

**Site and Reach Assessment
Evaluation of Treatment Alternatives
SR 20 MP 100.7 (Skagit River)**



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Executive Summary

This report presents a Site and Reach Assessment and Evaluation of Treatment Alternatives conducted for a Chronic Environmental Deficiency (CED) site located along SR 20 approximately three miles east of Rockport. Recurring bank erosion at this CED site in 2004, 2006, and 2007 has required emergency placement of riprap to prevent damage or catastrophic failure of the roadway. WDFW and local tribal natural resources staff have expressed concern about the use of riprap for bank protection, and are insisting on use of more ecologically appropriate bank treatments, as well as mitigation for lost or damaged habitat attributable to recent repairs.

Site-based factors contributing to the identified chronic environmental deficiencies at this location include:

- Jet scour caused by the lateral bar (sediment deposition) opposite the CED site.
- Toe erosion caused by reduction in bank roughness associated with recent repairs and reduction or elimination of bank vegetation by recent floods.
- Constriction scour caused by sediment accumulation in the side channel opposite and downstream from the site, which acts to hold the channel against the bank.

The **reach-based mechanism** contributing to bank failure at this location is associated with extensive riprap placement (>2000 feet) along SR 20 upstream of the CED site, which results in sediment deposition and formation of the lateral bar just upstream of the site, producing the site-based mechanisms of failure (jet scour, toe erosion, constriction scour) identified above.

Objectives (desired outcomes) for bank treatments at this CED site include:

- Preserve SR 20 as a primary route for local, commercial, and recreational traffic, and protect the public by reducing/eliminating the risk of catastrophic loss of this section of roadway.
- Minimize the need for corrective maintenance of the streambank on an ongoing basis.
- Minimize road-related impacts to aquatic and riparian habitats that occur or would be expected to occur in and around the site.
- Minimize the risk to recreational users (primarily rafters and boaters) on this reach.

Treatment alternatives evaluated in this report included: no action (emergency riprap placement), groins/barbs, buried groins, engineered logjams, log toes, roughened rock toes, and road relocation. Based on the mechanisms identified above, a successful solution will divert flows directed at the CED site by the lateral bar located opposite the site. This would involve use of flow-directional treatments (groins and/or engineered log jams). Depending on the nature of the flow diversion and the anticipated geomorphic response of the river, additional treatments (e.g. log toes, hybrid rock/log toes, bank-integrated log jams) may be required to protect the bank downstream of the site. Legal and institutional constraints appear to preclude relocation of the roadway, and will likely limit the manner and extent of in-channel treatments.

Evaluation and selection of the appropriate combination of treatments will require the use of a two-dimensional hydraulic model to properly evaluate the hydraulic and geomorphic response of the river. Data collection in support of model development and calibration is currently underway.

Introduction

The Washington State Department of Transportation (WSDOT) established the Chronic Environmental Deficiency (CED) program as a strategy to provide for highway improvements to specific locations where repeated maintenance and preservation activities create unacceptable environmental impacts. Projects identified as chronic environmental deficiency problems are prioritized using an environmental retrofit index, which gives special weight to protection of fish habitat (WSDOT 2002).

This report presents a Site and Reach Assessment conducted for a Chronic Environmental Deficiency (CED) site located adjacent to SR 20 at MP 100.7 along the Skagit River approximately three miles east of Rockport. SR 20 is the primary route in this area for local, commercial, and recreational traffic.

The Site and Reach Assessment describes landscape-, land use- and infrastructure-related contributing factors for the identified deficiencies, and presents an evaluation of corrective treatment alternatives. The general approach used described in Chapters 2-5 of the Integrated Streambank Protection Guidelines (Washington Department of Fish and Wildlife, 2003) and the Level 1 geomorphic assessment described in Hydraulic Engineering Circular (HEC) 20 (Federal Highway Administration 1995).

The site and reach assessment described in this report is primarily a tool for identifying causative factors and developing conceptual solutions. It is neither a “cookbook” approach to solving CED problems, nor a substitute for site-specific analysis and detailed design. It is anticipated that this approach will result in a project proposal that meets or exceeds applicable standards and other requirements for protecting public safety, preserves transportation infrastructure, and gains regulatory approval from resource agencies.

Methods

This Site and Reach Assessment included a review of relevant aerial photos, ground photos, field notes, and measurements taken at the site, topographic maps, geology maps and reports, fish distribution data, and hydrologic data. Sources of information include:

- Aerial photos taken in 1962, 1969, 1978, 1987, 1991, 1998, 2003, and 2006
- Ground photos and field notes taken during site visits in November 2004, July 2006, and June 2007
- GIS coverages of 24K USGS topographic maps for this area
- GIS coverages of 100K WDNR/USGS geologic maps, and accompanying reports for this area
- Fish distribution information available from the Washington Department of Fish and Wildlife fish distribution database (WLRIS)
- Low-order bathymetry data collected during a boat survey in July 2006

Problem Description

This CED site is located adjacent to SR 20 at MP 100.7 along the right bank of the Skagit River (RM 72 on USGS 7.5 min quad), approximately three miles east of Rockport (Figure 1). SR 20 (North Cascades Highway) is the primary route for local, commercial, and tourist traffic in this area. In fall of 2003, a 100-year flood event damaged portions of the existing bank protection (riprap) upstream of the site, necessitating emergency rock placement to prevent failure of the road bed. In November 2004, significant bank erosion was observed at the site, progressing to within eight feet of the pavement. This erosion required emergency repair in the form of approximately 40 feet of riprap. Additional bank erosion occurred on either side of this repair in November 2006, and required an additional 150 feet of riprap to prevent roadway failure.

Bank erosion has continued upstream and downstream of the 2006 repair, progressing to within four feet of the edge of pavement. In addition, a portion of the 2006 repair is being undermined and has begun to fail. This additional erosion required approximately 100 feet of additional emergency riprap placement in July of 2007 to prevent damage to or loss of the highway. In addition, a large cottonwood tree that was undermined and has fallen into the river was anchored to the bank in front of the riprap placement to help divert flows. WDFW and local tribal natural resources staff have expressed concern about the recurring placement of riprap for bank protection under emergency declarations, both at this and at other sites around the state. They are insisting on application of more ecologically appropriate solutions, including techniques recommended in the Integrated Streambank Protection Guidelines (ISPG), road relocation, and mitigation for lost or damaged habitat attributable to recent repairs.

This portion of the Skagit River supports all native salmonid species (coho, chum, pink, sockeye, steelhead, chinook, and bull trout/Dolly Varden). Chinook, steelhead, and bull trout are listed as “threatened” under the federal Endangered Species Act. The Skagit River possesses the largest run of native chinook salmon in the Puget Sound Region, and the largest run of chum and pink salmon in the United States outside of Alaska; a substantial portion of adults in each of these species spawn within this reach.

This portion of the Skagit is designated as a Wild and Scenic River, and is renowned as one of the premiere locations in the United States for viewing bald eagles in a wild setting. The assessment reach is heavily utilized by rafters and kayakers for eagle-viewing trips.

Based on previous WSDOT experience with other sites having these characteristics (ESA-listed fish, Wild and Scenic designation), permitting for additional riprap and/or in-channel stabilization techniques is likely to be difficult to obtain under all but emergency conditions. In addition, there are tribal trust lands and cultural resources in the vicinity which will require assessment, consultation, and accommodation, and may further limit available treatment alternatives.

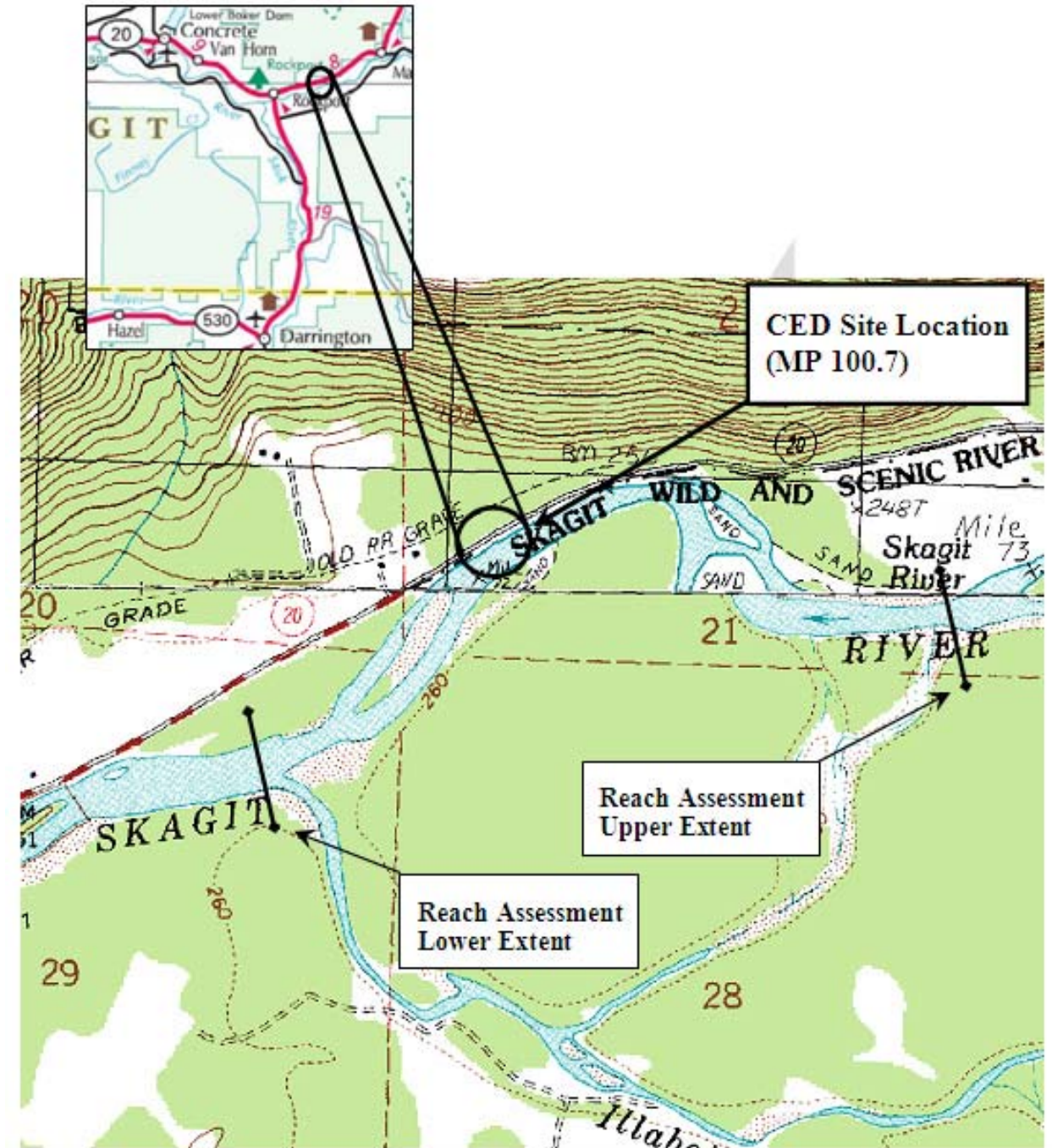


Figure 1. Location of the chronic environmental deficiency site at SR 20 MP 100.7.

Site Assessment

This CED site consists of approximately 600 linear feet of embankment adjacent to SR 20 (Figure 2). This embankment drops at a slope of 1:1 or steeper to the Skagit River, which flows approximately 8 ft below the roadbed elevation at normal winter flows. The site includes:

- The 2004 repair area (~ 40 feet).
- The 2006 repair area (~150 feet).
- The 2007 repair area (~ 100 feet).
- Approximately 150 feet of at-risk streambank occurring both upstream and downstream of the repair areas described above.

