

## Channel Migration Assessment Clallam County: Pacific WRIA 20

April 2013

Final Version April 2018



DEPARTMENT OF  
**ECOLOGY**  
State of Washington

# Channel Migration Assessment

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## Chapter 1 Introduction

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### 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 oversteepens 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, generally increasing with the size of the channel. 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 typically consists of several distinct zones (Rapp and Abbe, 2003). 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 river or 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. In such circumstances the CMZ may extend beyond delineated FEMA flood hazard zones. In other cases, such as heavily vegetated small channels, the CMZ may be considerably smaller than the FEMA 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. 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 image from 2009 shows that the stream in this residential development has moved, eroded and deposited sediment along the banks, 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.

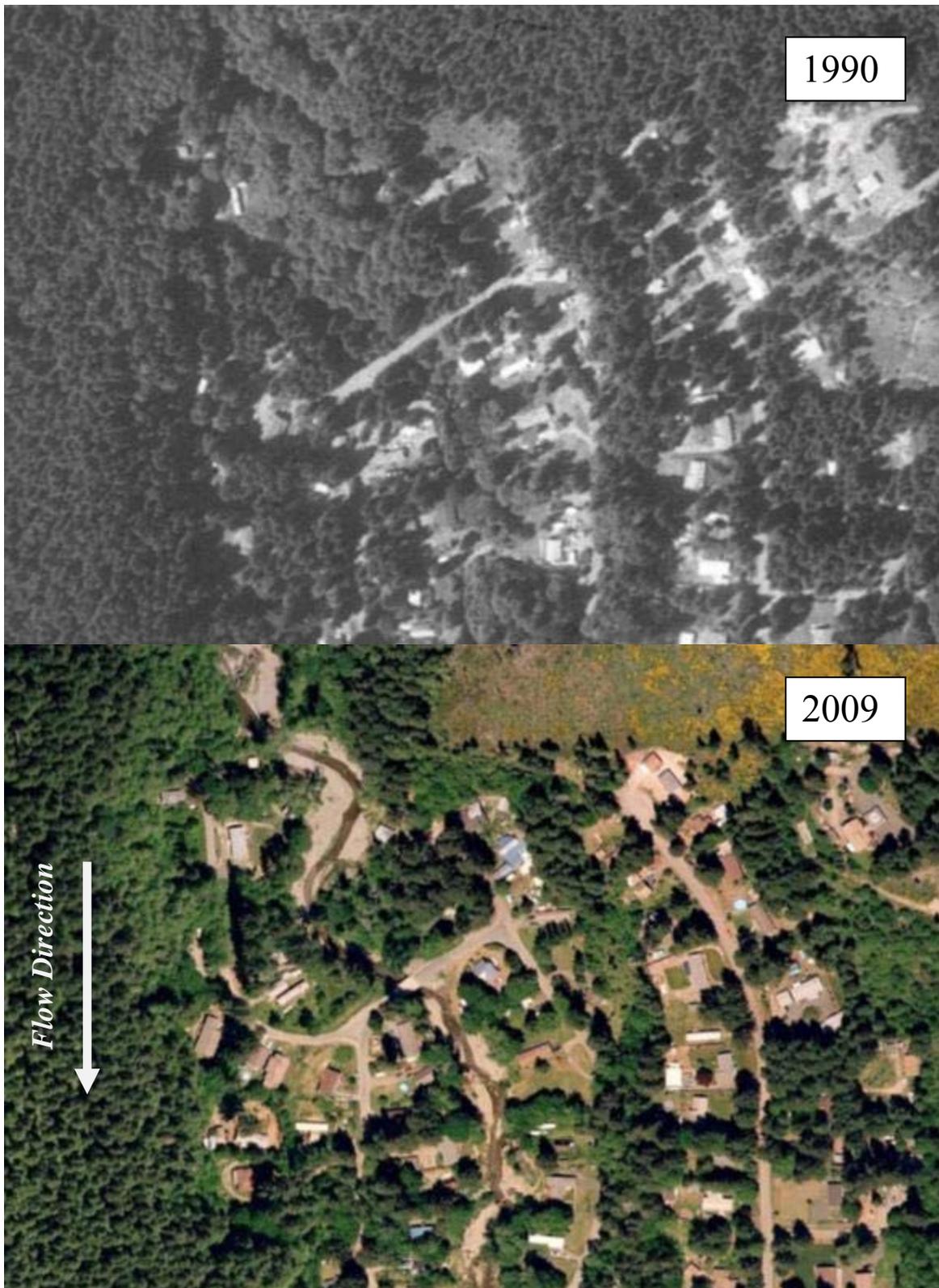


Figure 1.1 Mission Creek near Belfair, WA. Note the change in width of the channel and additional deposition between 1990 (upper photo) and 2009 (lower photo) in this residential neighborhood.

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 delineate "general" channel migration zones for county governments in the Puget Sound region that have not yet done CMZ delineations and are currently updating their SMPs. Identification of channel migration zones also supports community efforts at complying with new FEMA regulations related to endangered species (see Chapter 2, Regulatory Context, for more details).

A Draft Channel Migration Assessment report, dated December 2011 and Final Version April 2018, was prepared by SEA for Clallam County streams that fall under the jurisdiction of SMA. Channel Migration Zone maps were delineated for all designated streams, which total approximately 140 miles, and are presented with the December 2011 draft and 2018 Final reports.

This report, also prepared by the SEA, provides information, methods, and maps for an additional 170 miles of streams in Clallam County to augment work on the county's Shoreline Master Program already in progress. Funding for this work was provided by the State General Fund. Streams selected for delineation included those 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 are "general" 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 pCMZs 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 pCMZ 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 digitized topographic maps and geologic maps, digital elevation maps (DEMs) 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, Department of Ecology 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 planning-level method be developed for this project to identify the general location of channel migration zones. The planning-level method was developed to enable Puget Sound communities to complete their SMP updates, which typically must be conducted under fast tracked schedules and with limited resources. In meeting this objective, the planning level:

- Relies on existing, readily available map and aerial photographic data to identify the general location of the CMZ.
- Relies on easy-to-accomplish LiDAR post processing methods to highlight low-lying topography adjacent to the channel and across the flood plain.
- Incorporates geomorphic and hydrologic (when available) knowledge and experience relevant to assessment area.

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

The planning-level method did not include field verification or detailed analysis of channel migration rates. Although historic aerial imagery dating back to the 1930s 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 Elevation Model” (REM) were developed for all sites where LiDAR was available (See Section 4.3 for details). These REM maps offered an accurate means of assessing relic channels, alluvial landforms (such as alluvial fans), potential inundation zones

(PIZ) and potential avulsion areas and provide important evidence of potential channel migration. Although the planning-level 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 a guide for delineating channel migration zones. The ‘planning-level’ 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 where more detailed channel migration zone studies should be conducted.

Detailed guidance for identifying CMZs is available on the Ecology website, which includes 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).

The other comprehensive reference for delineating channel migration zones in Puget Sound is the Framework for Delineating Channel Migration Zones by Rapp and Abbe (2003).

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 2013 with Ecology funds 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 2013. 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 2013 therefore, appropriate judgment should be applied to the use of the conclusions, recommendations, and opinions presented in this report.

## Chapter 2 Regulatory Context

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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 require 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). 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) (emphasis added).

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. No timber harvest, road construction or salvage is permitted within CMZs 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

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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 two distinct physiographic zones located in water resource inventory area (WRIA) 20: 1) the southwestern interior and Olympic Foothills and 2) the northwest interior and western coastal area. See inset map in Figure 3.1 showing the locations of the streams and the area of the physiographic zones. The Olympic Mountains lie outside of the area evaluated in this study.

The first physiographic zone is the southwestern interior and Olympic Foothills, the area that lies south of Lake Crescent and extends to the County line on the south and the Pacific Coast on the west. Streams in this zone generally flow west from headwaters in the western Olympic Mountain foothills onto a broad glacio-fluvial plain. Streams in this zone include tributaries of the Quillayute River: the Sol Duc (tributaries include Shuwah, Bockman, Beaver, Bear and Camp Creeks), Bogachiel, Calawah, Sitkum Rivers and Elk Creek. This area has moderate relief at the eastern end in the Olympic foothills where elevations vary between 4,000-foot ridges to 1,450-foot valley bottoms. Relief on the glacio-fluvial plain is modest, ranging from 250 feet on the highest terraces to 50 feet on the active alluvial plain.

The second physiographic zone in the study area is the northwest interior and western coast, which lies southwest of the Crescent formation (see figure 3.1). Streams in this zone flow through relatively deep canyons into Lake Ozette (Big River, Umbrella and Crooked Creeks) or southward to a confluence with the Quillayute River (Dickey River and its tributaries: East, West and Middle forks, and Colby Creek) and north northwest to confluences with Sooes River (Pilchuck and Snag Creeks). This area has modest relief. Highlands reach elevations of nearly 1,600 feet and valley bottoms are around 50 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). See Table 4.2 for descriptions of the erosion potential for these bedrock types.

