of the project area are available from the Puget Sound River History Project website (<http://riverhistory.ess.washington.edu/>) and the USGS, although not all are georeferenced for use in GIS. Some imagery is available from the 1930s, giving a 70 to 80-year period of reference. Most of the older imagery is lower resolution than modern aerial imagery and can be of limited use for smaller streams. Government Land Office maps from the late 1800s are sometimes available and can provide valuable information on whether major changes in channel planform or location occurred on larger streams. Where needed, these older images provided additional information on migration processes.

Geology and soils layers were consulted to provide information on the erodibility of the channel banks and floodplain. Different types of deposits have differing relative resistance to erosion, which influences the potential for channel migration. Table 4.2 displays common surface deposits and their erosion potential, which was used to help estimate channel migration where those deposits occurred.

Table 4.2 Surface geology and erosion potential.

Surface geology deposits	Fluvial erosion potential
Holocene alluvial and active alluvial fan deposits; landslides; peat; glacial deposits—recessional outwash, outburst flood, recent volcanic deposits—lahars, ash	High
Glacial—coarse undifferentiated drift and fractured till, terraces (coarse grained), advance outwash such as the Esperance sands, or coarse clasts	Moderate High
Undifferentiated glacial drift with clay matrix (Pleistocene or older alluvium and alluvial/debris fans, landslides), terraces with clay matrix	Moderate
Basal till	Low

Bedrock along streams is generally considered a geologic control on channel migration. However, coarse sediment during transport can erode bedrock (Sklar and Dietrich 2001, 2004; Montgomery 2004), but not at rates that were likely to be significant for this assessment. Less

resistant bedrock such as glacial and debris flow deposits, however, can experience significant erosion and be subject to channel migration.

Alluvial soils comprising floodplain and terrace banks directly influence channel morphology and erosion rates. NRCS SSURGO soil data were used to estimate the bank and floodplain erosion potentials with soil texture as the primary variable. Soil texture was chosen over other factors because knowledge of soil texture provides an indication of cohesive properties of the banks or floodplains. Also considered was the soil erodibility factor. While this erodibility factor typically relates to upland rill erosion, it also applies to sediment detachment associated with the shear stresses induced by stream flow. Heavily vegetated soils are significantly more resistant to erosion than areas where the vegetation has been disturbed or cleared.

In addition to the data described above, Table 4.3 lists additional sources of data consulted and considered in the CMZ assessment. Data reviewed for the project included GIS layers maintained by the Department of Ecology and aerial imagery available from public sources including Google Earth, which includes a time series of aerial imagery.

Table 4.3 GIS data layers used in mapping general channel migration zones for Shoreline Master Program updates.

Data¹	Source/ custodian²	Scale/ resolution	Purpose
National Hydrography Data	USGS/EPA	1:24k	Base stream location layer for comparison to stream location in aerial photograph time series assessment
Shoreline Management Act (SMA) Suggested Arcs	Ecology	1:24k	Provides location of the upstream jurisdiction point for state shorelines
SSURGO soil data	NRCS	1:24k	Used to evaluate fluvial erosion potential of bank and floodplain soils. Soils with greater than 30% sand were considered to have high fluvial erosion potential.
Washington State Geology	DNR	1:100k	The geology layer provides information on the relative valley wall and slope stability in relation to fluvial processes. The landslide layer provides information on landslides along stream and stream valleys and potential sediment sources to streams.
Landslides (DGER)	DNR-DGER	1:24k	
Light Detection and Ranging (LiDAR) elevation data	Puget Sound LiDAR consortium	30cm-1m vertical accuracy; 2-meter cell size	LiDAR provides information on channel locations through time and is used to derive a relative water surface elevation maps, evaluating sinuosity, confinement, and channel slope.
DEM 10 m	UW/USGS	1:24k	

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DEM 10-meter hillshade	UW/Ecology	1:24k	The 10-meter DEM is used to evaluate general valley and stream characteristics, for example, valley and stream gradient, valley configuration where LiDAR is not available.
2006, 2009 NAIP orthophotos	National Agricultural Imagery Program	2006 (18 in horizontal accuracy); 2009 (24 in horizontal accuracy)	The orthophoto time series and USGS 24K DRG images are used to identify channel change over time, channel planform (e.g., meandering, multi-channel), changes in riparian vegetation, land use/development, in-channel woody material, and infrastructure such as bridges, roads, railroads, wastewater treatment plants. Publicly maintained state roads and railroads were considered barriers to channel migration and the boundary for disconnected channel migration zones (DCMZ).
DOQQ	USGS	36-inch horizontal accuracy	
Washington State 24K DRG Image Library	USGS	1:24k	
FEMA Flood Hazard Zones	FEMA	1:24k	Location of FEMA 100-year special flood hazard area in relation to valley bottoms and current channel location. Shows estimated location of 100-year flood to help determine potential avulsion pathways and PIZs.
Railroads	WSDOT	1:24k	Provide information on potential channel migration barriers as defined under the Shoreline Management Act and Shoreline Master Program guidelines. Provide registration points for georeferencing maps and aerial photographs. In general, roads and railroads were visible in the aerial imagery, which was used as the primary source for infrastructure location relative to channels.
Washington State Routes	WSDOT	1:24k	
Washington State Local Roads	WSDOT	1:24k	

¹All data sources have metadata that meets the Washington State Geographic Information Council Geospatial Data Guidelines or FGDC Content Standards for Digital Geospatial Metadata. See Appendix D (QAPP) for more details.

²State Acronyms: University of Washington (UW); Washington Department of Natural Resources (DNR); Washington Department of Fish and Wildlife (WDFW); Washington Department of Ecology (Ecology); Washington Department of Transportation (WDOT).

4.4 Streamlined Method for Channel Migration Assessment

The general channel migration assessment completed for this study is based on analysis of existing GIS data. The streamlined, planning-level method used for this study differs from more detailed methods such as Rapp and Abbe (2003), which estimates historic channel migration rates, avulsion hazards, erosion hazards, and disconnected CMZ. Rapp and Abbe (2003) or other more specific methods should be used for site-specific investigations to delineate detailed channel migration zones in areas designated in this report as having the potential for channel migration.

The following outlines the procedure used to delineate the areas that have a high probability for channel migration.

1. GIS Database Management

GIS-mapping projects were created to develop the channel migration assessment for each stream in the analysis. Data sources included in the review and delineation are described in the section above. Due to the size of the project area and budget limitations, field data were not collected.

GIS shapefiles were created for the channel migration assessment, as well as for supporting features such the stream line with segment breaks and river miles, alluvial fans and features, geomorphic features, and areas that should have a geotechnical assessment where the channel migration assessment intersects a valley wall or terrace (Table 4.4). Each feature is described in more detail in the sections below. The three counties with the most stream miles to assess under the EPA grant were Mason, Skagit, and Clallam Counties.

Table 4.4 GIS files created for the channel migration assessment.

Filename	File Type	Purpose
[County code] ¹ streams.shp	polyline	Streamline with segment breaks (this layer was adapted from the layer provided by Ecology with the study stream segments, which was based on the USGS hydrography layer)
[County code] landforms.shp	polygon	Alluvial valley and alluvial fans
[County code] features.shp	point	Geomorphic evidence for channel migration
[County code] XS.shp	line	Cross-sections from LiDAR
[County code] CMZ.shp	polygon	Estimated channel migration zone delineation and disconnected channel migration zone protected by certified structure (described in section 5 below)
[County code] geoflag.shp	line	Potential geotechnical hazard requiring further investigation

¹ The [County code] refers to the county where the assessment is being conducted

2. Reach Delineation

Streams were subdivided into geomorphic reaches for the channel migration assessment. Each reach was assigned a unique identifier using the format: [County code] [stream number]

[segment number]. Numbering of geomorphic reaches started at the downstream end and increased in the upstream direction. Criteria considered when delineating reach breaks included:

- a. Changes in gradient (proportional to sediment transport capacity)
- b. Changes in valley width
- c. Tributary inputs (increasing discharge)
- d. Change in channel type
 - i. Braided channels
 - ii. Meandering braided channels
 - iii. Anabranching channels
 - iv. Single thread straight channel
 - v. Single thread meandering channel
- e. Changes in infrastructure or channelization
- f. Changes in geology/erodibility of substrate
- g. Changes in land use pattern

3. Document Reach Characteristics

Physical characteristics of the stream were documented in a data sheet (see completed segment data sheets in Appendix F for each geomorphic reach). The data sheet provides information on the data used to complete the assessment, geomorphic features observed in each reach, stream characteristics, infrastructure, and notes from the analyst and QA/QC review (See Appendix F for more details, and data sheets for each segment as an example). The data sheet provides supporting details for each segment map, and factors considered in the delineation. Some data sheets may contain more or less information, depending on the features present, data included on forms for adjacent segments, and professional judgment.

4. Delineate areas of potential channel migration

The area of potential channel migration was defined for this study as the area with a high probability of channel movement, according to the regulations (WAC 173-26-020(6)). The general channel migration zone includes the active channel corridor, the avulsion hazard areas, and the erosion hazard buffer, which will be explained in detail in this section. Once the general channel migration zone was established, additional features such as potential inundation zones, disconnected channel migration zone, alluvial fans, and the geotechnical buffer were added.

Active Channel Corridor

The active channel corridor, as defined for this method, generally corresponds to the meander belt of the active channel and has a width approximating the meander amplitude of the analysis reach (Figure 4.4). The active channel corridor varies in width depending on the characteristics of the stream channel in a given reach. In some cases, the active channel corridor was difficult to determine and meander amplitudes from other nearby sections of channel were used. For example, in areas where the channel had been modified or straightened, meander amplitudes from nearby reference sections that had not been modified were used instead if the geomorphic characteristics of the reaches were similar.