Site history

The section of SR 20 in the vicinity of the CED site (MP 100.7 to 101.4) is constructed on an alluvial terrace and runs along the outer bend of an elongated meander of the Skagit River. Until the 1970's, the road relied on a 30 – 40 foot wide vegetated buffer (trees and shrubs) for bank protection. By the 1970s, the river had eroded enough of the streambank and its vegetation to require placement of riprap along approximately 2500 feet of roadway. No further bank protection was known to have been installed or repaired until the winter of 1993-94, when 500 feet of roadway was damaged by flooding, necessitating replacement with larger stone along the damaged bank sections (information provided by John Tellesbo, WSDOT Northwest Regional Maintenance Supervisor).

In October of 2003, a 100-year flood occurred in the upper Skagit. The peak water surface elevation at the CED site extended nearly to the top of a line of Jersey barriers which were installed at the pavement edge to prevent inundation of the roadway (Figure 3). Small areas of the existing riprap protection were damaged, but further downstream the unprotected bank was stripped of its vegetation, and bank erosion is presumed to have begun at the site. Erosion continued through the winter of 2003 and into the fall of 2004 until the top of the bank came to within eight feet horizontally of the edge of pavement (Figure 4). WSDOT-NWR maintenance personnel performed an emergency repair of this damage in late November of 2004, installing riprap along 40 feet of bank. Additional bank erosion occurred immediately downstream during the winters of 2004 and 2005 (Figure 5), requiring construction in November, 2006 of an additional 150 feet of riprap immediately upstream and downstream of the 2004 repair. Since then, additional erosion occurred over approximately 100 feet of bankline immediately upstream and downstream (Figure 2), and a portion of the 2006 repair was undermined by a scour hole forming at the toe of the bank (Figure 7).

Bank failure mechanisms

Bank material at and downstream of the site consists of alluvial fine sand and silt (Figure 8) with a few lenses of coarser sand and gravel. Resistance to erosion is provided primarily by any vegetation growing on the bank. The undisturbed bank downstream is well-vegetated, and there is a dense root mat extending to a depth of about 24 inches. Along SR 20, the rooting density and strength of the bank vegetation (particularly trees) may be limited by the steep slopes, the presence of riprap, and the narrowness of the buffer. Below the root mat the bank material is highly erodible, and the bank is susceptible to toe erosion, undercutting, and subsequent bank failure.

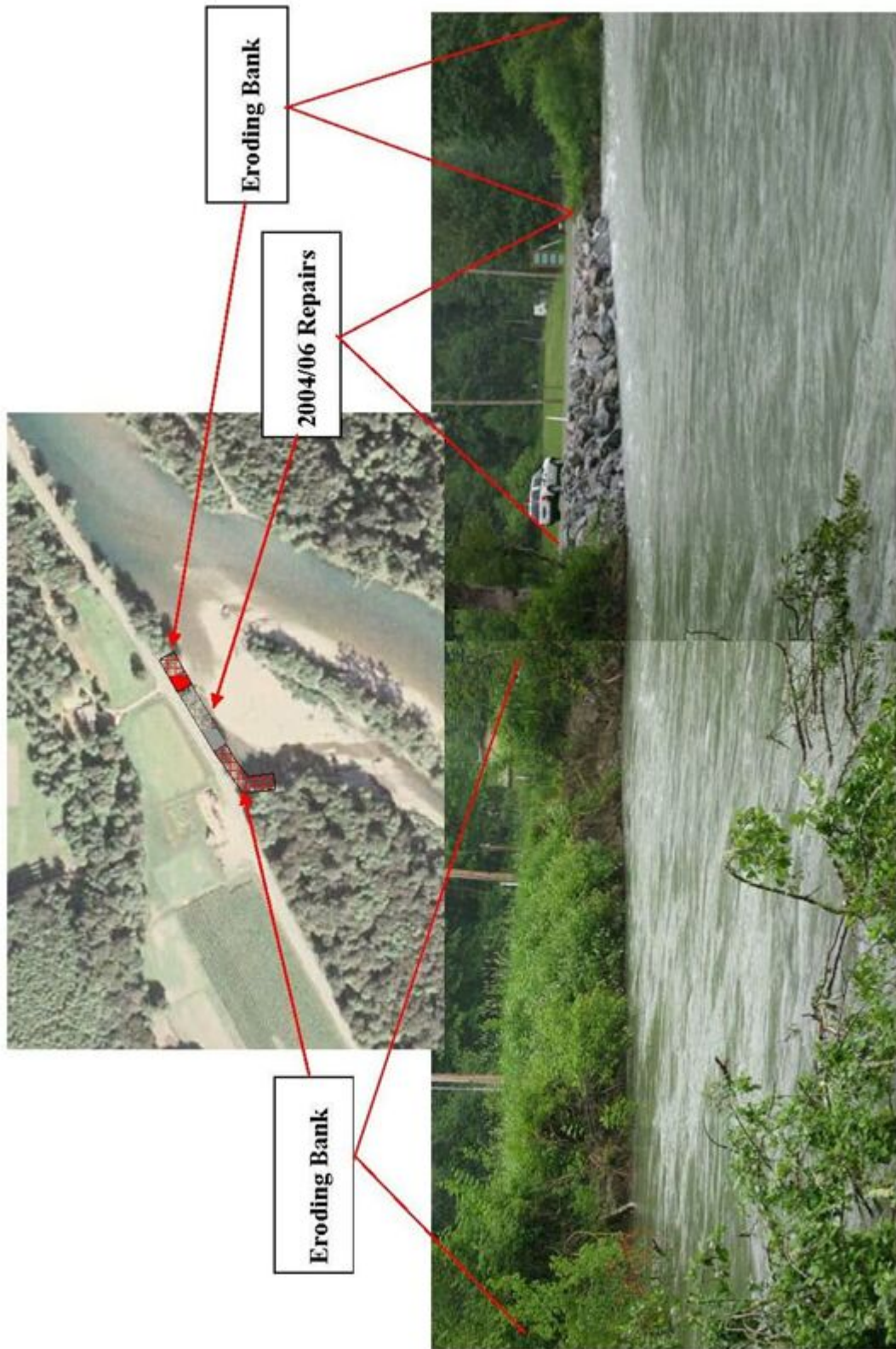


Figure 2. Aerial and ground view of SR 100.7 CED Site.



Figure 3. Bank section upstream of CED site showing comparative river stage .



Figure 4. Bank erosion progressing to within eight feet of the roadway (11/23/04).



Figure 5. Bank erosion downstream of 2004 repair.



Figure 6. 2006 repair, looking downstream.



Figure 7. Undermining of 2006 repair.



Figure 8. Bank material (alluvial fine sand and silt).

A review of historical aerial photos (1962 , 1969, 1978, 1987, 1991, 1998, 2003, 2006) shows the progression of bank erosion over the last 44 years (figures 9 and 10). During this period, the bankline has migrated both directly towards the road, and along the road in a downstream direction. Maximum migration distance since 1962 is approximately 300 feet.

In the photo sequence, the erosion of the bank line appears to follow the migration downstream of the island opposite the assessment site. At larger, higher-velocity discharges, a lateral bar formed in front of the bank directs flows directly at the bank line (Figure 11), which results in toe erosion, undermining, and eventual failure of the bank. Placement of riprap protects the bank face on which it is placed, but the smoothed bank line transfers erosive energy downstream, resulting in erosion of unprotected banks. In addition, impingement of the directed flow against the riprap face directs a portion of the flow downward, creating a scour hole, which undermines the toe of the riprap and may result in slumping and eventual failure of the riprap.

In addition, sediment accumulation in the side channel downstream of the site has “pinned” the thalweg of the channel against the bank, increasing the potential for bank failure on the downstream terrace by means of constriction scour and toe erosion.

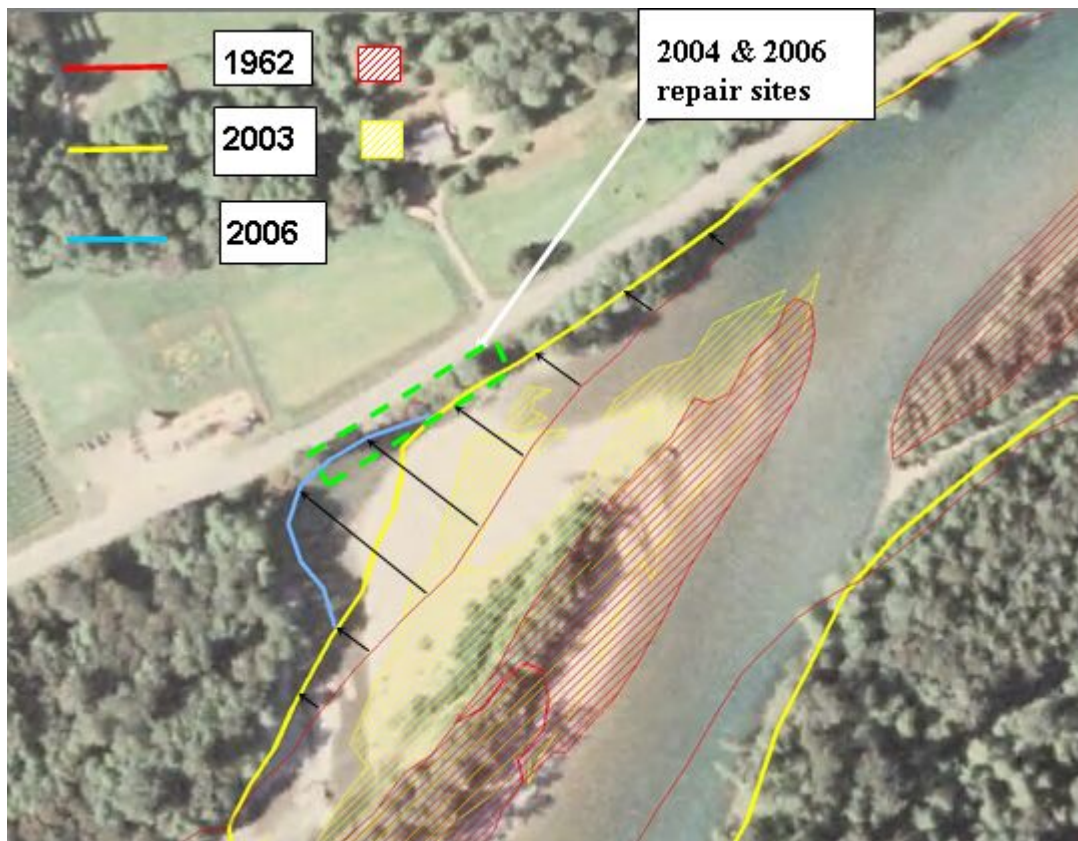


Figure 9. Migration of bank line and island near assessment site.

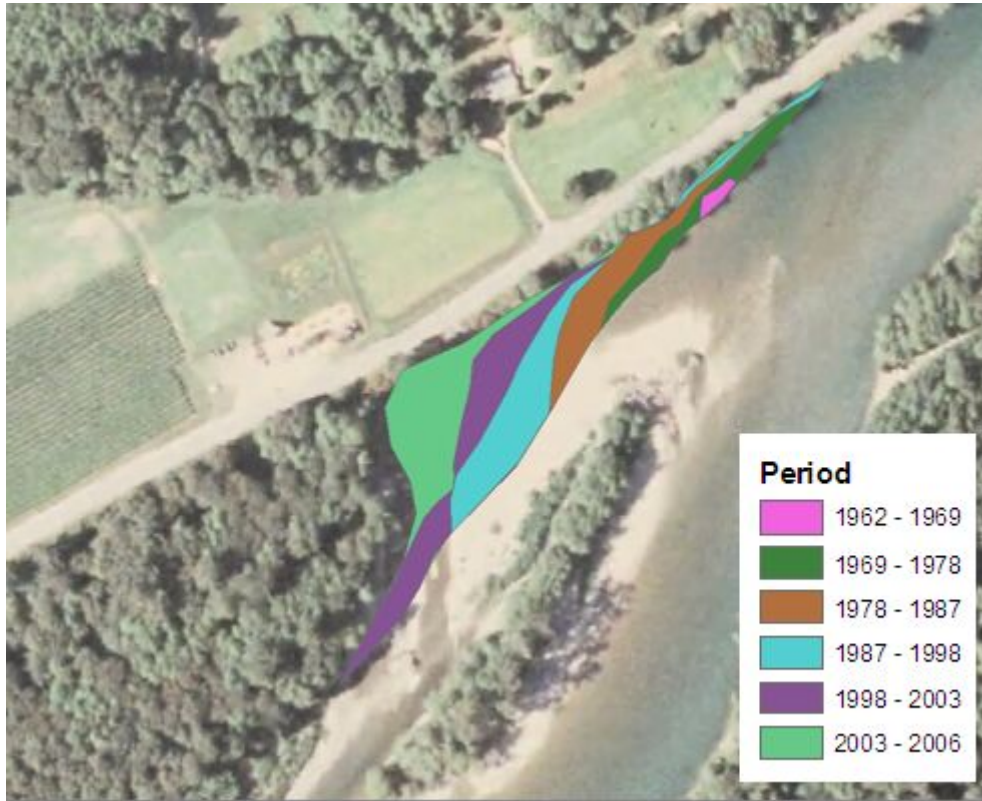


Figure 10. Area of eroded bank in period between successive air photos.