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 highly 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.

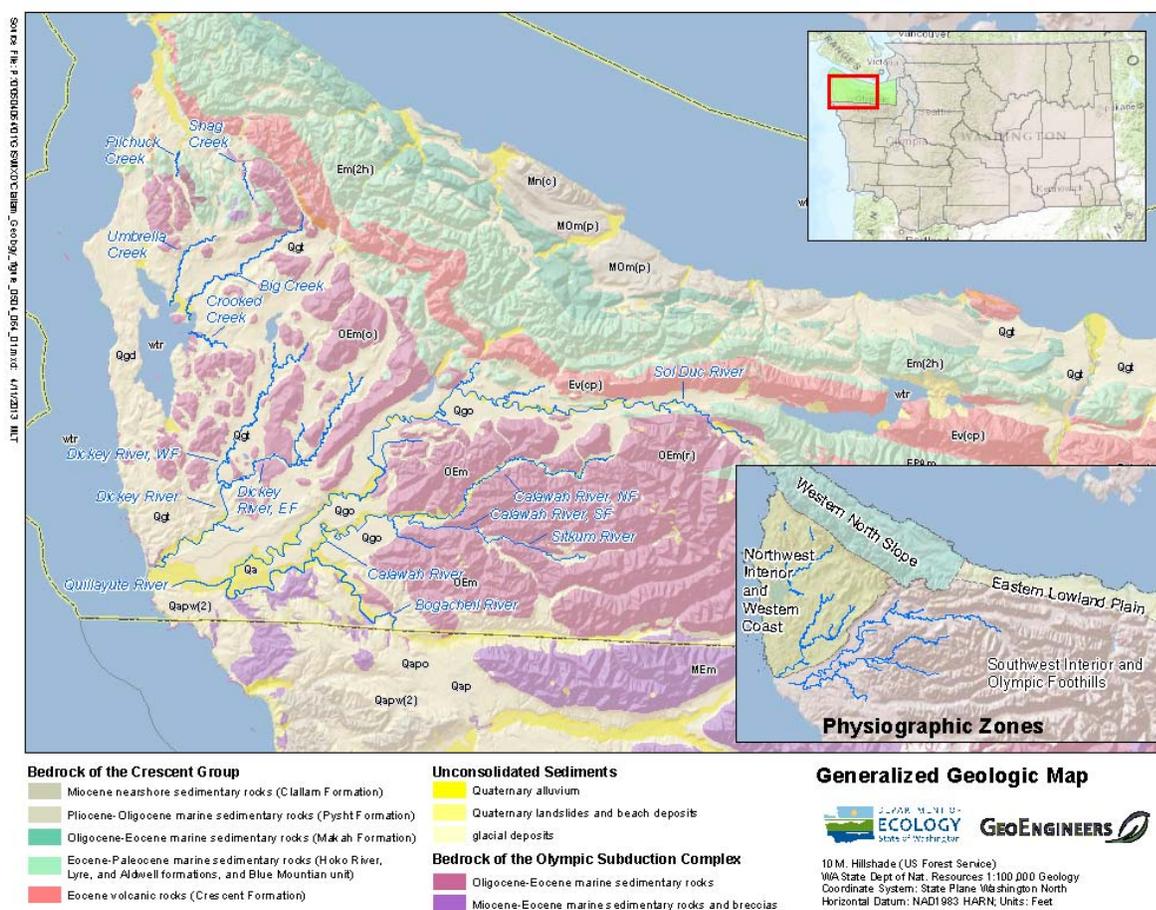


Figure 3.1 General geology and physiographic zones of the Clallam County assessment area.

The modern landscape of Clallam County was primarily formed by glaciation, paraglacial 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 and glacial outwash fills the broad valleys in the south-central part of the 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 River 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.

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 either was deposited directly from floating ice masses or consists of variable, layered glacial deposits that may include outwash, till, and glacial lacustrine deposits (Gerstel and Lingley, 2000); thus, drift has a generally moderate fluvial erosion potential. Glacial till is unsorted sand, gravel, silt, and clay deposited beneath the base of a glacier. Un-fractured 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 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 relative to 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, and streams incised deep valleys into the lowland plain and western foothills. 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 flood plains along the western lowland (Schasse et al., 2004; Polenz et al., 2004; and citations therein). The resulting alluvial valley fill is highly erodible and forms a very low relief surface, enabling streams to readily migrate across the whole valley bottom. Stream reaches upgradient from the effects of sea level fluctuation, are largely controlled by bedrock; these reaches have slowly incised since the retreat of the glaciers and continue to degrade to the present day (Polenz et al., 2004).

### 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). Muschinski and Katz (2013) using hourly precipitation at an Aberdeen weather station found that frequency and intensity of extreme storm events significantly increased since 1940.

## Chapter 4 Planning-Level Method

This chapter describes the planning-level method developed for determining general CMZ locations 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 (see Appendix E). 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 (Appendix D).

### 4.1 Definitions

This report uses language specific to the field of geomorphology as well as terms and acronyms specific to the planning-level 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 planning-level method developed for the general pCMZ delineations included in this report differs from the method described in Rapp and Abbe (2003) and by the Department of Ecology. The planning-level 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).

<b>Term used in this report</b>	<b>Definition</b>	<b>Similar term used in Rapp and Abbe (2003)</b>
<b>Active channel corridor</b>	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)
<b>Avulsion Hazard Areas</b>	The area in the floodplain at risk of avulsion	Avulsion Hazard Zone (AHZ)
<b>Erosion Hazard Buffer</b>	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)

<p><b>Disconnected Channel Migration Zone (DCMZ)</b></p>	<p>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).</p>	<p>Disconnected Migration Area (DMA)</p>
<p><b>General Channel Migration Zone (CMZ)</b></p>	<p>The result of the planning-level 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><b>Geotechnical Setback Buffer</b></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 REM 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><b>Alluvial Fan</b></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, debris flow, or waterway 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><b>Potential Inundation Zone (PIZ)</b></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

Pacific streams within Clallam County were selected for planning-level channel migration assessments based on several criteria including:

- Puget Sound SMP update schedule
- Channel confinement, gradient, and floodplain
- Erosion potential of stream banks
- Evidence of channel movement
- Land Ownership
- 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 170 miles of streams in Clallam County WRIA 20 were assessed; those are in addition to the approximate 40 miles of WRIA 18 – 19 Puget Sound streams previously assessed. The Sooes River was initially assessed and boundaries presented in the WRIA 18 – 19 report as a singular WRIA 20 outlier. It is used as an example for certain conditions in this report due to its location in the northwest interior and western coast physiographic zone, however, the pCMZ boundaries are not provided again in this report; please refer to the WRIA 18-19 report for the pCMZ boundaries. 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. Streams on federal lands (primarily Olympic National Forest and Olympic National Park) or tribal lands (Quillayute Reservation) were not included, and many of those certainly experience channel migration.