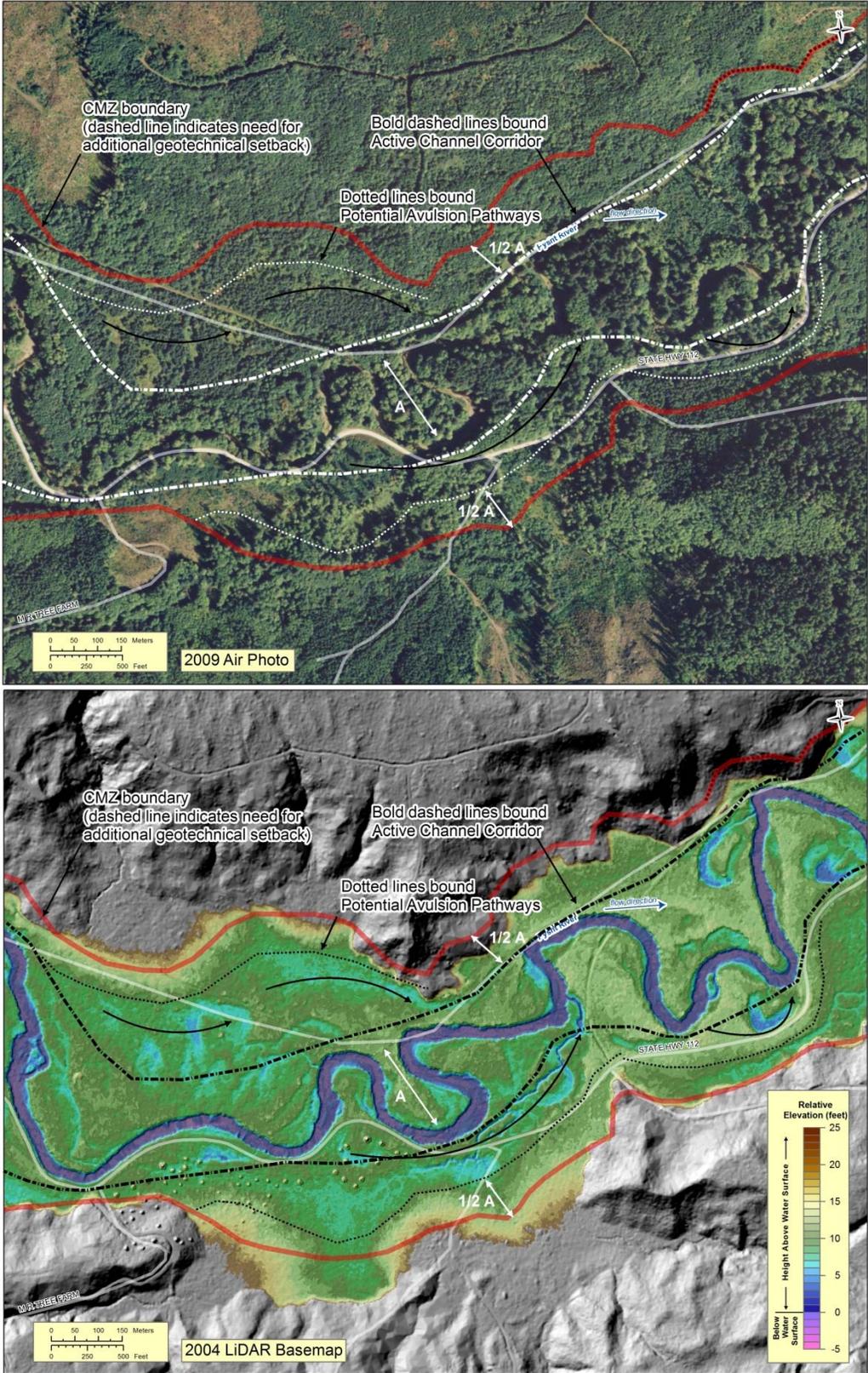


Figure 4.4 Aerial image (above) and RWSE map (below) for Pysht River showing the Active Channel Corridor, potential avulsion pathways, and channel migration buffer.

Avulsion Hazard Areas

Avulsion hazard areas typically occur in side channels or low-lying portions of the floodplain that could be activated if accumulations of wood or sediment were to obstruct and deflect flows laterally, or if flooding were sufficiently intense. Such avulsions are common in streams flowing through forested floodplains around Puget Sound. Accumulations of wood can produce stable structures which alter flow hydraulics and trigger sedimentation on the upstream side (Abbe and Montgomery 1996, 2003, Montgomery and Abbe 2006). Accumulation of sediment in the stream channel (aggradation) increases the potential for channel migration. An example of a recently formed logjam affecting channel migration is shown in Figure 4.5. Rapp and Abbe (2003) discuss the importance of considering vertical channel variability in assessing channel migration and Brummer et al. (2006) recommend that CMZ delineations in forested areas in Washington account for 2 m of vertical variability of the streambed and valley bottom areas within 2 meters (m) of the bankfull elevation are susceptible to channel migration. Potential avulsion pathways and low-lying portions of the floodplain were delineated from the RWSE maps in GIS and included in the channel migration boundary.

Non-meandering streams (defined by a narrow active channel corridor where no bank erosion is apparent) can be subject to avulsions if there is a low-lying area adjacent to the stream and the active channel becomes obstructed by a logjam or landslide deposit, or if the stream is subject to an overbank flood event. If the avulsion channel is situated in a similar context as the main channel, such as forested banks, then a similar erosion hazard area was applied. If a non-meandering stream avulses into a more erosive setting such as agricultural fields lacking forested banks, then the avulsion hazard area would need to be substantially larger than the pre-existing active channel corridor. In this case, the avulsion hazard area was extended the width of the disturbed floodplain.

The avulsion hazard area was delineated if one or more of the following criteria were present: low lying ground that is equal to or below the water surface elevation of the current channel as indicated on the RWSE map, the avulsion path would shorten the length of the stream channel, or the stream was located in an erodible substrate. Additional avulsion factors considered included: presence of relict channels, potential for logjams or landslides to elevate water surface elevations upstream of low-lying areas, evidence of aggradation, and upstream or downstream tributaries that could contribute sediment or floodwaters. Potential avulsion pathways and low-lying portions of the floodplain were delineated from the RWSE maps in GIS and included in the channel migration boundary.

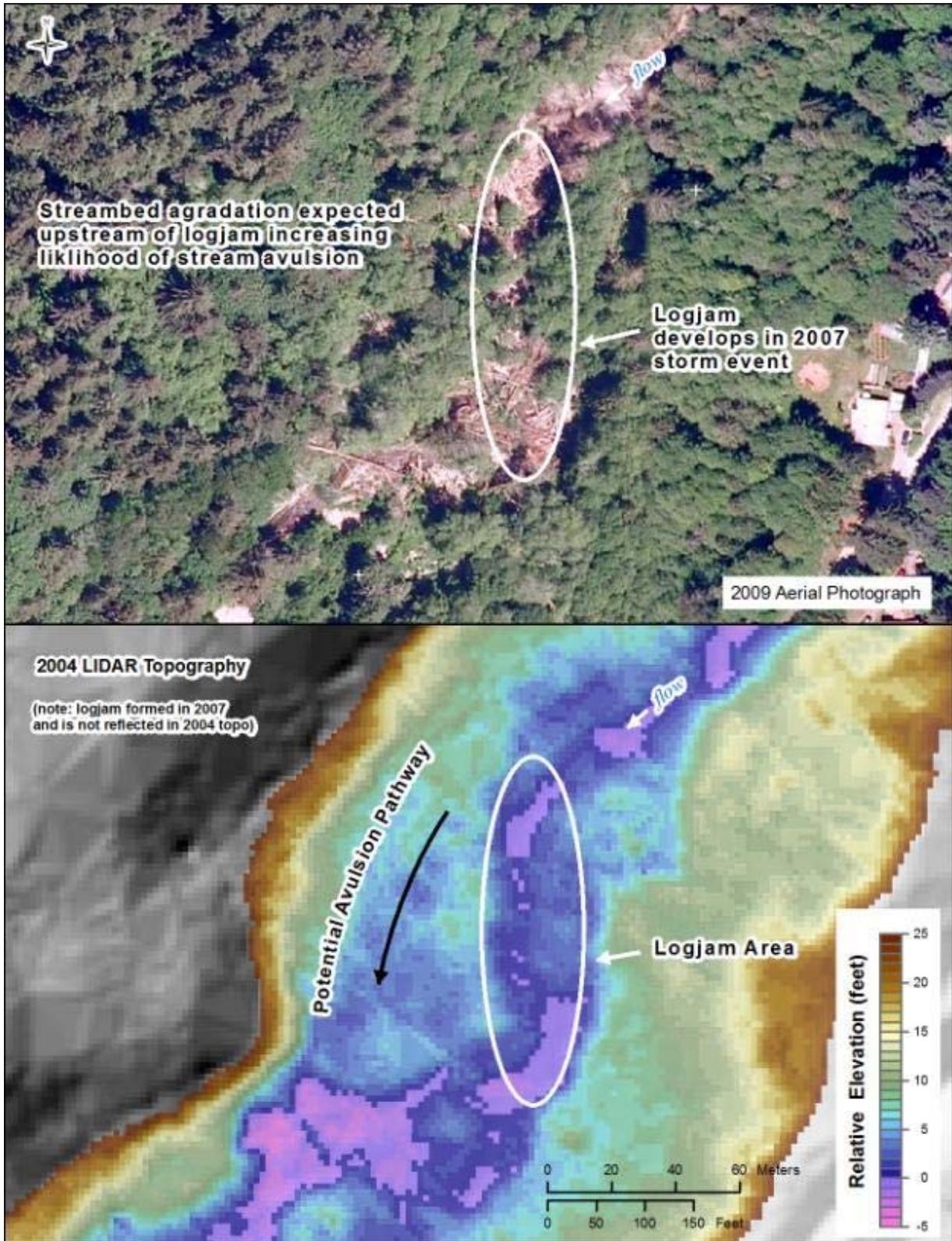


Figure 4.5. Mission Creek near Belfair, Washington provides an example of wood accumulations that trigger channel migration (channel widening and lateral migration). This section of Mission Creek is downstream of the location shown

in Figure 1.1, and may contain some of the riparian woody material removed from the streambank at that location.

Erosion Hazard Buffer

An erosion hazard buffer was applied to account for future channel migration beyond the active channel corridor and potential avulsion pathways. The buffer width was based on the meander geometry of the study reach, topography near the stream, and erodibility of earth materials near the stream (the substrate). In low relief areas with highly erodible substrate the buffer was set at 50% to 100% of the meander amplitude. In areas of modest to high relief and in areas with less erodible substrates the erosion buffer was set at 1 channel width to 50% of the meander amplitude. This buffer width, Figure 4.4, was based on historic activity, professional judgment of assessment team, and erosion hazard considerations presented in King County Critical Area Ordinances for channel migration zones (King County 1999) that are applicable to any stream in Washington State. The width of the erosion hazard buffer was adjusted based on geomorphic conditions in each reach, including rate of recent channel migration, erodibility of the substrate, floodplain development, stream size and power, location in the valley bottom, and geomorphic setting such as an underfit or actively forming valley (described below). The erosion hazard buffer is a mapping action, intended for informational and planning purposes, not a required or recommended regulatory buffer for locating shoreline use and development.

Physical characteristics of the reach informed the decision where the erosion hazard boundary was located beyond the active channel corridor and avulsion hazard areas. Factors considered in this process included:

- Indicators of past channel migration from aerial imagery,
- Floodplain topography such as side channels and oxbows,
- Erosion potential of bank materials based on soils and geologic data,
- Characteristics of the valley margin such as indicators of previous stream erosion,
- Potential influence of wood accumulations or landslides that obstruct and deflect flows and raise water elevations.

Table 4.5 summarizes the general guidelines used for initial delineation of the erosion hazard buffer, which were then adjusted based on the factors described above. The next sections describe typical geomorphic valley types in Clallam County and how they were delineated.

