RECLAMATION

Managing Water in the West

Channel Migration Zone Study
Jefferson County, Washington

Duckabush, Dosewallips, Big Quilcene and Little Quilcene Rivers

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Channel Migration Zone Study for the Duckabush, Dosewallips, Big Quilcene and Little Quilcene Rivers, Jefferson County, Washington

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U.S. Department of the Interior
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U.S. Department of the Interior
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INTRODUCTION

At the request of the Jefferson County Natural Resource Division, Reclamation undertook this channel migration zone study. Jefferson County needed this analysis to define flood hazard zones along the Duckabush, Dosewallips, Big Quilcene and Little Quilcene rivers for development and planning purposes.

The objective of this study is to (1) delineate the historical channel migration zone (HMZ) based on available historical aerial photography and maps; and (2) identify additional areas of possible lateral migration or avulsion based on geomorphic mapping and field observations.

Portions of four rivers in Jefferson County, Washington including the Duckabush, Dosewallips, Big Quilcene and Little Quilcene rivers, were the focus of this study's investigation. The study reach for each river extends from its mouth to either the U.S. Forest Service boundary or to a point where bedrock confinement minimizes lateral migration (Figure 1).

*Figure **1**. Study area location*

Channel migration zone studies identify areas that have historically been part of the active channel and that are prone to channel erosion and avulsion. These types of studies can be particularly important in the northwest, where the influence of large woody debris (LWD) can cause rapid and dramatic changes in channel location during a single flood, creating new channels and damaging the property of unsuspecting landowners. Practical application of the results in city or county planning can decrease damages and losses during floods by limiting development in areas prone to channel migration and erosion or by engineered protection of these unstable areas.

In recent years, new methodology for delineating the channel migration zone (CMZ) along rivers in the state of Washington to assist in flood hazard management and habitat assessment has been outlined in Rapp and Abbe (2003) and is generally applied in this study. Several terms are defined in Rapp and Abbe (2003) and together define the extent of the CMZ on a given river:

Historical Migration Zone (HMZ)—the collective area the channel occupied in the historical record.

Avulsion Hazard Zone (AHZ)—the area not included in the HMZ that is at risk of avulsion over the timeline of the CMZ. The term avulsion is defined as 'a sudden cutting off or separation of land by a flood breaking through a meander or by a sudden change in current whereby the stream deserts its old channel for a new one' (Bates and Jackson, 1980).

Erosion Hazard Area (EHA)—the area not included in the HMZ or the AHZ that is at risk of bank erosion from stream flow or mass wasting over the timeline of the CMZ. The EHA has two components: the Erosion Setback (ES) and the Geotechnical Setback (GS). The ES is the area at risk of future bank erosion by stream flow; the GS is defined by channel and terrace banks that are at risk of mass wasting (due to erosion of the toe). The GS projects from the ES at a side slope angle that forms a stable bank configuration, thereby accounting for mass wasting processes that will promote a stable angle of repose.

Disconnected Migration Area (DMA)—the portion of the CMZ where man-made structures physically eliminate channel migration. The DMA is delineated in an additional study by Perkins (2004) performed in collaboration with this investigation.

Rapp and Abbe (2003)

The application of these terms in the current study will be discussed in further detail in the Methods section. For this study, the timeline of the CMZ as discussed in the above definitions is 100 years.

PHYSICAL SETTING

In the rain shadow of the Olympic Mountains, the Duckabush, Dosewallips, Big Quilcene and Little Quilcene rivers drain the forested areas of the Olympic Peninsula and empty into the Hood Canal and Quilcene Bay along the eastern side of the Olympic Peninsula. During the Holocene (<10,000 years), these rivers have cut through glacio-fluvial sediments and Tertiary rocks to form their current channel morphology. Channels with single or multiple threads transition to distributary systems at their entrance to the Quilcene Bay or Hood Canal. Elevations range from approximately 8,000 ft to sea level in which rainfall is the primary form of precipitation in each watershed. The largest floods for the Duckabush and Dosewallips rivers are on the order of 10,000 and 13,000

ft^3/s, respectively in the historical record. Floods on the Big Quilcene and Little Quilcene are somewhat smaller. The largest peaks are 3,200 and 820 ft^3/s, respectively.

ACKNOWLEDGEMENTS

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DATA SOURCES

Historical aerial photography from 1939 to 2002 and maps prior to aerial photography were used to delineate the channel position and to define the HMZ (*Table 1*). Aerial photographs were rectified approximately every 10 years for the Dosewallips, Big Quilcene and Little Quilcene rivers. Rectified photographs and channel positions for the Duckabush River were obtained from the Army Corps of Engineers study (USACE, 2003). In this study, channel position was delineated approximately every 5 years from 1942 to 2000. Additional topographic maps and rectified General Land Office (GLO) plat and U.S. Coastal and Geodetic Survey T-sheets from the 1800's were used to provide information prior to aerial photography. LIDAR flown by the Puget Sound LIDAR Consortium was available for the majority of the study area also and was useful for observing surface morphology and for remote measurement of terrace heights in the geomorphic investigation.

METHODS

In order to develop a map of channel migration zones, information about historical channel movement as well as the extent and character of alluvial deposits had to be gathered. Searches for historical aerial photography as well as maps or other anecdotal information on channel position were conducted at various agencies such as the U.S. Geological Survey (USGS), USDA aerial photography field office (APFO), Army Corps

of Engineers Engineering Records, and Washington Department of Natural Resources (WDNR). Once aerial photos and maps were obtained, they were rectified using coordinates from pre-existing orthophotos and digital elevation models.

Table 1. Historical aerial photography and maps

Year of Photography	Vendor	Scale	Type	Rectified
2003	WDNR	1:12,000	CLR	N
2002	WDNR	Orthophotos (Dose only)	CLR	Y
2000	WDNR	Orthophotos	b/w	Y
1997	WDNR	1:12,000	b/w	N
1990/1991	USGS (NAPP)	1:40,0000	b/w	Y
1985	WDNR	1:12,000	b/w	N
1981	WDNR	1:12,000	b/w	N
1980	FSA	1:40,000	b/w	Y
1975	WDNR	1:24,000	CLR	N
1970	USACE	1:36,000	b/w	Y
1967	WDNR	1:60,000	b/w	N
1965	WDNR	1:12,000	b/w	N
1957	FSA	1:20,000	b/w	Y
1951	USGS	1:37,400	b/w	Y
1942	National Archives	1:20,000	b/w	Y
1939	UW	High-altitude	b/w photos	Y
1925	USGS	1:31,680	Topographic maps	N
1880s	UW	1:31,680	Government land office plat maps	Y
1883-1884	UW	1:10,000	U.S. Coastal and Geodetic Survey T-sheets	Y

USFS U.S. Forest Service
APFO Aerial Photography Field Office, U.S. Department of Agriculture
FSA Farm Service Agency, U.S. Department of Agriculture
SCS Soil Conservation Service, U.S. Department of Agriculture
USGS U.S. Geological Survey
UW University of Washington Puget Sound River History Project http://riverhistory.ess.washington.edu
WDNR Washington Department of Natural Resources

Detailed information on the methods of rectification can be found in Appendix B and in metadata that accompanies the digital data. The active channel was then mapped on each set of photos using a stereoscope and transferred to the digitally recitifed aerial photos. A few sets of photos that were already rectified when they were received, such as 1939, 2000 and 2002, were only mapped digitally. The 2000 and 2002 digital orthophotos are used as the map base to overlay active channels from various photograph years.

The field work component of this study focused on documenting characteristics of alluvium along the study reaches. This included describing materials in banks and bluffs, measuring bank heights, and describing morphology and vegetation on each surface. Field observations of channel morphology, bed material, width, and relative abundance of LWD from reach to reach were also made to assist in defining reach boundaries, assessing channel changes, and analyzing channel processes on each river. Additional information about human impacts to each river was gathered by mapping the extent and character of revetments in the field and talking with landowners about river processes and history along their properties.

PREVIOUS WORK

While this section is not a comprehensive review of previous work in the area, it discusses several references pertinent to this study. It appears from researching previous literature that limited work has been conducted on the geomorphology of the rivers in the study area. The U.S. Army Corps of Engineers (USACE) conducted a study on historical channel migration on the Duckabush River from 1942 to 2000, where they digitized historical channel locations from rectified historical aerial photographs (USACE, 2003). This study concluded that although the river has experienced some decreased lateral movement due to stabilized reaches, the overall sinuosity and channel character has not changed drastically during the study period.

Garcia (1996) studied the geomorphic evolution of the Dosewallips River drainage basin where he documented the time and extent of glacial advances in the basin as well as controls on the development of incised and alluvial reaches along the Dosewallips River. He found that these differences could be attributed to differential erosion of glacial sediments versus more resistant bedrock and that some river alignments could be attributed to structural features of the Olympic Mountains. Garcia also documented soil formation of Pleistocene and Holocene age for use in relative age dating and correlation of Holocene surficial deposits along the eastern side of the Olympic Mountains.

Several studies on the Big Quilcene relating to sediment management and stream/watershed restoration have been performed in recent years as the demand and interest for improving conditions along the river has increased. These studies have focused on assessing watershed conditions or river habitat and providing a scientific basis for river management and stream restoration (USFS and Washington State DNR, 2000; Brian Collins and Associates, 1993; Philip Williams and Associates, LTD, 1995; Engineering Services Associates, 2003).

REACH DESCRIPTIONS

Reach boundaries are defined based on present channel morphology, which reflects channel slope, bed material, abundance of LWD, and geologic constraints. The location of reach boundaries can be found in plates that accompany this report as well as in the text that follows in subsequent sections. Although the size of the four rivers in this study varies considerably, overall similarities in their morphology can be observed. The mouth of each river is a fluvio-deltaic zone in which sediments transported from the upper watersheds are deposited in an estuarine environment. Reaches upstream of the deltas are generally the most affected by anthropogenic modifications. These reaches are generally confined, single channels with low amplitude meanders. Their migration during the historical period is limited because levees and revetments have restricted their lateral movement. Upstream of major developments, the four rivers return to a more natural configuration that consists of relatively straight reaches that transport sediment and wide reaches with multiple channels that act as areas of sediment deposition or storage. Generally, a greater amount of LWD is found in these reaches. The uppermost portion of each river's study area transitions to a narrow valley and single channel thread. In these reaches, canyon or bluff walls are close to the active channel, and consequently limit historical channel migration. In this section, subreaches for each river are described in detail.

Duckabush River

Reach A extends from the mouth of the Duckabush River to the Highway 101 road embankment which essentially isolates much of the delta in this reach from receiving flood flow from the Duckabush river. Flow has historically been routed underneath the 101 Bridge near the south end of the delta since its construction in the 1930's (Engineering Services Associates, 2003) and branches into a distributary network that has not diverged far from the current distributary system. Historical General Land Office plat maps, T-sheets, and geomorphic evidence of abandoned channels mostly to the north of the current channel shows that this entire delta was part of active channel migration. The estuarine environment on the Duckabush river is essentially relegated to Reach A as the road embankment acts as a barrier to salt water advancing upstream from the Hood Canal, with the exception of two culverts and the Highway 101 Bridge. Geomorphic surfaces in this reach are generally gravelly or sandy and are relatively flat and close to water surface elevations.

Reach B extends from the Highway 101 Bridge to the east end of River Road. This reach consists of a low amplitude meandering channel with long revetments built to protect development on both sides of the river. With the exception of the upstream end of the reach, the channel has been in a relatively stable configuration for the historical period, most likely a result of the bank stabilization efforts along this reach (Figure 2). This reach also has a distinct lack of LWD and several abandoned channels on the north side of the river that were evidently all or part of the main channel prior to the historical period (Figure 3). The T-sheet shows at least one of these distributary channels in its survey.

Figure 2. Bank stabilization along the Duckabush River looking upstream.

Figure 3. Abandoned channels along the Duckabush River near Olympic Canal Tracts

Reach C extends from the east end of River Road to the Olympic National Forest Service boundary, which is the upstream end of the study area. This reach is characterized by a relative abundance of LWD and relative lack of revetments. Several relatively confined single channel reaches with high terraces and bedrock are interspersed with reaches that have wider channels, and have historically experienced growth of large-amplitude asymmetrical meanders and subsequent channel cutoffs. These areas typically are depositional zones, containing the largest numbers of LWD, multiple channels, and extensive gravel bars.

Dosewallips

Reach A extends from the mouth of the Dosewallips River to the Highway 101 Bridge. Historically, the channel has been located underneath the Highway 101 Bridge and maintained its position by revetments lining the channel banks. Due to these man-made constraints, the distributary network that would normally be part of this type of system is more limited than unmodified deltaic networks. Several channels that diverge to the north still receive overbank flow from the current channel and can be viewed while walking downstream from the current channel. Other previous channels on the south side of the river are possibly obscured due to landscaping in the Dosewallips State Park grounds. To the north, several abandoned channels that diverge much farther upstream from the current channel indicate that the active channel of the Dosewallips River has been in several different locations along a north-south transect of the delta. This observation is borne out by General Land Office plat maps from the 1880's, which show a major branch of the Dosewallips diverging to the north in the vicinity of the abandoned channels. As in the case of the Duckabush River, the Highway 101 road embankment limits the estuarine environment to this reach.

Reach B extends for approximately ½ mile upstream from the Highway 101 Bridge and appears to be a zone of deposition with large gravel bars, multiple channels and LWD with greater abundance than adjacent reaches. Revetments are also abundant in this reach, protecting development on the north side of the river and the Dosewallips State Park on the south side.

Reach C is a roughly mile-long straight reach that extends from the west end of Brinnon Lane to the northern end of the bedrock constriction upstream of Brinnon Flats. At the upstream end of Reach C, the Dosewallips River flows between bedrock and a knob of Quaternary sediments and bedrock. Although several abandoned channels have their entrance point within this reach, channel position has changed little during the historical period and has remained narrower than adjacent reaches.

Reach D extends from the boundary of Reach C to the eastern end of the Lazy C community. This reach generally has a much wider channel than adjacent reaches with large asymmetrical meanders and extensive lateral movement during the historical period. The presence of LWD and extensive gravel bars suggests that this reach is a depositional zone.

Reach E extends from the east end of Lazy C to the downstream end of the bedrock canyon. The Dosewallips River is a single narrow channel that trends northwest-southeast through this reach and flows against the bedrock wall on the right bank. The few bends present in this reach are related to bedrock protrusions that force the river toward the opposite bank. Lateral movement during the historical period has been minimal through this reach.

Reach F is located in a north-south trending bedrock canyon located just downstream of its confluence with Rocky Brook tributary. The channel is steep and narrow with coarse grained bed material. Historical movement is minimal due to the bedrock in the valley walls. At the upstream end of this reach historical accounts indicate that a splash dam was built by Sims Logging Company in 1917 and operated for 9-10 years (Engineering Services Associates, 2003). Logs that accumulated behind the dam were reportedly flushed all the way to the mouth of the Dosewallips when water was released from behind the dam. These induced floods may have impacted the downstream river system by eroding stream banks, incising channels and may have been important in creating the narrow, straight channel in reach E.

Reach G extends from Rocky Brook to the Olympic National Forest boundary, which is the western end of the study area. This reach is generally characterized by a single, relatively straight channel that flows along the south side of the Dosewallips valley. LWD is located in areas of the channel that are wider, such as in the vicinity Rocky Brook. One major avulsion has taken place in this reach during the 1950's (Figure 4) and has been relatively stable for the last 50 years.

Figure 4. Site of major avulsion along the Dosewallips River in Reach G. Flow is from left to right.