Figure 11. Lateral bar directing flow towards the bankline at the CED site.

The *site-based mechanisms* associated with bank failure at this location are:

- *Jet scour* caused by the lateral bar opposite the CED site.
- *Toe erosion* caused by reduction in bank roughness associated with recent repairs and reduction or elimination of bank vegetation by recent floods.
- *Constriction scour* caused by sediment accumulation in the side channel opposite and downstream from the site, which acts to hold the thalweg against the bank.

It is likely that these erosion mechanisms will continue to act to cause bank failure, unless measures are taken to adequately redress them. This conclusion is based on the evaluation of historic trends in channel morphology and the presence of similar conditions and bank materials downstream of the CED site. In the extreme case, bank erosion along the roadway could, over time, continue downstream over 2200 feet to the existing rip-rapped bank at MP 100.3.

Reach Assessment

Definition of Project Reach

The defined reach for this assessment extends approximately one-half meander wavelength upstream and downstream from the project site (Figure 1), from the confluence with Illabot Creek (RM 71.4) upstream to a point near an unnamed left-bank floodplain channel at RM 72.8. Some influences on reach hydrology, geomorphology, and habitat quantity and quality occur further upstream from the defined reach, but will still be considered as part of this assessment.

Hydrology/Watershed Conditions

The assessment site is located on the Skagit River approximately five river miles upstream of its confluence with the Sauk River. The upper Skagit watershed (upstream of the Sauk confluence) drains 1665 square miles of the North Cascades and is steep and mountainous, with heavy winter rainfall and an extensive and deep winter snowpack.

Land cover is primarily forest, with about 20 percent of the watershed in glacial/alpine open areas. Much of the upper watershed is designated as national park or wilderness area, but most of the lower watershed has been harvested at least once. There is a small amount of agriculture/pasturage and residential development, mostly in and around the small towns of Newhalem, Marblemount, and Rockport, and along the river between Marblemount and Rockport.

Approximately 70 percent of the watershed area is regulated by the three dams (Gorge, Diablo, and Ross) operated by Seattle City Light. Operation of the dams is primarily for hydropower generation, although they can provide flood control storage when required. To mitigate for the dams impacts to fish and fish habitat, the dams are “hydraulically coordinated” to maintain sufficient instream flows to protect the eggs and embryos of steelhead, chinook salmon, pink salmon, and chum salmon from dewatering during incubation, and minimize stranding of chinook and steelhead fry. Flow requirements vary from year to year depending on precipitation and river levels. The net result of this mitigation affects flows that are substantially less than would be required to cause appreciable amounts of erosion or move appreciable amounts of sediment, and is not considered as contributing to bank failure at this site.

The US Geological Survey operates a stream gage two miles downstream of the site (Skagit River near Rockport, WA – USGS ID 12184700); however, no rating curve has been developed (and so no discharges are available) for this site. For this assessment, flow statistics were estimated for the assessment reach using data from three nearby gaging stations:

- Skagit River at Concrete (USGS ID 12194000).
- Baker River at Concrete (USGS ID 12193500).
- Sauk River near Sauk (USGS ID 12189500).

The length of the common period of record for these three stations (WY1944 – WY2005) is 62 years. In general, the discharge for the assessment reach was estimated as:

$$Q_{\text{reach}} = Q_{\text{Skagit}} - (Q_{\text{Baker}} + Q_{\text{Sauk}})$$

Median daily flows in this reach of the Skagit range from approximately 4000 cfs in late September and early October to approximately 11000 cfs in June and early July (Figure 12). The high flows in June and July are associated with spring/summer melt of the high elevation snow-

pack, and tend to be sustained for three to six weeks depending on air temperature and the amount of snowpack.

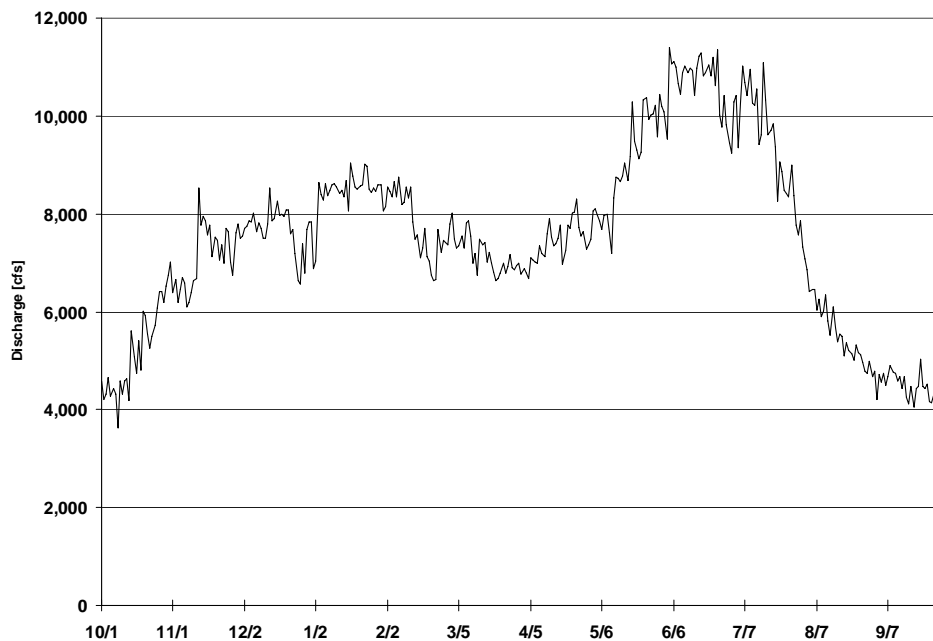


Figure 12. Estimated median daily flow in the vicinity of the reach (WY 1944-2005).

Instantaneous peak flows were also estimated for the reach using daily discharge data from the above stations. The peak daily discharge corresponding to the event which created the instantaneous annual peak at the “Skagit at Concrete” gage was obtained for each station, and the peak daily flow for the reach was calculated using the above formula. This was converted to an estimated instantaneous annual peak discharge by applying a “peaking factor” (ratio of instantaneous peak to daily peak) derived for each event occurring at the “Skagit at Concrete” gage to the peak daily discharge calculated above. A frequency analysis was conducted for this set of instantaneous annual peaks using the PEAKFQ software (USGS, 2005) to determine discharges for selected exceedance probabilities using the standard “Bulletin 17B” methodology. Frequency analysis results are shown in Table 1. All estimated peak flows greater than a 50 percent exceedance (2-year recurrence) event are shown in Figure 13.

Large peak flows (floods) in this reach are generated by three processes. The snowmelt peak occurs sometime between late May and early July and will normally range between 17000 and 30000 cfs; during milder winters this may represent the annual peak flow. About one-third of the snowmelt peaks exceed the estimated 50 percent annual exceedance flow (2-year event), and are likely of sufficient magnitude to transport sediment and cause toe erosion of streambanks.

The other two processes generating large peak flows are rain-only and rain-on-snow events. They can occur anytime between October and March, but about three-fourths occur between the months of October (20 percent), November (33 percent), and December (20 percent). Most of the larger events (including the flood-of record in October, 2003) at least started out as rain-on snow events, although by time these floods approached their peaks, most of the runoff was generated by the very large amounts of rain that had fallen. Approximately 60 percent of these events ex-

ceed the 50 percent annual exceedance flow (2- year event); taken with the number of snowmelt peaks which also exceed this value, it suggests that the standard flood frequency approach may not be appropriate, and that the actual 50 percent exceedance flow is somewhat higher. Regardless, it may be reasonably assumed that the majority of these peak flows are likely of sufficient magnitude to transport sediment and cause toe erosion of streambanks.

Table 1. Estimated Flood frequency statistics for assessment reach.

Recurrence Interval (years)	Annual Exceedance Probability	Peak Flow (cfs)
2	50%	32,230
5	20%	45,990
10	10%	55,710
25	4%	68,680
50	2%	78,810
100	1%	89,360

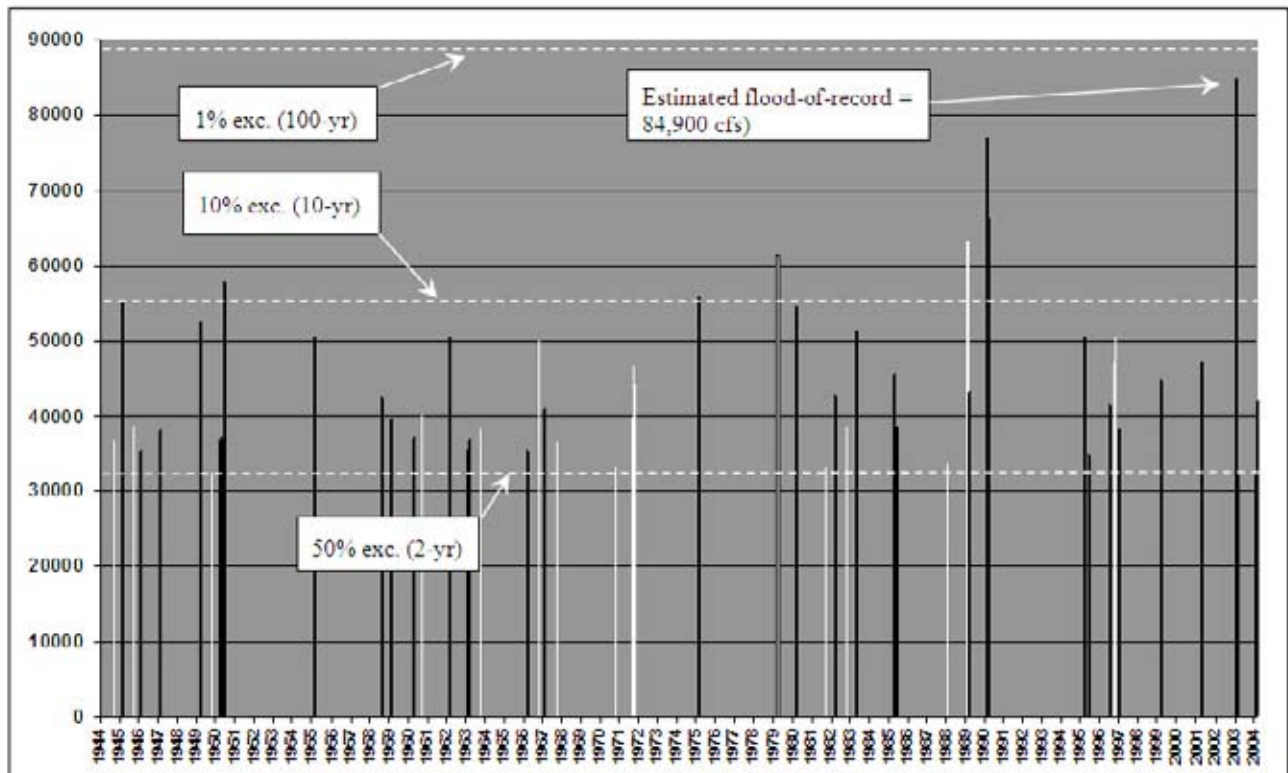


Figure 13. Estimated peak flow time series for assessment reach.