Table 4.5 Decision guidelines used to identify the erosion hazard buffer and geomorphic features

Feature	Guideline
Erosion hazard buffer base width	In low relief areas with highly erodible substrate, set buffer to 50% to 100% of the meander amplitude (Figure 4.4).
	In areas of modest to high relief and in areas with less erodible substrates, set erosion buffer to one channel width to 50% of the meander amplitude.
Avulsion Hazard Areas	Delineate an avulsion hazard area when one or more of the following criteria are present: low lying ground that is equal to or below the water surface elevation of the current channel as indicated on the RWSE map, the avulsion path would shorten the length of the stream channel, and the stream is located in an erodible substrate. Additional

	avulsion factors to consider: presence of relict channels, potential for logjams or landslides to elevate water surface elevations upstream of low-lying areas, evidence of aggradation, and upstream or downstream tributaries that could contribute sediment or floodwaters.
Wetlands	With no defined channel- do not include in CMZ
	With defined channel, include in CMZ
Alluvial Fans	If the channel is on an alluvial fan, delineate the entire alluvial fan as a CMZ. If an alluvial fan falls within valley bottom, delineate as separate alluvial fan.
Small streams without poorly defined or visible channel	Confined- delineate valley bottom as CMZ
	Unconfined or underfit- active channel corridor or valley bottom
Valley edges or terraces	If unconsolidated or easily erodible, include valley edge in buffer and include geotechnical buffer
	If resistant to erosion, look for indicators of past erosion (scallops, etc), and place CMZ boundary at extent of past erosion in valley wall and include geotechnical buffer. Indicators of past valley wall erosion include: scallops in valley walls, slumps, landslides, undercutting.
Potential Inundation Zone (PIZ)	Label areas of the valley bottom that are at or below the approximate water surface elevation as indicated on the RSWE map.
Disconnected Channel Migration Area (DCMZ)	Identify infrastructure in the valley bottom that meet the criteria for barriers to channel migration. In Clallam county, these include railroads and state highways. Delineate area within the erosion hazard buffer and behind the infrastructure as a DCMZ.
Geotechnical setback buffer	If the regulatory CMZ boundary intersects a terrace or valley wall greater than 25ft above the approximate water surface elevation, add geotechnical buffer flag

Actively Forming Valleys

Many streams evaluated by this study have formed the valley in which they flow by incision into an upland surface composed of unconsolidated sediments. These valleys formed during the Holocene period (following the recession of the Puget Ice lobe approximately 10,000 years ago) and continue to expand as the stream episodically erodes the valley margin. A key indicator that a stream valley is actively forming and expanding the valley is the presence of concentric arcs along the valley margin that have a radius of curvature similar to the meander geometry of the adjacent stream. Figure 4.6 illustrates an example of such erosion in an actively forming valley. The stream is presently flowing directly against the hillslope at a 90 degree bend and has eroded a concentric arc into the valley margin. Topography above the stream channel indicates mass wasting (slumps) are occurring and young vegetation visible in the air photo indicates recent instability. This example provides evidence that the stream has sufficient power to erode material

at the valley margin in that section of the river. Note that the valley margin has similar sized arcs in areas up- and downstream where the channel is not flowing against the hillslope. These arcs in the valley margin are evidence that the river migrates across its valley over time and episodically removes sections of the hillslope at the valley margin. Given that such erosion is expected to continue into the future, the channel migration boundary must be set back from the valley margin (into the hillslope) in anticipation of additional valley wall erosion.

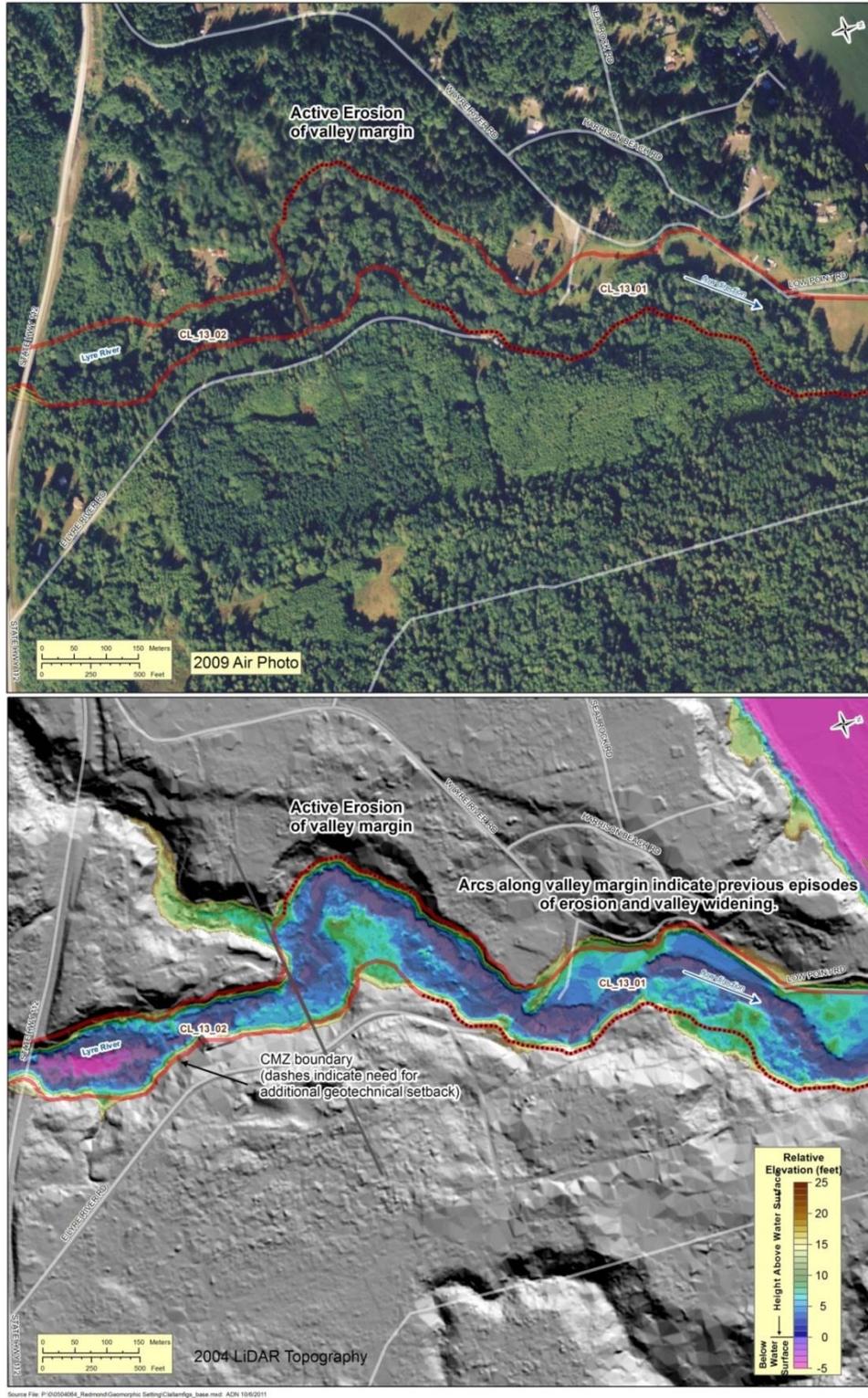


Figure 4.6 Aerial imagery (above) and RWSE map (below) showing a reach on the Lyre River where the stream is actively widening its valley.

Figure 4.7 presents an example of an underfit reach of Sooes River. The lower reaches of Sooes River flow within a valley that was created by a much larger channel that existed during the period of glacial recession. The valley margin has erosional features with a radius of curvature that is much greater than the radius of curvature associated with Sooes River. It is unlikely that the current Sooes River channel migrates across the entire valley in its current regime. As such, the channel migration delineation includes only that portion of the valley within a corridor that encompasses the active channel and an erosion hazard buffer equal to one half of the meander amplitude. The lower gradient of the underfit segment of the channel translates to a lower stream power available to erode the valley margin. Therefore, the channel migration area does not extend into the hillslope, or require an additional geotechnical setback, as indicated for the actively forming valley segment downstream. Clearing vegetation within the floodplain would elevate risk of increasing bank erosion and avulsions, so the assumption is that vegetation will remain intact in low lying areas. In cases such as this highly sinuous reach of Sooes River (Figure 4.7), where the creek has a distinct meander envelope (area defined by outer apexes of meander bends that contains the stream), the channel migration delineation includes only that portion of the valley within a corridor that encompasses the active channel and a migration and erosion hazard buffer equal to one half of the meander amplitude.

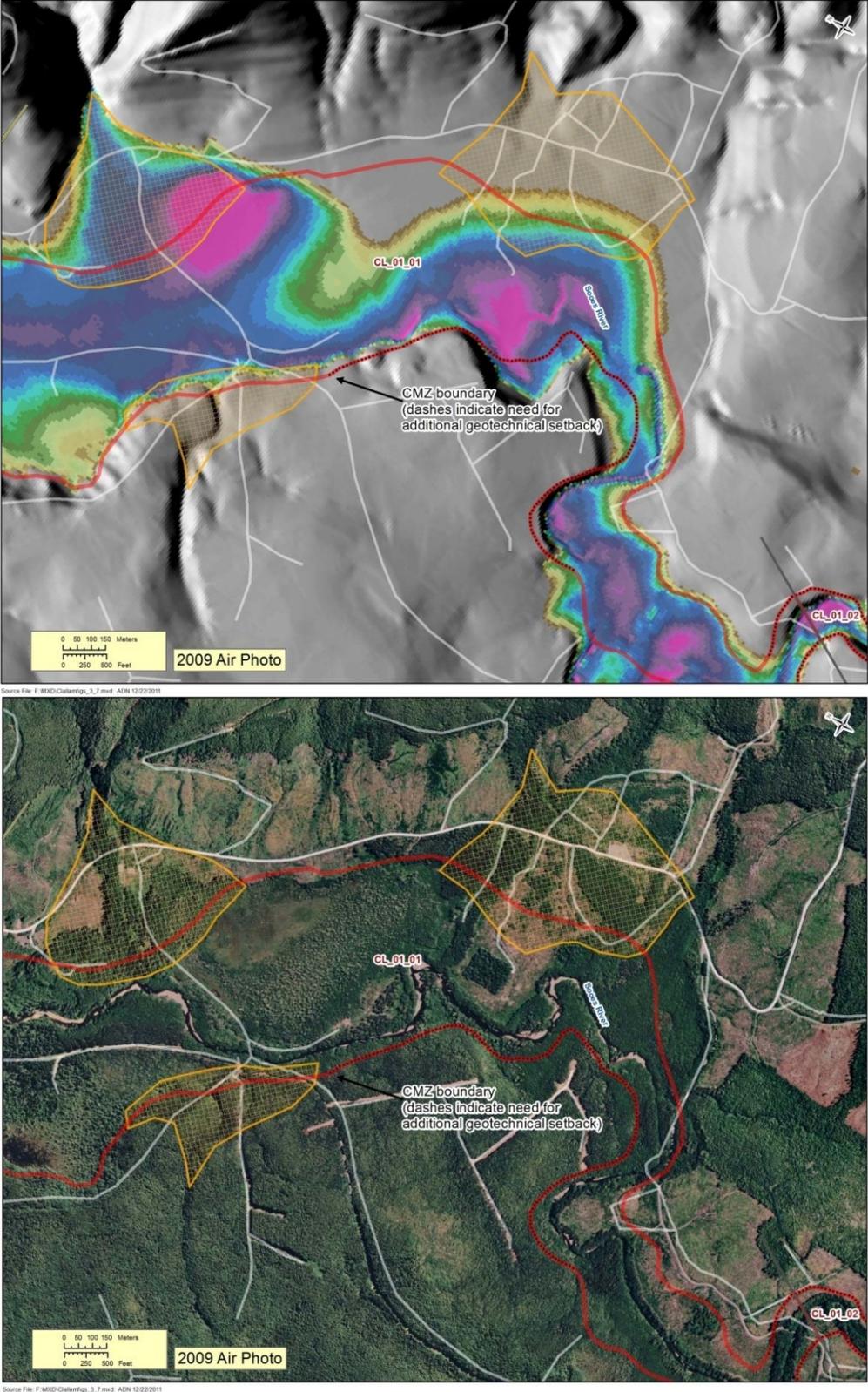


Figure 4.7 DEM hillshade with relative water surface elevation (from 10m USGS DEM) (above) and aerial image (below) for a reach of Sooes River that is considered underfit.