Big Quilcene

Reaches on the Big Quilcene River appear to alternate between relatively straight, narrow reaches with little LWD and few secondary channels and sinuous wide reaches with greater amounts of LWD and multiple channels. Reach A extends from the mouth of the Big Quilcene River to Rogers Road. The distributary network at the downstream end narrows into a single narrow channel upstream with low amplitude meanders and numerous revetments along the channel banks. This reach in particular has been tightly confined by levees on both sides, although portions of the north levee were removed in the 1990's.

Reach B extends from Rogers Road for approximately 3800 ft upstream and is characterized by a narrow, straight channel at the downstream end of the reach that transitions to a meandering gravelly channel with low vegetated bars and secondary channels that. Lateral migration in the upstream portion of the reach has been common historically while in the downstream portion of the reach, the channel has remained relatively confined with little LWD in the channel when compared to the upstream part of Reach B. This dramatic difference in channel morphology points to potential channelization in the lower reach, which notably contains a continuous levee on the south side of the river that ties into the Reach A levee.

Reach C extends from the Quaternary bluff on the left bank for approximately 4500 ft upstream. Reach C is an expansion reach with relatively abundant LWD, gravel bars, and multiple channels. Two engineered log jams designed by Herrera are part of LWD studies on the Big Quilcene River (Herrera Environmental Consultants, Inc., 2003).
Reach D appears to be an incised, steep and narrow reach with little LWD and extensive revetments along the right and left banks. The revetments are emplaced to protect the Highway 101 bridge, fish hatchery and private property downstream of Highway 101. Lateral migration has been limited historically, most likely due to human constraints placed on the river and incision that is evident downstream of the Highway 101 bridge in the form of meanders that were previously active through the 1950's. By 1971, the meanders were cutoff and are presently about 10 ft above the active channel.

Reach E extends from the fish hatchery to the north end of the Hiddendale community. This reach is relatively wide and sinuous compared to the adjacent reaches and contains extensive gravel bars, multiple channels, and LWD. The fish hatchery diversion located in the middle of the reach diverts water to the fish hatchery. Extensive rip rap upstream of the diversion has been emplaced to direct the river toward the left bank. The channel has aggraded essentially to the level of the rip rap (Figure 5). Flow over the top of the barrier was evident during field work and may be causing channel incision downstream of the rip rapped area. Extensive lateral migration throughout the historical period including growth of large meanders and cutoff channels has been typical for this reach.

Figure 5. Looking downstream at aggradation behind revetments in the Big Quilcene River. Note that forested areas are the same elevation as the channel.

Reach F extends from the north end of the Hiddendale community to the Olympic National Forest boundary, which is the southern limit of the Big Quilcene study area. The channel narrows upstream from approximately 60 to 30 feet and is a single channel confined at the upstream end by high terraces and bedrock. Several rip rap barbs along the right bank of the Hiddendale community provide some bank protection.

Little Quilcene

Reach A extends from the mouth of the Little Quilcene River to the Center Road Bridge and is characterized by extensive levees and revetments built along the channel that create a straight narrow reach at the downstream end and have limited lateral erosion throughout the historical period. The channel is dominated by well sorted gravel, sparse LWD and thick vegetation along channel banks and levees, except in landscaped areas of private property.

Reach B extends from the Center Road Bridge for 3800 ft upstream and consists of an alternating wide and narrow, sinuous channel within a vegetated low floodplain. Revetments are less common in this reach than in Reach A, but do exist along a few eroding banks and where the Little Quilcene main channel is near Highway 101.

Reach C extends for 1500 ft upstream and downstream of the Highway 101 Bridge and is characterized by a narrow single channel reach with high banks or bedrock bluffs on both sides of the stream. Lateral migration has been minimal in the historical period.

Reach D extends from the first bend upstream from the Highway 101 Bridge to the upstream boundary of the Little Quilcene study area. The upstream extent of mapping was terminated at the point where the channel became too narrow to accurately map historical channel position. This reach is sinuous with alternating wide and narrow channels and low vegetated terraces, gravel bars, and greater amounts of LWD. The reach is unconfined on its west side, but flows against high Quaternary bluffs on its east side.

MAP EXPLANATION

Active Channel

The active channel is the area relatively free of vegetation and showing modification by recent streamflow. For each year of aerial photography, the active channel was mapped within the study reach. In the case of GLO plat maps and U.S. Coastal and Geodetic Survey T-sheets, the channel was traced so that it could be overlaid with more recent historical datasets. Evaluation of the plat maps and T-sheets show some areas that are clearly incorrect in their locations; in these cases, the 1880's channel delineations were ignored.

Levees and Revetments

Most levees and revetments were mapped during the field work component of the study and consisted of large blocks of rip rap placed along river banks to prevent lateral erosion. In many cases, the rip rap was composed of multiple generations as material was eroded by floods and then replaced along the bank following floods (Figure 6). Rock barbs were also common features particularly on the Big Quilcene River in reaches C and F. In some cases, vegetation had covered much of the original features so that while most features mapped were visible, the presence of some were inferred based on adjacent rip rap or the topography of the feature itself. Some revetments included a combination of rip rap and cabled logs oriented parallel to the river bank, while a limited number were composed of concrete blocks or solid concrete walls.

The most extensive revetments were commonly found on the lower reaches of each river, where they act to straighten the channel, direct flow to the outlet and prevent distributary networks from forming. Other revetments, particularly on the Big and Little Quilcene rivers were located in the deltas and were meant to reclaim agricultural land by preventing tidal waters from flowing into the upper reaches of the estuary. Revetments were primarily mapped to provide important information about areas that were previously part of the channel migration zone but have currently been isolated from channel migration due to the commitment by private landowners or government entities to protect these areas of development. The delineation of the disconnected migration area (DMA) as defined by Rapp and Abbe (2003) depends heavily on this map feature and is discussed by Perkins (2004).

Figure 6. Photograph showing multiple generations of revetments along a stream bank of the Duckabush River, Olympic Canal Tracts.

Historical Migration Zone (HMZ)

The HMZ is defined by Rapp and Abbe (2003) as "the collective area the channel occupied in the historical record". The historical record is defined in this study from the late 1800's to 2003, a period of approximately 100 years, and is based on the availability of historical information for defining the HMZ. On each river, channel position is delineated at least every decade from 1939 to 2000 while General Land Office (GLO) plat maps and other topographic maps provide information prior to 1939 (see Table 1). In cases where the GLO plat maps or T-sheets do not appear to be reliable, the historical period is limited to 1925 to 2000, a period of 75 years. In these areas, the HMZ boundary does not include the 1880 GLO or T-sheet channel position. The 1925 topographic maps were not rectified and therefore only provide a qualitative comparison of channel position from 1925 to 1939.

The HMZ, then, encompasses channel positions from all years in its delineation (Figure 7). Where channel delineations fell outside of bedrock or Quaternary sediment contacts due to uncertainty in aerial photo rectification, the HMZ was defined along the bedrock or Quaternary sediments contact. Thus, in some cases, channel delineations will fall slightly outside of the HMZ delineation.

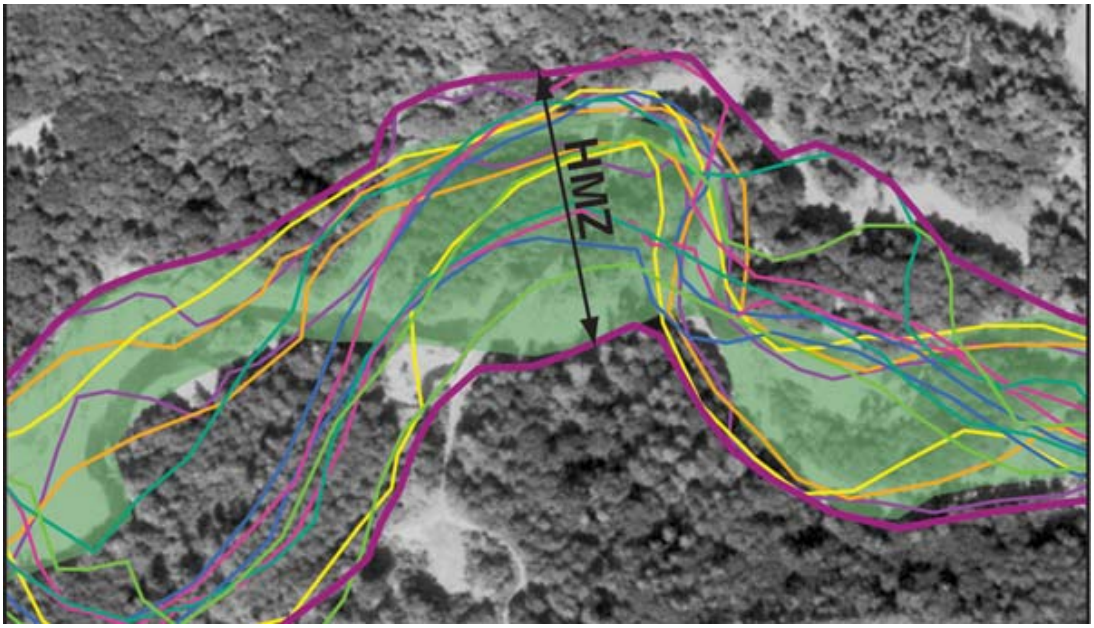

Figure 7. Example of the HMZ along the Quilcene River. Flow is from left to right.

Field observations of the HMZ show active channels with sparse vegetation on point bars and mid-channel bars. Alder vegetation on low terraces, and log jams at abandoned channel entrances are also typical observations in areas that have been active historically but are currently not part of the main channel. Many of these abandoned or secondary channels still receive limited low flow underneath log jams with immature vegetation lining the channel banks. Surface topography is generally irregular with bar and swale topography on low terraces (0-4 ft); substrates are composed of a weak gravelly soil (Figure 8).

Figure 8. Photograph looking at a transect of an HMZ surface along the Duckabush River.

Avulsion Hazard Zone (AHZ)

The AHZ is defined by Rapp and Abbe (2003) as "the area not included in the HMZ that is at risk of avulsion over the timeline of the CMZ". The timeline of the CMZ for this study is 100 years. As stated in the introduction, an avulsion is defined as 'a sudden cutting off or separation of land by a flood breaking through a meander or by a sudden change in current whereby the stream deserts its old channel for a new one' (Bates and Jackson, 1980). In this study, the AHZ is defined by surface morphology, soil development, surface height above the active channel, and vegetation. Surfaces that are part of the AHZ commonly have relict, subdued channels that are both visible on LIDAR as well as in the field (Figure 9); topography is irregular with higher islands of mature vegetation and lower areas of channels and gravelly bars with younger vegetation. AHZ surfaces range from 3 to 8 feet above the active channel, depending on the reach characteristics. In some areas, lower terraces were included in this category where the HMZ did not completely cover them. Vegetation that is commonly found on these surfaces includes alders, swordfern, cottonwood and blackberry bushes.

Erosion Hazard Area (EHA)

The EHA is defined by Rapp and Abbe (2003) as "the area not included in the HMZ or the AHZ that is at risk of bank erosion from stream flow or mass wasting over the timeline of the CMZ. The EHA has two components: the Erosion Setback (ES) and the Geotechnical Setback (GS). The ES is the area at risk of future bank erosion by stream flow; the GS is defined by channel and terrace banks that are at risk of mass wasting (due to erosion of the toe). The GS projects from the ES at a side slope angle that forms a stable bank configuration, thereby accounting for mass wasting processes that will promote a stable angle of repose."

In this study, the ES is generally located on higher terraces that appear to be elevated far enough above the channel to be prone to lateral erosion rather than channel avulsion. These terraces are typically planar with few subdued channels on their surfaces and are 8-10 ft or greater above the active channel, depending on location. Vegetation is more mature than the HMZ or AHZ and consists of swordfern, cottonwood trees and large cedar stumps (Figure 10) that were part of the virgin forest and have been able to survive many of the other species whose stumps have since rotted. Where these stumps are present, they indicate that the surfaces are at least several hundred years old. Much of the vegetation is also thickly covered with moss or other fungi and have a forest floor covered with downed trees. Surfaces that are defined as part of the ES also have greater soil development with fine-grained surface soils over gravelly substrates.

The width of the ES was defined on a reach-by-reach basis, using processes observed during the historical record to determine the possible amount of lateral erosion during a 100-year period. The assumption here is that channel migration will progress at a rate or in a similar manner in the next 100 years as it has for the past 100 years. There is considerable uncertainty in this assumption as factors such as climate and hydrology do not appear to be uniform in behavior. Changes in these factors could be important in the location and rate of channel migration.

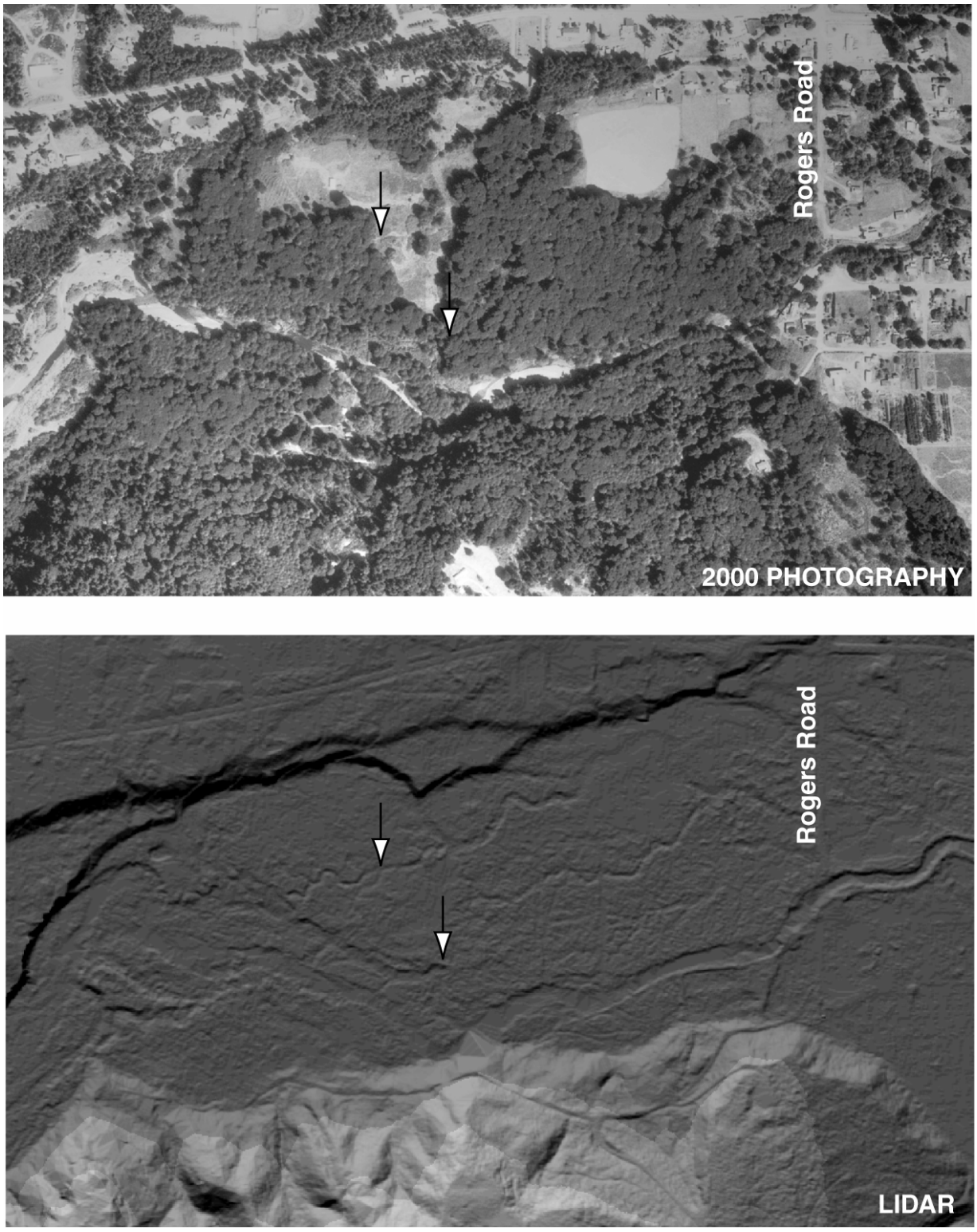

Figure 9. Comparison between aerial photography and LIDAR along Reach B of the Big Quilcene River. Arrows point to relict channels on the AHZ surface. The main channel of the Big Quilcene River flows from left to right through the center of each picture.