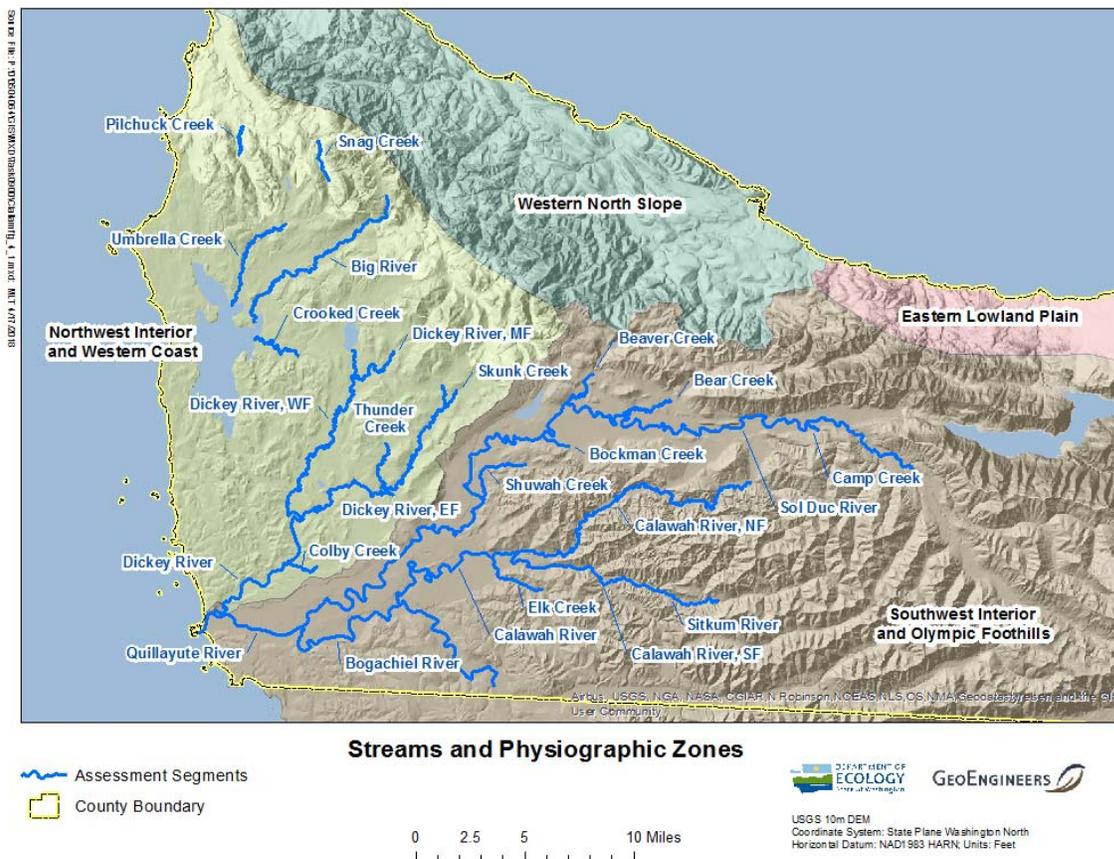


Figure 4.1. Streams selected for assessment in Clallam County. Some streams on federal lands were not assessed.

### 4.3 Data Sources and Processing

The method developed for this report is a planning-level approach that primarily relies on recent airphotos 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, landslide scarps, and infrastructure such as roads and railroad beds are clearly displayed even for smaller streams that are obscured by vegetation (Figure 4.2). In areas where LiDAR was unavailable, USGS 10m DEMs and topographic maps were used.

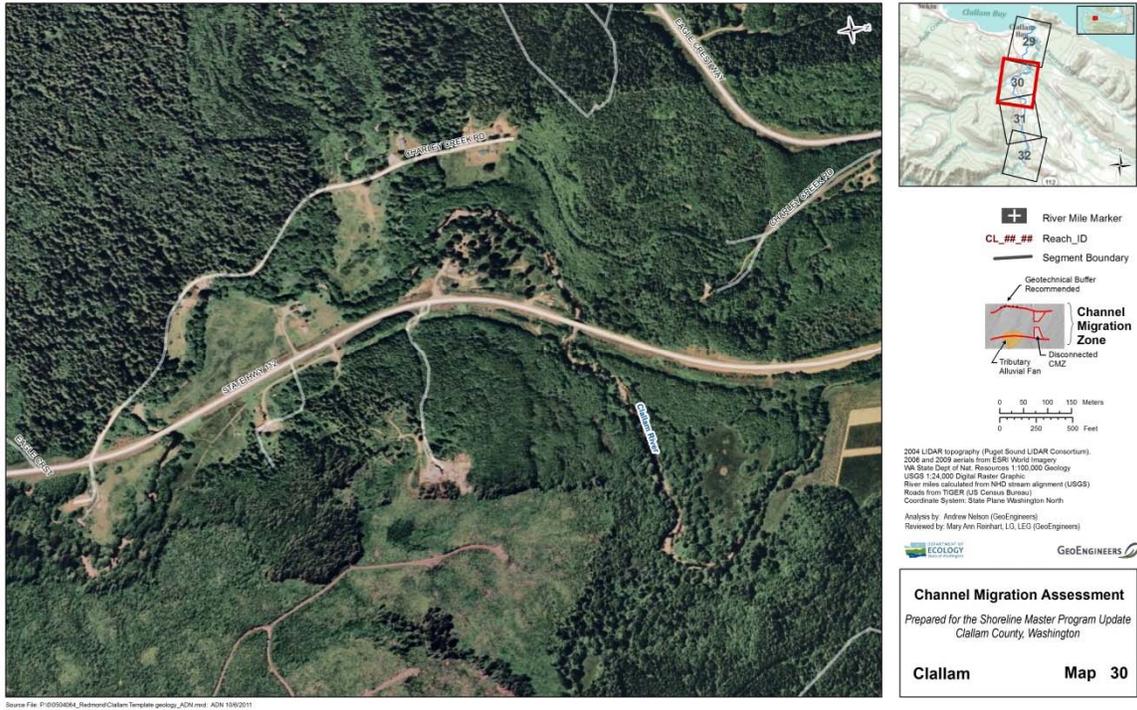
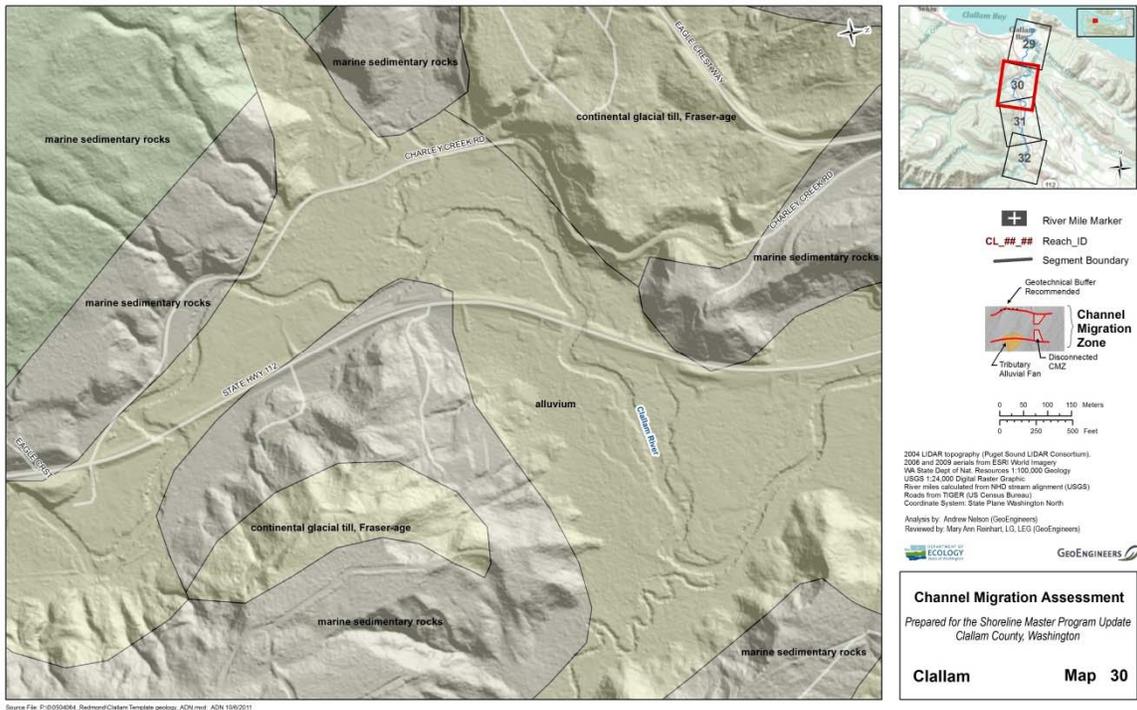


Figure 4.2. Example of LiDAR map with geologic map overlay (above) and aerial imagery (below) from Clallam River showing features visible on a high-resolution DEM including stream channels, roads, and development. Note that the topography and stream channel are clearly visible on the LiDAR map.

