To: Jeff McGowan, Salmon Habitat Specialist
Skagit County Public Works

From: Shawn Higgins, Leif Embertson PE, and Tim Abbe PhD PEG
Natural Systems Design, Inc.

Date: April 13, 2016

Re: Channel Migration Evaluation for the Skagit River at Martin Road (RM 68.5-69)

Project Background

Martin Road is a County road providing local access to a rural residential community in the Skagit River Valley near Rockport. The road intersects SR 530 about 900 feet south of the Skagit River Bridge, heads east for a distance of about 0.5 miles, then turns 90 degrees to the south and connects with Rockport-Cascade Road (Figure 1). Martin Slough is an approximately 75 foot wide floodplain channel crossing under Martin Road in two locations via 3-foot diameter culverts upstream and downstream of the 90 degree bend in Martin Road. Both culverts are identified as barriers in the Washington State Fish Passage Inventory (WDFW, 2015). Beavers regularly construct dams in or next to the culverts which further exacerbate local flooding concerns. Freshwater rearing habitats in floodplain areas like Martin Slough have been degraded by historical land use practices and isolation of these floodplain habitats by road crossings or other impairments are currently limiting population sizes of Chinook salmon and other species in the Skagit River Basin (Beamer et al., 2005).

Skagit County Public Works Natural Resources Division (Skagit County) has sponsored the Martin Slough Fish Passage Feasibility and Design Project to restore connectivity to off-channel habitat in the Skagit River floodplain. Skagit County initially proposed replacing the two culverts crossing Martin Road with wider spans to address fish passage issues at Martin Slough. The Salmon Recovery Funding Board (SRFB) review panel expressed concern regarding the long term effectiveness of constructing a replacement culvert or bridge at the downstream site given the probability of continued channel migration toward Martin Road. The County then re-scoped its application as a feasibility study to examine the need for a crossing at Martin Slough and the long term plan for Martin Road given the channel migration hazards.

Natural Systems Design, Inc. (NSD) was contracted to assess the channel migration hazard at Martin Road. The purpose of this memorandum is to synthesize the processes driving streambank erosion at the project site and evaluate conceptual design approaches to bank protection/stabilization. Skagit County will then compare the costs/benefits of bank protection alternatives to an alternative that would consider vacating a portion of Martin Road between the two culvert crossings and enable removal of the road fill obstructing Martin Slough at the downstream crossing. The SRFB review panel supported replacement of the upstream culvert provided that fish passage can be assured at the downstream site.

Two recent publications describing geomorphic processes, flood, and erosion hazards in the project reach preceded this study. The Skagit River System Cooperative (SRSC) and NSD (2014) completed a restoration feasibility level geomorphic assessment and hydraulic analysis of the reach from the SR 530 Bridge at Rockport to the confluence with Illabot Creek. Washington State Department of Transportation produced a subsequent assessment evaluating flood and erosion risks to infrastructure at SR 530 and SR 20 (Shanz, 2015).

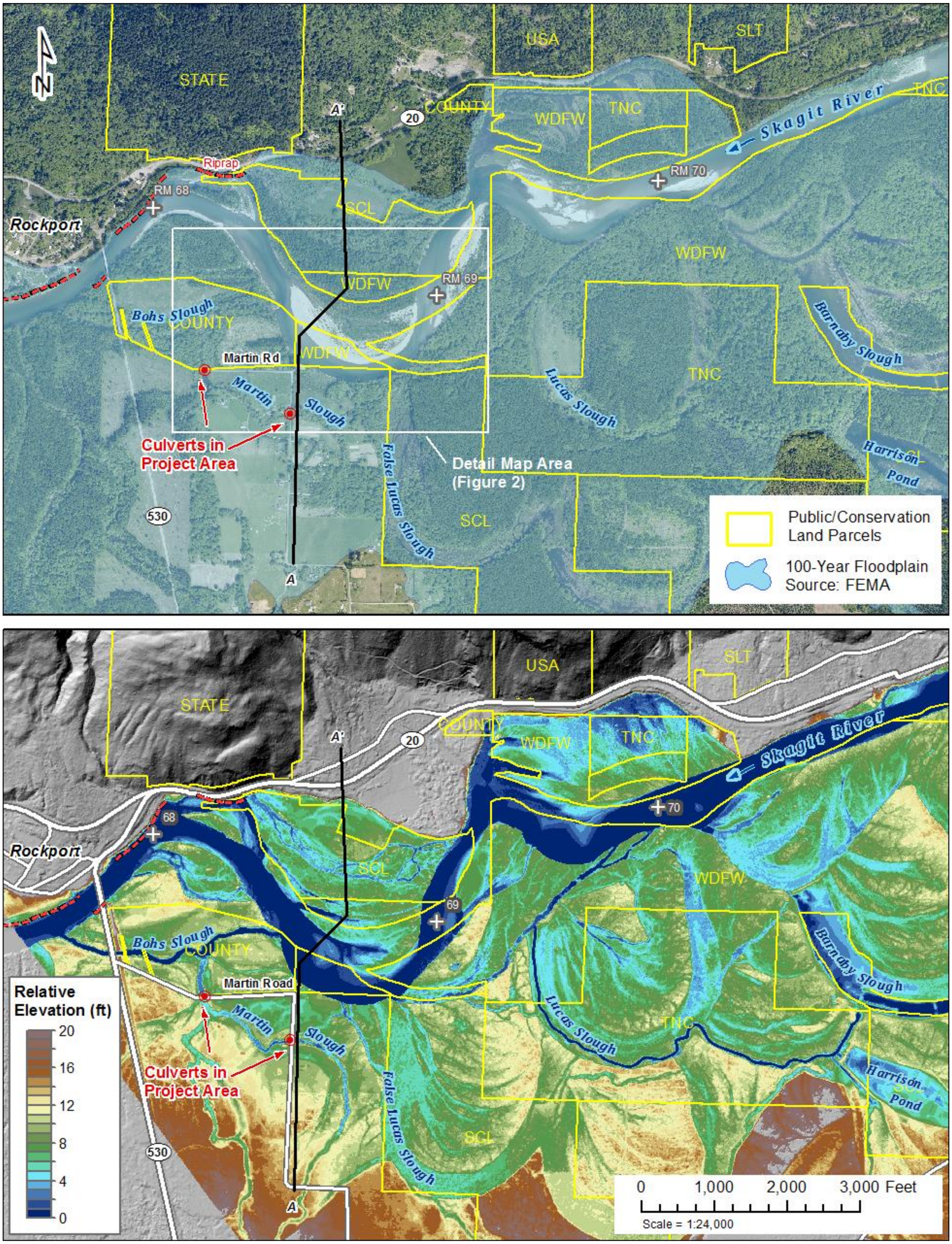


Figure 1. Reach maps showing 2015 aerial imagery and floodplain topography based on 2005 LiDAR DEM and supplemental topographic survey. Cross-section A-A' is shown in Figure 3.

Site Description and Geomorphic Setting

The project site encompasses the large meander bend in the Skagit River upstream from the inlet to Bohs Slough (Figure 1). The outer (left) bank has rapidly migrated south in recent decades and the bank edge is was about 160 feet from the 90 degree bend in Martin Road in 2015 (Figure 2). Washington Department of Fish and Wildlife (WDFW) owns the parcel extending north and east from the 90 degree bend and previously managed a water access site with parking and a restroom that has since been removed due to the erosion hazard. A gravel access road to the WDFW site has been blocked off; however, the site is still used for viewing bald eagles and other wildlife and is accessed from parking along the road edge. Skagit County owns the parcel north of Martin Road that includes part of the eroding bank between the WDFW access site and Bohs Slough. The parcel including the left bank to the east (upstream) of the WDFW site is in private ownership.

The project reach is located in an unconfined segment of the Skagit River Valley upstream of the confluence with the Sauk River just downstream (west) of SR 530 and the town of Rockport. The broad, alluvial valley ranges between 1.3 and 1.8 miles in width and has been shaped over time by channel migration processes. Meander scars from previous channel alignments create a complex network of backwater sloughs and floodplain channels upstream of Martin Road (Figure 1). The active channel (including the wetted low flow channel and un-vegetated bar surfaces) is approximately 500 feet in width and has a maximum depth of 12 to 15 feet at bankfull stage. The channel has a pool-riffle morphology with an average gradient of 0.002 feet/feet (0.2%).