Figure 10. Vegetation on an EHA surface showing cedar stump in foreground.

LWD is considered to be an important factors in the evolution of channel morphology and formation of stream habitat in the northwestern U.S. (Abbe, 2000). An increase or decrease in the amount of LWD in the channel may cause channel changes that are not easily predicted using the present channel geometries. Nonetheless, direct evidence of past behavior appears to be the best information for determining a practical width for the ES. Techniques used in this study include measuring the rate of lateral migration of meander bends where there was a distinct observable and measurable trend. The ES is based on the calculation of the ES coefficient in Equation [1]:

$$C_E=E_R(T_E/T_R) \qquad [1]$$

where E_R=rate of erosion (calculated by channel migration rates)
T_E=average time channel is expected to erode at one location (based on meander growth and cutoff)
T_R=average time for river to reoccupy same location (based on historical data)

The ES coefficient C_E is then multiplied by the timeline of the CMZ, which in this case is 100 years, to obtain the width of the ES. The first assumption in using this equation is that the materials being eroded at the measurement location are similar to those where the result is applied. The second assumption is that the rate of erosion at the measurement location can be applied to locations with differing hydraulic geometries and LWD arrangements. The growth of meander bends on rivers in the study reach tends to occur

over decadal time scales before the bend is cutoff by subsequent flows and appears to progress sporadically through the decade rather than at a uniform rate. Other techniques for determining the ES coefficient included the measurement of meander amplitude or average channel width, assuming that the channel could not erode more than one meander amplitude or channel width if it had not migrated further than that during the historical record. The ES was determined for each reach along the four rivers. Since the width of the ES differs from once reach to the next, intermediate widths at the boundaries between reaches were used to avoid abrupt changes in the width of the ES and allow for a smooth transition from reach to reach.

Since there is a great amount of semi-consolidated glacial sediments that may be prone to lateral erosion and mass wasting, the delineation of a GS is also appropriate in many locations. Although Rapp and Abbe (2003) recommend a more rigorous geotechnical study to determine the GS, a 1:1 slope was assumed in this study and is similar to Jefferson County's regulations concerning setbacks from steep slopes. The GS was defined where Quaternary sediments were less than 40 feet high or were observed to retreat measurably during the historical record and were located adjacent to the active channel or adjacent to the ES. Where Quaternary sediments had greater height and were determined to not retreat measurably during the historical record, they were not assigned a GS and should be covered under Jefferson County's regulations concerning setbacks from steep slopes. When the bluffs were located adjacent to the active channel, they were assigned the full value of the EHA (ES + GS). If they were located away from the active channel, they were assigned any remainder of the ES not covered on the high terraces and the value of the GS based on the measured height of the bluff.

Quaternary sediments

Geologic maps used to define the extent and character of Quaternary sediments along each study reach include Birdseye (1976), Carson (1976), Garcia (1996), and to a lesser extent Tabor and Cady (1978), Yount and Gower (1991) and Yount et al. (1993). The most common Quaternary sediments found adjacent to the modern channels and Holocene alluvium are recessional deltaic deposits usually greater than 6 m thick, recessional outwash in meltwater channels, approximately 1-5 m thick, and lodgement till. Ice-contact stratified drift and lacustrine deposits are also common along the Duckabush and Dosewallips rivers. These deposits were for the most part formed during the Fraser Glaciation as the Puget Lobe of the Cordilleran Ice Sheet advanced to its terminal position around 14,150 ^{14}C yr BP and began its retreat by 13,600 ± 280 ^{14}C yr BP to 13,700 ± 150 ^{14}C yr BP (Mosher and Hewitt, 2004). Local drift from valley glaciers originating in the Olympic Mountains may also comprise a portion of the deposits.

Bedrock

Bedrock along the Duckabush and Dosewallips Rivers is part of the Tertiary Crescent Formation, which includes basalt flows and mudflow breccias. In some places a thin layer of drift generally less than 2 m thick may overly the Crescent Formation. The Big and Little Quilcene rivers also flow along bedrock outcrops of the Crescent Formation; in

some locations, the Little Quilcene River flows adjacent to Tertiary sedimentary units of shale, siltstone or mudstone (Birdseye, 1976; Carson, 1976).

DISCUSSION

Delineation of the Channel Migration Zone

The channel migration zone (CMZ) includes the HMZ, AHZ and EHA within its limits and is defined as "the area where a stream or river is susceptible to channel erosion " (Rapp and Abbe, 2003). The unconstrained CMZ has its widest extent at the mouth of each river and decreases in width upstream as the valley floor narrows. In the deltaic areas, the CMZ is defined mainly by a wide HMZ with a historical distributary channel network and an extensive fan-shaped AHZ typically on both sides of the HMZ. In upstream reaches where the valley floor is narrower, the HMZ, AHZ and EHA are present, with the AHZ generally closer to the active channel than the EHA.

Duckabush River

There are two reaches where an AHZ is delineated on the Duckabush River. In Reach A, the AHZ is delineated where abandoned distributary channels can be observed on aerial photography and in the field. The width of the AHZ is determined by the extent of these abandoned channels. In Reach C, the AHZ is delineated on low channelized surfaces near the Olympic National Forest boundary that are approximately 3-5 ft above the active channel. The EHA is delineated on surfaces in reaches B and C. In Reach B, channel width and position has remained very similar throughout the historical period, where revetments have held the channel in its current geometry and the active channel has not migrated more than one channel width. The ES is thus defined by average channel width measured every 500 ft for each historical channel delineation (1942 to 2000). A GS is also defined in this reach where the ES intersects bluffs of Quaternary sediments that are less than 40 ft high. A width of 30 ft is added to the EHA in these locations and is based on a 1:1 slope.

The EHA in Reach C is based on a channel migration measurement at point 1 (Figure 11) from 1990 to 2000 using equation [1] where E_R=10 ft/yr based on four measurements made across the area eroded between 1990 and 2000. An alternate estimate was also made between 1990 and 1997 at 15 ft/yr (Appendix A). 2003 aerial photography and field observations show that this meander has recently been cutoff by a straight channel along the right bank and support the hypothesis that meander growth is limited to a decadal timescale. The width of the ES in this reach is 170 ft using a T_R=10 years and T_E= 60 years. A GS of 30 ft is also added to this reach where the ES encounters bluffs that are approximately 30 ft high.

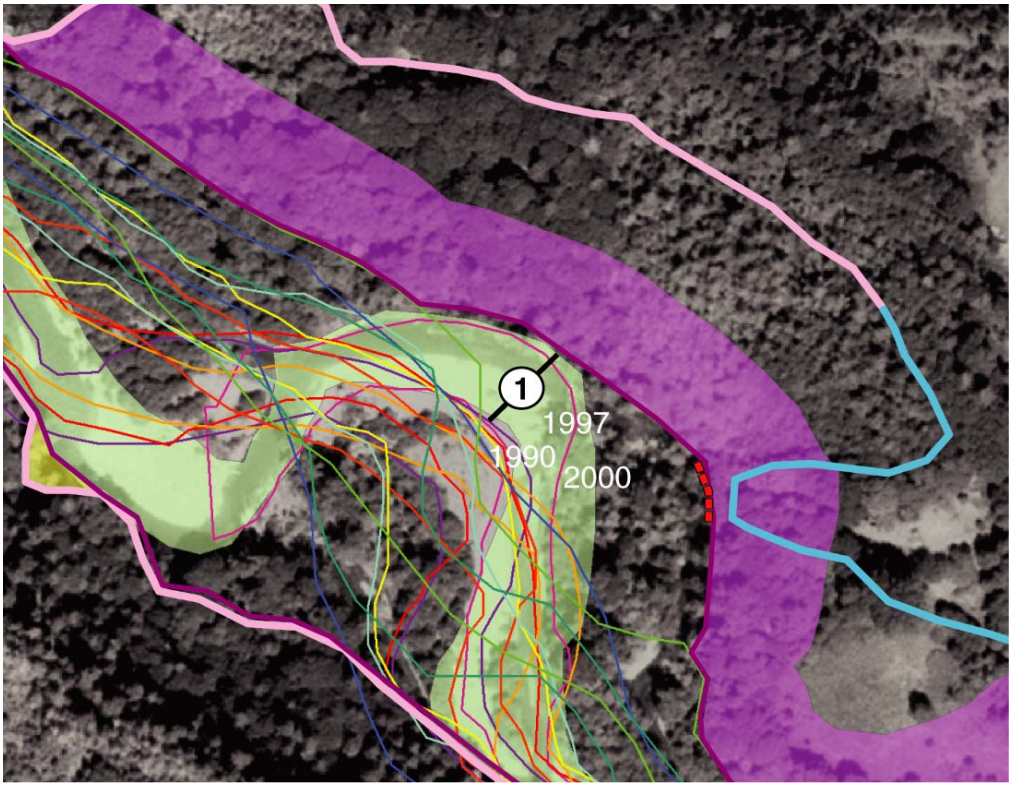

Figure 11. Measurement location (point 1) for channel migration in Reach C, Duckabush River. Purple line=1990; pink line=1997; transparent green=2000. Flow is from left to right.

Dosewallips River

Surfaces delineated as avulsion hazards exist in every reach along the Dosewallips River with the exception of Reach F, which is a confined bedrock canyon. They are generally more extensive than the other rivers studied primarily because the river has a wider alluvial valley and more room for alluvial deposits to be preserved. AHZ's that impact developments and recreational lands are located in the downstream reaches A, B, and E. In reaches A through C, the AHZ spans the breadth of alluvial deposits on the north side of the Dosewallips River in the Brinnon community. East-west trending abandoned channels can be observed on aerial photography and through field observations (Figure 12*);* entrances from the current channel can also still be observed, although somewhat elevated above the active channel at points 1 and 2 in Figure 12. In Reaches A and B, the AHZ is also defined on the south side of the River and encompasses the majority of Dosewallips State Park. This surface, although smoothed by landscaping, shows irregular topography and has been inundated during historical floods (personal communication, Dosewallips State Park Ranger, 2004). Revetments have prevented most flooding of the park; however, some erosion of these structures has occurred, creating a need for continued maintenance of these structures and commitment by the state to protect this park from flooding and future channel migration. Although conversations with the Dosewallips State Park Ranger indicated that these revetments were constructed during the 1950's, channel positions during the 1970's and 1980's are located behind the current revetments and suggest a later date for these structures.

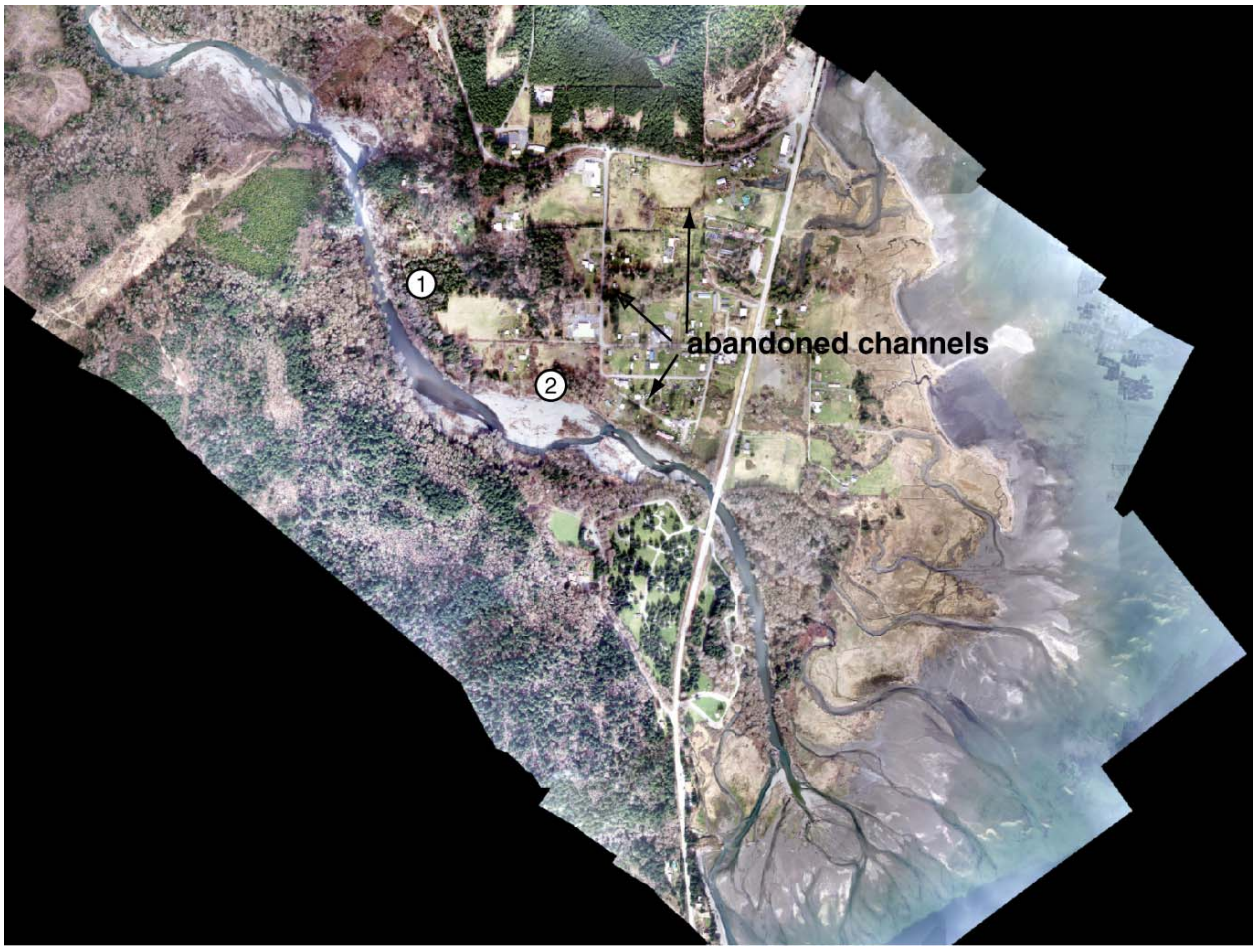

Figure 12. Abandoned channels along the Dosewallips River.

In Reach E, the EHA spans the length of the Lazy C community and adjacent lands upstream of the community on the north side of the river. While the river appears to be incised through this reach and has been very stable historically, geomorphic evidence in early photographs and LIDAR indicate that numerous channels have existed on this surface in the past (Figure 13). Due to what is interpreted to be historical incision at the upstream end from splash damming in the early 1900's (Engineering Services Associates, 2003), only the lowest part of this surface was delineated as the AHZ. This area shows recent aggradation with sediment burial of riparian trees. Further work could determine the rate of sedimentation to assess whether aggradation could progress at a rate upstream to a level that might cause an avulsion hazard on a greater extent of the surface. Recent large flows along the Dosewallips River have inundated the margins of this surface on the upstream end (point 1 in Figure 14) and areas of the Lazy C community that are closest to the active channel.

Figure 13. 1951 aerial photograph showing channels on the Lazy C surface (black arrows). Flow is from left to right.

In Reach G, the AHZ is defined along the north side of the Dosewallips River where flows have inundated during the historical period, and where it may be possible for an avulsion to occur. The AHZ is also defined along the left bank of the pre-1950 active channel. This area is unlikely to become part of the active channel given the present channel position; however, if the pre-1950 channel were to receive a large flow and reactivate as the main channel, avulsion would be much more likely.

