COAL CREEK ALTERNATIVES FEASIBILITY STUDY

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Prepared for Skagit County Public Works

by:

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Executive Summary

Coal Creek is located within Skagit County near the towns of Sedro-Woolley and Hamilton. It drains a portion of Lyman Hill and flows into the Skagit River. Coal Creek has been an ongoing maintenance problem for Skagit County at the Minkler Road Bridge. In 1985, Skagit County acquired property and constructed a sediment basin to capture and store bedload sediment immediately downstream of the Minkler Road Bridge to alleviate recurring flooding and damages to the bridge. Periodic maintenance of the sediment basin occurred for several decades until 2009 when the strategy to remove the sediment in the basin was questioned in relationship with fisheries habitat.

A 2009 Hydraulic Permit Approval issued by Washington State Department of Fish and Wildlife required Skagit County to reevaluate the management strategy and consider alternatives that address the fish habitat needs and look at the problem from a watershed scale. Skagit County retained Element Solutions and Kerr Wood Leidal (KWL) to assess the Coal Creek alternatives feasibility.

The study identified widespread upper basin instability and virtually unlimited sediment sources in the upper watershed. On average, Coal Creek deposits approximately 3,100 cubic yards of sediment in the Minkler Road sediment basin annually. Field evidence indicates that volumes much larger than this could occur during debris flows that originate in the upper watershed and transport to the alluvial fan. The upper watershed conditions will continue to contribute significant volumes of sediment to the alluvial fan for the foreseeable future and ongoing management will be needed.

A planning-level alternatives analysis was conducted to determine what alternatives best met the objectives of Skagit County and the stakeholders. Integration of two alternatives implemented concurrently appears to best address the overall project objectives: setback levees and sediment removals downstream of Minkler Road. Further development and implementation of the proposed management strategy will require cooperation with adjacent landowners, regulatory agencies, and stakeholders. In addition, consideration of land-use regulations or other risk reduction measures to address the Coal Creek alluvial fan hazards should be part of the comprehensive management strategy.

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1 Introduction

Minkler Road Bridge has a long history of frequent flooding by Coal Creek. The flooding problem is exacerbated by instream sediment deposition that decreases channel capacity and increases flooding frequency and flood heights. If the sediment in the channel is not managed, the channel completely fills in and impacts to the bridge and possible channel avulsions result.

Skagit County has managed the sediment in Coal Creek for the past 25 years with a sediment trap located downstream of the Minkler Road Bridge. A Hydraulic Permit Approval in 2009 required Skagit County to assess potential management alternatives that consider sediment management from a watershed perspective, including the upper watershed and fish habitat conditions. Element Solutions and Kerr Wood Leidal Associates Ltd. were retained by Skagit County to assess the Coal Creek watershed, and develop and evaluate the feasibility of management alternatives in the watershed context.

1.1 Project Objectives

The objectives of this project are to:

- Gain a comprehensive understanding of management issues from a watershed perspective (fish habitat conditions, land use, slope stability, sediment transport, public safety, Infrastructure management);
- Identify and perform an analysis of management alternatives;
- Identify the most viable and sustainable management alternative to address the problems of Coal Creek;
- Develop a funding strategy for implementation.

1.2 Work Program

The work program for this study is summarized in Table 1.

Table 1: Work Program for Coal Creek

Task	Description
1. Project Initiation	▪ Meet with County to review the scope and schedule, confirm responsibilities, identify key stakeholders, discuss stakeholder engagement strategy, set future key meetings, obtain rights of entry, and collect and review existing data. ▪ Obtain existing GIS data and reports, including LiDAR and digital orthophotos, maps and assessments of the watershed basins, existing studies, and land use information.
2. Sediment Budget	▪ Identify, map and quantify sources and quantities of sediment contribution. ▪ Perform field analysis of grain-sized distribution of sediment contributions from each source. ▪ Estimate sediment stored in the channel, bars and floodplain. ▪ Estimate the rate of sediment transport and throughput and compare this information with the sediment information provided in the Northwest Hydraulic Consultants *nhc)* report (2008). ▪ A GIS model will be set up as part of the sediment budget assessment.

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3. Habitat Assessment	▪ Conduct field assessment of the stream for existing fish and wildlife habitat conditions on the alluvial fan. ▪ Document field findings.
4. Alternatives Identification	▪ Inventory a range of alternatives to address the sediment management for the watershed, which may include: o managing point sources o managing in-stream storage o allowing for natural storage; and o infrastructure modifications. ▪ Conduct an initial alternatives vetting and coordinate with Skagit County representatives for the consideration of alternatives feasibility and limitations.
5. Alternatives Analysis	▪ Evaluate the alternatives based on criteria established by Skagit County and the vested interests, likely including WDFW, Upper Skagit Tribe and the Skagit River System Cooperative, WA Dept. of Transportation, and potential local representation. ▪ Identified criteria include: likelihood of implementation; impacts on fish; ongoing maintenance needs. ▪ Estimate approximate costs for both near-term and long-term. ▪ Determine whether a relative cost-to-benefit assessment (integrating a relative resource value into project costs and then comparing this to the alternative's overall relative benefit), will help to inform the decision-making process.
6. Plan Documentation	▪ Document the Sediment Budget, Habitat Assessment, and the Alternatives Analysis. ▪ Develop a plan that incorporates our findings and recommendations. ▪ The plan will include identification and discussion of funding sources and strategies to best achieve plan implementation in both short and long-term time frames.
7. Plan Presentation	▪ Present the Coal Creek Alternatives Feasibility Study and Plan to Skagit County upon completion of the project.