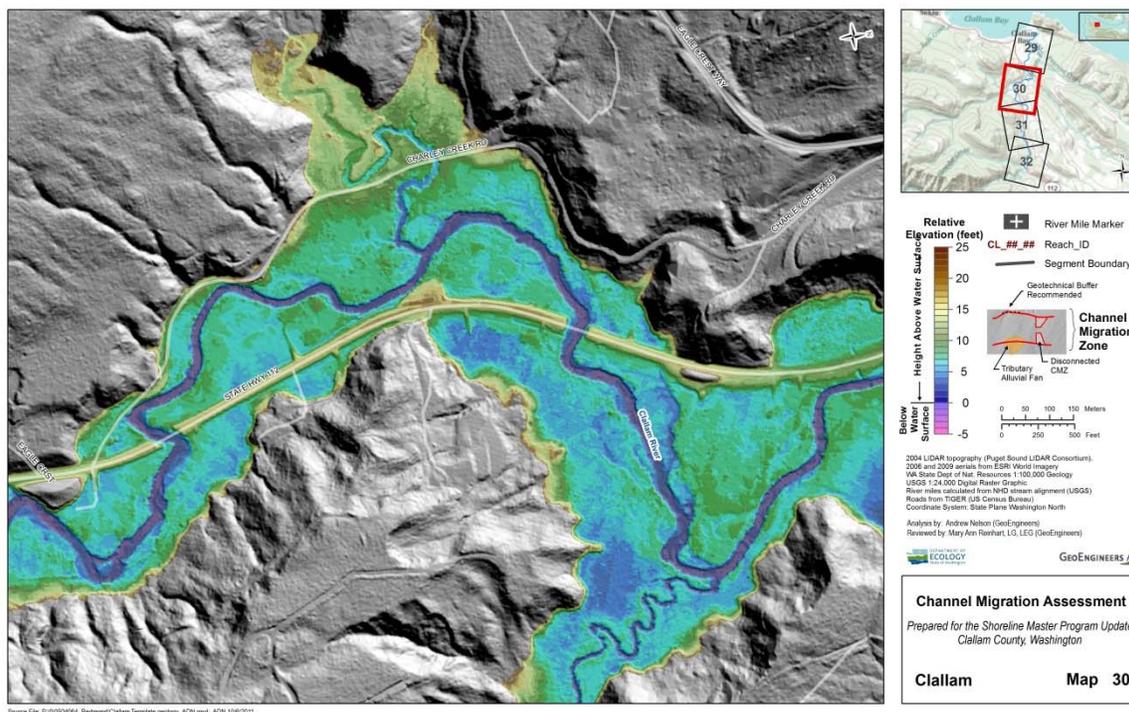


Figure 4.3. Relative elevation model (REM) map for the same section of Clallam River as Figure 4.2.

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 stream channel. This map product is referred to as a detrended DEM, height above water surface (HAWS), and relative water surface elevation (RWSE) model, (also called relative elevation models, [REM]) 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. REM maps were developed by Ecology by a methodology described in Appendix B of the QAPP (Appendix D). Figure 4.3 is the REM map for the same section of Clallam River shown in Figure 4.2.

Multiple geomorphic features can be distinguished on the REM 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 (inundation) 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 if 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 CMZ not only includes the entire valley, but extends into the valley hillslopes. In such cases, the planning-level 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 planning-level assessment utilized aerial imagery available on the internet (Google Earth) that generally dates back approximately 20 to 30 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 have occurred in the last century.

Geology and soils layers were consulted to provide information on the erodibility of materials comprising 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.

<b>Surface geology deposits</b>	<b>Fluvial erosion potential</b>
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	Moderately 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 and 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. Table 4.3 lists typical rock types and their fluvial erosion potential.

Table 4.3 Typical bedrock types, strength, and fluvial erosion potential. (Adapted from Attewell and Farmer 1976)

<b>Typical rock types</b>	<b>Strength classification</b>	<b>Unconfined fracture strength (MPa)</b>	<b>Fluvial erosion potential</b>
weathered and weakly-compacted; highly fractured; marine sedimentary rocks	Very weak	10-20	Moderate-High
weakly-cemented sedimentary rocks; tuffs,	Weak	20-40	Moderate
competent sedimentary rocks; tuff breccia	Medium	40-80	Low
competent igneous rocks; some metamorphic rocks and fine-grained sandstones, schists; some low-density coarse-grained igneous rocks	Strong	80-160	Very Low
quartzite; dense fine-grained igneous rocks	Very strong	160-320	None

Alluvial soils comprising floodplain and terrace banks directly influence channel morphology and erosion rates. NRCS SSURGO soil data were used to assess the bank and floodplain erosion potentials with soil texture and/or the content of sand and silt adopted as the primary variables. Soil texture and sand versus silt content was chosen over other factors because knowledge of these soil components 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 soils in areas where the vegetation has been disturbed or cleared.

In addition to the data described above, Table 4.4 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 4.4 GIS data layers used in mapping general channel migration zones for Shoreline Master Program updates.**

<b>Data<sup>1</sup></b>	<b>Source/ custodian<sup>2</sup></b>	<b>Scale/ resolution</b>	<b>Purpose</b>
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 elevation map maps, evaluating sinuosity, confinement, and channel slope.
DEM 10 m	UW/USGS	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.
DEM 10-meter hillshade	UW/Ecology	1:24k	
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 such as bridges, roads, railroads, wastewater treatment plants. Publicly maintained state roads and railroads were considered barriers to
DOQQ	USGS	36-inch horizontal accuracy	

**Channel Migration Assessment  
Clallam County: Pacific WRIA 20**

Washington State 24K DRG Image Library	USGS	1:24k	channel migration and the boundary for disconnected migration areas (DMA).
FEMA Flood Hazard Zones	FEMA	1:24k	Location of FEMA 100-year special flood hazard area in relation to valley bottoms. 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	

<sup>1</sup>All 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.

<sup>2</sup>State 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 Planning-level Method for Channel Migration Assessment

The general channel migration assessment completed for this study is based on analysis of existing GIS data. The 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 migration areas. 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 4.5). Each feature is described in more detail in the sections below.

Table 4.5 GIS files created for the channel migration assessment.

Filename	File Type	Purpose
[County code] <sup>1</sup> 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 migration zone protected by certified structure (described in section 5 below)
[County code] geoflag.shp	line	Potential geotechnical hazard requiring further investigation

<sup>1</sup> 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

While data sheets were completed for this step of the Clallam pCMZs for Puget Sound Streams WRIA 18-19 (see Appendix E of that document), no data sheets were compiled for the Pacific Streams WRIA 20 pCMZs due to time and resource limitations. However, the same data was used to delineate the pCMZs in both reports.

## 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 zones, 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. In cases where the stream is well entrenched in glacial soils, the active corridor included only the stream/river channel.

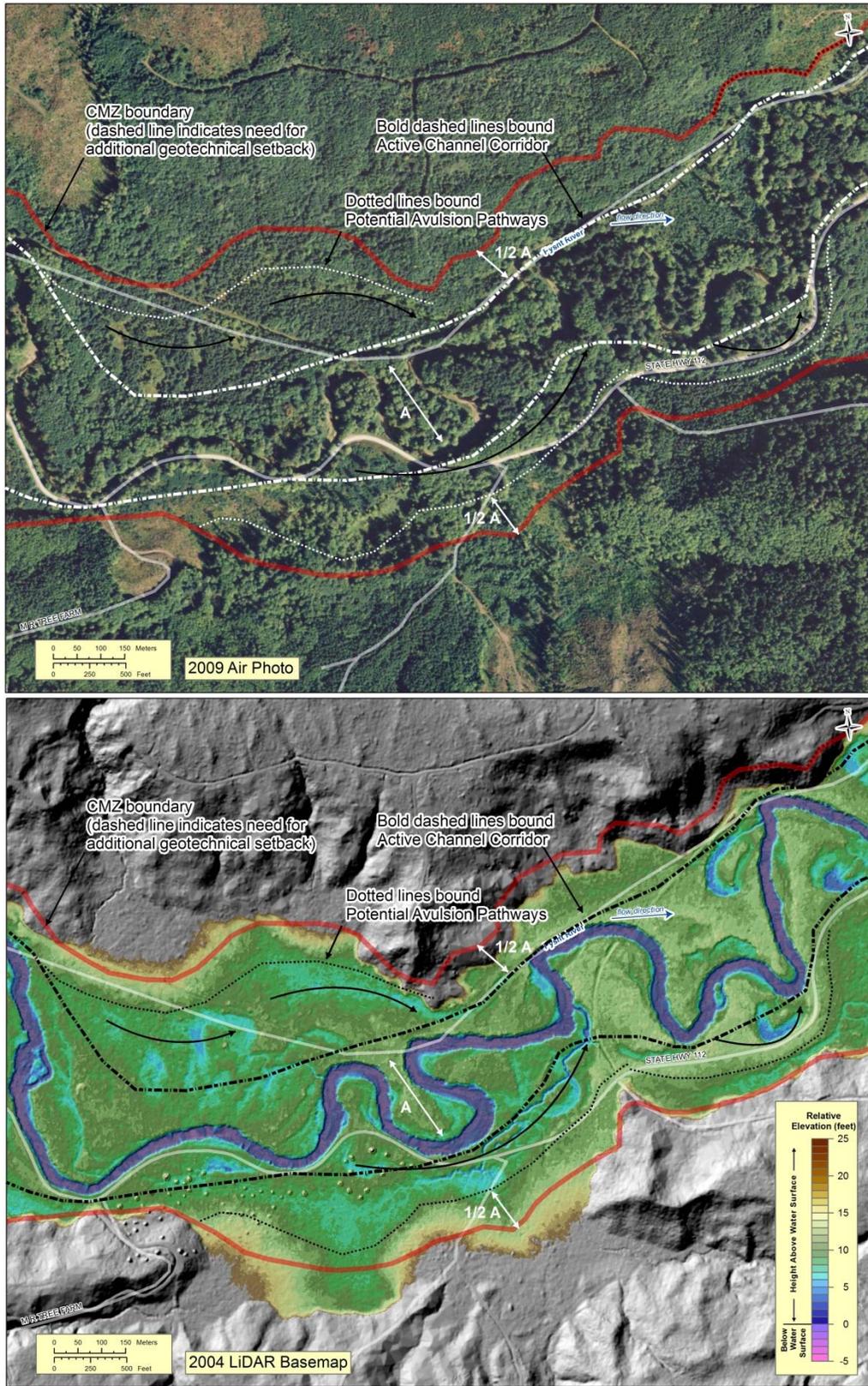


Figure 4.4 Aerial image (above) and REM map (below) for Pysht River showing the Active Channel Corridor, potential avulsion pathways, and channel migration buffer.