The EHA, which only includes an ES, is limited in extent along the lower reaches of the Dosewallips River and becomes more extensive upstream of Reach F. A GS was not required along the Dosewallips River because slopes along the river are either bedrock or are Quaternary sediments covered by Jefferson County's regulations concerning setbacks from steep slopes and do not retreat at a measurable rate where a GS would thus need to be defined. In Reaches B and C, the EHA is defined by average active channel width, which is greater than the width of the high terrace such that the entire terrace is part of the EHA. In Reach D, the EHA is defined by 7 historical channel migration measurements from 1970 to 2002, a period of approximately 30 years (point 1, Figure 15). The meander just downstream demonstrates that the meander growth and cutoff appears to take place over an approximate 20-year period, which defines the value for T_E. Historical channel delineations show that the meander position along the left bank began forming between 1957 and 1970 and has continued to grow through 2002, a period of approximately 40 years (T_R). Over a 100-year period, the EHA is calculated to be about 400 ft using Equation [1].

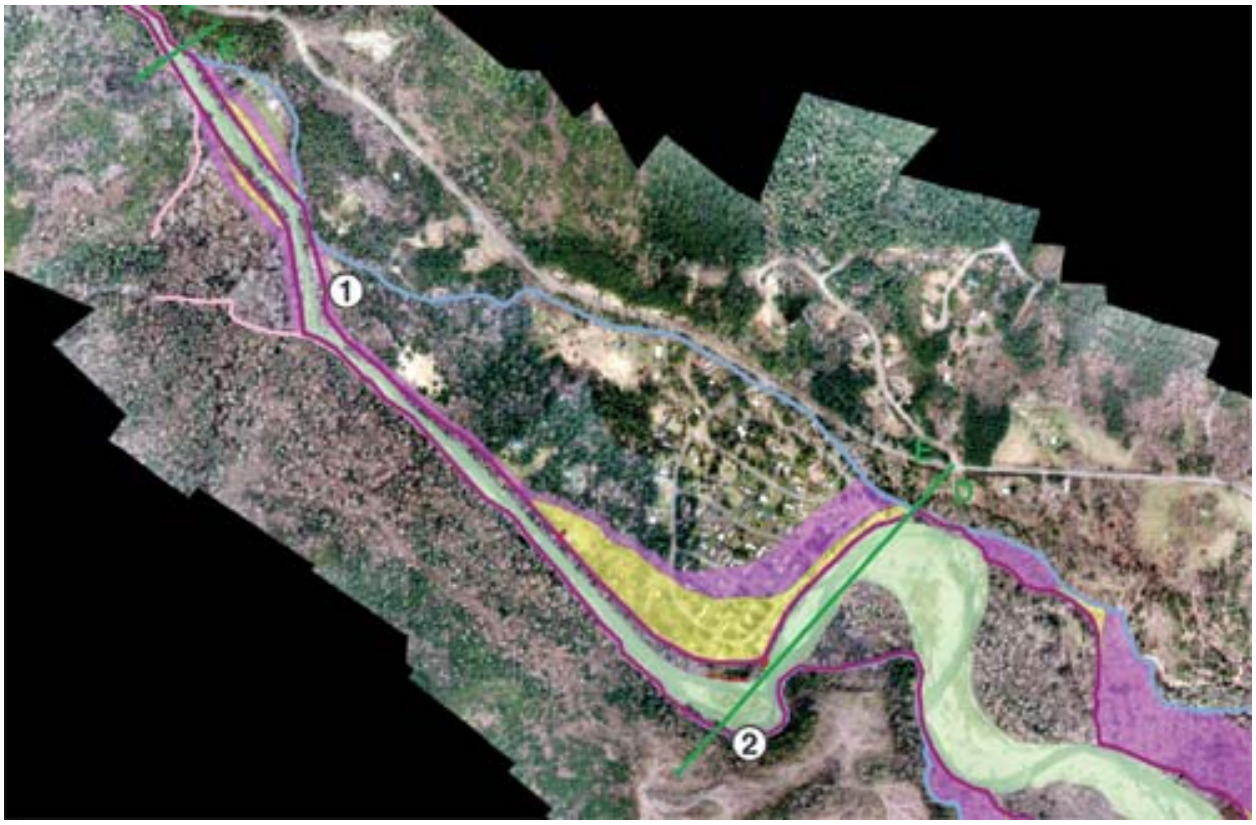

Figure 14. CMZ delineation for the Lazy C area along the Dosewallips River.

Upon first glance at historical channel delineations, it appears that the cliff at the upstream end of Reach D (point 2, Figure 14) appears to retreat at a measurable rate. Further investigation of historical aerial photography shows that the cliff has not retreated measurably and any differences in the lateral position of the cliff are within measurement and rectification error. Comparisons between 1957 and 1980 aerial photography were made digitally and manually. On the digitally rectified aerial photos, the width between the left bank of the active channel and the bluff on the right bank was compared between 1980 and 1957. The 1957 channel width included low surfaces on the right bank (south side) of the active channel. Measurements showed that these widths were approximately 340 ft in 1980 and between 320 and 330 ft in 1957. Two manual measurements were also made. Since landmarks common to both aerial photo sets were difficult to find and the scales also differed considerably, proportional distances along a common intersect were instead compared using roads as fixed points on either side of the river. First, the distance from a road bend on the south side of the river to the bluff was measured and found to be identical along this reach. Second the distance from the left bank of the active channel to the bluff was measured along a transect crossing the widest portion of the active channel and found to differ by approximately 3%, which is well within measurement error.

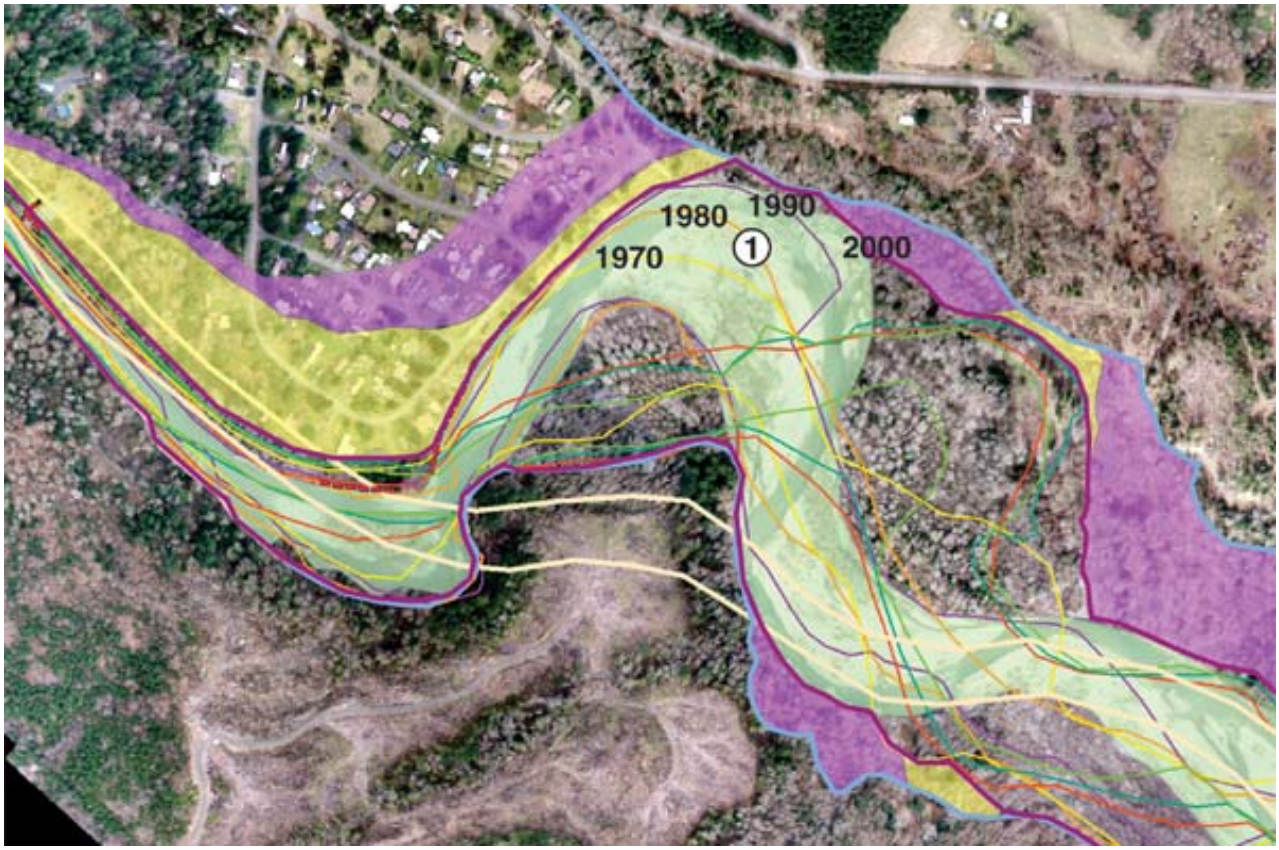

Figure 15. Channel migration measurement along the Dosewallips River, Reach D. Flow is from left to right.

In Reach E, the channel has been relatively stable, not migrating more than one channel width along the entire reach. The EHA is thus defined by an average channel width of 67 ft and is located on high terraces along the right and left banks. At the boundary with Reach D, the EHA transitions to a width of 230 ft, which is the average of the EHA width in reaches D and E. In Reach G, the EHA is also defined by an average channel width of 100 ft. A channel migration rate was also made in this reach along the pre-1950 channel, the ES result of 750 ft using Equation [1] appeared to be anomalously wide and was not used.

Big Quilcene River

On the Big Quilcene River, the HMZ encompasses the lateral extent of historical channels. An early 1990's channel avulsion is also included in the southern portion of the HMZ; the avulsion was subsequently leveed along the previous channel by heavy equipment (Monte Reinders, Jefferson County Public Works, personal communication to S. Perkins, February 2004). The AHZ is a broad and extensive surface in downstream reaches A and B while it is limited to narrow bands along the active channel in upstream reaches C through E as valley width narrows. The narrowest reach at the upstream end (Reach F) does not have an AHZ defined. In reaches A and B, the AHZ is defined by extensive multiple channels which create an irregular surface morphology visible on aerial photography and LIDAR (Figure 16). On the north side of Reach A, it merges with the AHZ for the Little Quilcene River.

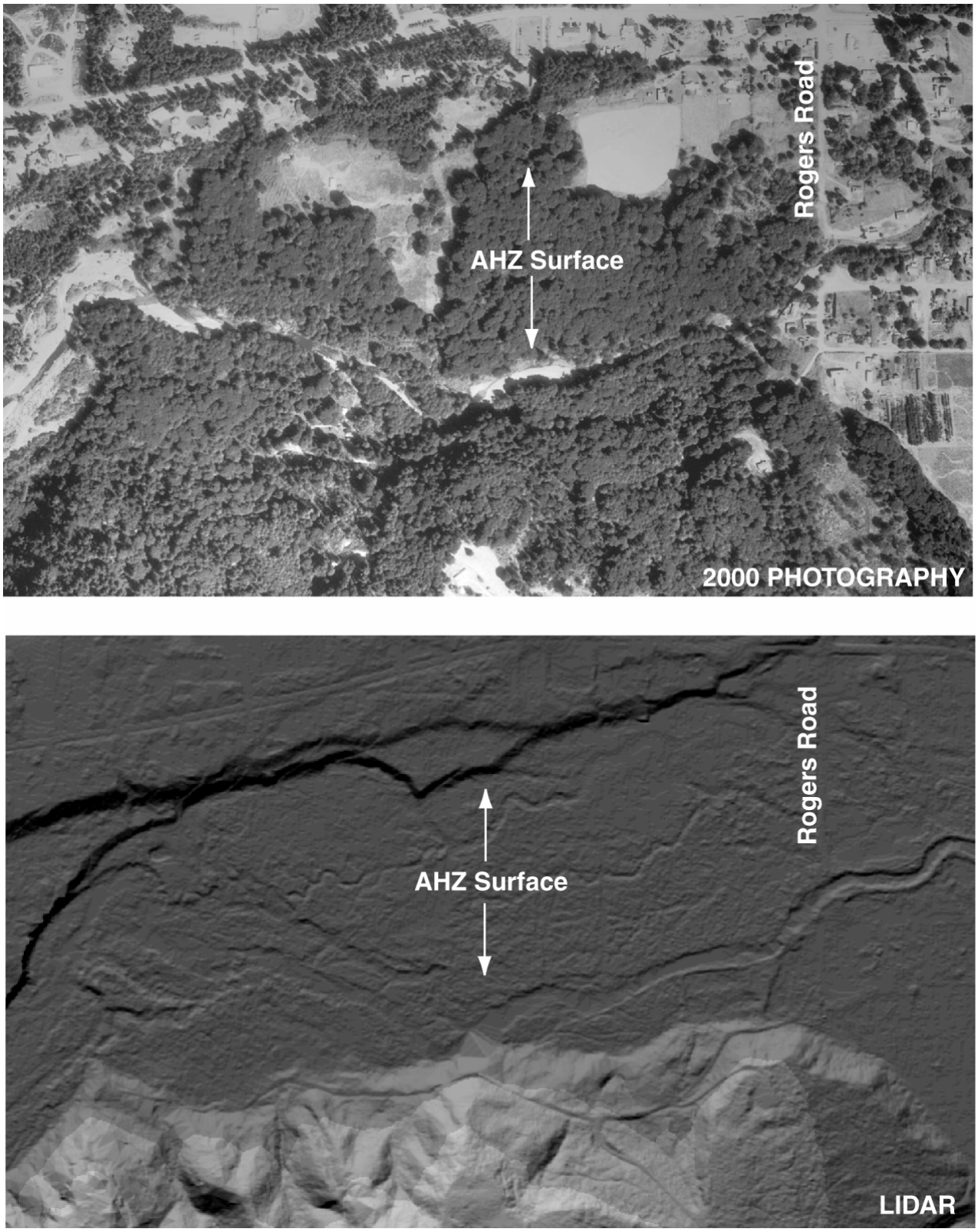

Figure 16. Example of the AHZ surface on aerial photography and LIDAR.

In the upstream reaches, the AHZ is defined by terraces of intermediate height and mature vegetation but with multiple channels still visible along the extent of the surface. In some cases, such as in Reach E, the AHZ surface may vary considerably in height due to construction of levees and revetments (Figure 17). At point 1 in Figure 17, for example, revetments and levees built to direct water over the fish hatchery diversion have caused the river to aggrade directly upstream of the structure and the AHZ surface to be a similar elevation to the channel bed. Directly downstream from the revetment, however, this same surface is approximately 5 ft above the channel bed (point 2, Figure 17).