Geology/Geomorphology

The upper Skagit River basin is made up of steep, mountainous terrain consisting of a complex mélange of metamorphic, marine sedimentary, and volcanic rocks. The valley floor of the Skagit within the assessment reach is made up primarily of recently reworked alluvium; glacial outwash lines a portion of the south valley wall, away from the current course of the Skagit, and alluvial fans line both valley margins where small drainages emerge from the mountains (Figure 14).

Valley width in the assessment reach ranges from 7000 to 11000 feet. The valley narrows considerably upstream (above the confluence with the Cascade River), and again narrows below the confluence with the Sauk River as it passes through a deep, confining outwash deposit that had dammed the river during the latter portion of the previous glaciation. Gradient through the assessment reach is 0.2 percent. The bed in the vicinity of the assessment site consists of a cobble-sized armor layer (D50 = 150 mm, D90 = 300 mm) overlying a gravel-sand substrate (D50 < 5 mm). Sediment transport is relatively high, with large and frequent high flow events supplying sufficient stream power, and abundant source material available from both upstream, and locally via erosion of alluvial terraces. .

There is abundant evidence (oxbow lakes, scroll bars, and abandoned channels) that, since the end of the last glacial period (~ 10,000 years ago), the Skagit has migrated frequently across the valley floor. A review of aerial photos (1962 – 2003) shows a 500 – 600 foot down-valley displacement of the head of the meander immediately upstream of the CED site over the 41-year period (Figure 15). Also, there appears to be a former overflow channel traversing the meander neck, which could serve as the new main channel after the meander cutoff eventually occurs. A site visit to this area revealed abundant evidence of recent inundation , including fresh overbank deposits, young (3 – 5 year old) understory vegetation, and multiple overflow channels (including the one identified above). The time frame for meander cutoff cannot be reliably predicted, but, based on the current rate of migration, may be on the order of 50-100 years or more. Once this occurs, risk to the roadway at the location of the CED site would be expected to substantially decrease.

At the scale of the assessment reach, the channel appears to be more or less stable vertically; there is no evidence of large-scale aggradation or degradation. Lateral migration is constrained over the middle third of the reach (including the CED site) by riprap placement along SR 20. This enforced lateral stability results in reduced bank roughness and transfer of erosive shear forces from the bank to the channel bed, resulting in a deepening of the thalweg and extension of the meander apex downstream along the base of the riprap. The lateral bar just upstream of the site (see site-based mechanisms of failure) appears to represent the point at which excess stream power is expended, resulting in sediment deposition. Consequently, the riprap contributes to bank failure at the site by creating the geomorphic features associated with the site-based failure mechanisms.

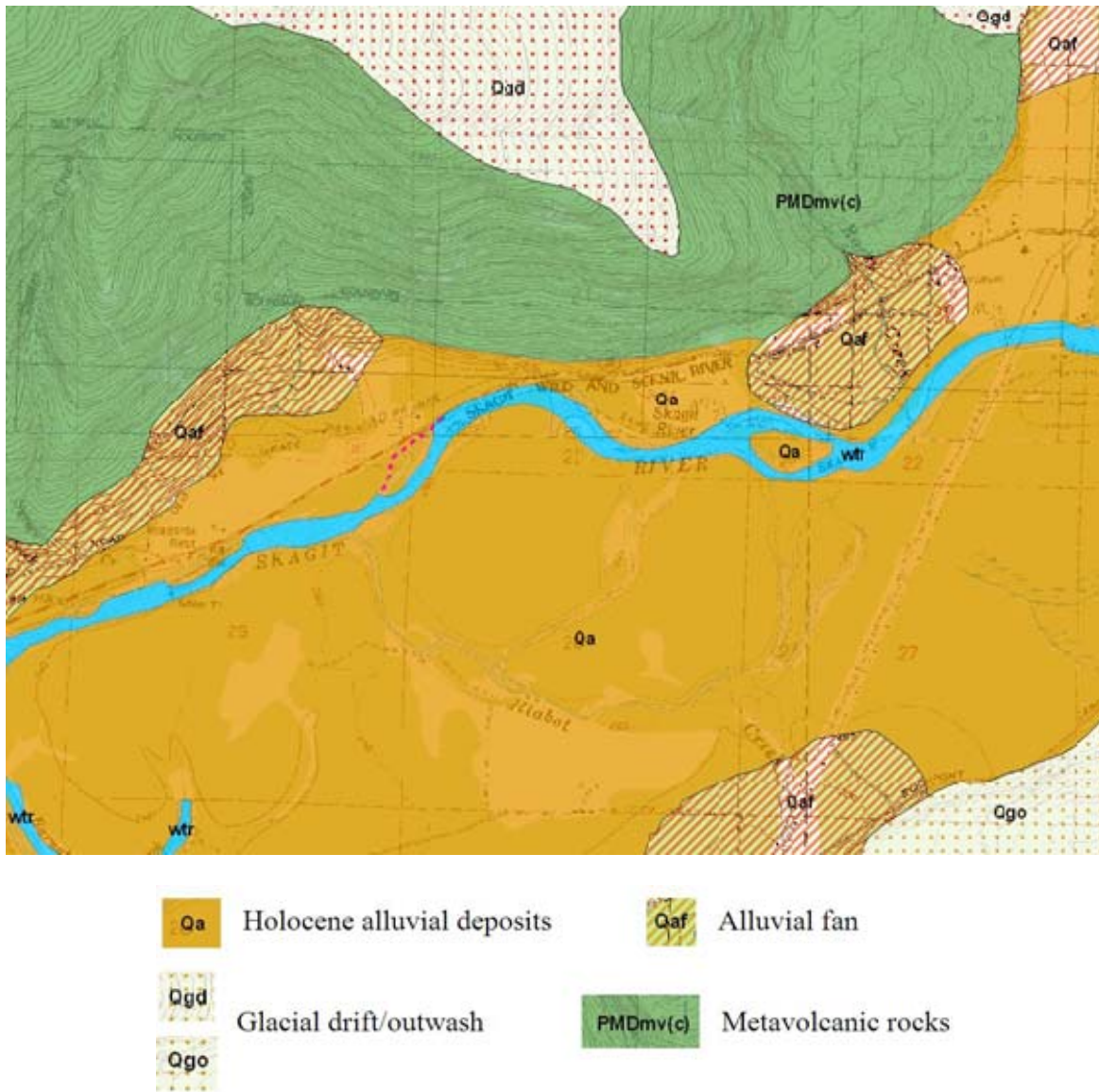


Figure 14. Geology in the vicinity of the assessment reach.

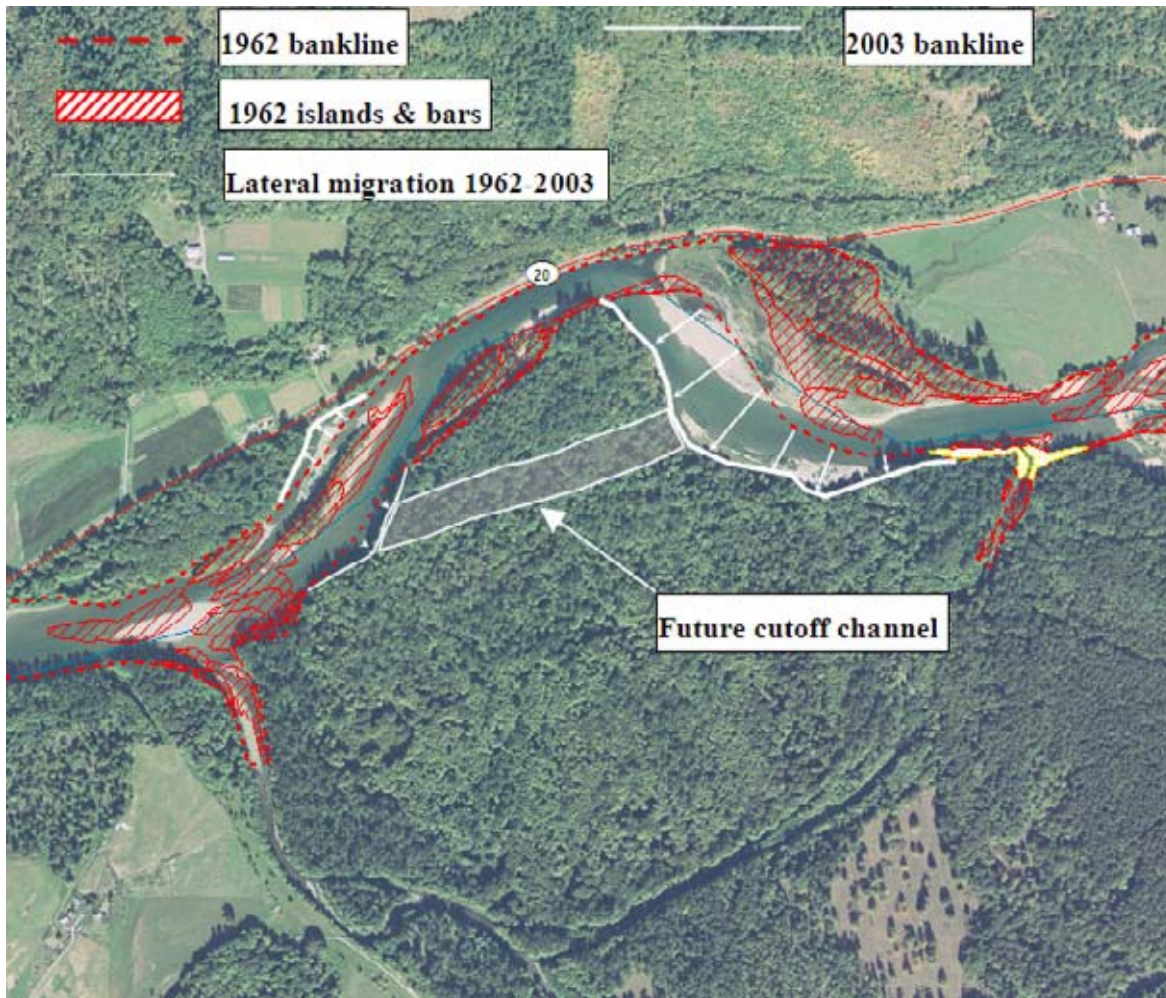


Figure 15. Aerial view of assessment reach showing lateral migration of meander and in-channel bars and islands (1962 – 2003).

Riparian Condition

Riparian forests in and near the assessment reach reflect the occurrence of regular disturbance typically found in geomorphically active floodplains. Older stands are mixed (western red-cedar/Douglas-fir/red alder); younger stands are dominated by alder of various ages, with younger trees occurring near the apex of point bars and along the margins of relic channels, and older trees found on islands and along portions of the floodplain not recently accessed by the river. Where banks and floodplain areas are disturbed by agriculture, residential development, or human infrastructure, riparian areas tend to have few or no trees or even shrubs.

Large Woody Debris

A small quantity of in-channel large woody debris (LWD) was observed near the assessment site, primarily smaller (non-key) sized pieces downstream of site. No significant in-channel log-jams were observed. Larger pieces formed a small jam at the upstream end of the island opposite the assessment site, and were instrumental in that island’s formation. Other large pieces were observed rafted onto bars as well as upstream along the left bank, where the river is actively eroding the bank and causing down-valley translation of the meander. Where LWD occurs in the ac-

tive channel, it does appear to function to supply or enhance aquatic habitat through pool formation, creation of low-velocity refuges, or as cover.