### *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 that areas of the valley bottom within 2 m of the bankfull elevation are susceptible to channel migration. Potential avulsion pathways and low-lying portions of the floodplain were delineated from the REM maps in GIS and included in the channel migration boundary.

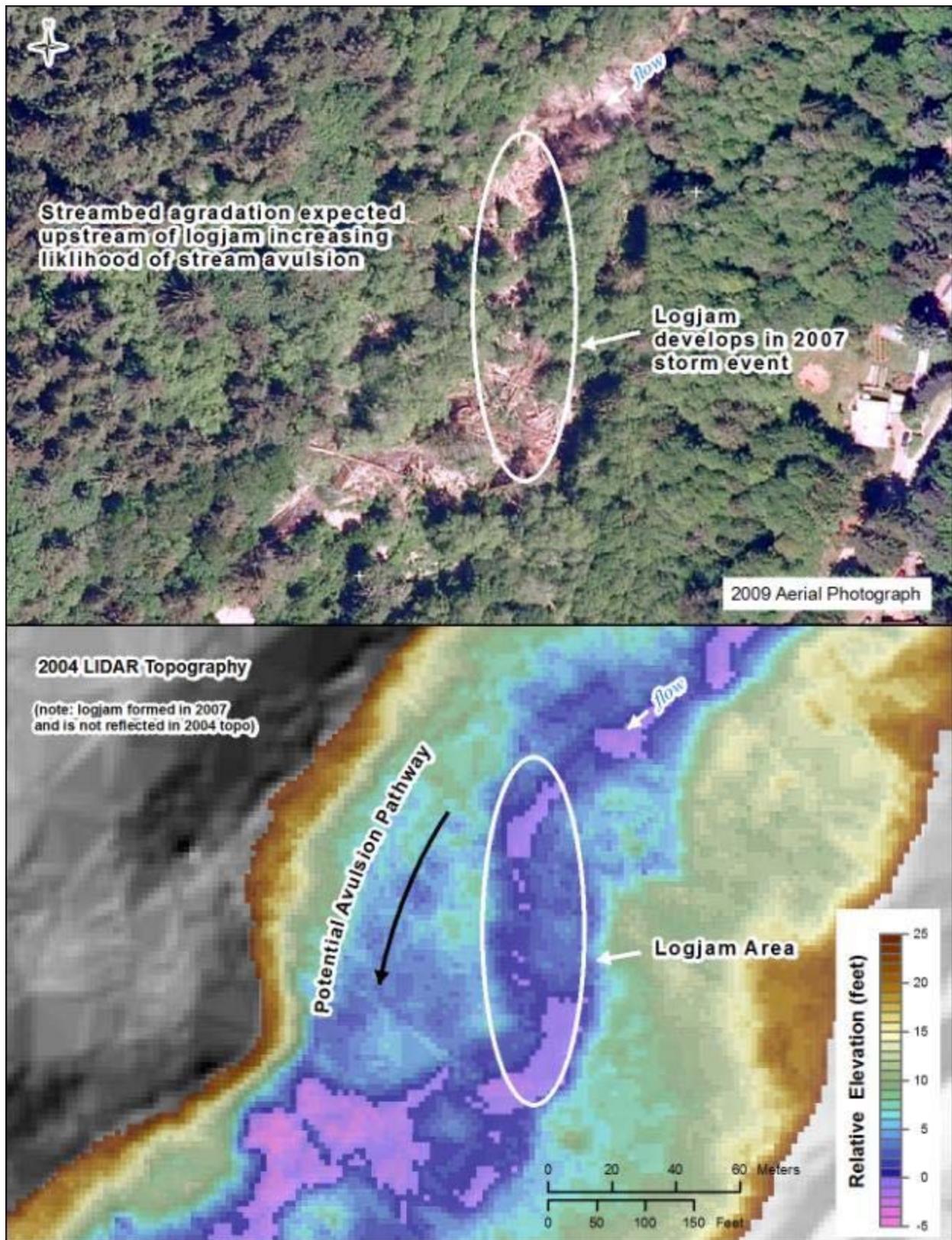


Figure 4.5 Mission Creek near Belfair, Washington. Example of wood accumulations that trigger channel migration (channel widening and lateral migration). This section of Mission Creek is downstream of the location shown in Figure 1.1, and may contain some of the riparian woody material removed from the streambanks 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 4.6 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 4.6 Decision guidelines used to identify the erosion hazard buffer and geomorphic features

Feature	Guideline
Erosion hazard buffer base width	Add between 1 channel width (entrenched streams) and 50% to 100% of the width of the active channel corridor to the corridor and avulsion hazard area. For non-meandering streams, look for adjacent reference reach.
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.
	Confined- delineate valley bottom as CMZ

Small streams without poorly defined or visible channel	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 setback 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 REM RSWE map.
Disconnected Channel Migration Zone (DCM)	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 DCM.
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 crescentic 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 crescentic 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.