Saltwater Deltas

Figure 4.8 presents an example of a saltwater delta. Many stream segments assessed in Clallam county flow directly into the Strait of Juan de Fuca. The delta environment at the mouth of these streams has a unique set of geomorphic processes operating and, therefore, unique channel migration characteristics. Delta environments are characterized by gradual aggradation of fine sediment. This aggradation causes the stream channel to become elevated above its floodplain and leads to a situation where avulsion is likely. Some erosion of valley walls is possible, but significant erosion is not likely over a 100-500 year time span. The position of the stream mouth is controlled by both fluvial and coastal geomorphic processes. Coastal processes that may influence the position of the streams mouth include movement of longshore bars, beach erosion, and possible future changes in sea level.

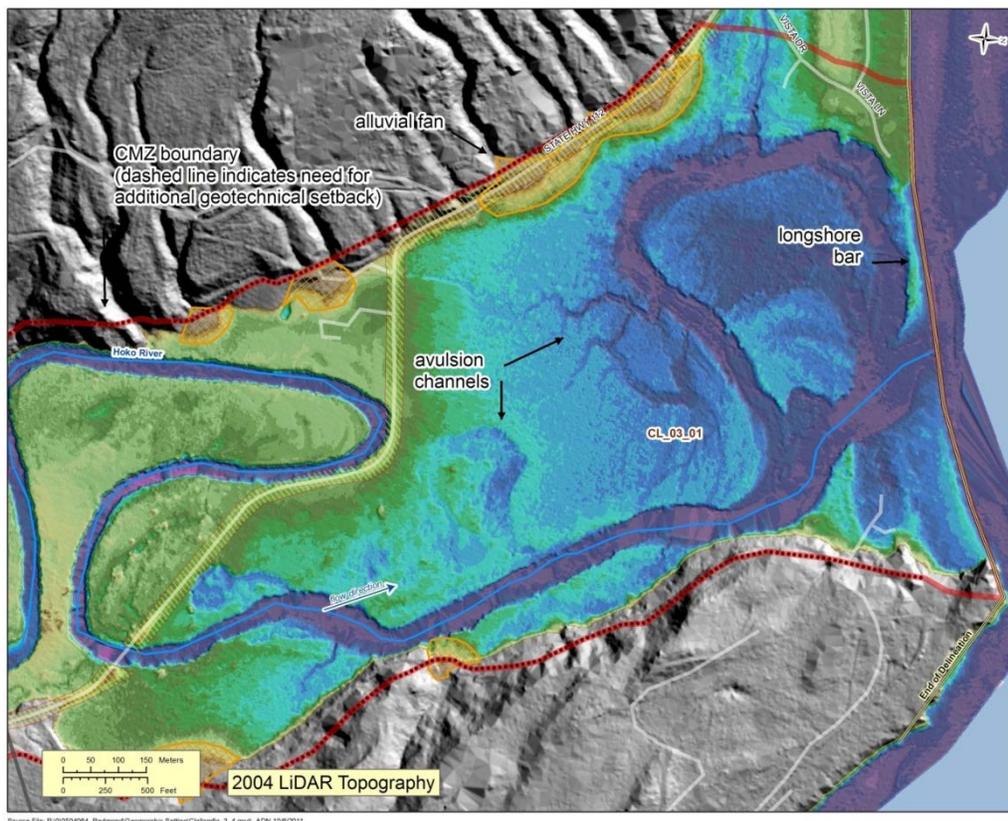


Figure 4.8 RWSE map of the delta of Hoko River showing a typical pattern of avulsion channels. A longshore bar has formed filling in the historical channel to the west of the current river mouth.

5. Identify infrastructure that is likely to affect migration and delineate Disconnected Channel Migration Zone (DCMZ)

Infrastructure construction and land development has commonly occurred in the floodplain and within the channel migration zone. Depending on the type of infrastructure and how it is constructed and the power of the stream, infrastructure can act as a barrier to channel migration or be susceptible to erosion and failure. In the event of a flood or failure, the infrastructure will often be repaired or replaced depending on the importance of the infrastructure and the extent of the damage. In general, only infrastructure with a public agency commitment for maintenance and that are substantial enough to withstand channel migration were considered barriers to

channel migration. Levees that are certified by the U.S. Army Corps of Engineers and state highways are the two cases which we assumed to act as barriers to channel migration. In both these cases, we assume the facilities were built to withstand channel migration or will be repaired in place (though there are cases where facilities have been moved after being damaged). State highways and federal levees and the areas behind them were mapped as DCMZ. See Figure 4.9 for an example of a DCMZ.

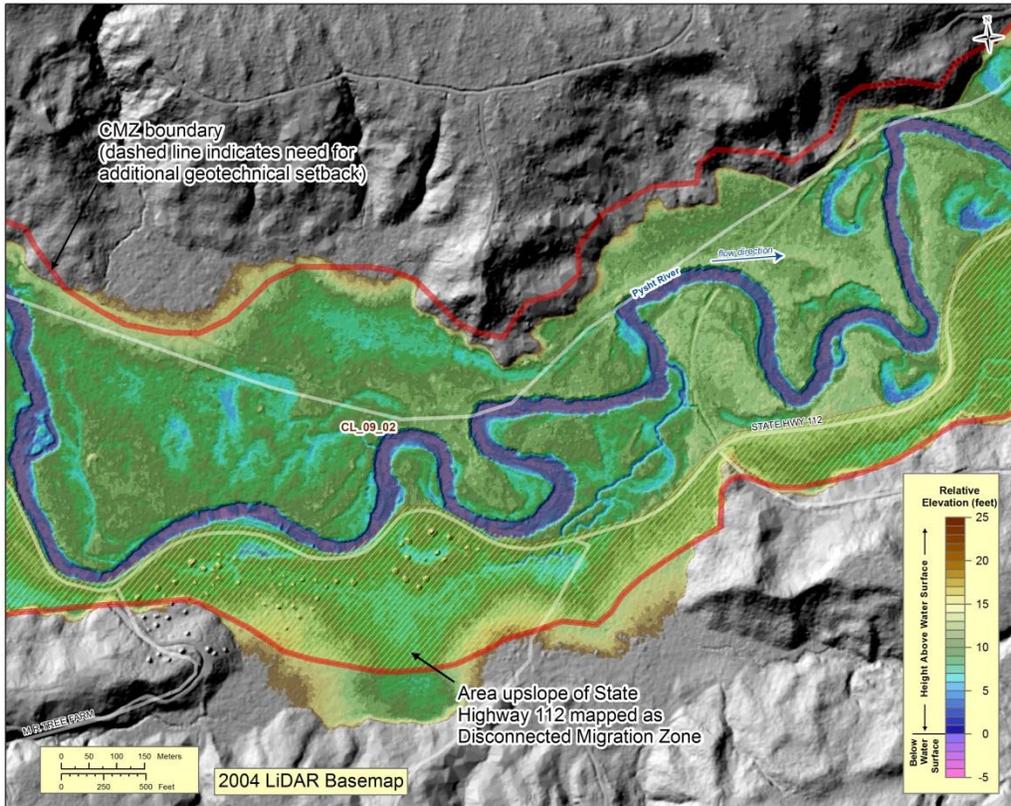


Figure 4.9 Disconnected CMZ along Pysht River. This figure shows the same location as Figure 4.4

A disconnected CMZ identifies an area that would lie within the CMZ if not for the highway or levee, thus helps planners, landowners and others understand that areas in disconnected CMZs would be at risk if the river got through the highway or levee.

The SMP guidelines include infrastructure that may be considered a barrier to channel migration. [WAC 173-26-221\(3\)\(b\) provides criteria for barriers:](#)

- *Within incorporated municipalities and urban growth areas, areas separated from the active river channel by legally existing artificial channel constraints that limit channel movement should not be considered within the channel migration zone.*
- *All areas separated from the active channel by a legally existing artificial structure(s) (as defined in the Shoreline Management Act, RCW 90.58.030, text added for clarification), that is likely to restrain channel migration, including transportation facilities, built above or constructed to remain intact through the one hundred-year flood, should not be considered to be in the channel migration zone.*

In areas outside incorporated municipalities and urban growth areas, channel constraints and flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the channel migration zone unless demonstrated otherwise using scientific and technical information.

Barriers to CMZs that would define disconnected CMZs include existing artificial structures are defined under the Shoreline Management Act definition for floodway (RCW 90.58.030):

“...protected from flood waters by flood control devices maintained by or maintained under license from the federal government, the state, or a political subdivision of the state.”

Little information was available concerning barriers to channel migration in Clallam County that meet the SMP and SMA criteria. Thus, only state roads and active railroads were considered to be the only structures to constrain channel migration.

6. Delineate tributary alluvial fans

Alluvial fans often form along the margins of larger valleys where tributaries enter the valley. Alluvial fans develop over time as the tributary deposits sediment at the location of a sharp reduction in channel gradient such as where a channel comes down from a hillslope into a much flatter valley. The loss in gradient reduces the sediment transport capacity of the tributary and it deposits the coarse sediment it is carrying and aggrades the channel. As the channel aggrades, flows are more likely to leave its banks and find new pathways down to the valley bottom. Sometimes the active channel on an alluvial fan can be 10's of feet above other portions of the fan (a cross-section of a fan shows a convex shape with the stream typically at the highest spot). Given the relief between the stream and the surrounding area, a channel flowing over an alluvial fan is prone to suddenly jump to an entirely new pathway. Once a new channel forms, it may undergo short-term down-cutting, but will eventually begin to aggrade and the process repeats itself, building a convex “fan” on the valley bottom with its apex where the tributary comes out of the confined channel within the adjacent hillslope. Given the process of how alluvial fans form, they are very dynamic landforms subject to frequent and sometimes catastrophic channel migration. The entire surface of an active fan is considered to lie within a CMZ, and thus the streamlined delineation delineated large alluvial fans where they occurred within the valley where a stream was being delineated. The DEM and RWSE maps are usually excellent in revealing the fans. No field surveys or other data were used to delineate alluvial fans, so these streamlined delineations should be considered approximate.