The watershed upstream of the project reach is a steep, mountainous area encompassing 1,655 square miles with headwaters in the North Cascades and approximately 8,000 feet of vertical relief. The flow and sediment regimes are regulated by three dams upstream of Newhalem and the contributing drainage area upstream of the dams accounts for 70% of the watershed area above Rockport.

The entire project area at Martin Road is within the Special Flood Hazard Area (100-year floodplain) mapped by FEMA as part of the Flood Insurance Study for Skagit County. Flood flows are most common in the period between October and March. Large flood events in recent decades include November 1995, October 2003, and November 2006. The Base Flood Elevation (water surface elevation of the 100-year flood) defined by FEMA is 239 feet NAVD 88 at the 90 degree bend in Martin Road. This flood stage corresponds to an inundation depth of 5 to 9 feet over the floodplain area where ground surface elevations range between 230 and 234 feet (Figure 3).

Bed material in the project reach is characterized by gravel- and cobble-sized sediments and there are active bars developing within dynamic segments of the reach. WSDOT (2007) sampled the bed approximately four miles upstream of the project site for the SR 20/MP 100.7 project and reported a cobble-sized armor layer (D_{50} = 150 mm, D_{90} = 300 mm) overlying a gravel-sand substrate (D_{50} < 5 mm).

The outer bend of the meander near Martin Road has a bank height ranging between 12 and 15 feet and bank material is composed of erodible alluvium. The bank stratigraphy reveals a coarse deposit of gravel- to cobble-sized sediment that is overlain by approximately 5 feet of flood deposited sand and sandy loam. Soils covering the adjacent floodplain area are mapped as Larush silt loam (Klungland and McArthur, 1989). The Larush series consists of very deep, well drained soils formed in mixed alluvium. The surface layer is fine sandy loam or silt loam about 15 inches thick. The subsoil is very fine sandy loam and silt loam about 19 inches thick. The substratum to a depth of 60 inches or more is fine sand and silt loam. The bank near the WDFW access site is capped by a 12- to 18-inch layer of compacted fill that is a remnant from the parking area eroded by recent channel migration.

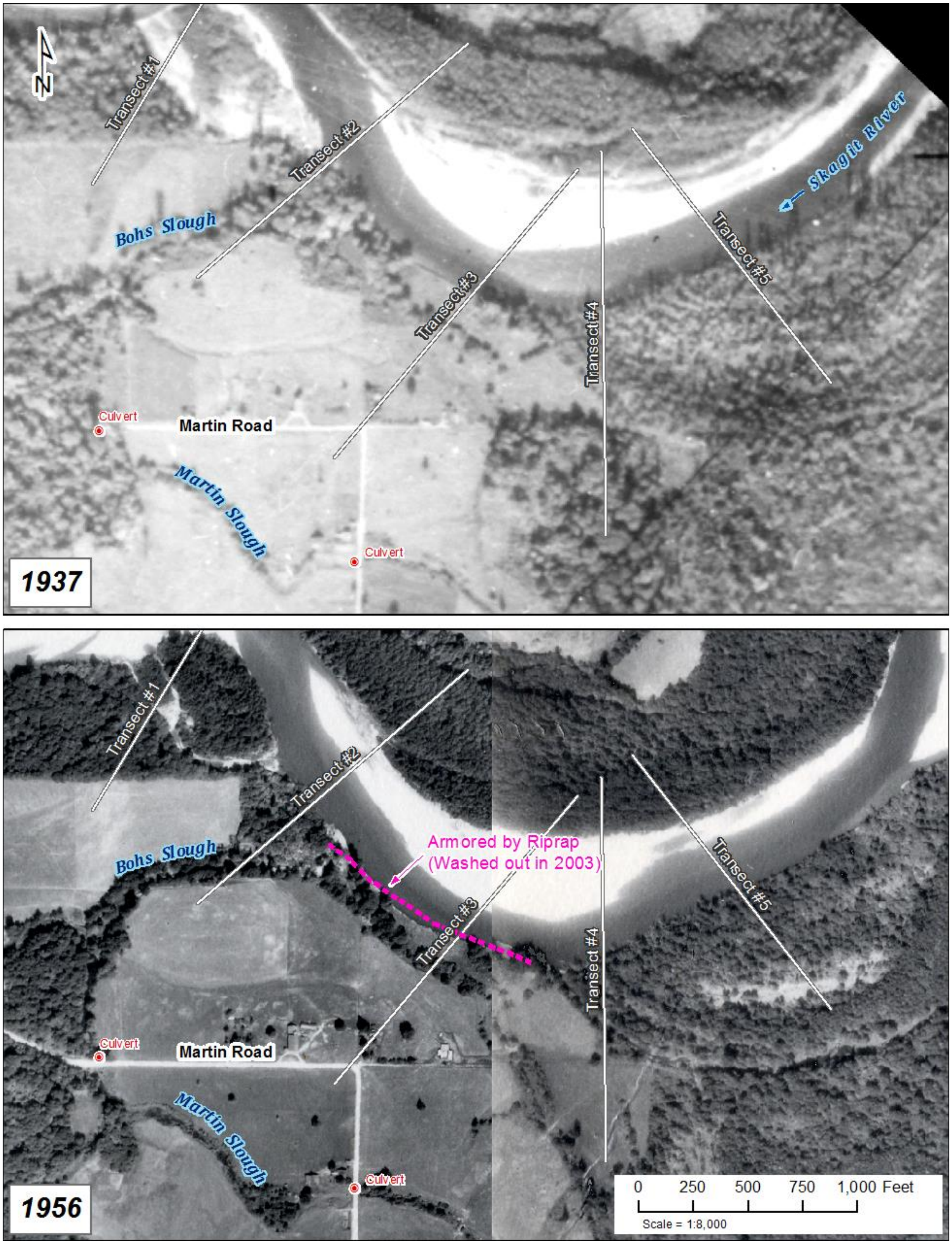
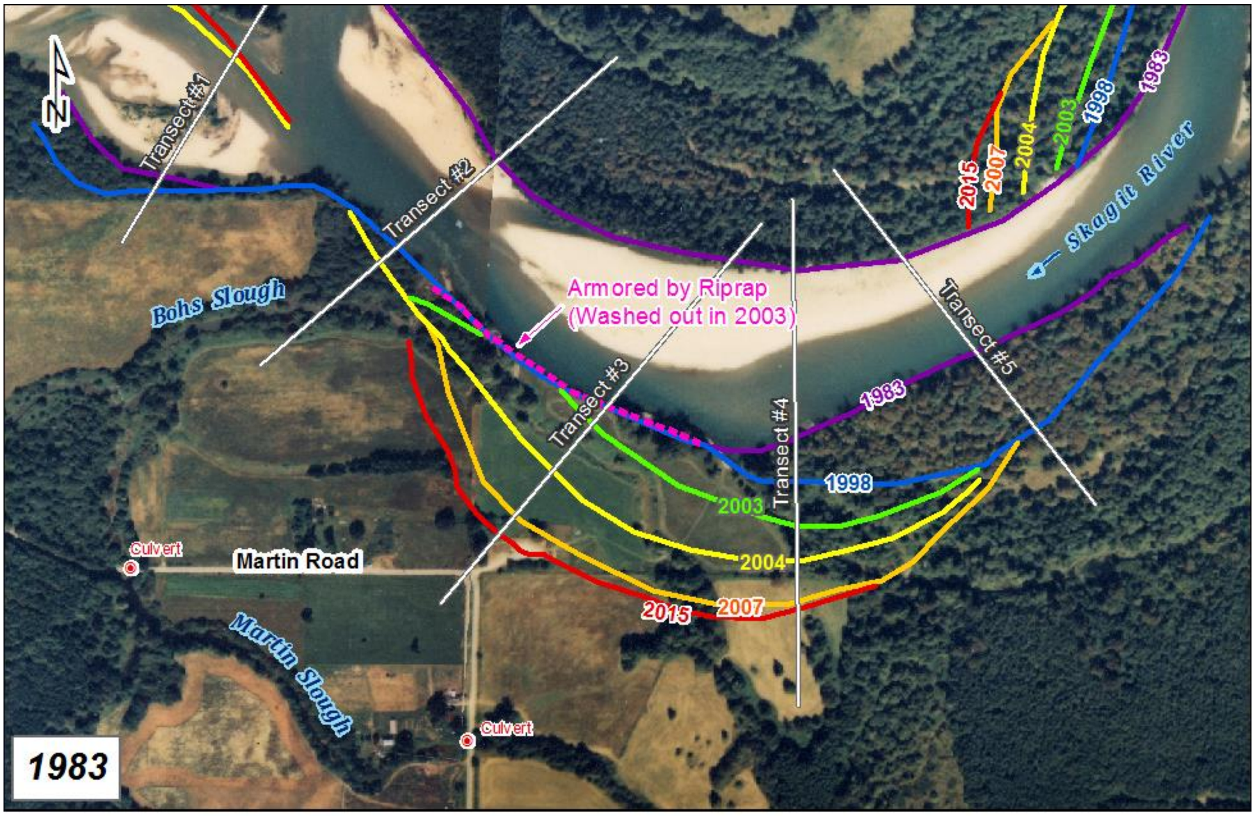