LWD recruitment potential is poor within the reach. Where unarmored banks occur, low-quality recruitable trees (alder and cottonwood) are readily available; however, these are of insufficient size to function singly as key pieces, and would function primarily as racking material for established log jams. For substantial portions of the assessment reach (as well as upstream and downstream of the reach), recruitment potential is poor due to bank armoring and removal of large conifers. The observed lack of in-channel LWD may reflect the limited recruitment potential, or it may be due to the fact that the reach has sufficient stream power to readily transport wood during large flows (such as the October, 2003 flood).

The *reach-based mechanism* associated with bank failure at this location is associated with extensive riprap placement (>2000 feet) along SR 20 upstream of the CED sit, which results in a deepening of the thalweg and extension of the meander apex downstream along the base of the riprap. Expenditure of excess stream power results in sediment deposition and formation of the lateral bar just upstream of the site, which is associated with the site-based mechanisms of failure (jet scour, toe erosion, constriction scour) identified in the site assessment.

Fish Utilization and Habitat Assessment

The reach was assessed for fish utilization and habitat by using the most recent scientific documentation for the project area, communication with habitat experts who know the site, and by referencing the most recent aerial photo taken of the site (NAIP 2006). The objective of the fish utilization and habitat assessment is to identify what species are present in the project reach, their life history phases, and what habitat types for those species are available for fish use. The assessment is intended to assist the decision making process for any short term or long term design solutions proposed for the site or the reach.

Species presence

The assessment reach is utilized by eight species of salmonids (Table 2) : chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), sockeye salmon (*O. nerka*), cutthroat trout (*O. clarki clarki*), bull trout (*Salvelinus confluentus*), and steelhead (*O. mykiss*). Other fish species found include sculpins (*Cottus* spp.), largescale sucker (*Catostomus macrocheilus*), and mountain whitefish (*Prosopium williamsoni*).

The reach provides habitat for Chinook salmon, bull trout, and steelhead are all listed as Threatened species under the Endangered Species Act (ESA) of 1973, as amended; and critical habitat has been designated for chinook salmon and bull trout within the reach. Chinook salmon, coho salmon, and pink salmon are included in the Pacific Salmon Fishery, under the Magnuson-Stevens Fishery Conservation and Management Act (MSA) of 1976, reauthorized by the United States Senate in 1996.

Habitat types

Habitat types for salmon have been well documented by existing scientific data for the project reach (NWIFC 2001) and by recent critical habitat designations for federally listed species. In summary, the mainstem channel provides habitat for adult migratory and foraging, juvenile rearing and out-migration, and spawning habitat for multiple runs of salmon that are documented in the reach. The reach has been designated as critical habitat for chinook salmon and bull trout and the recent federal register publication (Federal Register 2005a, 2005b) assigns Primary Constituent Elements (PCE) to describe habitat for each species (Table 3). The PCEs provide a description of habitat types and components of habitat necessary for the life history of each species.

Adult migratory and foraging habitat

Adult migratory and foraging habitat refers to entire river corridor between its banks, when fish migrate upstream to spawn, are foraging for insects or small fish, and/or are resting in pool habitat. Chinook salmon, coho salmon, chum salmon, and steelhead may typically be present in the river at any time, but are likely more concentrated prior to and during their spawning period within the reach. A recent study on bull trout demonstrates their migratory abilities to forage between river systems. A number of fish were tagged during the study in the Snohomish River that returned to the Skagit River. Several of these fish showed site fidelity and returned to the Snohomish River or estuary the following year (Goetz et. al. 2004). Bull trout also feed on juvenile salmonids, which provide a consistent food source in the river. For these reasons, adult bull trout may be present in the reach at any time of the year.

Table 2. Federally protected species summary for the reach

Species	Runs ¹	Utilization	SASSI Status (2002)	ESA Listing	MSA
Bull trout	Upper Skagit Bull trout	-Migration/forage -Juvenile rearing -Spawn in tributaries.	Unknown	Threatened w/ designated critical habitat	N/A
Chinook salmon	Upper Skagit/ Mainstem Tributary Chinook	-Migration/forage -Juvenile rearing -Spawn in mainstem and select tributaries.	Depressed	Threatened w/ designated critical habitat	Pacific Salmon Fishery
Coho	Skagit coho	-Migration/forage -Juvenile rearing -Spawn in mainstem and tributaries.	Healthy	N/A	Pacific Salmon Fishery
Pink salmon	Skagit pink	-Migration/forage -Juvenile rearing -Spawn in mainstem and select tributaries.	Healthy	N/A	Pacific Salmon Fishery
Steelhead	Skagit Mainstem Tributary/ Winter Steelhead	-Migration/forage -Juvenile rearing -Spawn in mainstem and select tributaries.	Depressed	Threatened	N/A

¹ Runs that have been summarized include only the runs that spawn in the project reach. Other runs for the salmon species are present in other life history forms as presented in Table 2.

Table 3. Primary Constituent Elements by Species

<i>Chinook</i>	<ul style="list-style-type: none"> ➤ Freshwater spawning sites ➤ Freshwater rearing sites ➤ Freshwater migration corridors
<i>Bull trout</i>	<ul style="list-style-type: none"> ➤ Reliable water source ➤ Water temperature ➤ Complex stream channel ➤ Spawning substrates ➤ Natural Hydrograph ➤ Varied flow sources ➤ Optimal Migratory Corridor ➤ Low Interspecies Competition

Table 4. General life history phases and run timing for salmon species in the defined reach of the Upper Skagit River.

Adapted from WDFW 1992, 1998, 2002, Goetz et. al. (2004), WDF 1979, Barkdull (personal communication, 2007), and Busby et. al 1996.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Life History Event -Salmon runs (from SASSI)												
Chinook salmon												
Upstream migration/ Adult Presence -Upper Cascade Spring Chinook -Upper Skagit/Mainstem Tributary Chinook	[Green shaded area]											
Spawning -Upper Skagit/Mainstem Tributary (mid-Aug. to Oct.)								[Orange shaded area]				
Juvenile rearing	[Purple shaded area]											
Juvenile out-migration			[Purple shaded area]									
Steelhead												
Upstream migration/ Adult presence - Skagit Mainstem Trib/Winter Steelhead -Cascade Summer Run -Cascade Winter run	[Green shaded area]											
Spawning Skagit Mainstem Tribu- tary/Winter Steelhead (early March to late June)			[Orange shaded area]									
Juvenile rearing	[Purple shaded area]											
Juvenile out-migration			[Purple shaded area]									
Bull trout												
Upstream migration/ Adult presence and for- age	[Green shaded area]											
Juvenile rearing	[Purple shaded area]											
Juvenile out-migration			[Purple shaded area]									
Coho salmon												
Upstream migration/ Adult presence -Skagit coho	[Green shaded area]											
Spawning (early Oct. to mid-Feb.)	[Orange shaded area]									[Orange shaded area]		
Juvenile rearing	[Purple shaded area]											
Juvenile out-migration			[Purple shaded area]									

Table 4, continued.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Life History Event -Salmon runs (from SASSI)												
Pink salmon												
Upstream migration/ Adult presence -Skagit Pink												
Spawning (odd years) (late August to October)												
Juvenile rearing												
Juvenile out-migration												
Chum salmon												
Upstream migration/ Adult presence -Skagit Chum												
Spawning (mid-November to December)												
Juvenile rearing												
Juvenile out-migration												

Juvenile rearing/juvenile out-migration

Juvenile rearing habitats for Chinook salmon, coho salmon, pink salmon, steelhead, bull trout, and chum salmon are all documented in the project reach (WDFW 2007). Juvenile rearing occurs year round within the project reach, and the juvenile out-migration period occurs from March through June (Barkdull, personal communication, 2007). Juvenile salmonids are more concentrated on the margins of small tributaries and large river systems. Scientific literature indicates that the abundance of juvenile Chinook salmon and coho salmon is positively correlated with increased wood cover associated with natural streambanks that have not been hydromodified with riprap in the Skagit River (Beemer and Henderson 1998). As a result of the study, juvenile Chinook salmon and coho salmon abundance was recorded as 5.4 times and 3.7 times higher in wood cover than in riprap, respectively. Spring Chinook are documented to rear in fresh water for a year or more and require certain habitat characteristics. They prefer to remain in the main-stem rivers and streams, and generally seek cover in pools, large substrate, large woody debris (LWD), and undercut banks (Reiser and Bjornn 1979). Juvenile bull trout are usually located in shallow backwater or side channels areas, while older individuals are often found in deeper water pools sheltered by large organic debris, vegetation, or undercut banks (64 FR 3456).

Spawning habitat

Chinook salmon, pink salmon, coho salmon, chum salmon, and steelhead spawn within the project reach where river conditions are favorable (WDFW 2007). A widely used traditional model for spawning habitat, the Instream Flow Incremental Methodology (Bovee 1982) uses estimates of water depth, water velocity, and substrate size to determine constraints of spawning habitat. In general, spawning habitat would be supported by shallower water associated with riffles (at least 30 cm deep), slower water velocities, and suitably-sized gravel substrate which varies by species). A more recent model has been developed to predict spawning sites for chinook salmon using geomorphic features in large river systems. This model indicates that reduced longitudinal

slopes of complex river channels will largely determine substrate availability unless the substrate is determined by significant bank erosion or inputs from nearby tributaries (Geist 1998). Spawning habitat located nearest to the bank failure at MP 100.7 is suitable for steelhead and chum salmon along the margins of the island located across from the bank erosion site. Exact future spawning locations would be dependent on changes in local geomorphic features which produce spawning habitat, including the amount and distribution of suitable substrate.

Off channel habitat

Off channel habitat includes the various side channels, large tributaries, small tributaries, and side channel sloughs mapped in the project reach (Figure 2). These habitat features provide refuge during larger flow events, and habitat complexity for adult and juvenile salmonids. Illabot Creek is a large tributary that drains to the mainstem within the project reach and is provides documented spawning habitat for bull trout, chinook salmon, coho salmon, and steelhead. Smaller side channels, sloughs, and tributaries are occur primarily south of SR 20. A small unnamed tributary continues north of SR 20 (through property owned by Cascadia Farms), but fish are not documented at this location (Figure 12).

A stand of mature riparian forest is located south of SR 20 and just downstream of MP 100.7, which contains the aforementioned unnamed tributary and another side channel. Fish may use this habitat for refuge during peak flood events and any side channels forming in the floodplain may be used in the future as the river dynamics change. This area functions as an intact riparian zone within the floodplain providing shade, bank stability, and functions of evapotranspiration that support habitat necessary for temperature regulation of salmonids. This section of the river also supports hyporheic flow. Hyporheic flow has been demonstrated to influence and support the location of spawning by chinook salmon (Geist 1998) and bull trout (Baxter and Hauer 2000), both of which are documented in the adjacent large tributary of Illabot Creek.

Evaluation of Treatment Alternatives

Background

Objectives (i.e. desired outcomes) for selected treatments at this chronic environmental deficiency site include:

- Preserve SR 20 as a primary route for local, commercial, and recreational traffic in this area, and protect the traveling public, by reducing or eliminating the risk of catastrophic loss of this section of roadway.
- Minimize the need for corrective maintenance of the streambank on an ongoing basis.
- Minimize road-related impacts to aquatic and riparian habitats that occur or would be expected to occur in and around the site.
- Minimize the risk to recreational users (primarily rafters and boaters) on this reach of the Skagit River.

Development and evaluation of alternatives is based on the matrix approach described in chapter 5 of the Integrated Streambank Protection Guidelines (ISPG, 2003). Selected treatments must be appropriate (in general, rated “G”, “G2”, or “F2”) for redressing one or more of the identified site- or reach-based mechanisms of erosion (see Table 5 for a summary of ratings).

For this CED site, the site-based mechanisms associated with bank failure at this location are:

- *Jet scour* caused by a lateral bar opposite the CED site.
- *Toe erosion* caused by a smoothed channel (recent bank repairs) and reduction or elimination of bank vegetation by recent floods.
- *Constriction scour* caused by sediment accumulation in the side channel opposite and downstream from the site, which acts to hold the thalweg against the bank.