7. Identify areas requiring geotechnical analyses for a geotechnical setback buffer

Once the erosion hazard buffer was delineated, the boundary was evaluated to determine if a geotechnical review was warranted. These areas occur where the edge of the channel migration area intersects a valley wall, terrace, or landform that is greater than approximately 25 feet above the water surface (Figure 4.10). Since ‘erodible’ high ground is no impediment to channel migration, when a channel cuts into high ground it will, by definition, over-steepen the slope. This sets up conditions to destabilize the slope and trigger a slide that can impact a much greater proportion of the hillslope than the toe erosion done by the stream. Since toe erosion can set up the conditions to impact a much greater area, it is important to recognize how channel migration can pose a threat to property located far above the stream (Rapp and Abbe 2003). The Lyre River example of valley expansion (Figure 4.6) was observed in many streams evaluated by this study. Many examples included obvious examples of shallow or deep-seated landslides, both recent and prehistoric that had occurred along stream valleys. The potential channel migration boundary in

reaches where evidence of valley widening is occurring includes the entire valley bottom plus a portion of the valley wall. The streamlined CMZ delineations were not intended to be precise, simply call out areas where a more detailed assessment, including a geotechnical analysis, is needed to determine the geographic extent of the hazard. The area where geotechnical setback buffer is needed is indicated on the maps with black dots in the CMZ boundary line.

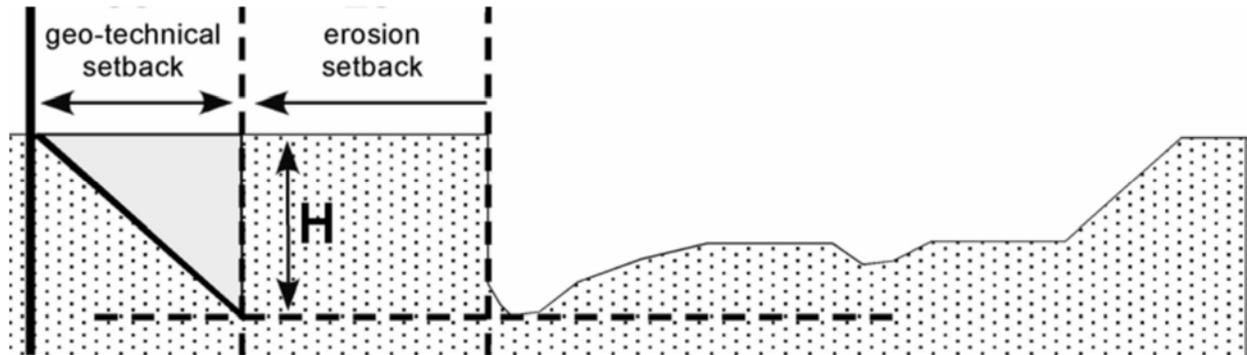


Figure 4.10 Illustration showing the basis for the geotechnical setback buffer. For purposes of this study, a geotechnical buffer was recommended any time H (height) was greater than 25 feet. The width of the geotechnical setback buffer was not determined for this study since it requires additional field data. (From Rapp and Abbe 2003).

8. QA/QC review

The final step in the general CMZ delineation consisted of peer review by senior geomorphologists. Initially, the QA/QC reviewers evaluated the channel migration maps and recommended any changes, if necessary. Then the reviewers met with Ecology and discussed the draft channel migration maps and the individual reviewers' recommendations for changes to the maps. Once changes were agreed upon, the changes were made, and the maps finalized in draft form.

Chapter 5 Quality Control and Quality Assurance

5.1 Quality Assurance Project Plan (QAPP)

As part of the EPA grant, Ecology prepared a Quality Assurance Project Plan (Appendix D) that describes the project and the quality control procedures in place for the entire study, which includes additional components to review existing CMZ delineations to see how they have responded to flood events since the delineation was conducted, and to update CMZ delineation methods based on new information. In addition to the data quality control in place by Ecology, quality control and assurance procedures employed for this phase of the project included analyst training, documented review of all delineation products by senior geomorphologists, and review by Ecology. The QAPP included in Appendix D was under review by EPA in 2011, then subsequently approved and published as final in 2012.

5.2 Limits of Analysis and Utility

As described above, this is a streamlined assessment that used available remote-sensed data as a basis for delineating areas of potential channel migration. It should be noted that the boundary line is an approximation - it does not represent a sharp boundary where one side of the line is subject to channel migration, and the other side is immune. Although LiDAR data and the derived RWSE map are powerful new tools for analyzing geomorphic features, they are not a substitute for field data collected on the ground. Therefore, this assessment should only be used as guidance as to where more specific channel migration and geotechnical studies should be conducted if development is planned within the approximate pCMZ boundaries established by this study.

This report has been prepared for Washington State Department of Ecology and is intended to assist in planning and updating Clallam County's Shoreline Master Program.

Within the limitations of scope, schedule and budget, Ecology and the Consultants services have been executed in accordance with generally accepted practices in the field of geomorphology and hydrology/hydraulics in this area at the time this report was prepared. The methods used to delineate the pCMZ's depicted in this report were developed in coordination with Washington State Department of Ecology and provide preliminary maps that comply with SMP guidelines, assist with planning and indicate areas where additional data and analysis should be conducted if a more detailed delineation is needed. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

Any electronic form, facsimile or hard copy of the original document (email, text, table and/or figure), if provided, and any attachments should be considered a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.

Chapter 6 Results and Sub Basin Descriptions

The results of the study include maps with relative surface elevations, general channel migration zones, disconnected CMZ, alluvial fans, geomorphic features, and areas where geotechnical buffers are recommended. Data sheets include notes on the physical characteristics and the geomorphology of each reach. This section summarizes the general geomorphic character of the streams within the study area.

Streams assessed in this study represent a variety of stream types and occur in drainage basins that range in size between 6 and 70 square miles in area. Key differences in geomorphic characteristics of individual streams affected the channel migration assessment. As described in Chapter 4, consideration was given to channel gradient, planform geometry, valley confinement, and geology. Streams flowing through an erodible substrate were assumed to have the potential for channel migration given adequate sediment supply and stream power for bedforms such as alluvial bars to develop. Brief basin summaries are presented here to provide general context and to summarize the information conveyed in the maps and data reports prepared in the analysis.

Stream characteristics vary between the three physiographic zones described in Chapter 3 (see Figure 3.1). The following sections describe geomorphic characteristics observed and processes operating in each physiographic zone that affects channel migration.

6.1 WRIA 18 – 19: Streams in the eastern lowland plain physiographic zone

Morse Creek, Lyre River, East and West Twin River, and Deep Creek all flow through lowlands along the Strait of Juan de Fuca that were shaped by Quaternary glaciation (see Chapter 3). These lowlands are covered in significant glacial deposits. As described in section 3.2, relative sea level history has had significant control over valley forming processes in this area. These streams incised steep walled valleys through marine sedimentary rocks of the Crescent Group to a base level approximately 200 feet below modern sea level. Aggradation associated with increasing relative sea level over the past 6,000 years has filled the lowest reaches of these river valleys with highly erodible alluvial sediment. Currently, channel migration in the lower parts of these stream valleys is caused by sediment deposition in the channel that forces lateral movement across the highly erodible low gradient alluvial plains the streams occupy. Where the channel abuts valley walls, significant erosion is possible, and the streams may undercut and destabilize banks leading to landslides in the valley margins (see Figure 4.6 for an example of one stream in this area where this process is occurring).

Upstream reaches of these creeks lie on marine sedimentary bedrock of the Crescent Group with a thin alluvial veneer. Here streams are degrading and actively eroding the generally weak bedrock of their valley margins to widen their valleys (Schasse et al. 2004). Channel migration occurs in response to the influx and deposition of sediment including periodically significant mass wasting events. Migration is facilitated by the width and topography of the valley bottom and by the presence of erodible of valley wall material.

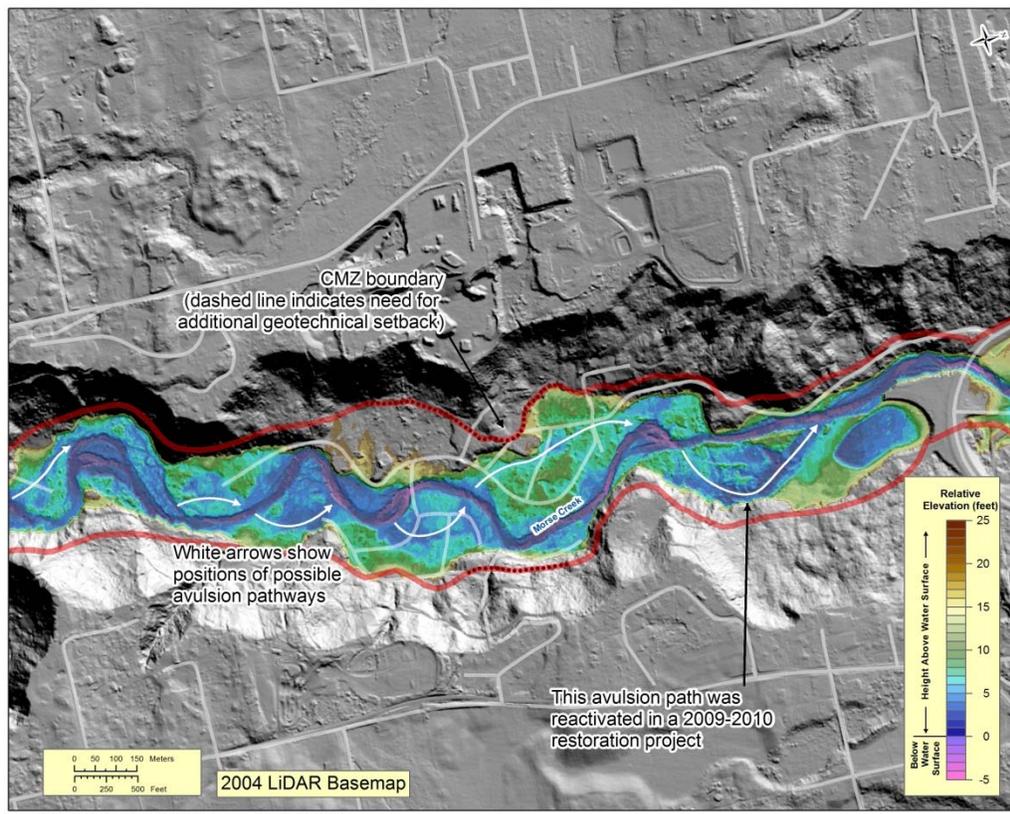


Figure 6.1 Abandoned channels along Morse Creek that represent potential avulsion pathways.