Figure 2a. Site maps with historical imagery from 1937 and 1956.



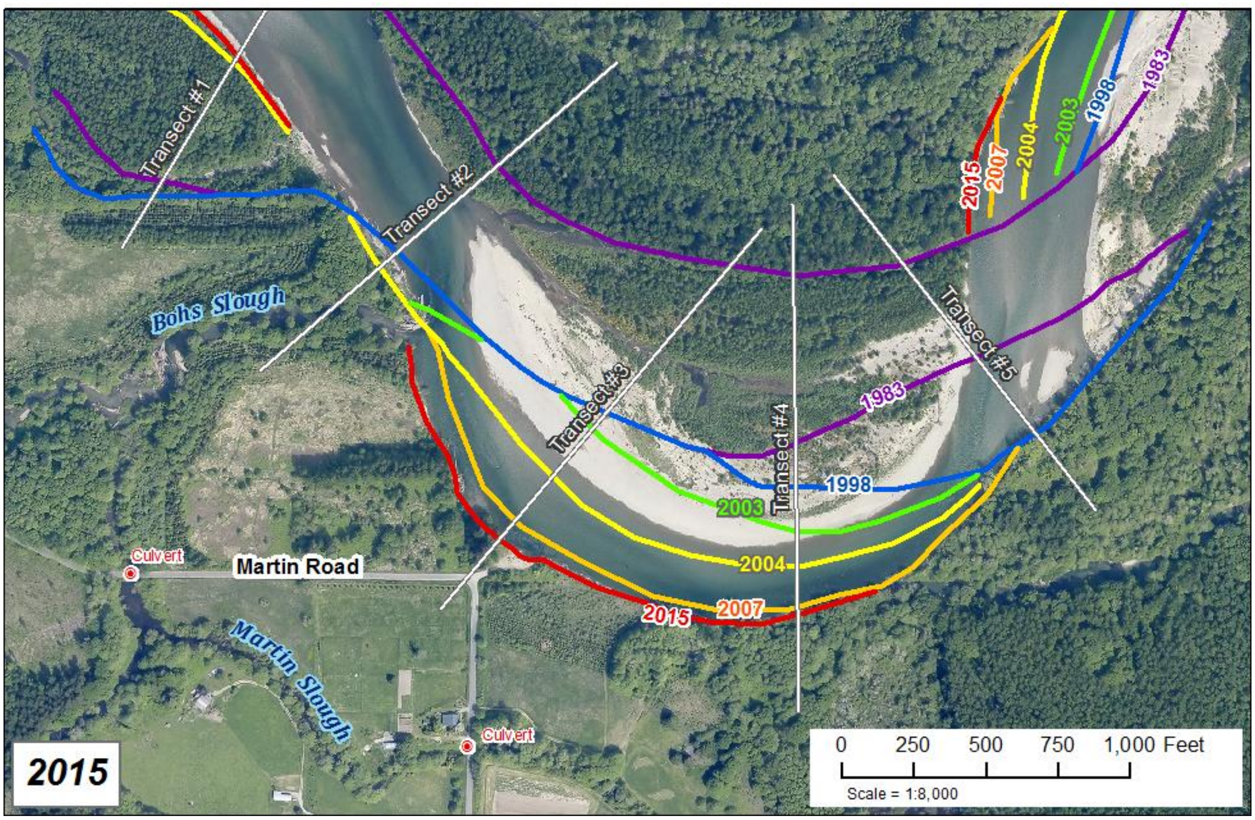


Figure 2b. Site maps with banklines digitized from images between 1983 and 2015. The river has migrated approximately 580 feet towards the road since 1998 at Transect #3.

Riparian vegetation is sparse along most the eroding streambank. A clearing at the WDFW site extends upstream over approximately 600 feet of the streambank (Figure 4). Riparian trees upstream of the clearing are primarily deciduous with some recent conifer plantings that are less than 10 feet tall. The existing vegetation is not sufficient in size to provide stable key pieces if recruited to the channel. Wood pieces, potentially part of a buried log jam, are protruding from the lower bank into the wetted channel in the area of recent erosion at the WDFW access site.

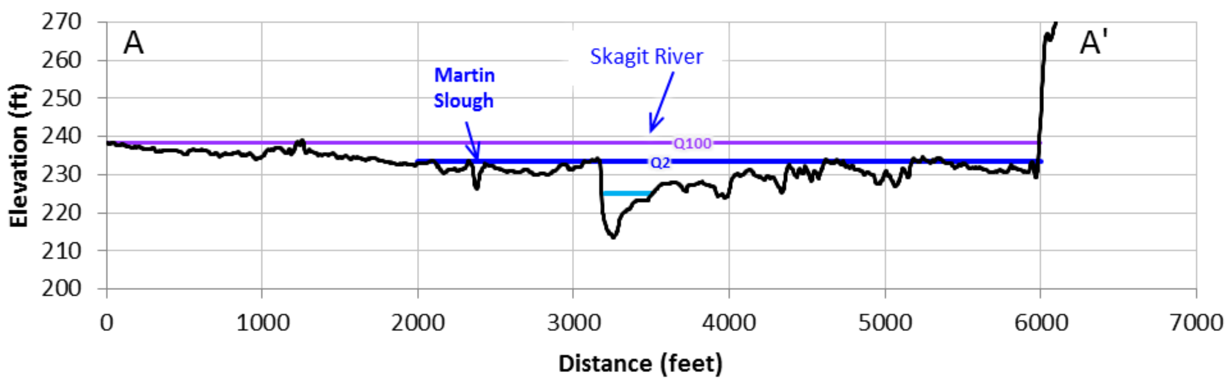


Figure 3. 2015 cross-sectional profile with the observed water surface elevation during base flow (7,600 cfs; light blue) and simulated water surface elevations for the 2-year (Q2) and 100-year (Q100) recurrence interval flows. The location of section A-A' is indicated on reach maps in Figure 1.

Figure 4. Photo looking upstream along eroding (left) bank at the WDFW access site near the 90 degree bend in Martin Road.

Historical records document a complex channel pattern and large abundance of instream wood in the Skagit River that has since decreased due to snagging (wood removal) and timber harvest in the riparian corridor (Collins and Sheikh, 2002). Stable wood jams are an important component of the river corridor that increase the number and depth of pools (Montgomery et al., 1995), form islands by inducing sediment deposition (Abbe and Montgomery, 1996), increase potential for floodplain inundation (Abbe and Montgomery, 1996; Collins et al., 2002; Brummer et. al., 2006), and create an anastomosing channel pattern with perennial secondary channels (Abbe and Montgomery, 2003; Montgomery and Abbe, 2006). Logjams can limit channel migration and reduce meander bend radius of curvature that can contribute to cut-off channels that limit further lateral expansion of the meander (Abbe and Montgomery 2003). Recruitment of key pieces that are large enough to resist entrainment and downstream transport by hydraulic forces is essential to create stable hard points in the floodplain that support development of mature forests which function as future sources of large wood; thus sustaining the floodplain-large wood cycle that maintains physical complexity and habitat diversity in forested alluvial valleys (Collins et al., 2012). Existing riparian conditions include a combination of clearings where forest development is impaired by current land use activities and forested areas that are in various stages of recovery from previous timber harvest.