Reach-based mechanism associated with bank failure at this location is associated with extensive riprap placement (>2000 feet) along SR 20 upstream of the CED site, which results in a deepening of the thalweg and extension of the meander apex downstream along the base of the riprap. Expenditure of excess stream power results in sediment deposition and formation of the lateral bar just upstream of the site, which is associated with the site-based mechanisms of failure (jet scour, toe erosion, constriction scour) identified in the site assessment.

Additional factors for evaluation and final selection of treatments will include:

- Potential fish habitat benefits and impacts.
- Risk of roadway failure (including risk to traveling public).
- Risk of creating recreational hazards to boaters.
- Permitting and other regulatory or institutional issues (mitigation, land acquisition).
- Long-term cost (including cost of mitigation, if necessary).

Table 5. Summary of ISPG matrix ratings for evaluated treatments.

Technique	Suitability				Habitat Impacts					Compensated By				
	Jet Scour/ Lateral Bar	Toe erosion	Toe erosion/ reduced veg.	Constriction scour / sediment	Riparian Function	Cover	Spawning	Complexity / Diversity	Flood refuge	Riparian Function	Cover	Spawning	Complexity/Diversity	Flood refuge
No action: Riprap	F ¹	F	F	F	H	H	H	H	H	n/a	n/a	n/a	n/a	n/a
Groins	G ¹	G	G	G ¹	L	L	L ⁴	A	A	n/a	D ⁵	D ⁴	C	C
Barbs	P ¹	F ³	G	P ¹	L	L	L ⁴	A	A	n/a	D ⁵	D ⁴	C	n/a
Buried Groins	F ⁶	G ⁶	G ⁶	G ⁶	A ⁶	A ⁶	A ⁶	A ⁶	A ⁶	n/a	n/a	n/a	n/a	n/a
Engr. Logjams	D ⁷	G	G	D ⁷	A	A	L	A	A	n/a	C	D ⁸	C	C
Log Toe	G ⁹	G ⁹	G ⁹	G	A	A	M	A	A	n/a	C	n/a	C	n/a
Rough. Rock Toe	F ⁹	G ⁹	G ⁹	F	L	M	M	M	M	n/a	n/a	n/a	n/a	n/a
Relocation	n/a	n/a	n/a	n/a	D ¹⁰	D ¹⁰	D ¹⁰	D ¹⁰	D ¹⁰	n/a	n/a	n/a	n/a	n/a

Key to Ratings:
n/a – no rating or not applicable

Suitability	Habitat Impacts	Compensated By
G – Good. Directly addresses mechanism of failure	H – High Impact	C – Compensates for Habitat Impact
G2 – Good in combination with treatment rated G	M – Medium Impact	D – Depends on site conditions
F – Fair. Does not fully address mechanism of failure	L – Low Impact	
F2 – Fair in combination with treatment rated G	A – Avoids Impact	
P – Poor. Does not address mechanism of failure	D – Depends on site conditions	
D – Depends on site conditions		

- 1 - Amended rating – see text for explanation
- 2 – Groins installed upstream of scour to improve flow alignment.
- 3 – Not enough bank roughness produced.
- 4 – Flow redirection techniques create habitat suitable for spawning, though the habitat created may vary from the habitat that is impacted.
- 5 – Assumes groins are a wood-catching structure; cover habitat depends greatly on tree species and age class
- 6 – Ratings are for unexposed groins; once exposed by erosion, ratings for “groins” apply.
- 7 - If ELJs are integrated into streambank, suitability is good (G) ; if detached from bank, suitability is dependent on local site conditions and will require more detailed analysis of hydraulic and geomorphic response.
- 8 – Depends on channel conditions and channel response after installation.
- 9 – In combination with other techniques rated as good (G), especially biotechnical treatments.
- 10 – Benefits or potential impacts correspond to bank treatments (if any) applied after relocation.

Evaluation

Treatment alternatives evaluated for this site are described as follows:

(1) No action

This alternative presumes that bank failure will continue to be addressed on an ad hoc, emergency basis. Repair will typically involve construction of a rock revetment (riprap) similar to the November, 2004, November, 2006, and July 2007 repairs. The repair will occupy only the footprint of the bank prior to failure bank, with little or no projection into the actively flowing portion of the river. Recurrent repairs are likely, as the lack of roughness and deformability of the hardened bank will tend to cause erosional forces to propagate downstream of the last repair site. The need for repair will continue until a natural anchor point or deflector (e.g. a logjam) is encountered, or until the bank erosion is no longer in close proximity to the road. Based on observations conducted as part of this assessment, approximately 150 feet of the bank immediately downstream of the 2007 repair is actively eroding. In addition, SR 20 is clearly vulnerable to further erosion for at least an additional 200 feet downstream of the actively eroding bank, and approximately 75 feet upstream from the 2007 repair site. In the extreme case, bank erosion along the roadway could, over time, continue downstream over 2200 feet to the existing rip-rapped bank at MP 100.3.

Fish habitat benefits and impacts. The following potential impacts to fish and fish habitat associated with recurrent emergency installation of riprap at the CED site downstream of MP 100.7 have been identified:

- Reduces complexity and diversity of bank habitat, creating less favorable conditions for fish (especially juveniles), including a reduction in cover and a more uniform, higher-velocity flow field.
- Reduces bank roughness and the resulting flow energy dissipation that would normally occur along a natural bank; this energy is transferred downstream, where it acts to erode unprotected banks and necessitate the placement of additional riprap.
- Prevents or severely limits natural erosional, sedimentation and riparian zone processes (lateral migration, bank undercutting, LWD recruitment) that are necessary to create complex habitat for both juveniles and adults of all species.
- Juvenile salmon have been documented to use the interstitial spaces for cover in riprap (Fischenich 2003); however, juvenile chinook and coho abundance was found to be 5.4 times and 3.7 times greater, respectively, for natural banks (Beamer and Henderson, 1998).
- Integration of large wood elements (boles with rootwads attached) may provide some improvement in habitat quality and fish abundance, depending on the type, size, and amount of wood used.
- The scour hole which may form at the toe may serve as a holding pool for migrating adults (especially chinook), but the quality of the pool may be limited by a lack of cover (overhanging vegetation, undercut banks, in-channel LWD).

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of emergency revetment (riprap) as “fair” for toe erosion and constriction scour and “poor” for jet scour. The jet scour rating is based on the possible transient (temporary) nature of the lateral bar. Given the immediacy of the threat to the road, and the evidence (based on historic aerial photo

analysis) of the longevity of the bar, the transient nature of the bar is currently not a consideration, and the rating is amended to “fair”. ISPG Matrix 3 rates habitat impacts as “high” for all habitat functions. This treatment provides no compensatory mitigation benefit for any habitat functions.

Risk of roadway failure. Due to the close proximity of failing banks to the roadway and the relatively high erosivity of the bank material, the current situation requires constant monitoring on the part of WSDOT maintenance staff, especially during moderate-to-high flow events. Without an effective interim or permanent solution in place, roadway failure is certain unless emergency repairs are conducted as required. Even with vigilant monitoring, there is some risk that the roadway will fail prior to implementation of an emergency repair, especially if flows overtop the existing revetment.

Actual structural failure of the roadway can result in injury or death to drivers if it occurs before the road can be closed. There is evidence (tension cracks in the pavement) that a small amount of sub-grade settlement has already occurred. The close proximity of the failed bank to the roadway poses an additional risk to the traveling public, if the failed bank approaches much closer to the pavement than the current four-to-six feet. In this event, a vehicle that momentarily leaves the roadway and encounters even a small void created by the failed bank may be pulled into the river, resulting in possible injury or death to its occupants.

Risk of creating recreational hazards to boaters. In general, placement of riprap along the channel margin has a relatively low profile with respect to the flow will have a relatively low risk to boaters who maintain an awareness of river conditions and exercise all necessary safe boating practices.

Permitting and other regulatory or institutional issues. Resource agencies, local tribal natural resources staff, and a local landowner have expressed concern about the recurring placement of riprap for bank protection under emergency declarations at this site, and insist on application of more ecologically appropriate solutions and mitigation for lost or damaged habitat attributable to recent and potential future repairs.

Long term cost (including mitigation) is typically less than \$100,000 per installation of 150 linear feet or less, occurring every one or two years (so far). In the event of roadway failure, costs will substantially increase, depending on the extent of failure and whether injury or death occurred as a result. Additional costs for mitigation depends on the quantity and type of habitat being replaced, and should include mitigation for 2004, 2006, 2007, and all subsequent repairs.

(2) Flow directional bank treatments.

(a) Groins (spur dikes) and barbs.

These structures are constructed primarily of rock (although they may include large woody debris elements), and extend from and are keyed into the existing streambank. They are designed to add bank roughness and deflect flow toward the center of the channel. Groins differ from barbs in that they have a higher vertical profile and consequently have a greater local effect on the channel.

By breaking up secondary flow cells (spiraling flow), groins and barbs can greatly reduce shear stresses and scour potential on the streambank. Scour holes are formed at the tip of each structure, while sediment deposition zones develop between structures. Over time, the scour holes may coalesce to deflect the thalweg towards the point bar on the opposite bank and deepen the center portion of the channel. A deposition zone may be created immediately below the last

(most downstream) structure; diversion of flow around this feature may increase bank shear, leading to toe erosion of downstream banks unless they are adequately protected.

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of groins (spur dikes) as “good” for toe erosion and “dependent on site conditions” for jet scour and constriction scour.

In the case of jet scour associated with a lateral bar, the groin design must account for the redirection of flow caused by the bar, as well as the effect that the groin-induced channel adjustment may have on the bar. At this site, proper design of the groins will shift the channel away from the bankline and result in partial or complete erosion of the lateral bar, eliminating the cause of the jet scour; the suitability rating is amended to “good”.

For constriction scour, the effects of further constriction of the channel by the groins must be accounted for. At this site, proper design of the groins will shift the channel away from the bank line and result in partial or complete erosion of sediment deposition creating the constriction.

For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of barbs as “good” for toe erosion caused by reduced vegetative structure, “fair” for toe erosion caused by a smoothed channel, and “dependent on site conditions” for jet scour and constriction scour. Suitability ratings for these failure mechanisms are amended to “poor”, given the large size and power of the river in this vicinity, and the need to provide a substantial shift of the channel away from the bankline.

ISPG Matrix 3 rates habitat impacts for groins and barbs as “low” for riparian, cover, and spawning habitat functions, and “avoids” for complexity/diversity and flood refuge habitat function. For spawning habitat, the groins are expected to erode the lateral bar (a likely spawning habitat) and transfer the sediment downstream, where it will likely deposit and form new spawning habitat; barbs may have a similar effect, but at a substantially reduced scale. For cover and complexity/diversity functions, “low” or “avoids” impact ratings are best achieved when large wood elements are incorporated into the groins/barbs or placed within the “hydraulic shadow” (low-velocity area on the lee side) of the groin/barb.

Groins provide compensatory mitigation benefit for complexity/diversity and flood refuge habitat functions. Compensatory mitigation benefit for spawning and cover are dependent on site conditions. For this site, cover benefit assumes that sufficient large wood elements are integrated into or are captured and retained by the groins. Spawning benefit presumes that spawning habitat is created or improved by sediment scoured from the vicinity of the groins (e.g. from the lateral bar). Barbs provide similar benefits, except that flood refuge is likely minimal or non-existent.