Along Morse Creek a series of abandoned channels lie on the opposite sides of the valley (out-of-phase) from the current channel position (see Figure 6.1). These abandoned channels represent potential avulsion pathways. One of these channels was intentionally activated in a restoration effort between 2009 and 2010, but the others cross through a developed residential neighborhood. Mass wasting has occurred along these valleys and future mass wasting events would likely cause catastrophic local changes in the channel position, rapid aggradation and consequent channel migration in up gradient reaches, and a large influx of sediment that would drive increased instability in the lower reaches. As of 2018, additional detailed analysis was completed for Lower Morse Creek and described in a January 2013 memo, provided separately from this report.

6.2 WRIA 19: Streams in the western foothills physiographic zone

This area includes Seiku River, the lower part of Hoko River, Little Hoko River, Clallam River, Pysht River, and South Fork Pysht River (Figure 3.1). Two factors separate creeks in the western foothills from creeks in the area of glaciated lowlands: 1) they reside on the western (wetter) side of the peninsula and are typically much larger (both because of higher precipitation volume and larger drainage basins); and 2) the upper portions of these streams flow in deep, confined valleys through high-relief foothills. As with creeks in the area of glaciated lowlands the history of dramatic changes in relative sea level has affected the valley forming the lowest reaches of these creeks. In this area, the creeks enter the Strait of Juan de Fuca flow over broad aggrading delta plains. Geomorphic features on these plains include avulsion pathways and relict sloughs, and longshore bars at the boundaries of the plains and Strait of Juan de Fuca. Channel migration in

the lower parts of these stream valleys is driven by sediment deposition in the channel that forces lateral movement across the highly erodible low gradient alluvial plains the streams occupy, slow aggradation that may result in avulsion to other low lying parts of the alluvial plain, and movement of longshore bars by coastal geomorphic processes that can cause movement of the channel mouth and the upstream channel. See Figure 4.8 for an illustration of one such low gradient alluvial plain and delta.

Where the channel abuts valley walls, significant erosion is possible. In this situation, streams may undercut and destabilize banks, and cause landslides. In upper reaches the streams flow in confined valleys cut into marine sedimentary rocks of the Crescent group. These valleys appear to be generally stable, but channels migrate across the valley floors as they transport bed load and respond to changing bedload sediment loading. Alluvial fans occasionally protrude into these valleys, the growth of which can deflect streamflow toward the opposite valley wall.

Streams in this area are particularly unstable at the boundary of steeper confined boundaries and the slowly aggrading delta plains. Coarse bedload (gravel and larger) is deposited in this area because of the reduced stream gradient. Instability in this area is caused by channel migration forced by apparently rapid aggradation in the recent past. This aggradation may be caused by an increase in sediment supply to streams associated with geomorphic instability in uplands, perhaps caused by road construction and timber harvest (c.f. Madej and Ozaki 1996).

6.3 WRIA 19 – 20: Streams in the northwest interior and western coast physiographic zone

The upper part of Hoko River, Herman Creek, and the Sooes River are the three delineated streams in this area. This area is characterized by broad glacial valleys that trend from NE-SW to E-W that were formed as the Juan de Fuca lobe of the continental glaciation spilled over foothills that lie to the north and East and flowed toward the Pacific Ocean. The upper part of Hoko River and the lower part of Sooes River are under fit and meander across some of the glacially defined low gradient valley bottoms. Where they are close to the valley margin, slight erosion of the valley walls is possible. Other parts of these streams and the lower part of Herman Creek flow through narrow valleys incised into deep deposits of glacial till and drift. These stream reaches have higher gradients and are actively eroding valley margins. Mass wasting occurs as streams undercut high and unstable valley walls. This mass wasting provides a sediment source that can drive lateral migration on the valley bottom and can directly influence stream position. Figure 6.2 shows a portion of Sooes River that contains both under fit and actively forming valleys. The upper part of Herman creek is confined in a steep bedrock valley. Limited migration is possible as the stream erodes valley margins.

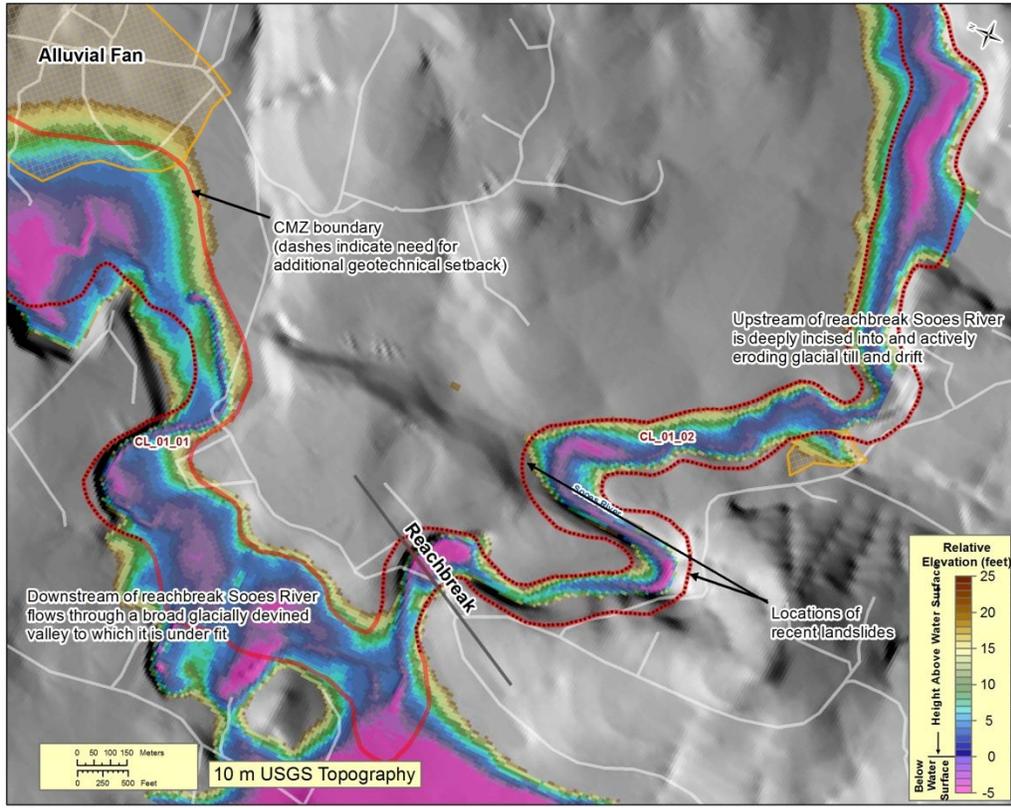


Figure 6.2 A portion of Sooes River the downstream reach is under fit and the upstream reach is actively eroding its valley margin.

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Appendix A Acronym List and Glossary

Acronyms

CMZ	Channel migration zone
DCMZ	Disconnected Channel Migration Zone
DMA	Disconnected Channel Migration Areas
DEM	Digital Elevation Model
DNR	Department of Natural Resources (Washington)
Ecology	Washington Department of Ecology
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code
LiDAR	Light Detection and Ranging
NMFS	National Marine Fisheries Service
NRCS	Natural Resource Conservation Service
PIZ	Potential Inundation Zone
QAPP	Quality Assurance and Project Plan
RCW	Revised Code of Washington
RWSE	Relative Water Surface Elevation
SEA	Shorelines and Environmental Assistance Program
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SSURGO	Soil Survey Geographic Database
USBOR	U. S. Bureau of Reclamation
UW	University of Washington
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDOT	Washington Department of Transportation

Glossary

Accretion: The gradual deposition of sediment along the edges of a channel by lateral migration. One of the bar formation processes that creates bars opposite of the meander bend.

Active channel corridor/meander belt: The area between the outside edges of meander bends of the main stream channel. See Figure 4.4 in the main report.

Aggradation: An increase in sediment supply and/or decrease in sediment transport capacity that leads to an increase in the channel bed elevation. An increase in base level can decrease sediment transport capacity, thereby initiating aggradation.

Alluvial channel: A channel formed in material (sand, gravel, cobbles, or small boulders) that moves during floods. Alluvial channels convey channel bed and bank materials under present flow conditions and adjust their dimensions, shape, and gradient under the present hydrologic regime. For the most part, streamflow, sediment supply, and woody debris control how alluvial channels change over time.

Alluvial fan: A low, outspread mass of loose materials (sand, cobbles, boulders), with variable slope, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain or upland valley; or where a tributary stream is near or at its junction with the main stream. It is steepest near its apex which points upstream and slopes convexly outward (downstream) with a gradual decrease in gradient.

Alluvial landscape: The area of land near an alluvial channel that has been modified by that channel in the past. In the Puget Sound, the alluvial landscape represents the area, typically in a valley bottom, where a stream channel has been located since the end of the last glaciations.

Alluvial terrace: An abandoned floodplain, produced by past vertical instability in the fluvial system. Alluvial terraces are inactive depositional surfaces within a current hydrologic, climatic, and tectonic setting. Alluvial terraces can result from a lowering of the river's base level, from channel incision, or from changes in hydrology.

Alluvium: Material (sand, gravel, cobbles, or small boulders) that is deposited by flowing water. Two processes occur simultaneously in anastomosing channels: (1) avulsion, which creates a pattern of multiple channels; and (2) lateral migration of the individual channels that exist within the anastomosing pattern (i.e., individual meander belts).

Avulsion: The process in which a stream rapidly abandons a developed channel and creates a new one. Channels may avulse into an abandoned channel (second-order avulsion) or create a new channel (first-order avulsion) depending on the preexisting boundary conditions that initiate the avulsion.

Avulsion hazard area: The portion of the CMZ where the channel could suddenly move to during an avulsion.

Bankfull stage: The stream level that corresponds to the discharge at which channel activity (sediment transport, the formation and/or reformation of bars, the formation and/or alteration of bends and meanders, etc.) results in the normally occurring morphologic characteristics of channel.

Bar: [streams] a general term for a ridge-like accumulation of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition; e.g. a channel bar or a meander bar. Examples include:

Point bars - Bars that are formed on the inside of meander channels.

Side bars - Bars that are formed along the edges of relatively straight sections of rivers.

Mid-channel bars - Bars found within the channel that become more noticeable during low flow periods.

Delta bars - Bars formed immediately downstream of the main confluences of a tributary and the main channel.

Biological Opinion: Under ESA section 7, all Federal agencies are required, "in consultation with and with the assistance of the Secretary, to ensure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any threatened or endangered species or result in the destruction or adverse modification of designated critical habitat." Thus, before a permit can be issued, "a written statement setting forth the Secretary's opinion and a summary of the information on which the opinion is based" that the issuance of the permit is not likely to jeopardize any protected species must be obtained.

Braided stream: A channel or stream that has interconnecting multiple channels formed by flow that repeatedly divides and converges around mid-channel bars. In the plan view, the channel resembles strands of a complex braid. Braiding is generally confined to broad, shallow streams of low sinuosity, variable discharge, high bedload, non-cohesive bank material, and a steep gradient. At bank-full discharge, braided streams often have steeper slopes and shallower, broader, and less stable channel cross sections than meandering streams. During periods of high discharge, the entire stream channel may contain water and the islands are covered to become submerged bars. During such high discharge, some of the islands could erode, but the sediment would be re-deposited as the discharge decreases, forming new islands or submerged bars. Islands may become resistant to erosion if they become inhabited by vegetation.