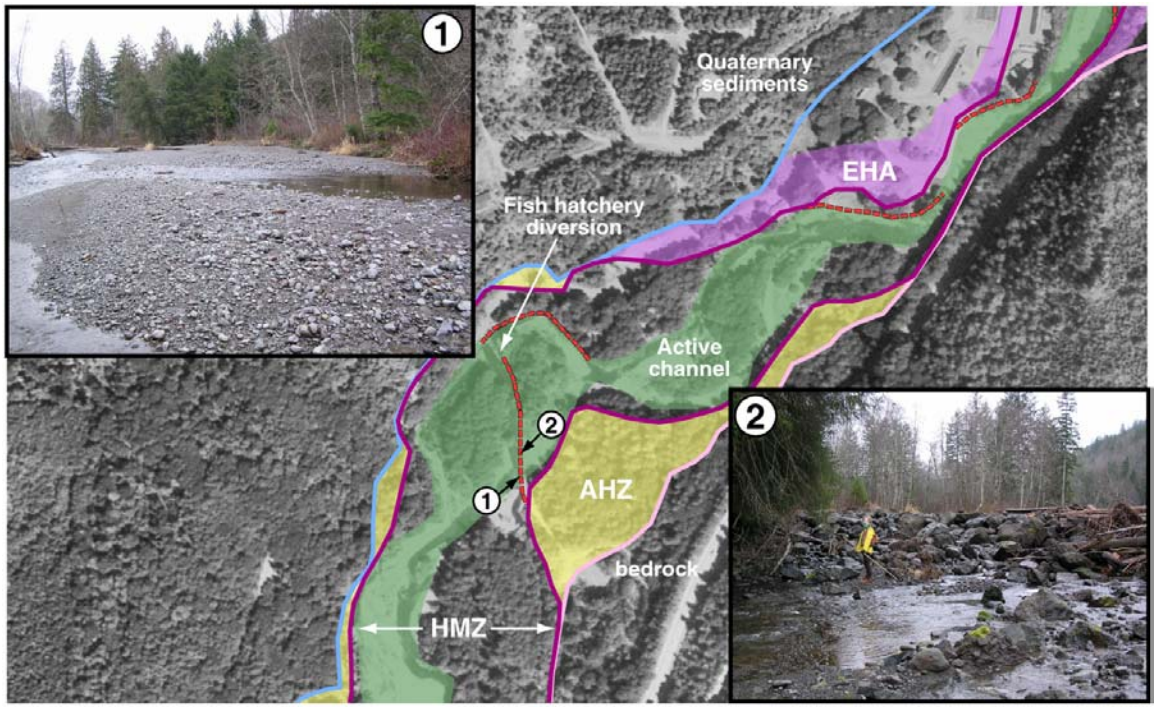

Figure 17. Changes in channel elevations due to human constructions. Flow is from left to right in the center photograph.

The EHA is delineated in reaches B through F and varies considerably by reach. In some cases, the EHA is defined solely by an ES where in other cases where low vertical bluffs are present, the EHA also includes a GS. In Reach B, the EHA was determined by calculating meander amplitude as well as a channel erosion rates (point 1, Figure 18). Meanders were most pronounced at point 1 in 1939 and 1942 aerial photography and had an average amplitude of 382 ft from 6 total measurements. The erosion rate was calculated using updated 2003 information (Latham, 2003) to include the erosion along this bank during recent floods. This new information is reflected in the location of the HMZ boundary at point 1. Since the erosion along the length of the bank was not uniform between 2002 and 2003, the 4-year period between 1998 and 2002 was used to calculate an erosion rate of approximately 43 ft/yr. Using a T_E of 10 years and a T_R of 60 years, the width of the ES is 720 ft. Assuming the channel location on the GLO plat maps is correct enough to place the channel position in a similar location for 120 years, the width of the ES would be reduced to 360 ft, comparable to the meander amplitude.

Regardless of which method is used, the width of the EHA is greater than any high terrace in Reach B so that the ES extends to the valley wall. A GS of 100 ft is added to the Quaternary bluffs on the north side of the river that are not covered by Jefferson County's regulations concerning setbacks from steep slopes. 100 ft is the maximum terrace slope width visible on the LIDAR and thus provides a conservative value since the slope retreat probably occurred over a longer interval than 100 years, the time frame of the CMZ.

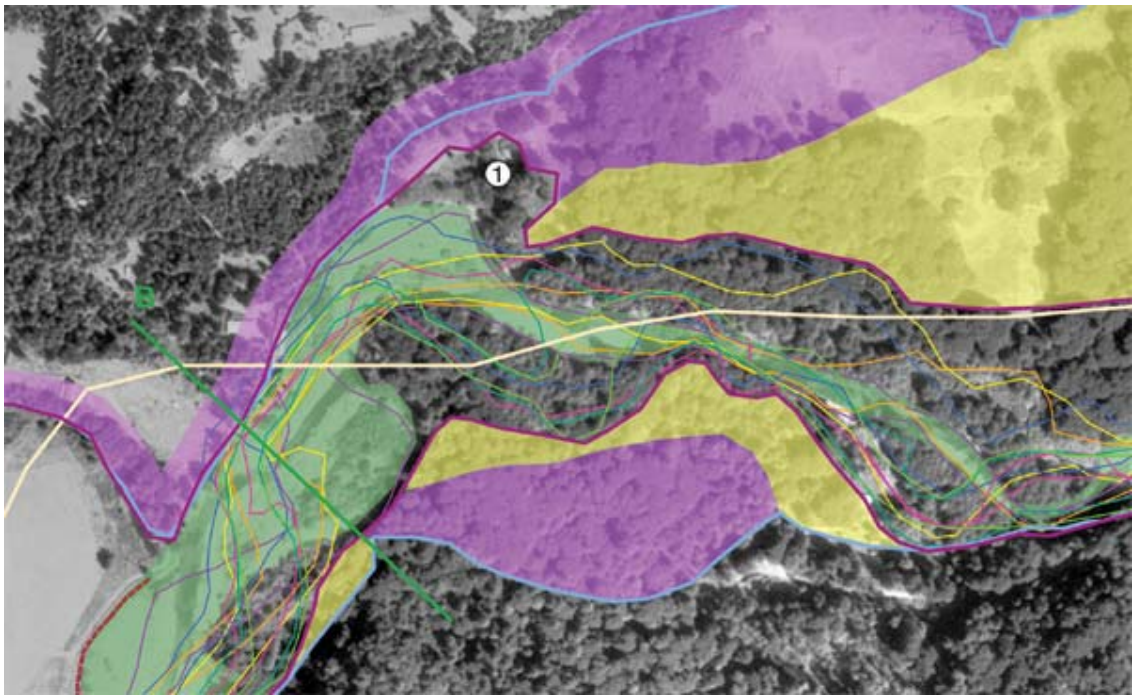

Figure 18. Channel migration measurement in Reach B of the Big Quilcene River. Flow is from right to left.

In Reach C, the HMZ encompasses the extent of all historical channel positions and includes the 1936 channel as mapped by Herrera (2003) along the back edge of the Holocene terrace at the downstream end of the reach. TheAHZ is limited to a few surfaces between the HMZ and bluffs of Quaternary sediment. The ES is defined by the amplitude of meanders in 1939 and 1942, which results in a 560 ft wide zone on higher terraces along the north side of the Big Quilcene River. A GS of 100 ft is defined where the ES or HMZ is adjacent to Quaternary sediments. The total EHA in these areas is then 660 ft.

An AHZ was not defined for Reach D since low surfaces were included in the HMZ and the remaining terraces were of great enough height to be an erosion hazard rather than an avulsion hazard. During the historical period, this reach has become deeply incised and has transitioned from a lower gradient depositional reach to a steeper gradient transport reach. This reach is judged to be no longer capable of growing bends within the timeframe of the CMZ. Since the channel has not migrated more than one channel width in most of the reach, average channel width was used to define the EHA. Channel width measurements were made every 500 ft along reach D for each year of data (Appendix A)

and were averaged to define an ES of 60 ft. Since this reach is bounded by bedrock, a GS was not required.

In Reach E, the AHZ is limited to a few terraces and lower surfaces not included in the HMZ. The EHA is defined by a meander that persisted from 1939 to 1957 and was cutoff by 1971 and completely abandoned by 1980 (Figure 19). The average amplitude, measured from 1939 to 1957 from a total of 12 measurements, is 400 ft and defines the ES for this reach and covers the entire width of high terraces in this reach.

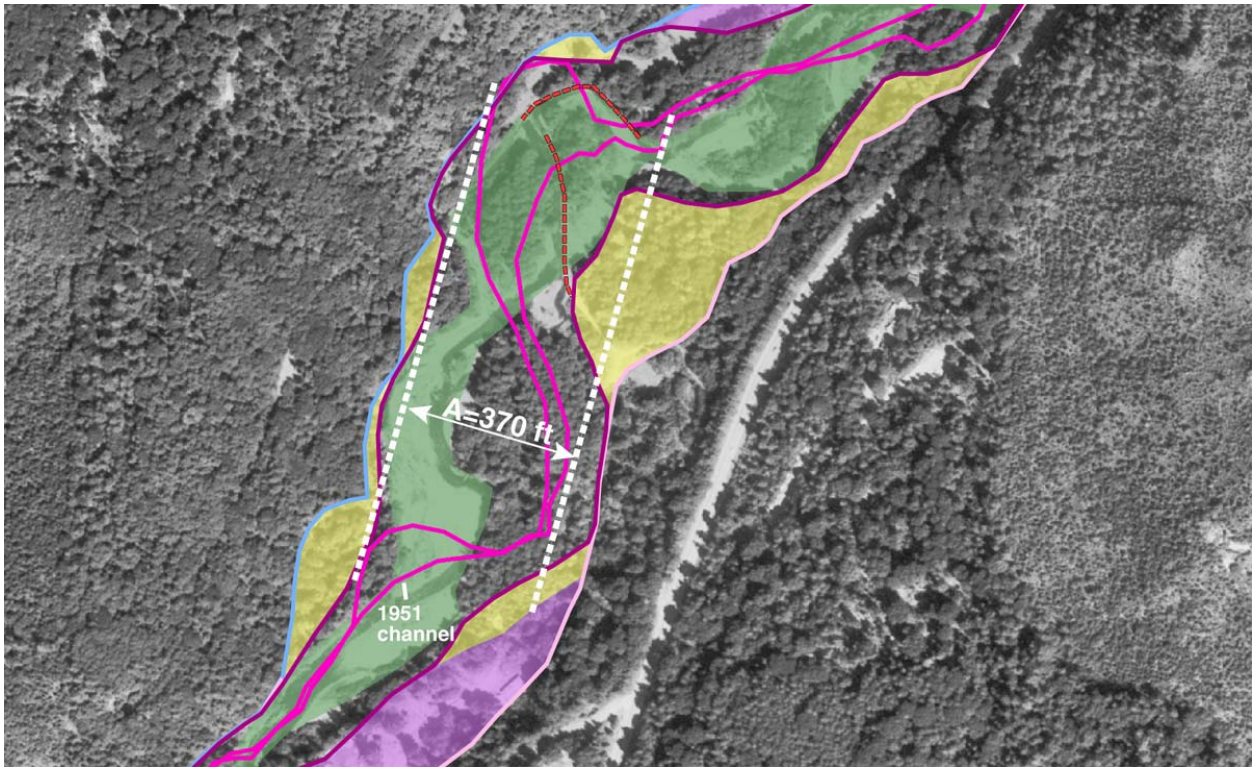

Figure 19. 1951 meander in reach E. The amplitude of 370 ft was averaged with meander amplitudes from 1939, 1942 and 1957 meander amplitudes to obtain an average of 400 ft.

In Reach F, it appears that the channel has migrated less than one channel width. Rectification error is more prominent in this reach due to the narrow channel width, which approaches the uncertainty in rectification. The HMZ is thus probably wider than the actual zone of historical channel migration and thus provides a conservative value for historical channel migration. The ES for higher terraces in this reach is defined by channel width measurements with an average of 40 ft. The shape and historical behavior of this reach is similar to Reach D, where the reach is steep and relatively straight, with most of the sediment transported through the reach rather than deposited and stored in the reach. It is unlikely that this reach will experience prominent meander bend growth within the timeframe of the CMZ.

Little Quilcene River

In Reach A, the AHZ is defined between the HMZ and Quaternary sediments on the south side where numerous channel splays can be observed on aerial photography as lighter bands of sediment (Figure 20). At its most southern extent, the Little Quilcene AHZ merges with the AHZ for the Big Quilcene River. On the north side of the Little Quilcene, the AHZ is defined between the HMZ and East Quilcene Road. This boundary is somewhat arbitrary, but reflects the fact that low surfaces along the Little Quilcene merge with deposits associated with Donovan creek. This reach of the Little Quilcene has had a history of channel modification spanning the historical period such that channel geometry has been severely modified and meander amplitude is not a viable method to determine the EHA. The EHA is thus defined by channel width measurements, whose average width is 65 ft (Appendix A). Although the area north of the channel along East Quilcene Road could also be mapped as an AHZ, the surface height above the active channel and its uphill grade to the north would suggest that this surface is more likely to experience bank erosion than avulsion.

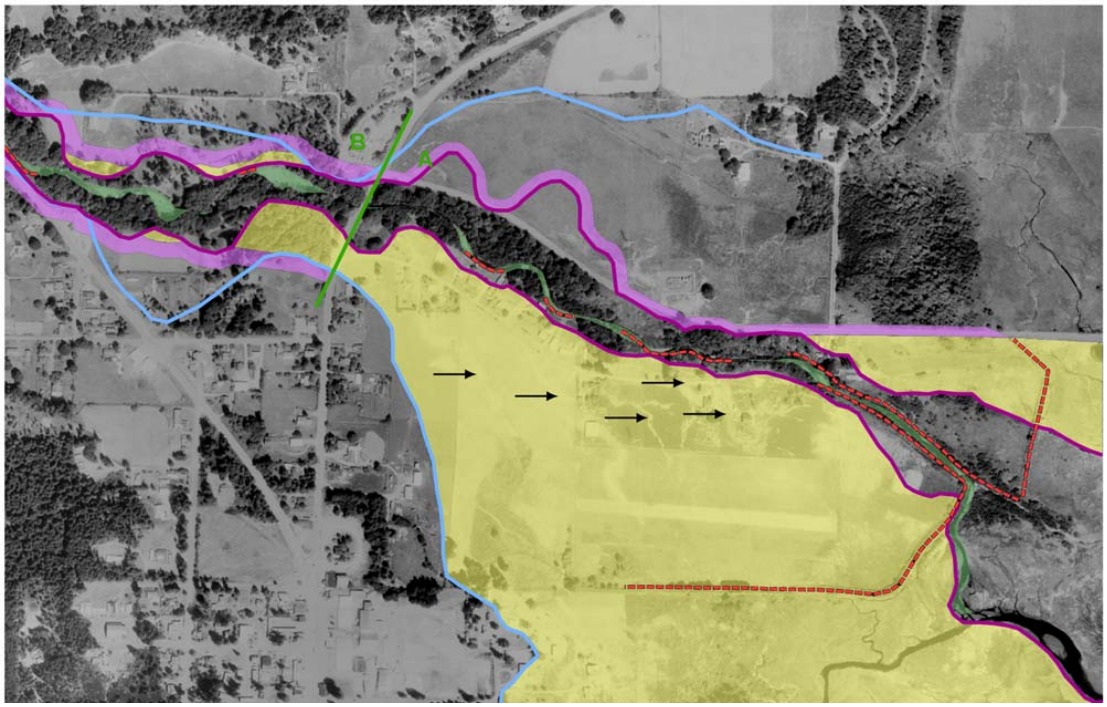

Figure 20. View of the lower Little Quilcene showing AHZ extent and channel splays evident as lighter bands (black arrows). Flow is from left to right.

The AHZ in Reach B is located along the left and right banks of the Little Quilcene River, in most areas where Quaternary sediments are set back from the active channel. Surfaces with the AHZ delineation have irregular topography and visible although somewhat subdued channels. The EHA in Reach B is defined by an ES and GS where the ES is 75 ft, defined by average channel width measurements since there were few locations to measure an erosion rate or meander amplitude. The GS is defined along erodable bluffs of Quaternary sediments that are approximately 7 ft higher than adjacent terraces using a 1:1 slope. The total width of the EHA would thus equal 82 ft.

Reach C is a confined reach with a single AHZ on the left where an abandoned channel is visible on LIDAR. The rest of Reach C is characterized by 20 ft high bluffs of erodible Quaternary sediments on the west side of the Little Quilcene River. An EHA of 20 ft is thus defined for this reach where Quaternary sediments are adjacent to the HMZ or AHZ.