Fish habitat benefits and impacts. The following potential benefits and impacts to fish and fish habitat associated with installation of groins and barbs at this CED site have been identified:

- Bank protection structures made up of large rock have been shown to have lower juvenile abundance for chinook, coho, and chum salmon relative to natural streambanks or bank protection which incorporated substantial quantities of wood (Beemer and Henderson 1998);

- Prevents or severely limits natural erosional, sedimentation and riparian zone processes (lateral migration, bank undercutting, LWD recruitment) that are necessary to create complex habitat for both juveniles and adults of all species.
- Alter flow, channel geometry, and habitat elements adjacent to and for a short distance (about 3 to 4 times their length) downstream.
- Local degradation (scour) in and around groins and barbs may impact spawning habitat by mobilization of spawning gravels or introduction of larger substrate originating from the diversion structure.
- Deflector structures, may alter the influx of hyporheic flow to the riparian forested area downstream of MP 100.7.
- Cover is provided by surface turbulence created by the structure, as well as by any large wood that is built into or trapped by the structure.
- Areas of quiescent flow between structures will provide resting and feeding areas for juvenile fish.
- Sediment deposition between structures may extend the bankline further into the channel, and allow revegetation, further stabilizing the bank.
- Diversion of flow structure away from the bank would provide some protection for downstream riparian areas that support off channel and juvenile rearing habitat for salmonids.

Risk of roadway failure. Properly designed groins should deflect flow away from the bankline and minimize the risk of erosion and subsequent bank failure. The risk of catastrophic road failure is low up to the point that the existing revetment is overtopped, at which point the risk changes to moderate-to-high

Barbs will not function effectively to erode the existing lateral bar and eliminate the jet scour erosion mechanism; the risk of roadway failure is moderate-to-high over the entire range of flows expected to cause erosion.

Risk of creating recreational hazards to boaters. In general, groins and barbs that impact flow patterns and channel bedform and occupy less than 25 percent of the channel width pose a low-to-moderate risk. The magnitude of this risk is proportional to the magnitude of that impact and the degree to which boaters maintain an awareness of river conditions and exercise all necessary safe boating practices. Inclusion of LWD into treatments may increase this risk, especially if LWD elements are not visible (i.e. underwater) and/or protrude into the main body of flow.

Permitting and other regulatory or institutional issues. Use of in-channel flow diversion structural treatments may be acceptable to resource agencies and tribal natural resources staff depending on the size of these treatments and the degree to which habitat-forming elements (e.g. LWD) are incorporated. Proposals will be evaluated on a case-by-case basis.

Long term cost is moderate to high, depending on the number and size of the structures installed. For a river the size of the Skagit, the cost of a groin installation is likely to be substantial (\$1 million to \$5 million). Mitigation costs for identifiable direct impacts to fish and fish habitat may also be incurred; these costs will vary according to the nature and extent of the required mitigation.

Applicability to CED site: Groins, if properly designed and constructed, are likely to be effective in diverting erosive flows away from vulnerable portions of the streambank and for maintaining or improving fish habitat in the vicinity of the site. Barbs, with their lower profile, are not considered effective for this site, given their inability to divert sufficient amounts of flow away from the bank.

(b) Buried groins.

These structures are similar to spur dikes, except they are constructed some distance behind the existing bankline. These structures are designed to arrest further erosion of the streambank after some lateral migration is allowed to occur. Once exposed, buried groins perform similarly to, and have the same benefits and drawbacks as regular groins, while allowing for normal channel function (e.g. lateral migration, large wood recruitment) prior to exposure.

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of buried groins) as “good” for toe erosion and constriction scour at an existing bank feature, and “fair” for jet scour caused by a lateral bar. Design of the groins should account for the likely channel alignment once the groins are exposed.

ISPG Matrix 3 rates habitat impacts for buried groins as “avoids” for riparian, cover, complexity/diversity and flood refuge, and “low” for spawning. Impacts associated with spawning may vary depending on the relative amounts of habitat impacted or created once the barbs are exposed.

No compensatory mitigation benefit is created for any habitat functions, except for spawning; benefits related to spawning habitat are dependent on channel conditions and response if or when the barbs are exposed, and hence are difficult to predict.

Fish habitat benefits and impacts. Buried groins avoid impacts to fish and fish habitat unless and until the barbs are exposed, at which point the impacts and benefits are similar to those described for groins above.

Risk of roadway failure. Risk is assumed to be minimal prior to exposure of the groins. Once exposed, risk is similar to those described above for groins; see discussion under treatment 2(a) above.

Risk of creating recreational hazards to boaters. Buried groins are assumed to pose no risk to boaters until they are exposed, at which point they would have the same risk and associated risk factors as groins and barbs; see discussion under treatment 2(a) above.

Permitting and other regulatory or institutional issues. Installation of buried groins at this site would require minor relocation of the roadway, which currently appears to be precluded by tribal trust land issues; see discussion under treatment 4 below.

Long term cost is moderate to high, depending on the number and size of the structures installed. Costs are similar in scale to regular groins (\$1 million to \$5 million), and may be somewhat less costly because no in-water work is involved.

Applicability to CED site: Because of the proximity of the roadway to the river, installation of buried groins is not possible at this CED site with the current road alignment. This alternative may be considered in the event that the road is set back from the channel, or downstream of the CED site where sufficient space between the road and the river exists.

(d) Engineered Log Jams.

These structures are constructed in series within the channel, either along, or angled away from, the toe of the streambank bank. They function in a manner similar to groins and barbs, diverting flow and erosional forces toward the center of the channel and creating deposition zones between structures. Engineered logjams can also add greater roughness to the channel bank, and in-channel jams are less vulnerable to channel changes that alter the angle at which the river approaches the structure.

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of engineered log jams as “good” for toe erosion and “dependent on site conditions” for jet scour and constriction scour. If the engineered log jams are integrated into the streambank, then design considerations are similar to those for groins(see description under treatment 2(a). If the jams are detached from the bank, then the number and configuration of the jams should be designed to divert enough flow away from the site to prevent additional bank erosion at and immediately downstream of the site.

ISPG Matrix 3 rates habitat impacts for engineered logjams as “avoids” for riparian, cover, complexity/diversity and flood refuge, and “low” for spawning. Impacts or benefits associated with spawning may vary depending on the relative amounts of habitat impacted or created after the jams are built.

Compensatory mitigation benefit is created for cover, complexity/diversity, and flood refuge habitat functions; benefits related to spawning habitat are dependent on channel conditions and response after jams are constructed, and hence are difficult to predict.

Fish habitat benefits and impacts. Engineered logjams are generally considered beneficial to fish, to the extent that they emulate the ecological functions of natural logjams. Specific ecological and habitat functions enhanced or created include cover, holding and rearing, spawning, detritus retention, and flood refuge.

After construction, jams may have temporary impacts on spawning and rearing habitat as channel substrate is redistributed. Because they require the use of heavy equipment for their construction, there may be substantial (though temporary) in-channel impacts (e.g. flow diversion, coffer dams, dewatering, equipment travel) that may require mitigation.

Risk of roadway failure. Risk to the roadway is contingent on the effectiveness of the logjams in diverting flow away from the vulnerable bankline. If they are effective, the risk to the roadway is low. Improperly designed or constructed jams may exacerbate erosion problems and increase roadway failure risk to moderate or high, especially if they result in unaccounted-for flow diversion or sediment transport.

Risk of creating recreational hazards to boaters. For bank-based logjams, risk and risk factors are comparable to groins, assuming that the structures are designed and constructed to be impermeable; see discussion under treatment 2a. Risk may be substantially higher if structures are permeable, due to the greater likelihood of boaters being pinned to the structure by flow. Risk may increase if LWD elements (either part of the original structure or racked onto the structure by subsequent flows) are not visible (i.e. underwater) and/or protrude into the main body of flow.

Permitting and other regulatory or institutional issues. Engineered logjams are viewed favorably by resource agencies and tribal resource staff because of their associated benefits to fish and fish habitat. They may also be viewed favorably by USFS (in the context of the Wild and Scenic River

designation) because they emulate naturally occurring river features. The Corps of Engineers may offer two views; the resource protection arm will view ELJs favorably as a habitat improvement, while the navigation arm may have a less favorable view, given that the Skagit River is considered navigable throughout this reach.

Long term cost is moderate to high, depending on the number and size of the log jams installed. Available cost information is limited, but for a river the size of the Skagit, the cost of structures is likely to be substantial (\$1 million to \$5 million or more).

Applicability to CED site: Engineered logjams are considered an experimental treatment; recent experience by WSDOT and others indicates that use of logjams for bank protection can be effective in they are properly designed and constructed. Determination of the appropriateness of this treatment will require additional analysis beyond the scope of this document.

(3) Structural treatments.

(a) Log Toes.

Log toes consist of logs or whole trees placed along the toe of the bank. Generally, these are placed with rootwads facing upstream, and may be embedded in the bank, or attached to other log elements which are embedded into the bank. Additional stability and structural integrity may be obtained by interlocking or cabling logs together, and/or anchoring with rock, pilings, or earth anchors. The branches, trunk, and rootwad add roughness to the channel, reducing shear stresses and increasing the bank's ability to resist erosion. Reduced flow velocity between structures creates sediment deposition zones that may subsequently become revegetated, further stabilizing the streambank.

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of log toes as “good in combination with other techniques rated as good” for toe erosion and jet scour and “good” for constriction scour. These ratings are contingent upon the availability of appropriate-sized wood to build the log toe. For this CED site, old-growth sized conifers with rootwads would be necessary, unless another treatment diverted enough flow away from the vulnerable bank and side channel to permit smaller-sized wood to be effective. Use of a log toe needs to be supplemented by biotechnical treatments (e.g. soil reinforcement, bank reshaping), unless the toe is extended to the vertical extent of the vulnerable portion of the bank.

ISPG Matrix 3 rates habitat impacts for log toes as “avoids” for riparian, cover, complexity/diversity and flood refuge, and “medium” for spawning. Compensatory mitigation benefit is created for cover and complexity/diversity.

Fish habitat benefits and impacts. Log toes in general are considered intermediate in impact between rock-based bank protection (rock toes and riprap) and natural banks. Impacts caused by log toes will vary according to the complexity of the structure; more rootwads and incorporation of non-structural “racking members” will create cover and flood refuge, especially for juvenile fish.

Risk of roadway failure. Risk to the roadway is contingent on the effectiveness of the log toe in keeping erosive flows away from the bank, and in the ability of the structure to maintain its structural integrity in a potentially high-velocity, high shear stress environment. If it is effective, the risk to the roadway is presumably low. If ineffective, whether it be due to the inability of the structure to prevent erosion, or maintain its structural integrity, then the risk to the roadway is high. The structure is expected to decay over time (the rate is dependent on the size and species used), and

periodic monitoring and replacement of decayed elements will be required to ensure the integrity of the structure.

Risk of creating recreational hazards to boaters. In general, log toes placed along the channel margin will have a low-to-moderate risk to boaters who maintain an awareness of river conditions and exercise all necessary safe boating practices. Risk may increase if LWD elements (either part of the original structure or racked onto the structure by subsequent flows) are not visible (i.e. underwater) and/or protrude into the main body of flow.

Permitting and other regulatory or institutional issues. Log toes are viewed favorably by WDFW and tribal resource staff, because of their associated benefits to fish and fish habitat. They may also be viewed favorably by USFS (in the context of the Wild and Scenic river designation) because they emulate naturally occurring river features.

Long term cost is moderate to high, depending on the number and size of logs required. Logs of the size necessary to function at the CED site (i.e. live old-growth) are likely to be very expensive, if they are even available. Log toes constructed downstream of the site may require smaller logs, and would likely be substantially less expensive. Flow diversion structures (e.g. groins or log jams), supplemental biotechnical bank treatments, and mitigation are also likely to be required and will add to the cost.

Applicability to CED site: Applicability is limited because of the proximity of the roadway to the river, which likely precludes embedment of the log toe into the existing bank. Construction of the toe waterward of the existing bank may be considered as an option; otherwise, this treatment may be applicable only if the road is set back from the channel, or downstream of the CED site where sufficient space between the road and the river exists. Success of this treatment depends on scaling the size and quantity of LWD elements to the anticipated flows. Integration of rock for support and shear resistance may also be necessary.

(b) Roughened Rock Toe.

This structure consists of suitably sized angular rock placed between the estimated depth of scour and the estimated lower limit of woody vegetation. Rock toes are designed to maintain hydraulic roughness by virtue of an irregular bankline and “loose” placement of angular rock. Integration of large woody debris pieces may also be used to increase roughness and channel complexity. These structures are often used (and are most effective) in combination with other treatments, including bank reshaping, anchor points, and soil reinforcement.