Hydraulic Analysis

Flood statistics estimated by USACE (2010) for the Skagit River at Rockport (upstream of the Sauk River confluence and representative of the project reach) are summarized below in Table 1. NSD produced 2-Dimensional (2D) hydraulic model simulations that included the project site as part of evaluations completed for the Habitat Restoration Alternatives Assessment in the Barnaby Reach of the Skagit River (SRSC and NSD, 2014). Simulated areas of flood inundation and flow velocity in the project area are mapped in Figure 5 for the 2-year (Q2) and 100-year (Q100) floods. The 2-year recurrence interval flow (50% annual chance of exceedance) simulation overtops the left bank and flows westerly across Martin Road into Martin Slough with flow overtopping the road again near the downstream culvert. Maximum flow velocity in the main channel ranges between 10 and 12 feet per second (ft/s) at the apex of the meander near Martin Road. The 100-year recurrence interval flow simulation (1% annual chance of exceedance) inundates a broad floodplain area extending across the valley bottom. Simulated velocities for the 100-year flood are lower than those presented for the 2-year event due to a substantial backwater effect produced by the SR530 highway embankment and bridge crossing just downstream of the project area. The backwater condition during extreme floods lessens the energy gradient of the flow and decreases velocity in the channel. Inundation areas delineated with the 2D hydraulic model are consistent with Base Flood Elevations in Flood Insurance Rate Maps by FEMA.

The prevailing mechanism of bank failure affecting channel migration hazards at Martin Road is toe erosion. Toe erosion is driven by flood flows that mobilize sediment grains from the streambank leading to undercutting and a subsequent collapse of the overlying bank material. Erodible sediment grains are entrained by flow when the effective shear stress exceeds the critical shear stress for grain motion. The total applied shear stress at a given flow is the force exerted by the flowing water per unit area of the bed and, assuming the condition of steady, uniform flow, is calculated as:

$$\tau_0 = \gamma RS \qquad (1)$$

where:

τ_o = total shear stress (lb/ft^2)
γ = specific weight of water (lb/ft^3)
R = hydraulic radius (ft)
S = energy slope (ft/ft)

The total shear stress is partitioned into components characterizing individual roughness elements for a given channel segment such that the effective shear stress available for sediment transport is some fraction of the total applied shear stress at a given location. The relative fraction of total applied shear stress available for sediment transport decreases with increasing amounts of stable wood or other roughness elements in the channel (Manga and Kirchner, 2000).

The critical shear stress for grain motion is derived using a function of the sediment grain size and calculated by a relation developed by Shields (1936) such that:

$$\tau_c = \tau_c^*(s-1)\rho g D \tag{2}$$

where:

τ_c = critical shear stress (lb/ft^2)
τ_c^* = Shields parameter
s = specific gravity of sediment
ρ =density of water (lb/ft^3)
g = constant for the acceleration due to gravity (ft/s^2)
D = grain size diameter (ft)

Reference values of critical shear stress for a range of grain size classifications using Wilcock et al.'s (2009) approximation of the Shields curve are summarized below in Table 2.

Hydraulic model simulations produce estimates of applied shear stress that can be compared to the critical shear stress values for streambank materials to evaluate sediment mobility at a given flow. Applied shear stress during hydraulic simulations for the 2-year flood exceeds 1 pound per square foot (lb/ft^2) in the project reach. Such forces are competent to entrain sediment particles less than 64 millimeters or 2.5 inches in diameter (Table 2). As such, we conclude that relatively frequent, moderate magnitude flood events will continue to mobilize the alluvial sediment at the bank toe and produce additional episodic bank failures that result in additional channel migration toward Martin Road. Localized variation of erosion rates along the meander bend are driven by factors such as bend radius, vegetation, and large woody material.

Spiraling flow patterns (secondary currents) along a bend result in a greater amount of shear stress along the outer bank and the magnitude of shear stress increases with the tightness of the meander. Maximum shear stress in a bend can be up to two times the shear stress acting on the bed or in a comparable straight reach of similar depth and slope. Given the dynamic nature of the Skagit River in the project reach, channel changes in the segment upstream of the project site will alter the attack angle of the approaching flow over time and change the location of maximum shear along the bend.

Woody vegetation along the bank produces localized resistance to erosion through root cohesion and increased flow resistance. Wood accumulations along the bank or in the channel partition shear stress, dissipate energy, and reduce erosion potential (Manga and Kirchner, 2000). On average, erosion rates along agricultural areas or floodplains with immature forests are more than double the erosion rates for floodplains with mature forest vegetation (Abbe, 2000; Micheli et al., 2004). The sparse riparian cover in the project area limits the effect of woody vegetation on bank stability. There are, however, wood pieces exposed in the lower bank at the project site that may be part of a buried logjam. The spatial extent and long-term stability of this buried wood is highly uncertain and would require detailed field investigation to assess. It is possible that the additional resistance produced by this wood will temporarily reduce erosion rates along the project site; however, it is also likely that erosion of adjacent bank materials upstream of the buried wood will undermine the logjam in future flood events, reducing its stabilizing effects.

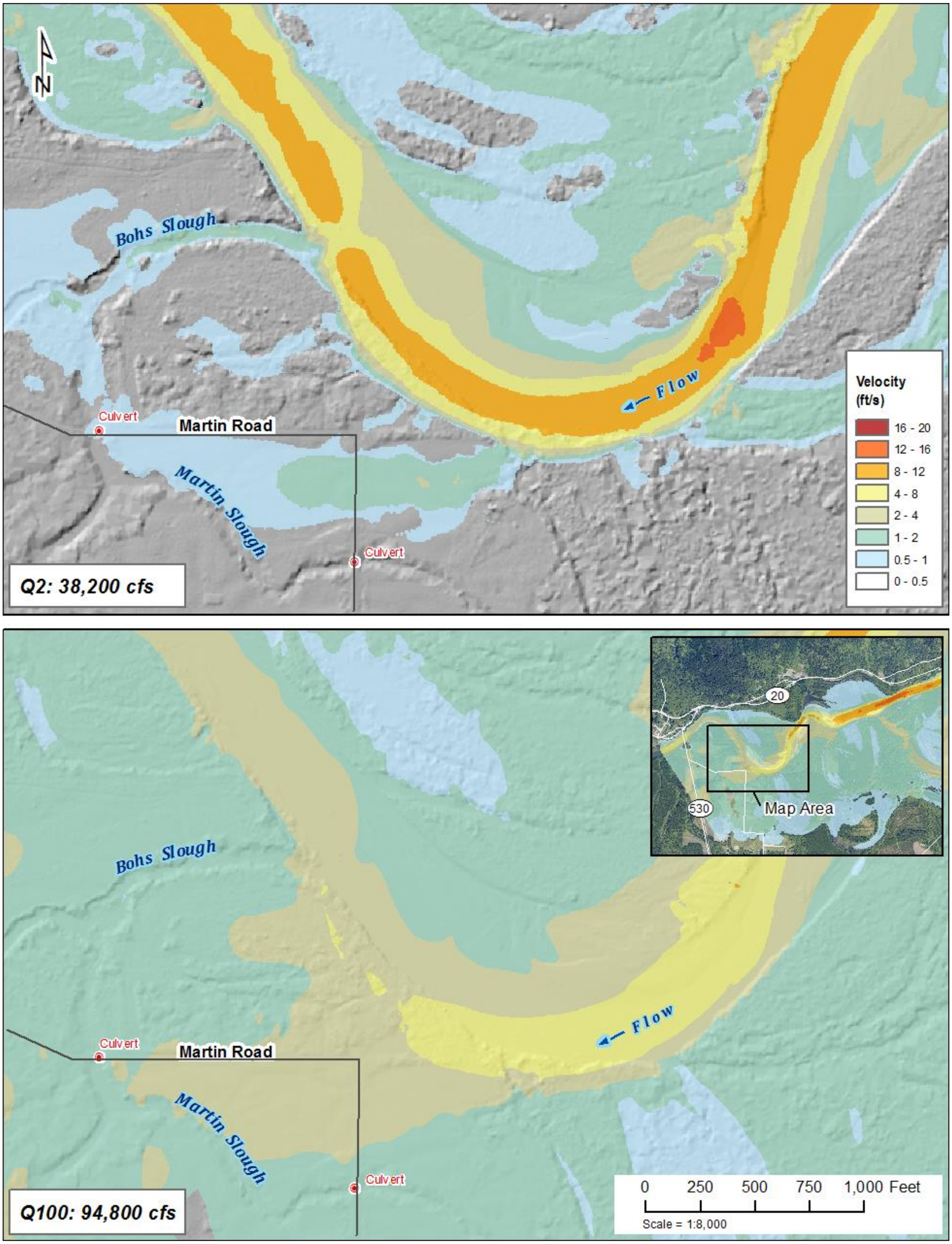


Figure 5. Simulated areas of flood inundation and flow velocity for the 2-year and 100-year recurrence interval flows.