In Reach D, an EHA is defined along both sides of the river in which high terraces with subdued channel topography are located on the west side and have an ES of 40 ft defined by average channel width measurements. Quaternary sediments along the east bank have an EHA of 55 ft, which includes an ES of 40 ft based on average channel width measurements and a GS of 15 ft for bluffs of Quaternary sediments.

Data uncertainty

Several sources of error are important to note in this study. These include error in aerial photo rectification and geomorphic mapping of historical channels and terraces. The authors of the Duckabush study (USACE, 2003) assume an uncertainty of ± 100 ft. Metadata from aerial photo rectification suggest that lateral offsets are relatively small, on the order of ± 10 ft or less (Appendix B). In practice, offsets between rectified photos especially in larger scale photo sets can be much greater, on the order of a channel width. Based on differences in the location of bedrock versus channel position, the error appears to be up to 170 ft, although high values such as these appear to be limited to the 1957 data set. The highest errors typically occur in the upstream most sections of each study area, where control is harder to obtain. Evaluation of the metadata is further explored in Appendix B. The error introduced by geomorphic mapping depends on scale and quality of aerial photography used to map historical channels, and the level of field checking and detail with which each contact is drawn. Based on these sources of error, a conservative estimate for the uncertainty in this study is on the order of ± 100 ft.

CONCLUSIONS

This report delineates hazards associated with channel migration along the Duckabush, Dosewallips, Big Quilcene, and Little Quilcene Rivers in Jefferson County, Washington. Historical channels as well as geomorphic mapping and observations provide the information necessary to define the historical channel migration zone (HMZ), avulsion hazard zone (AHZ) and erosion hazard area (EHA). The HMZ encompasses the lateral extent of historical channels from approximately 1880 to 2000/2002 using topographic maps and rectified historical aerial photography. The AHZ occupies low to intermediate height terraces with subdued channels that are prone to future channel avulsion and is most extensive in deltaic areas of each river where abandoned channels or channel splays cover a large portion of the valley width. The EHA combines the erosion setback (ES) and geotechnical setback (GS) and is defined on a reach-by-reach basis. The ES, which defines the width of the area prone to lateral erosion, is located on higher terraces with planar surfaces, subdued channels in places and large cedar stumps. The width of the ES is defined by the magnitude of historical channel changes and the variation in width and character of channel geometries from 1939 to 2000/2002. The GS, which defines the

width of high bluffs prone to lateral erosion and slumping, is located on bluffs of Quaternary sediments that are low enough to be erodible and not covered by Jefferson County's regulations concerning setbacks from steep slopes. A 1:1 slope is used to define the GS for these bluffs.

This study utilizes geomorphic field evidence to define channel changes, avulsions and lateral erosion that could naturally occur without regard to modifications imposed by man-made features along the channel. Levees and revetments were mapped in the field in order to show the location of channel modifications and to aid in the practical application of this study for flood hazard assessment in Jefferson County. As a companion to this study, channel migration hazards and disconnected migration areas (DMA) are defined and discussed for each river by Sue Perkins (Perkins, 2004) using the information gathered from this study and taking into account channel incision and current channel geometries.

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APPENDIX A

ES data

Erosion Setback (ES) Calculations:

Duckabush River
Reach A: none defined
Reach B: ES=94 ft based on average channel width measurements
Reach C: ES=170 ft based on channel migration measurement from 1990-2000

Dosewallips River
Reach A: none defined
Reach B: ES as wide as channel width
Reach C: ES as wide as channel width
Reach D: ES=400 ft, defined by channel migration measurements
Reach E: ES=67 ft, defined by average channel width measurements
Reach F: none defined
Reach G: ES=100 ft, defined by average channel width measurements

Big Quilcene River
Reach A: none defined
Reach B: ES covers entire terrace, meander amplitude greater than terrace width
Reach C: ES=560 ft, defined by meander amplitude
Reach D: ES=60 ft, defined by average channel width measurements
Reach E: ES covers entire terrace, meander amplitude greater than terrace width
Reach F: ES=30 ft, based on average channel width measurements

Little Quilcene River
Reach A: ES=65 ft, defined by average channel width measurements
Reach B: ES=75 ft, defined by average channel width measurements
Reach C: none defined
Reach D: ES=40 ft, defined by average channel width measurements

Duckabush

Reach B

point no.	1942	1957	1965	1975	1985	1997	2000	average
1	85.8	96.4	95.7	86.2	75.3	153.2	100	
2	84.2	72.5	96.5	74.8	116.5	56.4	63.4	
3	103.1	99.4	38.9	99.4	67.2	61	81.9	
4	129.7	97	41.5	117.7	64.7	100	62.9	
5	113.8	95.7	88.6	124.4	71.7	51.2	48.2	
6	120.5	157.4	56.4	186.1	102.5	69.5	65.6	
7	149.8	149.5	96.5	130.5	110.9	85.4	58.6	
average	112.4	109.7	73.4	117.0	87.0	82.4	68.7	92.9

Reach C

point no.	1990-1997	1990-2000	
1	46.5	54.6	
2	117.6	94.2	
3	130.9	125.3	
4	131.6	157.6	
rate =	15.2	10.8	ft/yr

Dosewallips River

channel migration measurements

Reach D

point no.	1970-1980	1980-1990	1990-2000	1970-2000
1	58.1	24.6	0.0	75.7
2	127.9	33.9	0.0	197.6
3	152.0	70.7	0.0	223.5
4	143.9	107.1	0.0	251.7
5	78.2	180.5	96.7	297.6
6	0.0	181.9	107.3	333.4
7	0.0	0.0	133.6	263.8
average	80.0	85.5	48.2	234.8
average/yr	8.0	8.6	4.8	7.8

Reach G

point no.	1939-1942	1942-1951	1951-1957	1939-1957	
1	101.5	0.0	123.1	304.4	
2	110.2	39.0	71.9	309.7	
3	93.8	70.0	83.8	335.2	
4	47.9	60.6	0.0	244.3	
5	26.0	88.7	0.0	161.8	
average	75.9	51.7	55.8	271.1	
average/yr	25.3	5.7	9.3	15.1	13.8

Reach E

point no.	1939	1942	1951	1957	1970	1980	1990	2000	average
0	90.7	116.2	107.1	70.0	116.2	119.8	87.1	123.5	
1	117.6	107.1	78.2	66.2	62.8	82.6	21.0	96.7	
2	100.0	114.6	66.2	58.1	58.1	52.0	29.0	75.7	
3	90.6	111.6	65.7	53.6	57.5	21.0	20.9	103.4	
4	75.8	45.4	65.7	24.6	58.1	37.2	24.6	54.8	
5	86.4	45.4	49.3	32.9	78.2	29.0	16.4	45.4	
6	98.7	70.7	75.7	75.5	75.7	23.2	29.0	52.6	
7	107.1	91.9	35.3	59.8	70.0	29.0	32.9	42.3	
8	101.6	67.8	61.8	66.2	88.5	20.9	46.8	103.4	
9	127.6	72.8	52.0	41.9	45.4	26.0	36.7	90.9	
average	99.6	84.4	65.7	54.9	71.1	44.1	34.4	78.9	66.6

Reach G

point no.	1939	1942	1970	1980	1990	2000	average
1	430.5	340	143.8	69.8	158.1	95	
2	174.3	96.2	205.4	85.4	110.6	144.3	
3	75.8	112.2	66.2	64	76.5	65	
4	46.8	110.2	90.2	41.2	62.2	76.4	
5	75.7	44.2	81.5	45.6	40.5	94	
6	90.9	62.6	93.1	50	40.2	71.5	
7	127.6	42.3	71.9	67.6	62.6	67.6	
8	90	87.1	98.9	169	155.6	102.9	
9	53.6	86.4	98.9	76.1	46.7	53.6	
10		76.4	88.7	36	36	76.4	
average	129.5	105.8	103.9	70.5	78.9	84.7	95.5

Big Quilcene River

Reach B

channel migration measurements

1998-12/02

raw units	conversion	ft/yr
1.5	96.8	
2.9	187.1	
3.8	245.2	
3	193.5	
2.3	148.4	
average	174.2	43.5

1998-4/01/03

raw units	conversion
1.5	96.8
3.1	200.0
3.9	251.6
4.2	271.0
3.9	251.6
average	214.2	42.8

12/02-4/01/03

raw units	conversion
0.3	19.4
0	0.0
0	0.0
1	64.5
1.9	122.6
1.9	122.6
1.6	103.2
average	61.8	61.8

Reach B

point no.	1939.0	1942.0	1951.0	1957.0	1971.0	1980.0	1990.0	2000.0	average
1	69.2	87.7	39.6	59.4	36.5	26.6	31.9	25.6	
2	142.8	95.8	19.8	36.5	35.4	31.9	39.6	25.0	
3	107.0	75.1	25.0	73.0	83.5	31.9	51.6	81.6	
4	159.6	134.0	53.9	168.5	92.4	144.2	76.2	101.0	
5	88.6	138.3	19.8	177.1	297.5	174.4	62.6	76.2	
6	91.2	62.6	88.6	340.7	204.4	51.6	67.4	47.7	
7	118.8	241.9	256.8	301.1	177.1	150.5	71.4	142.8	
8	59.4	59.4	140.0	174.4	97.8	61.9	230.9	253.6	
average	104.6	111.9	80.4	166.3	128.1	84.1	79.0	94.2	106.1

Reach D

point no.	1939.0	1942.0	1951.0	1957.0	1971.0	1980.0	1990.0	2000.0
1	67.1	67.3	46.4	36.1	36.5	31.0	36.1	57.0
2	82.6	47.6	70.2	63.8	57.7	21.3	33.0	62.2
3	208.1	31.4	57.7	108.5	145.7	15.5	68.9	103.2

4	113.3	47.1	21.9	66.1	70.2	25.8	29.2	63.0	
average	117.8	48.4	49.1	68.6	77.5	23.4	41.8	71.4	62.2

Reach E

point no.	1939.0	1942.0	1951.0	1957.0	1971.0	1980.0	1990.0	2000.0	
1	47.6	40.3	16.3	18.6	46.2	55.8	46.2	41.6	
2	25.8	48.7	11.5	34.6	50.8	41.6	27.8	10.0	
3	20.6	25.8	26.3	20.6	36.1	20.6	15.5	10.0	
4	31.0	32.6	11.5	42.6	27.8	11.5	26.3	10.0	
average	31.3	36.9	16.4	29.1	40.2	32.4	29.0	17.9	29.1

Little Quilcene

Reach A

point no.	1939	1942	1951	1957	1971	1980	1990	2000	average
1	165	106.5	20.2	30.3	111.5	25.2		27.2	
2	51.5	65.8	81.4	55.5	70.8	22.6		25.2	
3	193.9	171.5	18.2	50.5	86	16		25.2	
4	106.5	120.4	117.7	101.6	135.4	11.3		33.9	
5	136.4	146.5	30.7	35.7	56.4	16		25.2	
average	130.7	122.1	53.6	54.7	92.0	18.2	20.0	27.3	64.8

Reach B

point no.	1939	1942	1951	1957	1971	1980	1990	2000	average
1	67.3	75	27.2	22.6	45.1	18.2		18.2	
2	328.1	293	16	20.8	15.1	15.1		60.8	
3	125	110.8	14.3	28.6	35.3	18.2		35.7	
4	101	110.8	51.5	30.7	105.4	20.2		25.2	
5	148.5	258.4	212.3	78.5	203.2	60	20	83.2	
average	154.0	169.6	64.3	36.2	80.8	26.3	20.0	44.6	74.5

Reach D

point no.	1939	1942	1951	1957	1971	1980	1990	2000	average
1		86	16	18.2	20.8	20.2		40.7	
2		107.3	36.4	47.9	11.3	54.4		83.2	
3		64.6	22.6	14.3	25.7	35.7	20	35.7	
average		86.0	25.0	26.8	19.3	36.8	20.0	53.2	38.1

APPENDIX B

Metadata

Channel Migration Hazard Maps for the Dosewallips, Duckabush, Big Quilcene, and Little Quilcene Rivers Jefferson County, Washington

FINAL DRAFT REPORT
August, 2004

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Introduction

The Dosewallips, Duckabush, Big Quilcene and Little Quilcene Rivers drain the steep eastern slope of the Olympic Mountains. The rivers are short and steep and confined to narrow canyons for most of their length. At the base of the mountain range, each river flows through a broader alluvial valley and thence a delta and estuary before entering Hood Canal. In these final few miles, the rivers deposit sediment in gravel bars and migrate laterally across their floodplains.

Channel migration creates hazards to private and public property and infrastructure by eroding land or cutting off access roads. Each of the four rivers has a variety of levees and revetments built to prevent channel migration, often at considerable public expense. Where it still occurs, channel migration creates habitat for fish and other riparian species by leaving behind a diverse network of relict channels, gravel bars, floodplains and terraces.

In 2003, the Jefferson County Department of Natural Resources contracted the United States Bureau of Reclamation (USBR) and Perkins Geosciences to produce maps showing the historic extent of channel migration and the zones at risk from future channel migration.

My work was conducted in collaboration with Jeanne Klawon of the United States Bureau of Reclamation. The USBR provided all digitizing, air photo rectification, and GIS map production including the maps for this report. Methodology and results for the USBR portion of the work is presented in their report, *Channel Migration Zones Study for the Duckabush, Dosewallips, Big Quilcene, and Little Quilcene Rivers, Jefferson County, Washington* (Klawon, 2004). This report is intended as a companion volume to the USBR report and the reader is referred to the maps contained in that report.

Study Methodology

I assisted Jefferson County and the USBR in locating historic aerial photographs and maps, and obtained and reviewed previous studies on the four rivers.

I participated in six days of fieldwork with Ms. Klawon in October 2003 and January 2004, during which we covered nearly all sections of the four study reaches. The remaining sections were walked by Ms. Klawon on additional days. During fieldwork we noted bank protection, bank height, geology, recent channel changes post-dating the 2000 base photos, LWD jams, terraces and old channel scars on the floodplain, old-growth trees or stumps that indicated old land surfaces, and the elevation of debris from a flood in late October, 2003.

USBR developed digitized, georeferenced maps showing historic channels, bank protection, and margins of the alluvial valleys (bedrock and Quaternary terraces) based on fieldwork and aerial photographic interpretation (Plates 1 through 4, Klawon, 2004).

Methods used to delineate channel migration hazard zones are described below.

Delineation of Unconstrained Channel Migration Zones

On March 9-12, 2004 I worked with Ms. Klawon at USBR's Denver office to delineate channel migration zones using the methods proposed in the Washington Department of Ecology's *A Framework for Delineating Channel Migration Zones* (Rapp and Abbe, 2003). The methodology is summarized below and described more thoroughly in the USBR report.

We divided each river into reaches based on channel pattern, rate and type of channel migration, and the presence of major barriers to channel migration such as Highway 101.

We mapped the **Historic Channel Migration Zone (HCMZ)** as the combined footprint of the 1939 through 2000 active channels (based upon 1939, 1942, 1951, 1957, 1971, 1980, 1991, and 2000 aerial photographs). The late 1800s channel shown on the Government Land Office (GLO) survey maps was included in the HCMZ only where the LiDAR map confirmed that a low, channelized surface was present. In many locations, the GLO river channel crossed hills and was clearly not an accurate survey.

Next, we mapped the **Avulsion Hazard Zone (AHZ**). An avulsion is the sudden switching of the main river channel to a new location. The old and new channels are separated by an uneroded island that is typically vegetated. The AHZ consisted of relatively low, frequently-flooded areas of the floodplain, typically with relict channels into which the river could readily switch course in an avulsion. Avulsions into somewhat higher channels were deemed more likely in the Big and Little Quilcene Rivers where LWD was observed to form stable jams that raised the bed elevation, compared to the two larger rivers. We queried the LiDAR maps on the Jefferson County web site with the elevation tool to determine the elevations of floodplain and relict channels relative to the current river channel. The LiDAR maps did not extend into the upstream portions of the Duckabush, Dosewallips and Big Quilcene rivers, so we relied on field observations in those areas. The entire network of present and former distributary channels in each delta was designated an Avulsion Hazard Zone. The presence of levees, road embankments, and revetments that might block avulsions was ignored at this stage of the mapping.