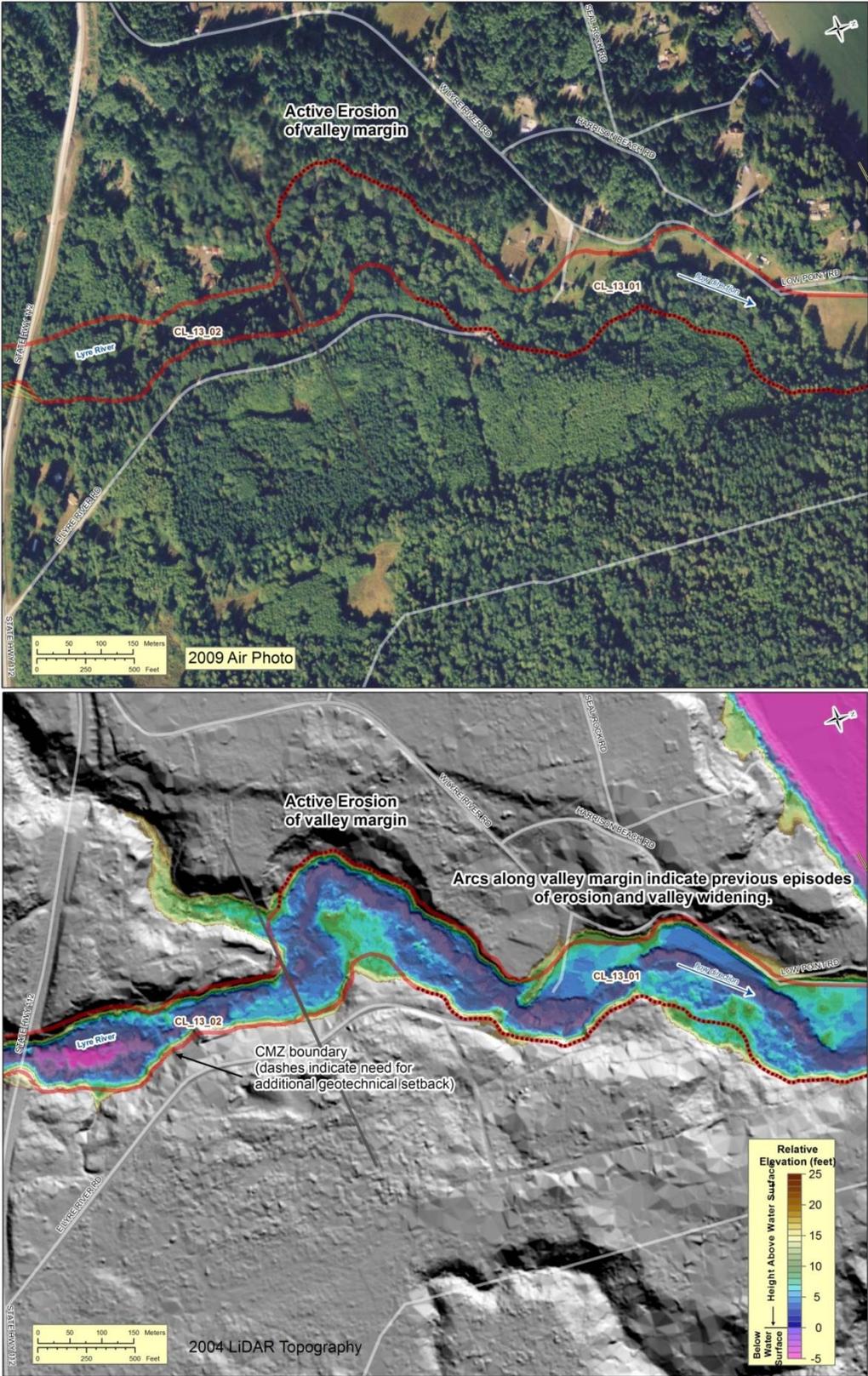
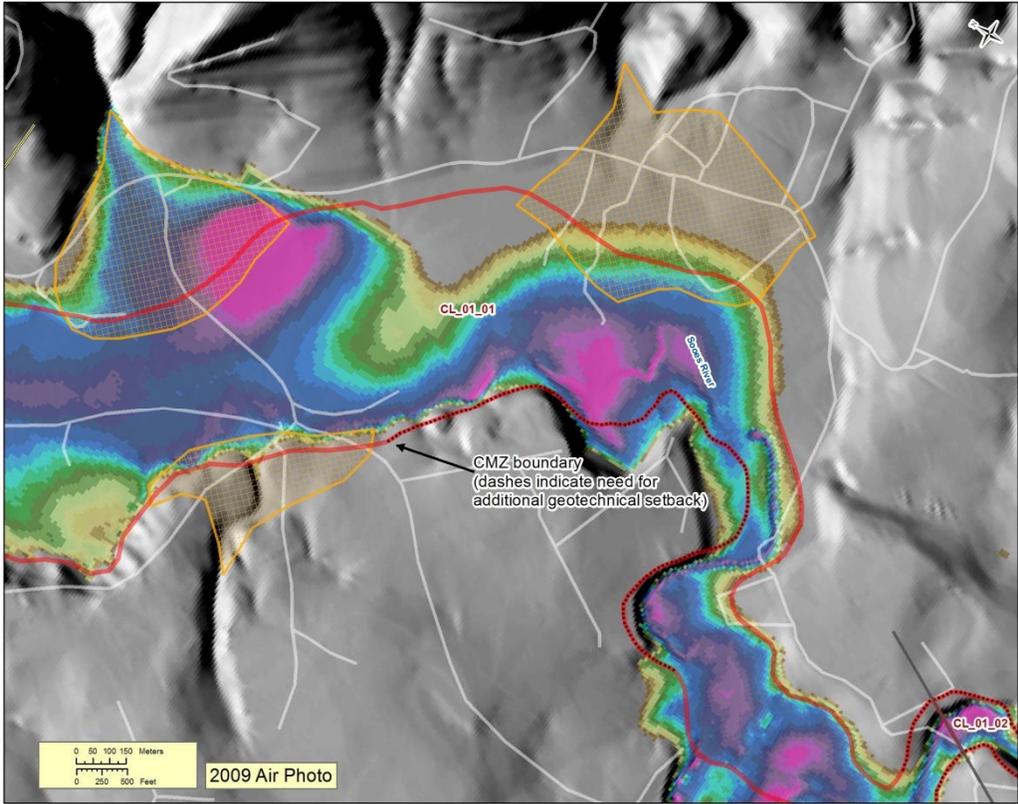


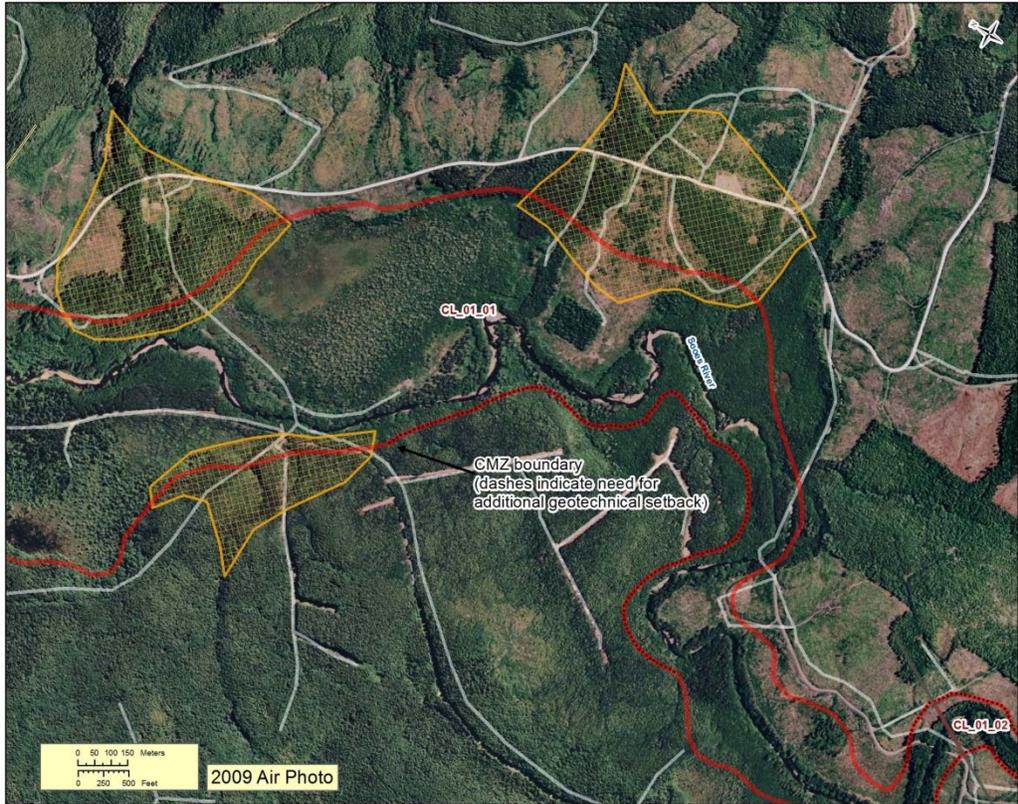
Figure 4.6 Aerial imagery (above) and REM map (below) showing a reach on the Lyre River where the stream is actively widening its valley.

*Underfit streams*

A stream flowing through a valley too large to have been formed by fluvial process resulting from the current stream is considered ‘underfit’ (Figure 4.7). Underfit streams in Western Washington often occupy valleys that were formed by fluvial processes linked to the glaciers. Two examples include valleys scoured by subglacial meltwater and valleys created by outwash channels draining from the terminus of the glacier and transporting much greater flow than is observed in the current hydrologic regime. The underfit streams evaluated in this study are typically low gradient reaches without sufficient power to do much geomorphic work such as extensive erosion of the valley margin. The area of potential channel migration in such cases generally occupies only a portion of the valley bottom as opposed to the entire valley bottom typically included for streams with actively forming valleys.



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Figure 4.7 DEM hillshade with relative elevation map (from 10m USGS DEM) (above) and Aerial image (below) for a reach of Sooes River that is considered underfit. In general, underfit streams are not as likely to migrate across entire valley bottom.

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.

The lower reaches of the Sol Duc River also flow within a valley created by glacial processes. The valley margin has erosional features with radius of curvature similar to current river bends. Some of the erosional features, including abandoned meanders and oxbow lakes, are present atop glacial terraces that are 50 or more feet higher than the current valley bottom. Figure 6.1 shows the Sol Duc River near the confluence with the Bogachiel River where the Sol Duc is deeply entrenched in a very broad valley floor. Multiple terraces are developed across the valley and abandoned meander channels and oxbow lakes deep enough to register on the HWSE map or hold water are present on a terrace located high above the current valley bottom. The low river gradient, minimal sediment supply, and insufficient power to cause erosion or avulsion into the abandoned meanders or oxbows indicate that these areas should be excluded from the CMZ. GLO maps from the late 1800s were evaluated, though not georectified in the GIS, to confirm the history of channel migration in these areas over the past century. In this case, the CMZ was delineated as one channel width on each side with geotechnical buffers added in areas where the channel abuts a high terrace comprised of highly erodible materials.