Table 1. Estimated flood frequency statistics for the Skagit River at Rockport. Data source: USACE (2010).

Annual Chance of Exceedance	Recurrence Interval (years)	Peak Streamflow (cfs)
50%	2	36,000
25%	5	46,200
10%	10	55,000
4%	25	68,100
2%	50	79,300
1%	100	92,500

Table 2. Critical shear stress values for unconsolidated sediment.

Sediment Classification	Grain Diameter (mm) Finer Than	Shields Parameter	Critical Shear Stress (lb/ft2)
Boulder	512	0.046	8.0
Large Cobble	256	0.046	4.0
Small Cobble	128	0.047	2.0
Very Coarse Gravel	64	0.047	1.0
Coarse Gravel	32	0.046	0.50
Medium Gravel	16	0.045	0.24
Fine Gravel	8	0.042	0.11
Very Fine Gravel	4	0.038	0.05
Very Coarse Sand	2	0.033	0.02
Coarse Sand	1	0.031	0.01
Medium Sand	0.5	0.035	0.006
Fine Sand	0.25	0.046	0.004
Very Fine Sand	0.125	0.063	0.003

Historical Erosion Rates

The project site is located in a dynamic channel segment that has migrated laterally across the floodplain. SRSC and NSD (2014) compiled a time series of historical maps and aerial imagery in a GIS database for visualization of channel changes and measurement of erosion rates. Banklines from the recent period 1983-2015 are overlaid with aerial imagery in Figure 2 showing historical channel changes at the project site. Measurements of channel migration along a transect towards Martin Road are summarized in Table 3.

During the time period between 1937 and 1956 images, the outer bend migrated 100 feet in a southwesterly direction toward Martin Road (Figure 2a). During this time pperiod (date unknown), a portion of the streambank adjacent to the project site was armored by riprap to protect private property and the WDFW access site from erosion. The bankline armored by riprap was approximately 700 feet to the northeast of Martin Road in 1956 (Figure 2a). The SRSC Hydromodified Streambank Inventory from 1998 mapped the riprap over a length of approximately 1,100 feet extending downstream from the outlet of Lucas Slough. Comments included in the SRSC inventory note the ripirap was discontinuous and that the lower 80 to 100 feet had previously washed out.

Riprap held the bank in a fixed position and resisted channel migration for several decades until erosion along the left bank upstream of the revetment in the 1980s and 90s initiated a sequence of channel changes that washed out the riprap and eroded substantial areas of the floodplain surface between the river channel and Martin Road. Channel migration washed out the upper portion of the riprap between 1998 and July 2003, eroding the bankline approximately 70 feet towards Martin Road (5.3 feet/year). A large flood then occurred in October 2003 (estimated return frequency of 50-years at USGS gage at Marblemount #12181000) resulting in an additional 220 feet of erosion (220 feet /year). Another large flood occurred in November 2006 (estimated return frequency of 10 years at the Marblemount gage) resulting in an additional 200 feet of erosion. The bank has migrated an additional 90 feet towards Martin Road since 2007 and has reduced the distance between the channel and the road edge to 160 feet in 2015 (Figure 2b).

Cumulative erosion at the bank migrating toward Martin Road has totaled 680 feet since 1937 (Figure 2 and Table 3). Averaged over time, the long-term erosion rate is 8.7 feet/year during this period; however, the bank was armored by riprap for over half this time and the recent erosion rates are substantially higher since the riprap washed out. Limiting the time interval to the period since 1998, average rate of erosion toward Martin Road has been 34.1 feet/year.

In order to evaluate the range and variability of historical erosion rates in the project reach, transect measurements were made at five locations spaced 1,000 feet apart (approximately two times the bankfull channel width). The long-term average erosion rates during the period 1937 – 2015 are summarized in Table 4. Channel migration over the 78 year period ranged between 280 and 710 feet with corresponding migration rates of 3.6 and 9.1 feet/year, respectively. Averaged over the 5,000 foot long channel segment, historical erosion rates were 6.3 feet/year during the period 1937 – 2015.

Table 3. Measurements of historical channel migration towards Martin Road during the period 1937 – 2015 (Transect 3 in Figure 2).

Year	Channel Migration (feet)	Time Interval (years)	Erosion Rate (feet/year)
1937 - 1956	100	19	5.3
1956 - 1998	0*	42	0.0*
1998 - 2003	70	5	14.0
2003 - 2004	220	1	220.0
2004 - 2007	200	3	66.7
2007 - 2011	30	4	7.5
2011 - 2015	60	4	15.0
1937 - 2015	**680***	**78**	**8.7***
1998 - 2015	**580**	**17**	**34.1**

* Migration constrained by riprap revetment during selected time interval

Table 4. Measurements of channel migration during the period 1937 – 2015 along 5 transects spaced 1,000 feet apart (Transect alignments are mapped on Figure 2b).

Transect	Channel Migration (feet)	Time Interval (years)	Erosion Rate (feet/year)
1	400	78	5.1
2	280	78	3.6
3	680*	78	8.7*
4	710	78	9.1
5	390	78	5.0
Average	**490**	78	**6.3**

* Migration constrained by riprap revetment during selected time interval

Channel Migration Zone

This assessment of channel migration hazards at the Martin Road project site utilizes historical information and observations from field reconnaissance to predict future channel changes and identify the area at risk of erosion. The Channel Migration Zone (CMZ) defines the area at risk of future erosion by a stream or river. Rapp and Abbe (2003) developed a framework for delineating a CMZ that identifies the following components of the river corridor:

1. Historical Migration Zone (HMZ) –area of channel migration over the period represented in historical aerial imagery;
2. Avulsion Hazard Zone (AHZ) – area at risk of avulsion over the timeline of CMZ;
3. Erosion Hazard Area (EHA) – erodible areas outside of HMZ and AHZ at risk of future channel migration (including an erosion setback and, where necessitated by high banks with steep slopes, a geotechnical setback);

4. Disconnected Migration Area (DMA) – portion of CMZ that is isolated by infrastructure that physically limits channel migration.

The collective areas are combined to map the CMZ such that:

CMZ = HMZ + AHZ + EHA – DMA

The HMZ is delineated from overlays of past channel alignments digitized by SRSC from historical imagery. NSD delineated three AHZs flanking the HMZ where existing side channels pose a high risk of future avulsion hazards. The AHZ includes an area crossing over Martin Road between the upstream culvert in Martin Slough and the 90 degree bend in Martin Road. Flood flows overtop the bank in this location and follow a preferential flowpath along a swale connecting the main channel to Martin Slough (Figure 5).

The EHA extends outward from the HMZ and AHZ to represent erodible areas at risk of future erosion. The long-term average erosion rate for the project reach (Table 4) was projected over a 100 year CMZ timeline to yield a 630 foot erosion setback defining the EHA (6.3 ft/yr times 100 years). The preliminary CMZ delineated with this method identifies a corridor greater than 4,000 feet wide in the project area.