Channel confinement: The width between the channel's valley walls relative to the width of the active channel. Used to describe how much a channel can potentially shift within its valley.

Channel gradient: The angle between the channel flow and the horizontal length of the stream reach. Measured as the change in channel elevation divided by stream or reach length.

Channel migration: The lateral or downstream shifting of a river channel within a river valley. The dynamic physical processes of rivers, including the movement of water, sediment and wood, cause the river channel in some areas to move, or "migrate," over time. This is a natural process in response to gravity and topography and allows the river to release energy and distribute its sediment load. Migration processes include bank erosion and avulsion. Aggradation causes

vertical channel change which is another migration process. The area within which a river channel is likely to move over a period of time is referred to as the **channel migration zone (CMZ)**

Channel migration zone: 1) WAC 173-26-020(6): "Channel migration zone (CMZ)" means the area along a river within which the channel(s) can be reasonably predicted to migrate over time as a result of natural and normally occurring hydrological and related processes when considered with the characteristics of the river and its surroundings." 2) Channel migration is a natural process associated with streams. Streams may migrate across valleys due to a variety of reasons including channel and bank erosion, meander chute cutoff, avulsion, aggradation and incision. The channel migration zone represents the area within which a given stream may migrate over time and includes avulsion hazard and erosion hazard areas (Rapp and Abbe 2003).

Channel reach: A specific portion of the length of a channel that has similar physical features, such as gradient and confinement.

Channel pattern: A configuration of a stream reach as seen in planform. Generally recognized channel patterns include meandering, braided, wandering, island braided and straight.

Critical Habitat: 1) Specific areas within the geographical area occupied by the species at the time of listing under ESA, if they contain physical or biological features essential to conservation, and those features may require special management considerations or protection; and 2) Specific areas outside the geographical area occupied by the species if the federal agency determines that the area itself is essential for conservation.

Degradation: Incision, or down-cutting of the channel bed.

Delta: A body of alluvium consisting mostly of stratified clay, silt, sand and gravel, nearly flat and fan-shaped, deposited at or near the mouth of a river or stream where it enters a body of relatively quiet water, usually a sea or lake.

DEM (Digital Elevation Model): A digital map representing the elevation of

Detailed channel migration assessment: Detailed assessments usually include geomorphic and hydrologic analyses, field measurements and evidence, mapping channel locations and fluvial features over time from archival maps, aerial photographs, and LiDAR, calculating channel migration rates, and evaluating avulsion hazard or probability. Detailed assessments may include hazard assessment, hydraulic modeling, hydrologic modeling to evaluate changes in high flow regimes, channel location probability analysis, bank stability analysis and geotechnical assessment for slope erosion including a geotechnical setback.

Disconnected CMZ/Disconnected migration area: The area located landward of man-made structures that restrict channel migration. Not all man-made structures are exempted from the CMZ shoreline regulations. The specific exemptions are outlined in [WAC 173-26-221\(3\)\(b\)](#), and are described below.

The DMA/DCMZ is based on regulatory exemptions that assume that existing human infrastructure control migration. The Washington State Shoreline Master Program defines exemptions, WAC 173-26-221(3)(b): Exemptions (DMA):

- Within incorporated municipalities and urban growth areas, areas separated from the active river channel by legally existing artificial channel constraints that limit channel movement should not be considered within the channel migration zone.
- All areas separated from the active channel by a legally existing artificial structure(s) that is likely to restrain channel migration, including transportation facilities, built above or constructed to remain intact through the one hundred-year flood, should not be considered to be in the channel migration zone.
- In areas outside incorporated municipalities and urban growth areas, channel constraints and flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the channel migration zone unless demonstrated otherwise using scientific and technical information

Legally existing structures: defined under the Shoreline Management Act (SMA) under the definition for floodway ([RCW 90.58.030](#)): ” lands that can reasonably be expected to be protected from flood waters by flood control devices maintained by or maintained under license from the federal government, the state, or a political subdivision of the state.”

Effective barriers to channel migration (Part of DMA):

- Structures that will endure beyond the design life of the CMZ (100+ years).
- Structures that have a public commitment to keep them intact and that protect populated areas.

Ineffective barriers to channel migration (Not part of a DMA):

- Constructed structures with no public commitment for maintenance.
- Structures made of erodible materials (such as sugar dikes).
- Areas that may be restored by removing levees, revetments, or other infrastructure.
- Within incorporated areas, structures built below the 100-year flood elevation.
- Within unincorporated areas, structures built above the 100-year flood elevation but will not remain intact during a 100-year event.

Ecotone: A transition area of vegetation between two different plant communities, such as forest and grassland. It has some of the characteristics of each bordering community and often contains species not found in the overlapping communities.

Entrenched channel: A channel that has cut vertically downward into streambed deposits or bedrock, resulting in a channel that is much deeper than it is wide.

Erosion Hazard Area (EHA): The area not included in the HMZ or the AHZ that is at risk of stream erosion including unstable valley slopes. From Rapp and Abbe (2003).

Erosion hazard buffer: The area added to the active channel corridor as a basis for the CMZ. It is based on ½ to 1 width of the active channel corridor and adjusted based on local conditions including geology, soils, geomorphology, vegetation, etc. See Figure 4.4 for an illustration.

Failure: A mass wasting event where a bank hillslope face destabilizes and moves downslope.

FEMA flood hazard zone: The extent of the FEMA regulatory special flood hazard area, also frequently called the 100-year flood zone.

Fluvial: Of or pertaining to rivers or streams; produced by stream action, e.g. fluvial landform.

Geomorphology: The branch of geology and geography which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of land forms.

Geotechnical Hazard: Hazards relating to mass wasting of rock and soil, as a result of the encroachment of an active channel into an adjacent terrace or valley wall. Erosion at the base of a terrace or valley wall can cause over-steepening and subsequent mass wasting that could impact land outside of the CMZ.

Geotechnical buffer: Channel and terrace banks at risk of mass wasting due to erosion of the toe were assigned a geotechnical buffer. For this study, geotechnical buffers were applied to the channel migration zone delineation where there was an elevation difference of 25 feet between the water surface as designated in the RWSE and the elevation of the delineation. Geotechnical buffers indicate where additional geotechnical review should be conducted in the field to determine the width of the geotechnical buffer.

Glacial outwash: generally well-sorted sand and gravel deposited by streams draining off of the glacier.

Historical Migration Zone (HMZ): The portion of the CMZ study area that the channel occupied in the historical record. From Rapp and Abbe (2003).

Holocene: The Holocene is a geological epoch in the Quaternary period that began at the end of the Pleistocene (around 10,000 years ago) and continues to the present.

Hydrology, Hydrologic: Having to do with flowing water.

Hydrologic regime: Changes with time in the rates of flow of rivers and in the levels and volumes of water in rivers, lakes, reservoirs, and marshes. The hydrologic regime is closely related to seasonal changes in climate. The hydrologic regime of rivers manifests itself by daily, ten-day, monthly, seasonal, and long-term fluctuations. It consists of a number of characteristic periods (phases) that vary with seasonal changes in the conditions under which rivers are fed.

Incision: The process of downcutting into a stream channel leading to a decrease in the channel bed elevation. Incision is often caused by a decrease in sediment supply and/or increase in sediment transport capacity. A decrease in base level can cause headcutting that migrates upstream and produces incision upstream and initiating aggradation downstream.

Infrastructure: Components of the built environment including buildings, roads, railroads, levees, etc.

Lacustrine: Belonging to or produced by lakes.

Lahar: A mudflow or landslide of pyroclastic material occurring on the flank of a volcano. The deposit of mud or sand formed from a lahar.

Landslide scarp: A scar of exposed soil on a landslide.

Large woody material (LWM) or large woody debris (LWD): Dead woody material greater than 20" in diameter on the ground or in a stream or river. It may consist of logs, trees, or parts of trees. Large woody debris contributes to long-term site productivity and health in several ways. It supplies nutrients to the soil, supports symbiotic fungi that are beneficial to conifers, and provides habitat for beneficial rodents and insects.

Lateral migration: The bank erosion process where the side to side movement of meander migration undercuts the bank. Lateral growth increases the meander bend amplitude.

LiDAR: LIDAR stands for "Light, Imaging, Detection and Ranging system". It is a three-dimensional laser scan that provides high definition surveying for architectural, as-built, and engineering surveys

Main channel: The main stream channel is the dominant channel with the deepest or lowest thalweg, the widest width within defined banks, and the most water during low flow periods. Main channel locations can be transient over time. Braided channels may not have a defined main channel.

Mass wasting: The down slope movement of material due to gravity (rather than water, wind, or ice, for example).

Meander: One of a series of freely developing sinuous curves or loops produced as the stream moves from side to side of its floodplain. **Meander bend** is the convex side of a meander.

Meander bend migration is the lateral or downstream movement of a sinuous curve in a stream within a river valley

Meander-bend cutoffs: The shortened channel resulting when a stream cuts through a meander neck or narrow strip of land between adjacent meander bends. Bend cutoffs leave behind an **oxbow lake**.

Meander scar: A crescent-shaped, concave or linear mark on the face of a bluff or valley wall, produced by the lateral erosion of a meandering stream which impinged upon and undercut the bluff; if it's no longer adjacent to the modern stream channel it indicates an abandoned route of the stream.

Meander belt: The area containing the stream channel between the outside edges of meander bends. See active channel corridor and Figure 4.4 in the main report.

Migration (river channel): The lateral motion of an alluvial river channel across its floodplain due to processes of erosion of and deposition on its banks and bars. In meandering streams, channel migration typically takes place by erosion of the cut bank and deposition on the point bar. In braided streams, channel change occurs due to sediment transport and the motion of barforms through the channel.

One hundred-year flood: A flood event with a 0.01 probability of occurrence in a given year. Used as a basis for FEMA special flood hazard area determination.

Outwash: A deposit of sand and gravel carried by running water from the melting ice of a glacier and laid down in stratified deposits.

Oxbow: A closely looping stream meander having an extreme curvature such that only a neck of land is left between the two parts of the stream.

Oxbow lake: A crescent-shaped, body of standing water along a stream created by a **meander-bend cutoff** or **avulsion**. Once isolated, oxbow lakes will slowly fill up with sediment, as point bar sands and gravels are buried by silts, clays, and organic material carried in by floods and by sediment slumping in from sides as rain fills up lake.

Physiographic zone: A portion of the Earth's surface with a basically common topography and common morphology.

PIZ: Potential Inundation Zone. A term developed for this report that includes areas of the valley bottom that are at or below the approximate water surface elevation as indicated on the RSWE map. These areas are likely subject to inundation when there is an over-bank flood.

Planform: The shape and size of channel and overbank features as viewed from above.

Pleistocene: The older of the two epochs of the Quaternary Period, spanning about 1.8 million to 10,000 years ago. It represents the interval of geological time (and rocks accumulated during that time) extending from the end of the Pliocene Epoch (and the end of Tertiary Period) to the start of the Holocene Epoch. It is commonly characterized as an epoch when the earth entered its most recent phase of widespread glaciation.