The **Erosion Hazard Area (EHA) was** delineated by USBR. The Erosion Hazard Area consisted of two parts: an Erosion Setback and a Geotechnical Setback.

The Erosion Setback extended beyond the outside edge of the HCMZ+AHZ where erodible alluvium or Quaternary terraces were present. The Erosion Setback was determined for a 100 year period. Erosion in these locations would occur through lateral migration of the river, typically by growth and translation of meander bends. The width of the Erosion Setback for each river reach was determined in one of three ways, as described in more detail in Klawon (2004):

1. the **bend amplitude**
2. the **Coefficient of Erosion** based on rate and frequency of erosion, multiplied by the 100 year design period for these maps (Rapp and Abbe, 2003), or
3. **one channel width** in locations where the river is straight and shows no recent history of developing bends or depositing sediment. The Erosion Setback allows for gradual erosion, or movement around a logjam should one form.

Where the Erosion Setback extended into erodible Quaternary terraces up to 40 feet in height, a Geotechnical Setback was added to account for slope retreat to a stable angle of repose. The Geotechnical Setback is a horizontal distance equal to the vertical height of the terrace above the river bed (1:1 ratio), consistent with standard setbacks in Section 5 of Jefferson County's Shoreline Master Plan. No Geotechnical Setback or Erosion Setback was mapped where bedrock was present or where channel migration would cause the river to erode into a valley wall higher than 40 feet. The valley wall would be unlikely to retreat a mappable distance and the landslide hazard is already covered under Jefferson County's Geologically Hazardous Areas regulations.

The four map plates in Klawon (2004) show the Historic Channel Migration Zone, Avulsion Hazard Zone, and Erosion Hazard Area. The three zones together comprise each river's potential channel migration zone if unconstrained by human engineering.

Channel Migration Hazard Map

I developed Channel Migration Hazard maps for each river by designating Disconnected Migration Areas and dividing the remaining channel migration zones (HCMZ, AHZ, EHA from the USBR maps) into areas of High, Moderate and Low Hazard on the maps that accompany this report.

Parts of the unconstrained channel migration zone are no longer available to the river for migration (although they still may be subject to flooding). Accordingly, parts of the unconstrained channel migration zones shown in the USBR maps were designated as **Disconnected Migration Areas (DMA)**.

Disconnected Migration Areas were delineated where there is a substantially-built, laterally-continuous levee or revetment already in place or a demonstrated commitment and ability of government agencies to prevent future channel migration. On March 26, 2004, I met with Jefferson County staff from the Natural Resources Division and Public Works Department to identify features beyond which channel migration will be prevented (Table 1). Armored banks protect many of these features already, and it can be assumed that additional revetments will be constructed to protect these features as necessary. The Public Works Department staff had greater confidence in their ability to prevent channel migration for the smallest river, the Little Quilcene, than for the Dosewallips, the largest river.

The final step was to map the relative level of hazard from channel migration. Obviously the risk of channel migration is not equal everywhere within the channel migration zones shown in the USBR maps. I divided the non-disconnected channel migration zones shown on the USBR maps into zones of High, Moderate and Low hazard. These zones roughly correspond to channel migration being likely in a time frame of less than 50, 50-100 and >100 years, respectively.

In any particular river reach, the probability of the river moving to a particular site within the migration zone is greatest for sites near the river or a former channel that the river is likely to reoccupy. Channel migration varies greatly from reach to reach depending upon geomorphology, sediment regime, and natural or man-made constraints on channel migration. High and Moderate hazard zones were assigned based on these factors (Table 2). Details are provided in Appendix A.

Table 1. Assumed Boundaries to Channel Migration used to Delineate Disconnected Migration Areas

Little Quilcene River
Highway 101
East Quilcene Road
Center Road
Brush Plant Loop
Avulsion Hazard Zone on both sides of Frank Beck Road

Big Quilcene River
USFWS hatchery
Highway 101 near bridge
South side of river in Quilcene, from the second dike west of Rodgers Street to east side of BPA lines
NOTE: no DMA was designated on the north side of the river in and just upstream from Quilcene, pending completion of a Jefferson County study to determine setback levee alignment. Portions of this area will be designated DMA once the study is complete in early 2005.

Dosewallips River
Town of Brinnon, from Highway 101 to as far west as the existing revetment
Dosewallips State Park in Reach B east (downstream) of large levee
Highway 101

Duckabush River
River Drive
Mountain Trail Road
Kelly Road
Highway 101 (assume fill is removed to reconnect a former channel north of the main bridge)
South bank revetment just west of 101 bridge

Limitations of Channel Migration Hazard Maps

The mapping procedure conservatively assumed that new meander bends or avulsions would occur at all likely sites. It is not possible to predict which sites will actually be occupied due to the stochastic nature of variables including flood magnitude and frequency, sediment deposition, and formation of logjams. It is likely that some areas within both the Moderate Hazard and Severe Hazard zones will not be occupied by the river channel during the next century. The mapped channel migration limits should therefore be used as an indicator of relative risk, rather than a precise prediction of the time in which the river will reach a given location.

On the other hand, there is a low but real possibility that the rivers could occupy portions of the valley floor beyond the limits of the Moderate Hazard zone. In most locations, the hazard zones are based upon 65 years of aerial photographs, so channel migration prior to human disturbance can only be inferred. Levees and revetments could fail, flow could be diverted around bridges blocked by debris jams, and avulsions could occur in unanticipated locations. Accordingly, all areas of the valley floor not mapped High, Moderate, or Disconnected, excluding high terraces, should be considered to have a low risk of encroachment by channel migration. This is consistent with morphological evidence that rivers have previously moved across the whole valley floor, such as embayments in the valley walls, a flat floodplain underlain by alluvial gravels, floodplain channels with the shape of meander bends, and documented historic shifting of the rivers. Accordingly, there is a low probability that channel migration could occur anywhere within the alluvial valley of each river beyond the High and Moderate hazard zones.

In narrow, confined valleys of each river where channel migration is slow (SN and SE channel types, typically the upstream ends of each river) the maps may show differences in river position between years. In most cases this was due to error in rectifying the distortion in aerial photographs, rather than bank erosion. In these locations the outer limit of the HCMZ was not used to delineate hazard zones (see Appendix A).

These maps do not depict flood risk. All migration hazard zones, including Disconnected Migration Areas, could be subject to inundation by floods depending upon their elevation relative to the river.

These maps do not depict landslide risk. All valley walls not formed of competent bedrock have a potential for landsliding that could be exacerbated if and when the river reaches them.

Table 2. Channel migration hazard assignment based on geomorphology and degree constraints on channel movement (page 1 of 2).

GEOMORPHIC TYPE	**DA** **DELTA / ALLUVIAL FAN with distributary channels**	**W** **WANDERING RIVER; straight at times following an avulsion**
TYPE OF CHANNEL MIGRATION	Avulsions, lateral migration	Meandering, bend cutoffs and avulsions
SEDIMENT REGIME	Deposition	Deposition, or mixed transport and deposition zones
CONSTRAINTS ON CHANNEL MIGRATION	SEVERE; extensive revetments, levees and/or cross-floodplain roads with limited bridges and culverts	NONE or FEW
RIVER REACHES	Little Quilcene A Big Quilcene A Duckabush A Duckabush B Dosewallips A Dosewallips B	Little Quilcene B Little Quilcene D Big Quilcene B Big Quilcene E Duckabush C Dosewallips D Dosewallips G [2]
HIGH HAZARD CHANNEL MIGRATION ZONE (typical [1])	HCMZ (+ AHZ + EHA where not blocked by constraints)	HCMZ + AHZ + half of EHA width
MODERATE HAZARD CHANNEL MIGRATION ZONE (typical [1])	Remainder of AHZ and EHA	Remainder of EHA

NOTES to Table 2

1. Transitional zones between reaches may differ from these typical guidelines. Other exceptions are discussed in Appendix A.
2. Dosewallips G has been a transport reach with a fairly straight channel during the photographic period of record, similar to Type SE. However, there is a still-active avulsion channel and a relatively wide, low floodplain in which avulsions could readily occur. The entire EHA is mapped as Moderate Hazard in this reach.

Table 2, continued

GEOMORPHIC TYPE	SE Currently STRAIGHT AND ENTRENCHED with narrow meander belt; meander belt formerly was wider with bends	SN Always STRAIGHT and NARROW, typically steeper with valley wall control
TYPE OF CHANNEL MIGRATION	Varies from minor or no bank erosion to bend growth within a narrower zone than historic.	Minor or no bank erosion, without bend growth
SEDIMENT REGIME	Transport, or supply where the bed has degraded	Transport
CONSTRAINTS ON CHANNEL MIGRATION	NONE to FEW now; likely was channelized in the past	NO man-made constraints; BEDROCK OR BLUFFS of glacial sediment constrain channel alignment
RIVER REACHES	Big Quilcene C [3] Big Quilcene D	Little Quilcene C Big Quilcene F [3] Dosewallips C [3] Dosewallips E [3,4] Dosewallips F
HIGH HAZARD CHANNEL MIGRATION ZONE (typical [1])	A distance of ½ to 2 EHA widths from the 2000 active channel	HCMZ
MODERATE HAZARD CHANNEL MIGRATION ZONE (typical [1])	Remainder of EHA	AHZ + EHA

NOTES to Table 2, continued

3. The downstream ends of these reaches transition to a Type W depositional channel, resulting in wider hazard zones.
4. Dosewallips E has been a straight, narrow, deeply entrenched channel through the entire period of photographic record. However, the LiDAR image shows former channels on the broad terrace north of the river. These relict channels may date back to times of glacial melting, but they also could be fairly recent if incision was caused by splash damming below RM 3.2 which occurred in 1917-1926 (ESA, 2003).

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This report was prepared by Susan J. Perkins, Licensed Geologist in the State of Washington. The original report transmitted to Jefferson County is stamped and signed in this location.

APPENDIX A

Assignment of Channel Migration Hazards Based on Geomorphology and Physical Constraints

This Appendix provides details and justification for classification of the Historic Channel Migration Zone (HCMZ), Avulsion Hazard Zone (AHZ) and Erosion Hazard Area (EHA) on the USBR maps into High and Moderate Hazard areas on the maps produced for this report. The basic classification scheme and assignment of river reaches to geomorphic types is summarized in Table 2 of the main report. The information is organized into one page for each of the four geomorphic channel types: Delta/Alluvial Fan (DA), Wandering River (W), Straight Entrenched (SE), and Straight Narrow (SN).

This Appendix only deals with areas most likely to be affected by channel migration within the next 50 or 100 years (High and Moderate Hazard, respectively). Low Hazard zones by default are the remaining areas of the valley floor beyond the High and Moderate Hazard zones. Disconnected Migration Areas are listed in Table 1 of the main report.

Delta/Alluvial Fan (DA) reaches

All four rivers end in deltas that historically had multiple distributary channels. The rivers transitioned upstream to alluvial fans in areas beyond tidal influence. The rivers' sediment load is deposited in the alluvial fans and deltas due to the declining gradient. Prior to human disturbance, whenever the main channel became filled with sediment it would avulse and form a new channel in a lower location. Over time, this resulted in a fan-shaped network of distributary channels. The DA channels have long been constrained by revetments, levees, and north-trending roads that block migration across the floodplain and provide limited openings in the form of bridges and culverts (Engineering Services Associates et al., 2003). Without these constraints, each river would have a wide AHZ encompassing the entire delta, and the alluvial fan upstream from the delta would have a broad AHZ flanked by a relatively narrow EHA. Instead, each river's migration zone necks down to a narrow opening at each bridge and gradually fans out downstream where not leveed. The mapped HCMZ is considerably narrower than it would have been without these constraints, and thus it accounts indirectly for their effects even in areas that are not completely disconnected from channel migration processes. The AHZs in the Duckabush River were assigned Moderate Hazard because there is little evidence of sediment deposition, whereas rapid sediment deposition on the other rivers makes avulsions more likely.

Delta/Alluvial Fan (EA) Reaches

DA River Reach	High Hazard Area	Moderate Hazard Area
General scheme	HCMZ + AHZ + EHA (if present) where constraints do not tend to direct river alignment away	Remainder of AHZ and EHA except far edges
Little Quilcene A	HCMZ + AHZ + EHA	None; rest is DMA
Big Quilcene A	HCMZ + AHZ channel close to river + 100' of erosion beyond it [1]	Remainder of AHZ, except high north area [1]
Duckabush A	HCMZ where not in shadow of 101 embankment	AHZ + remainder of HCMZ, except far sides are Low hazard
Duckabush B	HCMZ except immediately upstream of 101 embankment	EHA + most of AHZ [2]
Dosewallips A	HCMZ and AHZ where not in shadow of 101 embankment	Remainder of AHZ, except SW portion next to 101 is Low hazard
Dosewallips B	HCMZ + AHZ on south side of river	A small sliver of north AHZ near upstream end[3]

1.Portions of Reach A and B on the north side of the Big Quilcene River could potentially be reclassified as Disconnected Migration Area following completion of a study by Jefferson County to determine setback levee alignment in early 2005.
2. The Moderate Hazard zone includes an historic estuary channel near 101 north of the main channel that has been proposed for re-excavation and connection (ESA, 2003).
3. The rest of the north AHZ is Low Hazard due to the angle at which straight Reach C enters Reach B . If the unlikely event that the river in Reach C were to bend to the east, the Reach B AZH could be reactivated, including a large old channel through the town of Brinnon.

Wandering River (W) Reaches

Wandering rivers (also called anastomosing) have irregularly sinuous channels that commonly split around forested islands and unvegetated gravel bars (Desloges and Church, 1989). Channel migration leaves behind seasonal and perennial side channels. Channel migration occurs via avulsions (sudden switching from one channel to another) and lateral migration of bends. Wandering rivers generally have a low sinuosity (below 1.3) and can become quite straight during periods following avulsions or bend cutoffs. Larger, tighter bends occur where the river encounters bedrock or cohesive glacial sediments along the valley wall.

In the study area, the wandering reaches have an active floodplain and are not entrenched. They have few or no armored banks and are able to migrate across their alluvial floodplains. (Although the upper part of Duckabush B was formerly a wandering river, it was treated as a Type DA reach due to its extensive bank armoring.) The sediment regime of these reaches ranges from depositional (Big Quilcene E, Little Quilcene B, Dosewallips D) to a mixture of transport and deposition zones (Little Quilcene B and D, Big Quilcene B, Duckabush C) to mostly transport (Dosewallips G). Channel migration hazard is greatest in depositional reaches because bar deposition causes the river to move laterally.

W River Reach	High Hazard Area	Moderate Hazard Area
General scheme	HCMZ + AHZ + ½ of USBR's calculated EHA width	Remainder of EHA
Little Quilcene B	HCMZ + low parts of AHZ + parts of EHA	Rest of AHZ & EHA
Little Quilcene D	HCMZ (there is no AHZ)	EHA [1]
Big Quilcene B	HCMZ + the AHZ channel closer to river with 160' erosion beyond it + ½ of EHA width elsewhere [2]	Remainder of AHZ and EHA (EHA is narrower in Quaternary terrace) [2]
Big Quilcene E	HCMZ + some AHZ + most EHA	AHZ in shadow of valley-spanning weir + EHA near upstream end
Duckabush C	HCMZ + AHZ + ½ of calculated EHA width where HCMZ +AHZ is narrow	Remainder of EHA (protected somewhat by protrusion of glacial terraces into floodplain)
Dosewallips D	HCMZ + AHZ + ½ of calculated EHA width in alluvium	Remainder of EHA (protected by bedrock protrusion at d/s end)
Dosewallips G	HCMZ + AHZ	EHA [3]

1.The mapped HCMZ may be overly wide due to photo rectification errors relative to the size of the creek, so the entire EHA was classified as Moderate Hazard.
2. Portions of Reach A and B on the north side of the Big Quilcene River could potentially be reclassified following completion of a levee setback study by Jefferson County in 2005.
3. Channel migration is less active in this reach due to little sediment deposition, so the entire EHA was classified as Moderate Hazard.