The bank of the Skagit River was 160 feet from Martin Road in 2015. Assuming continued channel migration at the long term average erosion rate of 6.3 feet/year, the eroding bank would intersect Martin Road in a period of 25 years. Recent channel movement at the project site has far exceeded the long term average with an erosion rate of 34.1 feet/year since 1998. Should channel migration continue at this more rapid rate, the eroding bank would intersect Martin Road in less than 5 years. Given the trajectory of recent channel adjustments and current meander configuration, erosion will likely continue at some rate between the recent rate and the long term average. As such, a reasonable planning timeline for Martin Road could assume the eroding bank will intersect road edge at some point during the next 5 to 25 years. It possible, however, that erosion from a single event could erode the remaining floodplain area and damage the road given that the remaining distance between the channel and Martin Road (160 feet) is less than the observed erosion from 2003 and 2006 flood events (220 and 200 feet, respectively). Streamflows associated with these recent flood events were not specifically measured in the project reach; however, flood frequency analysis at the USGS gage near Marblemount estimate the 2003 flood as an approximately 50-year event and the 2006 flood as an approximately 10-year event.

There remains an element of uncertainty due to localized variations in shear stress, bank strength, and potential for development of new wood jams that alter flow hydraulics. In general, projections of channel migration are more reliable in the near future and become more uncertain over longer time periods. Both near and longer term channel migration will be dependent on the occurrence and magnitude of flood events, sediment deposition, and occurrence of stable logjams within the project reach.

Continued channel adjustments at the bend upstream of the project site will affect erosion patterns in the project area. The right bank on the bend just upstream and across the river from the project site is migrating westerly (downstream) and altering the meander geometry in the approach section to the bend at Martin Road (Figures 2b and 5). If the channel continues this westward trend of migration, the initial change in channel location would likely steepen the angle of approach into the Martin Road bend, and increase the rates of migration along the left bank toward Martin Road. Over time, however, continued migration of the bend upstream of the project site could intersect older channel features in the floodplain and trigger an avulsion that cuts off the meander bend, decreases shear stress along the outer bend at Martin Road, and reduces erosion rates relative to the recent period when flow has been concentrated along the outer bend. This avulsion could occur in response to formation of a large log jam capable of deflecting flow west and across the interior of the bend (across the channel from Martin Road). This scenario is plausible given that the floodplain area being eroded by this upstream meander contains relic channel scars and side channels that could be re-activated. Given the trajectory of channel migration along the right bank, the nearest floodplain channel likely to capture substantial flow is approximately 450 to 700 feet from the present bankline. The recent channel migration rate at the bank has averaged 15 feet/year since 1998. At this rate, we estimate the process whereby a meander cutoff would occur is in the range of 30-50 years at that location.

Evaluations of climate change impacts on peak flows in the Skagit River basin project increasing flood frequencies and magnitudes over the 21st century in association with warming temperatures and a greater proportion of winter precipitation occurring as rain versus snow (Lee and Hamlet, 2011). Model simulations of future climate with the A1B emissions scenario project a 49% increase in the 100-year flood magnitude upstream of the project site at Ross Dam and 53% increase in the lower Skagit River near Mount Vernon by the 2080s (Hamlet et al., 2010). Future projections of climate change impacts have not yet been incorporated into hydraulic model simulations but will substantially increase flood inundation and sediment transport capacity as well as accelerate channel migration rates in areas of the project reach that lack sufficient resistance, by wood or other material, to partition shear stress and inhibit toe erosion. As such, it is possible that CMZ delineation based on historical migration rates may under-predict the potential area of future erosion and warrant a more detailed evaluation of potential impacts of future changes in hydrology on bank erosion and channel migration processes.

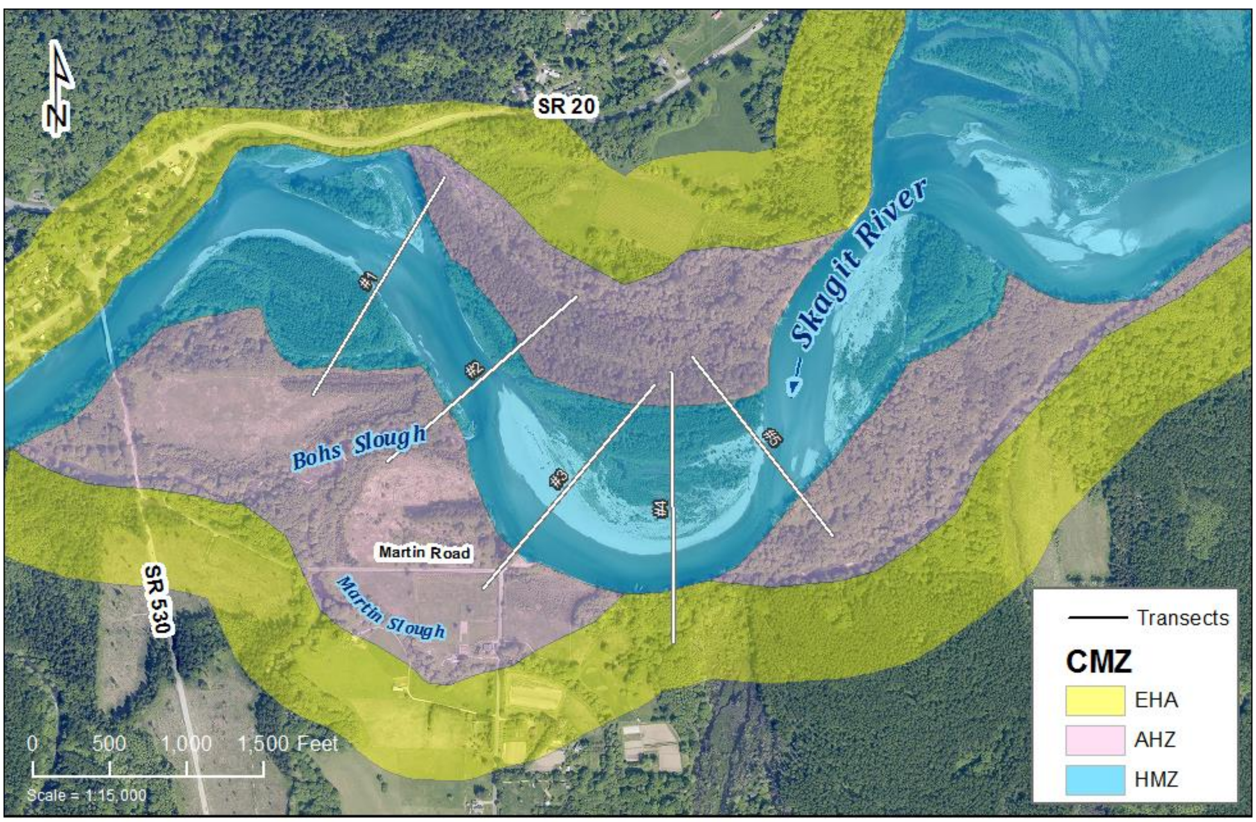


Figure 6. Channel Migration Zone (CMZ) delineated for the project area at Martin Road.

Bank Protection Alternatives

Two bank protection alternatives were considered to evaluate conceptual design approaches that would stabilize the eroding bank near Martin Road and reduce erosion hazards threatening Martin Road and crossings over Martin Slough. This evaluation is part of a feasibility study to consider the relative costs and benefits of bank protection measures along with an alternative proposal to abandon a segment of Martin Road, thus eliminating the need for at least the lower road crossing in Martin Slough. It is assumed that Skagit County is developing the road abandonment alternative independently of this memorandum. The purpose of this evaluation then is to describe the scale of bank protection treatments necessary to resist the erosive forces of the Skagit River and to summarize two alternative approaches in regards to: (1) treatment functions and services, (2) infrastructure influence and other constraints, and (3) long term sustainability and stability. Bank protection alternatives were developed independently of cost considerations. Planning level cost estimates are presented for each alternative; however, we assume that Skagit County will decide whether either of the proposed alternatives are practical given available budget resources and other considerations.

Project objectives considered in developing the two bank protection alternatives include:

1. Stabilize the streambank and reduce rates of erosion toward Martin Road;
2. Minimize adverse impacts to adjacent property and infrastructure; and
3. Maintain or enhance ecological values of the project reach.

Two general approaches were considered to differentiate bank protection alternatives:

1. Strengthening the bank and increasing resistance to flow; and
2. Re-directing flow to reduce the hydraulic forces on the eroding streambank.