Quaternary: The second period of the Cenozoic geologic era, following the Tertiary, and including the last 2-3 million years.

RWSE (Relative Water Surface Elevation): A map derived from LiDAR data that shows elevations of the land surface adjacent to a stream relative to the elevation of the approximate water surface of the stream.

Relict channel: An abandoned channel that is not presently active.

Rectification: The operation of matching a scanned photograph or map with projected electronic data (I.e. parcel lines or an orthophoto).

Rill Erosion: The formation of numerous, closely spaced rills due to the uneven removal of surface soil by streamlets of running water.

Riparian: A riparian zone or riparian area is the interface between land and a river or stream. Plant habitats and communities along the river margins and banks are called riparian vegetation, characterized by hydrophilic plants.

River [streams]: A general term for a natural, freshwater surface stream of considerable volume and generally with a permanent base flow, moving in a defined channel toward a larger river, lake, or sea. Rivers are a subset of **streams**.

Secondary (or side) channel: Any channel on or in a floodplain that carries water (intermittently or perennially in time; continuously or interrupted in space) away from, away from and back into, or along the main channel. Secondary channels include: side channels, wall-based channels, distributary channels, anabranch channels, abandoned channels, overflow channels, chutes, and swales.

Sediment load: The solid material that is transported by a natural agent, especially by a stream.

Stade: A substage of a glacial stage marked by a secondary advance of glaciers.

Stream: (a) Any body of running water that moves under gravity to progressively lower levels, in a relatively narrow but clearly defined channel on the ground surface, in a subterranean cavern, or beneath or in a glacier and transports sediment and dissolved particles. (b) A term used in quantitative geomorphology interchangeably with channel; (c) (under the shoreline management act). A naturally occurring body of periodic or continuously flowing water where: (1) The mean annual flow is greater than twenty cubic feet per second; and (2) The water is contained within a channel. A channel is an open conduit either naturally or artificially created. This definition does not include artificially created irrigation, return flow, or stock watering channels [WAC 173-22-030]. Rivers, creeks, brooks and runs are all streams.

Stream discharge: discharge is the volume rate of water flow, including any suspended solids, dissolved chemical species and/or biologic material, which is transported through a given cross-sectional area. Frequently, other terms synonymous with discharge are used to describe the volumetric flow rate of water and are typically discipline dependent. For example, a fluvial hydrologist studying natural river systems may define discharge as streamflow, whereas an engineer operating a reservoir system might define discharge as outflow.

Stream power: The amount of work (material transportation) a channel reach can do. It is measured by flow per unit of time times channel slope. Work and energy have the same units. Stream power has a number of definitions depending on the time rate at which either work is done, or energy is expended. It is a useful index for describing the erosive capacity of streams, and relates to channel pattern, development of bed forms, sediment transport, and the shape of the longitudinal profile.

Stream reach: A length of a stream channel that is uniform with respect to discharge, gradient, channel shape, bank composition, valley shape, sediment supply and other factors.

Streamlined method: The method used in this study to identify the general location of channel migration zones in accordance with WAC 173-26-201(c)(vii). This planning-level method identifies the general location of the channel migration zone using only existing GIS data without field data collection, calculating channel migration rates, or modeling. The general channel migration zone (pCMZ) includes historic channel locations, potential avulsion hazard zones, potential erosion hazard areas, and disconnected channel migration zones. This assessment should only be used as guidance as to where more specific channel migration and geotechnical studies should be conducted if development is planned within the approximate boundaries established by this study.

Study reach: The portion of the channel that is within the study area.

Substrate: A substratum or an underlying stratum. The underlying layer of rock or material.

Terrace: An elevated surface above the existing level of a floodplain or shore that is created by past stream erosion.

Till: Unsorted sand, gravel, silt, and clay deposited beneath the base of a glacier.

Topographic relief: The configuration of a surface including its elevation and the position of its natural features.

Translational migration: The down valley movement of meander bends caused by bank erosion concentrated at the outer bank between the bend apex and the downstream crossing.

Unconfined fracture strength: The amount of force necessary to fracture or crush a sample of rock that is unconfined or compressed.

Underfit stream: A misfit stream (or underfit stream) is a stream that is too small to have eroded the valley which the stream occupies. When a period of glaciation modifies the landscape by creating glacial valleys, the rivers that occupy such valleys after the ice has retreated are not in proportion with the size of the valley. Given the scale of most glacial valleys, most of them contain misfit streams.

Valley: An elongate, relatively large, externally drained depression that is primarily developed by stream erosion or glacial activity.

Appendix B Shoreline Master Program Regulations Addressing Channel Migration

Inventory and Analysis requirements:

[WAC 173-26-201\(3\)\(c\)\(vii\)](#): Inventory shoreline conditions:

Local governments shall, at a minimum, and to extent information is relevant and reasonably available, collect the following information:

(vii): General location of channel migration zones and flood plains.

What does reasonably available mean for determining a potential migration area?

- Information on channel characteristics such as channel gradient and confinement.
- Existing GIS geology and soils data to evaluate erosion potential
- [WAC 173-26-221\(3\)\(b\)](#): based on the historic record, geologic character and evidence of past migration over the past 100 years
- 2 to 3 time series of aerial photographs, maps, LiDAR or whatever is available.
 - ix) Already states that aerial photographs may be necessary to identify cumulative impacts

[WAC 173-26-201\(3\)\(d\)\(i\)\(D\)](#): The species composition and structural diversity of plant communities in river and stream areas and wetlands that provides summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration and to supply amounts and distributions of woody debris sufficient to sustain physical complexity and stability.

Critical area requirements:

The SMP regulations include channel migration under guideline sections that address shoreline habitat, resources, and critical areas

- [WAC 173-26-201\(3\)\(d\)\(i\)\(D\)](#): channel migration included as one of the ecosystem functions and processes of overall condition
- [WAC 173-26-221\(2\)\(c\)\(iv\)](#): Critical areas
 - CMZ included as a critical freshwater habitat
 - New development in the CMZ limited to that which does not:
 - Cause net loss of ecological functions
- [WAC 173-26-221\(2\)\(c\)\(iv\)\(C\)\(IV\)](#): Requires that SMPs include standards to implement principles described above .

Flood Hazard Reduction provisions:

The SMP guidelines section on Flood Hazard Reduction [WAC 173-26-221\(3\)](#) has greater detail

- [WAC 173-26-221\(3\)\(b\)](#): Applicable shoreline master programs should include provisions to limit development and shoreline modifications that would result in interference with the process of channel migration that may cause significant adverse impacts to property or public improvements and/or result in a net loss of ecological functions associated with the rivers and streams.

- [WAC 173-26-221\(3\)\(b\)](#): Failing to recognize the [channel migration] process often leads to damage to, or loss of, structures and threats to life safety
- [WAC 173-26-221\(3\)\(b\)](#): Exemptions

The SMP guidelines recognize that previous human actions may deter channel migration. Areas may be removed from the channel migration area if:

- *Within incorporated municipalities and urban growth areas, areas separated from the active river channel by legally existing artificial channel constraints that limit channel movement should not be considered within the channel migration zone.*
- *All areas separated from the active channel by a legally existing artificial structure(s) (as defined in RCW 90.58.030) that is likely to restrain channel migration, including transportation facilities, built above or constructed to remain intact through the one hundred-year flood, should not be considered to be in the channel migration zone.*
- *In areas outside incorporated municipalities and urban growth areas, channel constraints and flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the channel migration zone unless demonstrated otherwise using scientific and technical information.*

Legally existing artificial structures are defined under the Shoreline Management Act definition for floodway (RCW 90.58.030): "...protected from flood waters by flood control devices maintained by or maintained under license from the federal government, the state, or a political subdivision of the state."

These exemptions need further consideration because in reality, structures do not always constrain channel migration or bank erosion.

- [WAC 173-26-221\(3\)\(b\)\(i\) - \(vii\)](#): Describes more specific flood hazard prevention principles, including encouragement to plan for and facilitate removal of artificial restrictions to natural channel migration.
- [WAC 173-26-221\(3\)\(c\)\(i\)](#): Standard generally prohibiting new development in shoreline jurisdiction where it would require new dikes or levees within the CMZ. "New development or new uses in shoreline jurisdiction, including the subdivision of land, should not be established when it would be reasonably foreseeable that the development or use would require structural flood hazard reduction measures within the channel migration zone or floodway." Includes list of specific developments that may be appropriate exceptions to the standard.

Modifications and Conditional Use provisions:

- [WAC 173-26-231\(3\)\(c\)](#): *Fills* must protect shoreline ecological functions, including channel migration processes.
- [WAC 173-26-231\(3\)\(f\)](#): Requiring conditional use permit for *disposal of dredge material* on shorelands or wetlands within CMZs.
- [WAC 173-26-241\(3\)\(ii\)\(E\)](#): Requiring conditional use permit for *mining* within CMZ
- [WAC 173-26-241\(3\)\(ii\)\(D\)](#) Mining within the active channel or channels (a location waterward of the ordinary high-water mark) of a river shall not be permitted unless:
(I) Removal of specified quantities of sand and gravel or other materials at specific locations will not adversely affect the natural processes of gravel transportation for the

river system as a whole; and

(II) The mining and any associated permitted activities will not have significant adverse impacts to habitat for priority species nor cause a net loss of ecological functions of the shoreline.

Shoreline Stabilization:

- [WAC 173-26-231\(3\)\(a\)\(iii\)\(A\)](#): New development should be located and designed to avoid future bank stabilization. New development that would cause impacts to adjacent or other properties and shoreline areas should not be allowed.
- [WAC 173-26-231\(3\)\(a\)\(iii\)\(B\)](#): New structural stabilization measures not allowed except when need is demonstrated to protect an existing primary structure and meets criteria outlined in WAC 173-26-231(3)(a)(iii)(B)(I-IV).
- [WAC 173-26-231\(3\)\(a\)\(iii\)\(C\)](#): Existing structures can be replaced if there is a demonstrated need to protect principle use or structures from erosion based on criteria listed in this section
- [WAC 173-26-231\(3\)\(a\)\(iii\)\(D\)](#): Geotechnical reports are needed to demonstrate need to prevent damage to primary structure. The report must show time frames and rates of erosion, and urgency for stabilization. Stabilization methods using Hard armoring solutions (defined in [WAC 173-26-231\(3\)\(a\)\(ii\)](#)) should not be permitted except if the structure will be damaged within 3 years.
- [WAC 173-26-231\(3\)\(a\)\(iii\)\(E\)](#): Standards for new stabilization structures (besides geotechnical reports) when found to be necessary include limiting the size to minimum, using measures to assure no net loss of shoreline ecological functions, using soft approaches, and mitigating for impacts.

Appendix C Identifying Channel Migration Reaches

Appendix D QAPP (2012)

Appendix E pChannel Migration Zone Maps for Puget Sound Streams Clallam County

Appendix F Data Sheets