Straight Entrenched (SE) Reaches

The SE reaches on the Big Quilcene River currently are relatively straight and entrenched within a narrow portion of their former floodplain and meander belt. The earliest air photos and LiDAR maps show they once were wandering channels with meander bends. The upper part of Reach D has been narrowly confined by revetments for many decades by the USFWS hatchery. The lower part of Reach D had a levee built across the northern meander bends in the 1960s. Reach C also appears to have been channelized, probably during the 1960s. Removal of LWD jams probably contributed to channel incision, as did a reduction in sediment load from Reach E following construction of a valley-spanning diversion dam above the hatchery water intake.

Big Quilcene D and the downstream 1/4 of Big Quilcene F are straight and steep, with little channel migration and few gravel bars. Meander bend development is unlikely in the short term or perhaps for centuries. Big Quilcene C is flatter, has active gravel bars, and migrates within a 200-to-500-foot wide zone. Its downstream end is aggrading and transitional to the wandering channel downstream, and it potentially could eventually widen its meander belt if not stopped by revetments.

Because the river is unlikely to reoccupy or expand beyond its HCMZ very soon, the High and Moderate Hazard zones were defined starting at the edge of the 2000 active channel as opposed to the edge of the HCMZ.

SE River Reach	High Hazard Area	Moderate Hazard Area
General scheme	A distance of ½ to 2 of USBR's calculated EHA widths from the 2000 active channel	Remainder of EHA
Big Quilcene C	A distance of 280 ft. (½ EHA width) from the 2000 active channel or narrow low areas adjacent to it. North side tapers tapers at downstream end to meet cliff with bedrock at base. Tapers down at steep upstream end.	Generally ½ EHA width from edge of High Hazard. Widens at upstream end to compensate for reduced width of High Hazard. Narrower in Quaternary terrace's downstream end, in the USBR EHA.
Big Quilcene D	Upstream of 101: a distance of 1 EHA width (60 feet) from the 2000 active channel. Downstream of 101: ½ EHA width from 2000 active channel.	Remainder of HCMZ and EHA, except north side is Low Hazard in shadow of 101 bridge.
Big Quilcene F (downstream ¼ only)	A distance of 60' (2 EHA widths) from the 2000 active channel.	Remainder of HCMZ, except 60' beyond High Hazard in EHA in transition to Reach E.

Straight and Narrow (SN)

The Type SN reaches have been straight and narrow throughout the historic record. They have a narrow or nonexistent floodplain and flow along a valley wall on one or both sides for at least part of each reach. Bedrock and erosion-resistant Quaternary sediments constrain the channel. There are no man-made constraints on river movement. The floodplains and terraces contain no scars of old channels except for the areas noted in the next two paragraphs.

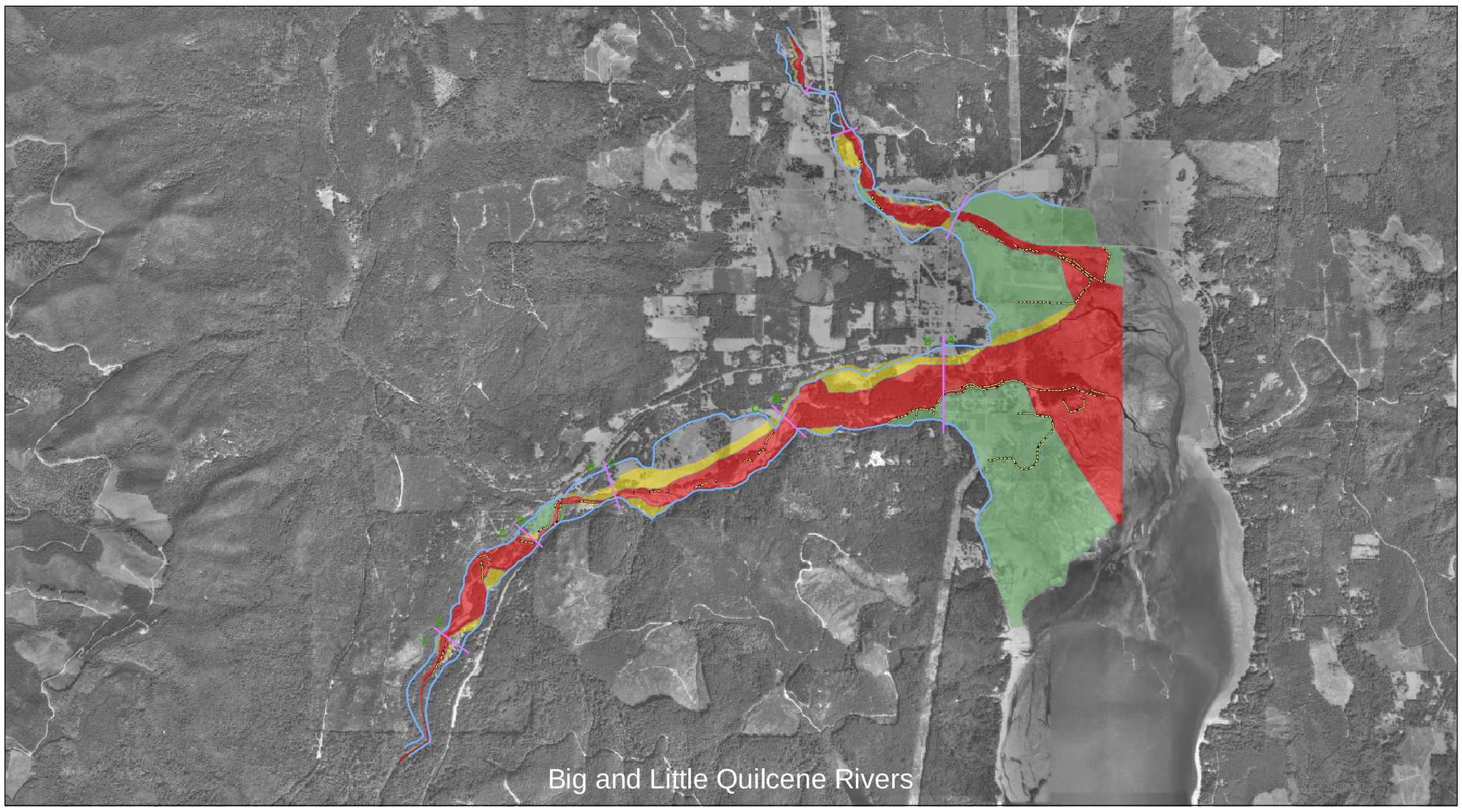
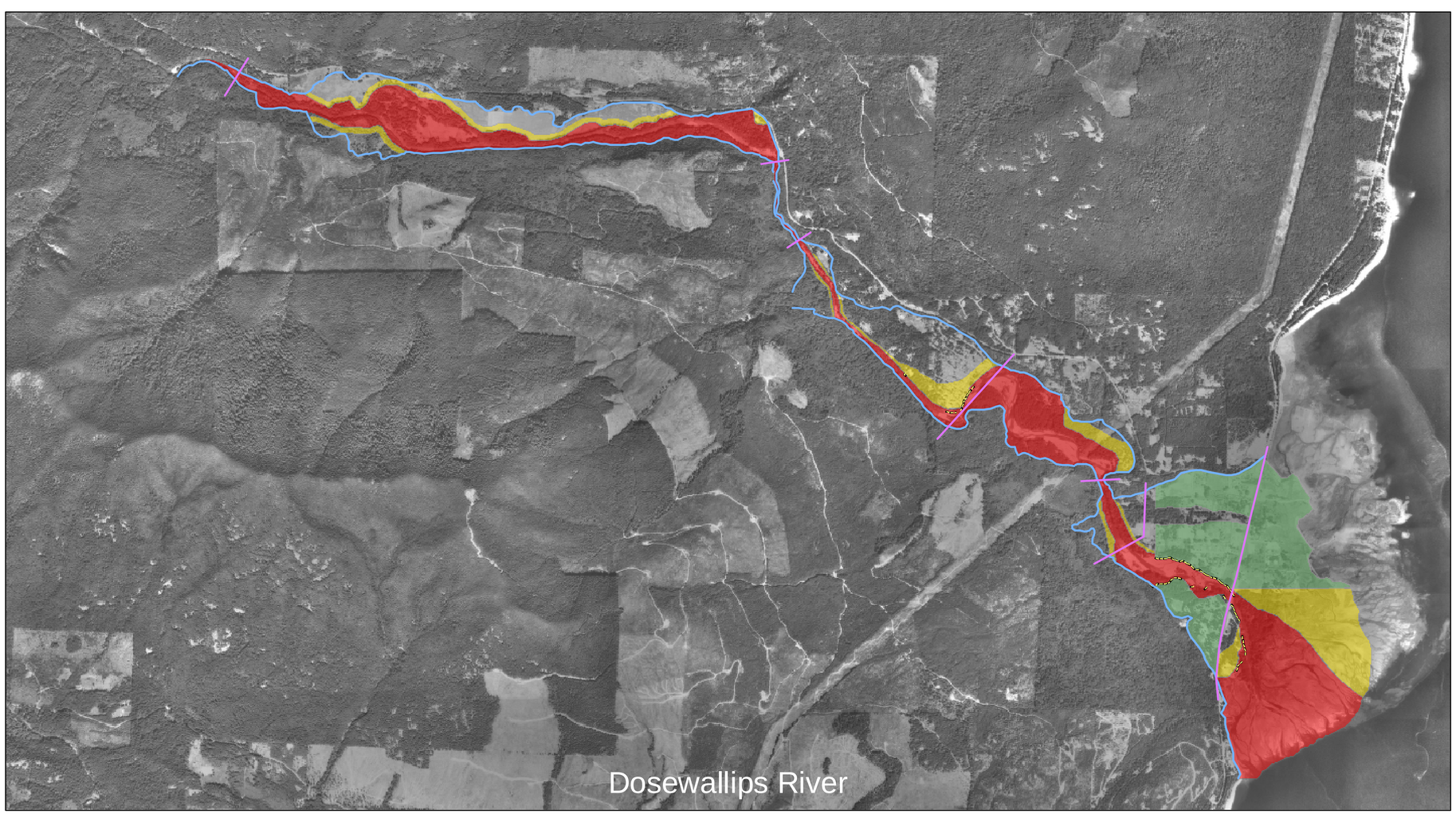
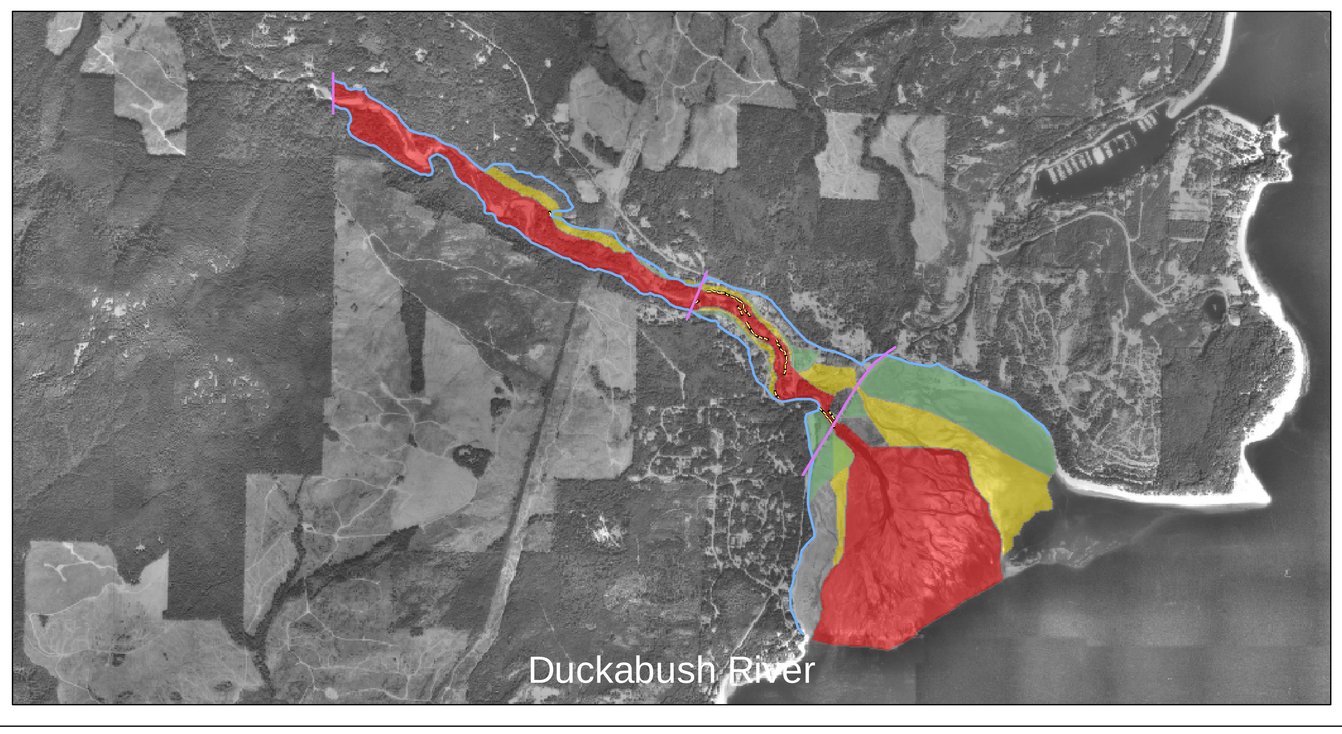
Dosewallips E has been a straight, narrow, deeply entrenched channel through the entire period of photographic record. However, the LiDAR image shows former channels on the broad terrace north of the river. These relict channels may date back to times of glacial melting, but they also could be fairly recent if the incision was caused by splash damming. Splash damming occurred below RM 3.2 in 1917-1926 (ESA, 2003).

The Type SN reaches are sediment transport zones except for the downstream ends of Big Quilcene F, Dosewallips C and Dosewallips E. Those areas are transitional to Type W depositional channel downstream, hence they have a greater potential for channel migration and wider hazard zones. There is evidence of several feet of recent aggradation at the downstream ends of Dosewallips C and E. Channel migration behavior in these zones should be reviewed once every 10 years and the hazard maps revised if appropriate.

SN River Reach	High Hazard Area	Moderate Hazard Area
General scheme	HCMZ	AHZ + EHA
Little Quilcene C	HCMZ	None; EHA and AHZ are Low Hazard due to straightness, bedrock control, and steepness
Big Quilcene F (upstream 3/4)	30' (~1 channel width) from 2000 channel, because photo rectification problems caused the HCMZ to be mapped too wide. Tapers upstream to edge of bedrock channel.	None
Dosewallips C	HCMZ plus narrow sliver of low floodplain AHZ on northeast side	EHA, + AHZ for 1 EHA width (67 ft.) beyond High Hazard on NE side
Dosewallips E	HCMZ	EHA+ AHZ
Dosewallips F	Channel only. Tightly confined bedrock canyon.	None

East Jefferson County
Channel Migration Hazard Map

Legend

- High
- Moderate
- DMA
- Reach Boundaries
- Valley Edge
- Revetments

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