Conceptual sketches of the two bank protection alternatives are illustrated in Figure 7. Discussion below addresses pros/cons of the two alternatives.

Alternative 1

(1) Treatment Functions and Services

A revetment will be designed to strengthen the bank and dissipate energy along the channel margin. The conceptual design for Alternative 1 includes a 2,200 foot long complex wood revetment to strengthen the bank resistance and yield an overall benefit to habitat-forming processes. The treatment length shown in Figure 7 extends upstream and downstream of the project site to anticipate future channel migration and prevent erosion around the endpoints that would undermine the stability of the structure as occurred to the previous bank protection at the site.

Traditional engineering practices would typically strengthen the bank resistance through placement of large rock, or riprap. Riprap, however, can have negative impacts on habitat-forming processes and often accelerates erosion of adjacent property (Cramer et al., 2003). Traditional riprap provides relatively poor fish habitat and tends to increase flow velocities in the channel. Juvenile fish sampling in the Skagit River documented substantially lower fish densities along banks covered in riprap as opposed to wood (Beamer and Henderson, 1998). In addition, placing riprap that would be effective in this location would be extremely difficult due to flow depths and velocities requiring rock quantities be bulked to account for challenges/uncertainties with instream placement. Further, past use of riprap for bank stabilization in nearby areas of the Skagit River include several examples of poor long-term performance. The most local example

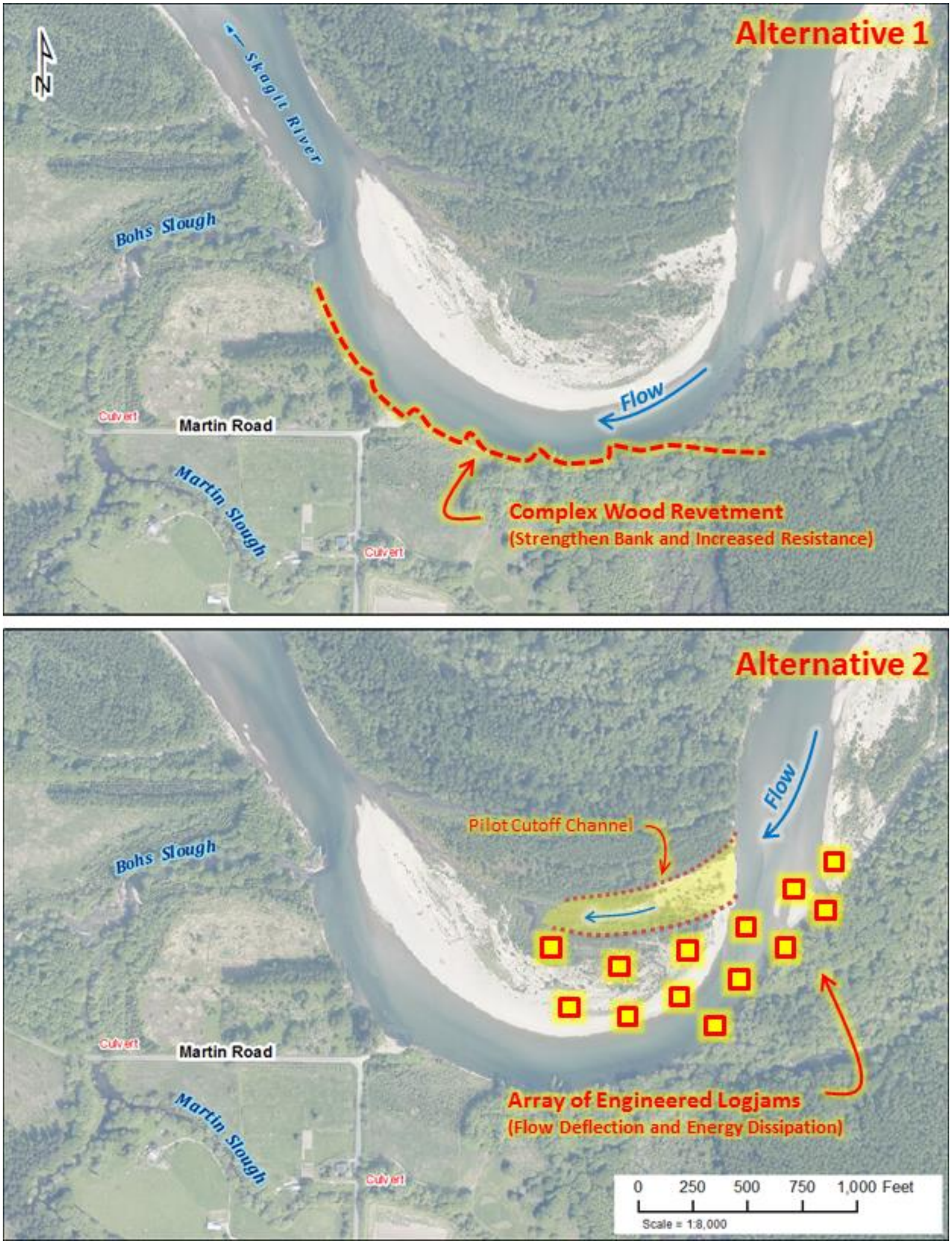


Figure 7. Concept sketches for two bank protection alternatives.

is the failed riprap that previously armored the bank near Martin Road but since washed out. Another example is the WSDOT Chronic Environmental Deficiency (CED) site where the Skagit River abuts SR 20 at milepost 100.7 approximately 3 miles upstream of the project area. Previous riprap protection washed out at the CED site in 2003 and subsequent emergency riprap placements in 2004, 2006, and 2007 failed to address the problem (Lautz and Acosta, 2007). Given the adverse ecological impacts and poor performance history, regulatory agencies and tribal natural resource departments would not likely permit a design approach based on traditional riprap in the project area.

Given these constraints, a more holistic design approach that protects property and infrastructure from bank erosion while allowing for natural, habitat forming processes to occur is recommended for the project site. The complex wood revetment varies in width to produce a roughened channel margin that reduces flow velocity and shear stress near the bank; shifting the area of maximum velocity and shear away from the bank and towards the center of the channel. Along smooth banks, such as bare soil or traditional riprap, flow velocity is high along the channel margin. Rougher banks increase flow resistance, lower flow velocity, and decrease erosion risk along the channel margin. (Figure 8). Examples of engineered, complex wood revetments recently constructed on the South Fork Nooksack and Skagit Rivers are shown in Figures 9 and 10, respectively.

The Skagit River example constructed at the WSDOT CED site in 2014 is likely the best reference to consider in regards to construction of a complex wood revetment at the Martin Road project site. Similar to the WSDOT site upstream, the thalweg is against the eroding bank near Martin Road and dewatering is not likely feasible given the flow regime of the Skagit River and other constraints. As such, construction will need to be completed with equipment located on the top of bank, as opposed to working in the channel, and material will be placed directly in the wetted channel. Such conditions limit many common construction approaches and the dolo-ballasted structure constructed by WSDOT is the most feasible approach to constructing a long-term stable revetment at the Martin Road site.