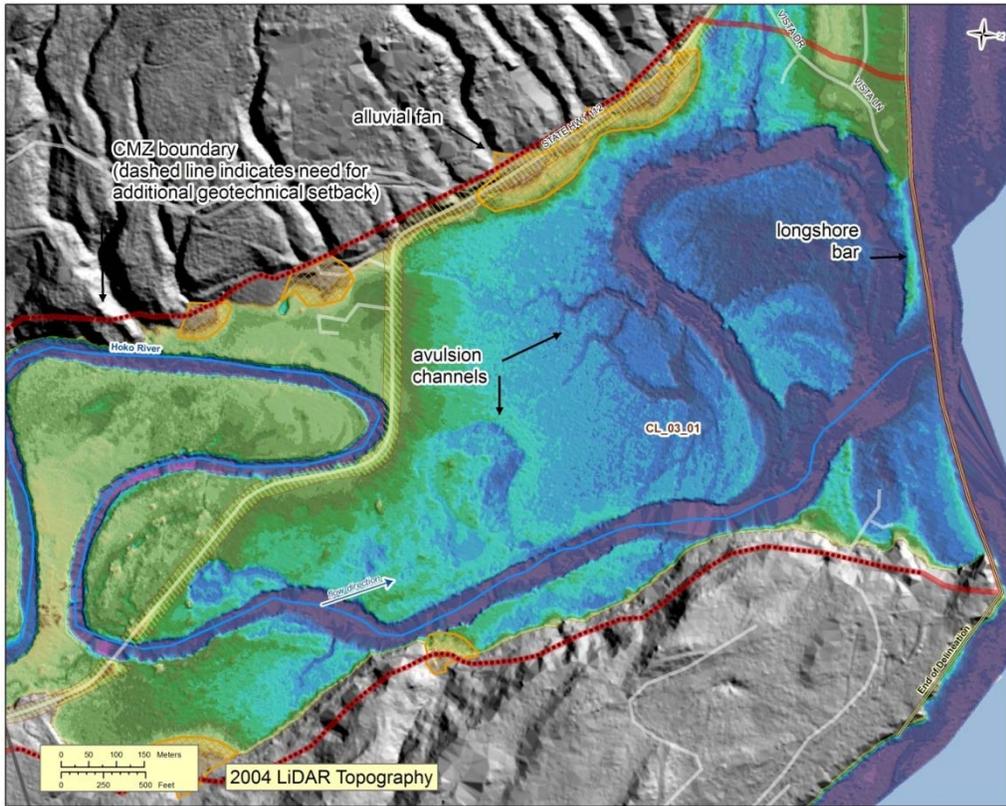


Figure 4.8 REM map of the delta of Hoko River showing a typical pattern of avulsion channels. A longshore bar has formed filling in the historical channel to the west of the current river mouth.

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 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 disconnected channel migration zones (Disconnected CMZs, or DCMZs). See Figure 4.9 for an example of a disconnected channel migration zone.

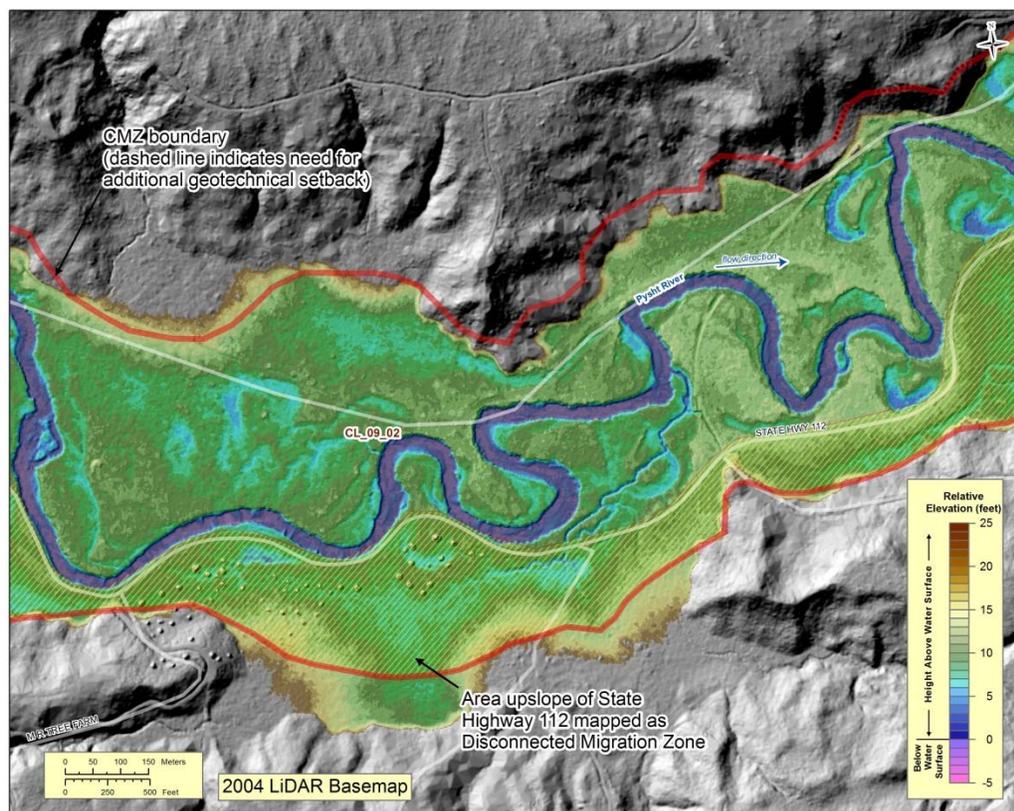


Figure 4.9 Disconnected migration area along Pysht River. This figure shows the same location as figure 4.4

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 to be barriers 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 planning-level delineation delineated large alluvial fans where they occurred within the valley where a stream was being delineated. The DEM and REM maps are usually excellent in revealing the fans. No field surveys or other data were used to delineate alluvial fans, so these planning-level 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 planning-level 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 areas where geotechnical setback buffer is needed is indicated on the maps with black dots in the CMZ boundary line.

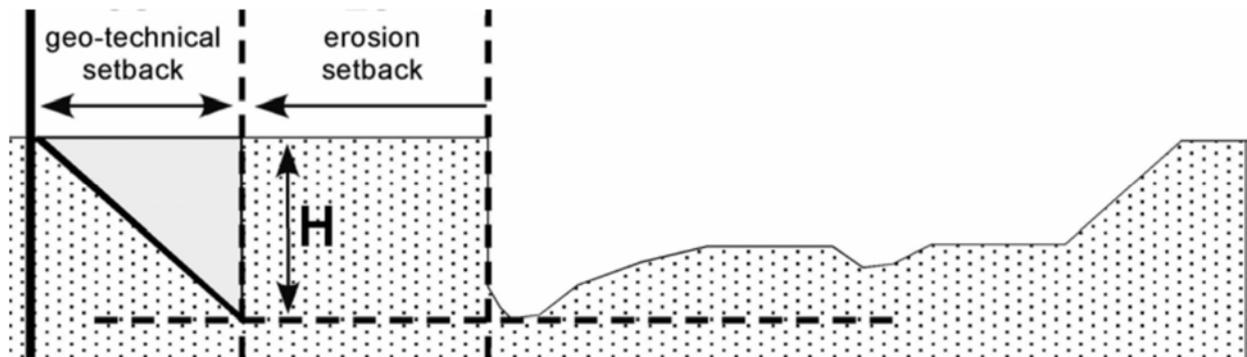


Figure 4.10 Illustration showing the basis for the geotechnical setback buffer. For purposes of this study, a geotechnical buffer was recommended any time H (height) was greater than 25 feet. The width of the geotechnical setback buffer was not determined for this study since it requires additional field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

## 8. Closed Canopy Streams

Closed canopy streams present unique challenges to CMZ delineations using methods that rely solely on remote sensing data without field verification of stream conditions. Significant erosion, stream widening, and channel migration generally will impact even large trees in the riparian zone, allowing detection on aerial photographs by trained reviewers. However, where the historical aerial photograph record covers a short period (less than 20 years) and LiDAR imagery is unavailable, as is the case with portions of the Dickey River West, Middle and East Forks, Skunk Creek, and Umbrella Creek, recognition of relic channels and potential avulsion pathways is further constrained. For closed canopy streams, an approximate CMZ represented by the topographic valley bottom and riparian corridor was delineated.

## 9. 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**

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### 5.1 **Quality Assurance Project Plan (QAPP)**

As part of the EPA grant that funded the WRIA 18 – 19 Puget Sound Streams CMA, 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. The QAPP also applies to the WRIA 20 Pacific Streams CMA described in this report.