Properly designed and installed rock toes are effective in arresting bank erosion and lateral channel migration. While rock toes do provide increased roughness over standard riprap, there is still potential for propagation of erosive forces downstream, increasing the potential for erosion of unarmored banks. Depending upon local flow patterns and the degree of projection into the channel, rock toes may cause deepening of the thalweg near the structure.

ISPG Matrix Ratings. For failure mechanisms identified at this site, ISPG (Matrix 1) rates suitability of roughened rock toes as “good in combination with other techniques rated as good” for toe erosion, “fair in combination with other techniques rated as good” for jet scour and “fair” for constriction scour. Use of a rock toe needs to be supplemented by biotechnical treatments (e.g. soil reinforcement, bank reshaping), unless the toe is extended to the vertical extent of the vulnerable portion of the bank.

ISPG Matrix 3 rates habitat impacts for roughened rock toes as “moderate” for cover, complexity/diversity and spawning, “low” for spawning, and “avoids” for flood refuge.. No compensatory mitigation benefit is created for any habitat functions.

Fish habitat benefits and impacts. All of the benefits and impacts described for riprap (see discussion under treatment 1, above) apply to roughened rock toes. Roughened rock toes are considered an improvement to a standard revetment, with respect to the modest increase in bank roughness and some cover provided by interstices created by the “loose” placement and any large wood elements that are built into or trapped by the structure.

Risk of roadway failure. Risk to the roadway is contingent on the effectiveness of the rock toe in keeping erosive flows away from the bank, and in the ability of the structure to maintain its structural integrity in a potentially high-velocity, high shear stress environment. If it is effective, the risk to the roadway is presumably low. If ineffective, whether it be due to the inability of the structure to prevent erosion, or maintain its structural integrity, then the risk to the roadway is high. Structural integrity is maintained by using appropriately-sized rock and extending the toe to the expected scour depth.

Risk of creating recreational hazards to boaters. In general, roughened rock toes have a relatively low profile with respect to the flow will have a relatively low risk to boaters who maintain an awareness of river conditions and exercise all necessary safe boating practices.

Permitting and other regulatory or institutional issues. In general, resource agencies and tribal natural resource staff do not view placement of rock favorably. Integration of LWD elements may be acceptable where use of rock is absolutely required; proposals will be evaluated on a case-by-case basis.

Long term cost is low to moderate, depending on the length of bank to be protected and the cost and availability of appropriately-sized rock. Flow diversion structures (e.g. groins or log jams), supplemental biotechnical bank treatments, and mitigation may also be required and will add to the cost.

Applicability to CED site: This type of structure is generally regarded as an effective bank protection treatment if properly designed and constructed. The proximity of the roadway to the river may limit the effective installation of this treatment at the CED site.

(4) Relocate the roadway.

Relocation of the roadway away from the migrating channel would reduce or practically eliminate the risk of catastrophic roadway failure associated with bank erosion at this site and reduce or eliminate the need for corrective ongoing maintenance of the streambank in or near the CED site. Setbacks of as little as 40 feet or as much as 400 feet from the current alignment may be considered. The minimum setback will allow for installation of more ecologically functional streambank protection techniques (including buried groins and log toes) without extending beyond the “footprint” of the existing bankline. The maximum setback roughly corresponds with an old railroad grade, which is located on an upper terrace approximately 20 feet higher than the current roadway. The land within these proposed setbacks is off WSDOT right-of-way and is occupied by several residences, and an agricultural operation including fields and a farm store and offices.

ISPG Matrix Ratings. This alternative is not formally rated in the ISPG Matrices.

Fish habitat benefits and impacts. Relocating the road would have the least impact and potentially greatest benefit to fish and fish habitat, especially if it were conducted in conjunction with restoration of a more naturally functioning bank. This is the only alternative that would allow the river to access (via lateral migration) the portion of the floodplain north of SR 20.

Risk of roadway failure. A minor relocation of the roadway (nominally, 40-60 feet) will provide a buffer from the river and to permit installation of flow diversion (groins), structural (log or rock toes) and biotechnical (vegetation) treatments landward of the current bankline. This will result in a low risk of roadway failure. A major relocation of the roadway (up to 400 feet west of the current alignment) will place it on a higher terrace, and sufficiently removed from the river to eliminate risk of failure for decades or longer.

Risk of creating recreational hazards to boaters. None.

Permitting and other regulatory or institutional issues. Major and minor relocation is likely precluded by one or both of the following:

- Potential opposition by local landowners and businesses, local communities, and Skagit County.
- The presence of tribal trust land within the relocation corridor (federal law and tribal sovereignty prevents taking by eminent domain), and the presence of known tribal cultural resources in and around this land.

Long term cost is moderate (in the case of a minor relocation) to high (in the case of a major relocation)

Applicability to CED site: While the combination of minimal or no risk to the realigned road combined with minimal or no habitat impacts makes this an attractive option, the legal/institutional issues identified above likely rule out this alternative.

Conclusions

Recurring bank erosion at this CED site in 2004, 2006, and 2007 has required emergency placement of riprap on each occasion for prevent damage or catastrophic failure of the roadway. WDFW and local tribal natural resources staff have expressed concern about the recurring placement of riprap for bank protection under emergency declarations, both at this and at other sites around the state. They are insisting on application of more ecologically appropriate solutions, including techniques recommended in the Integrated Streambank Protection Guidelines (ISPG), road relocation, and mitigation for lost or damaged habitat attributable to recent repairs.

This portion of the Skagit River supports all native salmonid species (coho, chum, pink, sockeye, steelhead, chinook, and bull trout/Dolly Varden). Chinook, steelhead, and bull trout are listed as “threatened” under the federal Endangered Species Act. The Skagit River possesses the largest run of native chinook salmon in the Puget Sound Region, and the largest run of chum and pink salmon in the United States outside of Alaska; a substantial portion of adults in each of these species spawn within this reach.

This portion of the Skagit is designated as a Wild and Scenic River, and is renown as one of the premiere locations in the United States for viewing bald eagles in a wild setting. The assessment reach is heavily utilized by rafters and kayakers for eagle-viewing trips.

The *site-based mechanisms* associated with bank failure at this location are:

- *Jet scour* caused by the lateral bar opposite the CED site.
- *Toe erosion* caused by reduction in bank roughness associated with recent repairs and reduction or elimination of bank vegetation by recent floods.
- *Constriction scour* caused by sediment accumulation in the side channel opposite and downstream from the site, which acts to hold the thalweg against the bank.

The *reach-based mechanism* contributing to bank failure at this location is associated with extensive riprap placement (>2000 feet) along SR 20 upstream of the CED sit, which results in a deepening of the thalweg and extension of the meander apex downstream along the base of the riprap. Expenditure of excess stream power results in sediment deposition and formation of the lateral bar just upstream of the site, which is associated with the site-based mechanisms of failure (jet scour, toe erosion, constriction scour) identified in the site assessment.

Identification of a specific “best” or “preferred” treatment or combination of treatments is currently precluded by the physical complexity of the site and reach, and numerous legal and institutional constraints described previously. Legal and institutional constraints appear to preclude relocation of the roadway, and will likely limit the manner and extent of in-channel treatments. Based on the identified mechanisms of failure, a successful solution will divert flows directed at the CED site by the lateral bar located opposite the site. This would involve use of flow-directional treatments (groins and/or engineered log jams). Depending on the nature of the flow diversion and the anticipated geomorphic response of the river, additional treatments (e.g. log toes, hybrid rock/log toes, bank-integrated log jams) may be required to protect the bank downstream of the site.

Evaluation and selection of the appropriate combination of treatments will require the use of a two-dimensional hydraulic model to properly evaluate the hydraulic and geomorphic response of the river. Data collection in support of model development and calibration is currently underway.

Addendum: Secondary Project Elements/ Mitigation

During the presentation of this analysis WSDOT has been approached by various stakeholders suggesting that additional work included in the CED project proposal as secondary project elements (i.e. not directly related to correcting the identified failure mechanisms at the site) or as mitigation. These are discussed below.

Downstream LWD placements in side channel.

Both Tribal representatives and local land owners have suggested that placement of LWD on or adjacent to the bank downstream of the emergency repair site could be beneficial in terms of helping to prevent downstream migration of the erosion problems as well as serving as project mitigation. Because this idea holds the potential to do double duty in terms of serving both infrastructure protection and habitat functions it appears to be a worth while option to investigate further. The chief issues involved are:

- Determining if the land owner (The Nature Conservancy) is amenable to work on their property.
- Entry onto the property to do work would involve crossing a jurisdictional wetland, and would require an access plan acceptable to regulators.
- There may be constructability issues associated with soft and potentially saturated soils on the site that may limit operability of heavy equipment.
- A design configuration for LWD that is acceptable to the various permitting agencies would have to be developed.

Each of the above issues requires further investigation that is beyond the scope of this report; however, the potentially positive benefits of downstream LWD placements for both habitat and infrastructure indicate that this follow-up work may be worthwhile.

Removal of upstream bank protection (Buller property).

Tribal , WDFW, and U.S. Forest Service representatives have proposed inclusion of a project element involving the removal of bank protection from a site (the “Buller property”) approximately one mile upstream of the project site. This proposal was originally conceived as habitat improvement and did not include the goal of infrastructure protection. It has been suggested by the proponents that the river would respond by breaching the unprotected bank and establishing a new alignment through the property that would result in a longer, lower gradient channel. In addition, restoration of riparian vegetation along the banks would add roughness and provide shade and cover for fish. The proponents believe that these responses would have a positive effect on the reach downstream by reducing slope and stream power. To WSDOT’s knowledge, there has been no detailed study of this proposal with respect to effects on downstream geomorphology or WSDOT infrastructure. A cursory examination of the sequence of aerial photos used in the reach analysis indicates the channel has migrated away from the bank, and the desired realignment may not occur unless a significant shift in channel planform occurs upstream; the near-term likelihood of such a shift cannot be reliably predicted without further assessment. If fact, it may take some time (years or decades) for the proposed realignment to fully develop.

As stated above, one of the stated reasons offered by some proponents for acquiring the Buller property and pursuing this proposal was the assertion that the channel would be lengthened, thus

reducing the channel gradient and thus the stream power and shear stresses which cause bank erosion to occur. Using LIDAR data acquired for this area, we identified an abandoned channel feature and an adjacent terrace which we believe would represent the likely location of the realigned channel. We measured the length of this feature against the existing channel we found it was actually slightly shorter (about 2900 feet for the new channel versus about 3075 feet for the existing channel). This challenges the above assertion and indicates that the benefits suggested by a longer channel (and thus a lessened channel gradient) would probably not be realized.

Another potential geomorphic response to the proposed action would be to allow the river to more easily access the floodplain during flood events, which could allow for some attenuation of flow and stream power. This may cause a small reduction in local base flood elevation, and may result in changes in flow and sediment transport patterns that may have positive, negative, or no effects on both habitat and infrastructure downstream. Depending on the magnitude and frequency of flooding in the future, this response could occur relatively quickly, as compared to channel realignment, but the full impact would probably not manifest itself for years to decades.

While the potential habitat benefits of the Buller property proposal are apparent at the conceptual level, the effects (beneficial or detrimental) to WSDOT infrastructure have not been analyzed and remain unknown. Because of this, and because it appears any effects would likely not occur in the near-term, inclusion of the Buller property proposal as part of the CED repair strategy does not appear justifiable. This is further reinforced by the fact that, while the identified site-based mechanisms for failure can be clearly linked to the problems at the CED site, the link between the CED site and proposed measures implemented that far upstream is far more tenuous. That said, the proposal may have considerable value as a mitigation site; however, additional study beyond the scope of this assessment must be undertaken to identify likely outcomes and impacts at both the site and reach level for both habitat restoration and infrastructure protection.

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