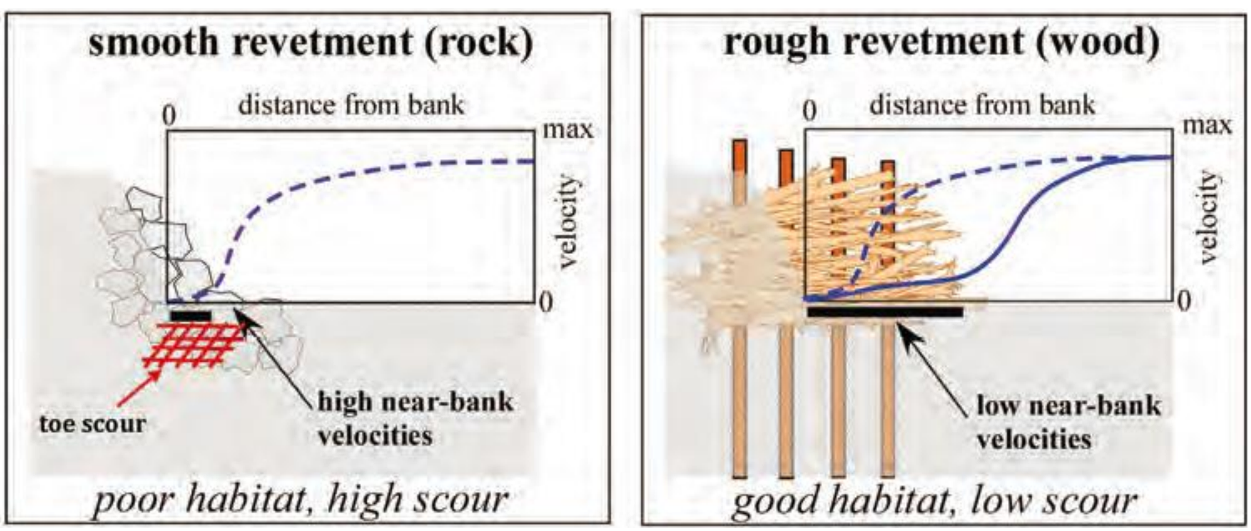


Figure 8. Illustration of how rougher banks reduce river velocities near the bank. Traditional bank protection tends to create a smooth bank where high flow velocities hug the bank (solid lines above). Where banks are roughened near-bank velocities are reduced (dashed lines), diminishing the risk of erosion and improving salmon habitat

(2) Infrastructure Influence and Other Constraints

The primary concerns regarding risks to infrastructure are increased erosion hazards to Martin Road and to SR 530. Alternative 1 completely removes the erosion hazard at Martin Road by design. The erosion hazard at SR 530 is primarily driven by risk of avulsion towards the SR 530 bridge crossing at Bohs Slough (Shanz 2015). As sketched in Figure 7, the complex wood revetment would terminate just upstream of the inlet connection to Bohs Slough. With Alternative 1, there is no anticipated increase in avulsion risk at Bohs Slough; however, the existing avulsion risk will remain.

The overall footprint of the complex wood revetment for Alternative 1 is relatively small compared to the active flow area. No substantial backwater effect, or increase in flood stage, would be expected under this alternative.

(3) Long Term Sustainability and Stability

The overall stability of the revetment will be driven by the construction approach and anchoring material. The interlocking, concrete dolos used at the WSDOT project upstream are the most stable anchor for use in site conditions similar to the bend at Martin Road. A dolo-ballasted, complex wood revetment would be stable for many decades allowing for riparian restoration activities to mature. Over the long-term, creation of such floodplain hard points support development of mature forests which function as future sources of large wood to increase stability of alluvial channels (Abbe and Montgomery, 1996, 2003; Collins et al., 2012).

(4) Planning-Level Construction Costs

The WSDOT project example upstream treated approximately 1,400 feet of streambank using a combination of bank revetments and Engineered Logjams (ELJs) plus an additional mid-channel ELJ at a total project cost of $7.5 Million. A simplified unit cost per treatment length was developed assuming the mid-channel ELJ added an additional 100 feet for a collective treatment length of 1,500 feet. The proposed treatment length at Martin Road is estimated at 2,200 feet or an additional 47%. Application of the additional treatment length to the WSDOT project cost yields a planning-level construction cost estimate of $11 Million for the complex wood revetment to protect Martin Road.

Figure 9. An engineered, complex wood revetment built by the Lummi Nation along the South Fork Nooksack River. The structure is stabilized with timber piles and rock collars creating a rough streambank very different than traditional rock revetments such as riprap.

Figure 10. An engineered, complex wood revetment constructed by WSDOT on the Skagit River to protect SR 20 at milepost 100.7. This structure is stabilized with concrete dolo anchors and ballast due to site constraints. Photo from WSDOT (2014).

Alternative 2

(1) Treatment Functions and Services

Flow in the project reach will be redirected by an array of Engineered Logjams (ELJs) to reduce the hydraulic forces on the eroding streambank. As opposed to strengthening the streambank as described by Alternative 1, this alternative aims to reduce the flow velocity and shear stress acting on the bank material near Martin Road. The ELJ deflector array would consist of multiple structures that are staggered in the active channel corridor to interrupt the flow patterns and create additional physical and hydraulic complexity. In this manner, the ELJs provide complimentary functions of deflecting the primary flow paths away from the bank at Martin Road and concurrently enhancing habitat-forming processes by mimicking the geomorphic effect of large trees and logjams that were historically an important component of the Skagit River (Collins and Sheikh, 2002).

The conceptual design sketch in Figure 7 represents the array as a series of structures, each approximately 80 feet in width. The average bankfull width in this section of the Skagit River is approximately 500 feet. Design of how many ELJs and of what size are required will be determined through additional hydraulic analysis in subsequent design phases. For this planning-level effort, we assume an array that collectively obstructs approximately 50% of the active flow in the treatment area. In addition to the ELJ array, a pilot channel will be excavated across the upper bar surface to encourage the new flowpath to cut off the inside of the bend and thus bypass the eroding bank near Martin Road. An example of a similar approach used in the Quinault River is illustrated in Figure 11.

Alternative 2 will likely be easier to construct than the proposed design for Alternative 1. Many of the Alternative 2 ELJs can be built upon dry gravel bars or shallow water areas as opposed to the channel thalweg. ELJs located within the channel would need to be designed such that they could be assembled in the “wet” similar to the apex ELJ at the WSDOT MP 100.7 project.

(2) Infrastructure Influence and Other Constraints

Some amount of continued bank erosion should be expected with Alternative 2 as the overly steepened bank stabilizes and vegetation is allowed to mature. In addition, it is possible that bank erosion could continue if streamflow velocities exceed threshold for incipient motion of the bank material such that Martin Road is eventually threatened. Similarly completed ELJ arrays have successfully slowed bank erosion but also incorporated a bank strengthening element. If future hydraulic analysis indicated a concern, a bank strengthening element could be implemented similar to Alternative 1 but smaller in scale.

Risk of avulsion hazards at Bohs Slough affecting the SR 530 bridge may be increased by Alternative 2 given how the new channel alignment would be oriented to impact the left bank at a steep angle in line with the inlet to Bohs Slough as opposed to the oblique angle of approach in the current channel configuration.

Additional concerns may be generated by a backwater influence upstream of the ELJ array created by the obstructions and additional channel roughness. The backwater influence is unlikely to affect SR 20 upstream as that section of the highway is elevated well above the floodplain. Most property to be affected by increased flood stages with this alternative are already in conservation ownership. The backwater upstream of the ELJs could steepen the hydraulic gradient along an existing side channel that connects to Lucas Slough; however, and increase risk of an avulsion along this side channel alignment. If such an event were to occur, the avulsion would effectively bypass the ELJ array as drawn and renew erosion along the outer bend at Martin Road.

(3) Long Term Sustainability and Stability

The Alternative 2 design plan reduces erosion risk at Martin Road compared to the existing condition; however, stabilization of the eroding bank is less certain relative to the design plan for Alternative 1. ELJ design will be developed with support from hydraulic modeling tools to demonstrate that near bank velocity and shear is less than the critical value for sediment mobilization. Given the dynamic nature of the project reach, future channel changes could result in a different flow pattern that may increase velocity and shear. If hydraulic analysis indicated a concern, a bank strengthening element could be implemented similar to Alternative 1 but smaller in scale.

(4) Planning-Level Construction Costs

The construction approach and materials required to build Alternative 2 are expected to be substantially cheaper in relation to Alternative 1. Construction bids for ELJs of similar size have been on the order of $100,000 per structure. In this planning-level evaluation, we assume an array with 13 to 15 structures would be required for Alternative 2. Assuming a markup of 50% contingency given the magnitude of uncertainty at this stage, we estimate a planning level construction cost of $2.25 Million for Alternative 2.

Figure 11 (next page). Channel migration hazard and bank protection treatments in the Upper Quinault River near South Shore Road. An array of ELJs was constructed in 2013 (phase 1) to deflect flow and enhance habitat-forming processes in the reach. The array of ELJs was expanded in 2015 (Phase 2) to include additional structures.


1994
W123.8


2012
123.808
W123.8


2013
Flow
123.808
W123.8
ELJ Locations
Phase 1
Phase 2
(Not Shown)

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