### 5.2 **Limits of Analysis and Utility**

As described above, this is a planning-level assessment that used available remote-sensed data as a basis for delineating areas of potential channel migration; it is not a risk assessment. 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 REM 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 for 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

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The results of the study include maps with relative surface elevations, general channel migration zones, disconnected channel migration zones, alluvial fans, geomorphic features, and areas where geotechnical buffers are recommended. 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 from 6 to greater than 70 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 two 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 Streams in the Southwest Interior and Olympic Mountain Foothills

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 lower parts of the Bogachiel, Sol Duc, and Calawah Rivers, and the confluence area between the Sitkum and Calawah Rivers are under fit and meander across some of the glacially defined low gradient valley bottoms. The glacio-fluvial valleys contain multiple terrace levels that extend from 30 feet to greater than 100 feet above the active stream bed elevation. Where the active channels are close to the valley margin, slight erosion of the valley walls is possible. The stream valley floors are covered in significant glacial deposits and alluvium. 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 lower than the current stream bed. Aggradation associated with increasing relative sea level over the past 6,000 years has filled portions of 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 stream lie on marine sedimentary bedrock of the Crescent Group and in some areas, a thin alluvial veneer overlies the bedrock. Here streams are confined by the relatively hard bedrock forming the valley margins). Local channel migration occurs in response to the influx and deposition of sediment including periodic mass wasting events. Sediment deposition is enhanced by large wood present in the channel that may steer flow toward erodible banks and set up flow patterns that induce sediment deposition upstream of key wood pieces. Migration is facilitated by the width and topography of the valley bottom and by the presence of erodible valley wall material, size and concentration of key LWD pieces, and sediment influx.

Channel migration over the course of the available aerial photographic record was observed on the Quillayute River, the Bogachiel River between its confluence with the Calawah and Sol Duc Rivers downstream of the town of Forks and on the Sol Duc River just upstream of the Highway 101 crossing about 1.75 miles north of Forks. Avulsions and bend migrations downstream were observed between 2006 and 2009 on the Bogachiel and between 1994 and 2005 on the Sol Duc.

The Sol Duc, Calawah, and Sitkum Rivers are deeply entrenched over much of their lengths. In the broad lowland valleys, multiple terraces present on the valley floor above the active channel document the history of aggradation followed by incision. Oxbows, cut-off meander bends and relic channels that maintain water levels sufficient to support lakes or wetlands but that are present on terraces perched at elevations too high for channel migration to occur in multiple locations along the Sol Duc and Calawah Rivers.

Elk Creek is a tributary to the Calawah River. Lower Elk Creek flows through outwash and is deeply incised in the most downstream reach. Incision decreases upstream until the stream flows into a valley constrained by marine sedimentary bedrock. Channel movement, widening, aggradation and wood recruitment increase as stream begins flowing through marine sedimentary deposits. The marine sedimentary bedrock is susceptible to landsliding. The DNR landslide GIS layer indicates that many slides deliver sediment to the stream. Elk Creek in the canyon has heavy vegetation canopy and cannot be seen from aerial photographs except where the stream is widening or aggrading. The visible log jams are seen in these areas. The LiDAR relative elevation model provided information on channel forms such as relic and side channels, alluvial fans and channel migration. The stream is underfit but the LiDAR indicates that the channel meandered across most of the valley in recent history.

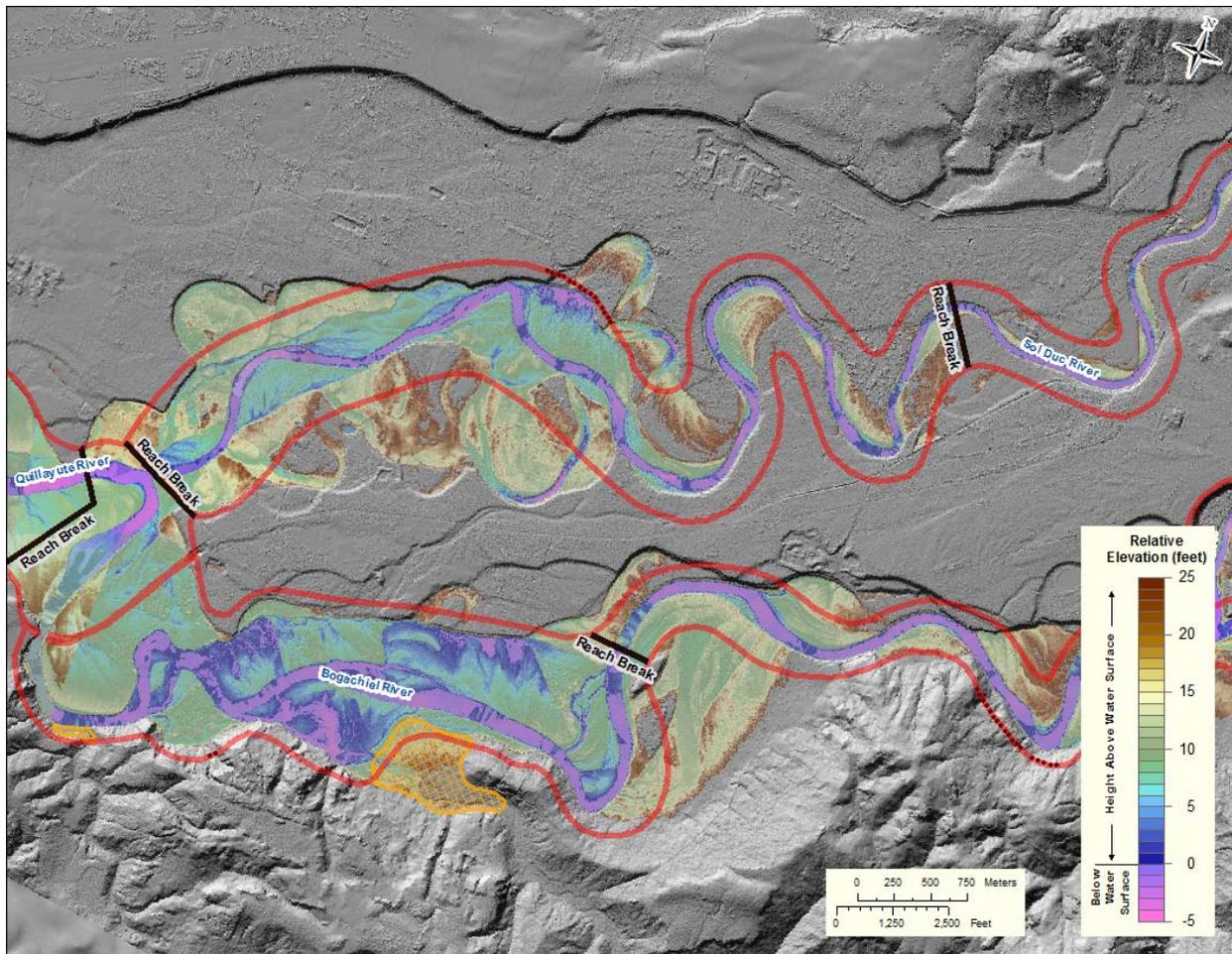


Figure 6.1 Relative elevation model shows the active channel entrenched in glacial terraces.

## 6.2 Streams in the northwest interior and western coast physiographic zone

The streams delineated in this area include the two tributaries to Sooes River; Pilchuck and Snag Creeks; three tributaries to Lake Ozette; Umbrella and Crooked Creeks and Big River; and the Dickey River and its tributaries; East, West, and Middle forks and Colby Creek. Broad glacial valleys that were formed by continental glaciation define streams in the southern portion of this area. Other parts of these streams flow through narrow valleys incised into deep deposits of glacial till and drift. The upper reaches of the Dickey River, both East and West Forks, and Thunder Creek are characterized by highly sinuous planforms with heavy canopy cover. The low gradient and dense vegetation of these streams decreases their potential to migrate. However, sandy soils in these areas suggest a greater potential for bank erosion and therefore a greater potential for migration. Aerial photographs show that the channels are migrating.

Increased sediment delivery to some streams in this area is associated with geomorphic instability in uplands, perhaps caused by road construction and timber harvest (c.f. Madej and Ozaki, 1996). 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.

Large, prehistoric landslides originating in the uplands on the east side of north-flowing Snag Creek control the creek's channel location, pinning the creek against the west valley wall.



Figure 6.2 Sediment deposition, bank erosion, and channel widening are taking place in Big River in areas of significant recent tracts of clearcutting.

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## Appendix A **Acronym List and Glossary**

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### *Acronyms*

BOR:	Bureau of Reclamation
CMZ:	Channel migration zone
DCMZ:	Disconnected Channel Migration Zone
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
REM:	Relative Elevation Map
SEA:	Shorelines and Environmental Assistance Program
SMA:	Shoreline Management Act
SMP:	Shoreline Master Program
SSURGO:	Soil Survey Geographic Database
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 insure 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's 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 REM 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.

**Planning-level 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). Equivalent to the WRIA 18 – 19 CMA's "streamlined method", this 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; it is not a risk assessment. The general channel migration zone includes historic channel locations, potential avulsion hazard zones, potential erosion hazard areas, and disconnected migration areas. 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.

**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.

**REM (Relative elevation model):** 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 stockwatering 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.

**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

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### **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**

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# Appendix D **Quality Assurance Project Plan for WDOE Channel Migration Assessments**

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# Appendix E pChannel Migration Zone Maps for Pacific Streams – Clallam County

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