1.3 Project Team

A compact team of geomorphologists, watershed analysts, and fisheries biologists evaluated the sediment sources, the nature of the sediment transport, the characteristics of sediment deposition, and the consequences of sediment deposition and channel maintenance activities on fish and wildlife habitat within the Coal Creek Basin. The team reviewed existing information, developed a sediment budget, conducted field verification and assessment of data, developed alternatives, consulted with local governments and regulatory agencies, and assessed the feasibility of sediment and habitat management alternatives and implementation strategies.

The Element/KWL team gratefully acknowledge the assistance of the following individuals for providing project information:

Kara Symonds – Skagit County
Janice Flagan – Skagit County
John Cooper – Skagit County
Jeff McGowan – Skagit County

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2 Coal Creek Watershed Analysis

This section provides a description of the Coal Creek watershed, and a summary of relevant background reports as well as recent field observations.

2.1 Watershed Description

2.1.1 Physiography

The Coal Creek watershed is located on Lyman Hill at the western front of the Cascade Mountains along the Skagit Valley (Appendix A-Figure 1). The watershed consists of multiple ephemeral and perennial mountain streams that coalesce in the steep upper watershed to a single channel that exits the mountain terrain and creates an alluvial fan on the Skagit Valley margin, and ultimately flows into the Skagit River via Skiyou Slough (Appendix A-Figure 2).

The drainage area of Coal Creek is approximately 2.1 square miles with a relief of approximately 3,800 feet (elevation approximately 85 feet at Minkler Road and a maximum elevation of 3,960 feet). The mean basin elevation is approximately 2,080 feet. The basin is generally steep with approximately 50% of the watershed having a slope of 30% or greater (Appendix A- Figure 3).

2.1.2 Hydrology

The mean annual precipitation for the watershed is approximately 60 inches. Peak flows in the area generally occur during the fall and winter when Pacific cyclones cause prolonged, orographically enhanced precipitation. These storms can last for several days and are often the cause of flooding in the Pacific Northwest. The associated flooding can be exacerbated by rapid rises in freezing level associated with warm marine weather fronts from the central Pacific.

The Coal Creek basin faces south and includes a range of elevations at which transient winter snow line elevations are common, and therefore the watershed is susceptible to rain-on-snow type hydrologic events. In western Washington, the transient snow zone generally occurs at elevations ranging between 1,200 ft and 4,000 ft (365 m to 1220 m) (Washington Forest Practices Board, 1997). Within the transient snow zone, it is not uncommon for shallow snowpacks to develop several times each year. These shallow snowpacks are subject to rapid melt when warm fronts from the central Pacific move into the area. Depending on the snowpack characteristics (e.g. water equivalent and meteorological conditions during a storm), the amount of additional meltwater released from snowpacks can be significant. Rain-on-snow conditions are considered to be the primary cause of peak flows throughout much of the western Washington Cascades (Acme Watershed Analysis, 1999).

A 100-year return period peak discharge is approximately 250 cfs for clear-water type floods. No gauging station exists for Coal Creek or nearby basins; therefore, peak discharges were estimated using published regional regression equations (USGS, 1997).

No estimation of debris flow, debris flood, or dam outburst type flooding magnitude or recurrence interval are known nor were they part of the scope of this project, but they are anticipated to be significantly higher than the clear-water floods (Jakob, 1996). An explanation of debris flows is provided in section 2.1.3.

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2.1.3 Geology and Geomorphology

Coal Creek geology in the upper watershed includes the Darrington Phyllite (Jurassic phyllite, phylonites, and greenstone) and to a lesser extent the Shuksan Greenschist (metabasalt) units overlain by Vashon Stade glacial sediments (Dragovich *et al*, 1999a) (Appendix A-Figure 4). We observed glacial mantling of ranging between 1 to 2 meters in several locations in the upper watershed. Glacial deposits in the lower watershed were substantially thicker (Appendix A).

The normal Coal Creek Fault (Tertiary) separates the Darrington unit from the Eocene Chuckanut Formation (Dragovich *et al*, 2000) near the base of Lyman Hill. Chuckanut sandstone, shales and conglomerate are exposed and form a narrow canyon through which Coal Creek flows. Exposures of Pleistocene glacial sediments (Everson Interstade basal till and outwash) were observed in the lower reaches of the watershed above State Route 20. The soil maps show that soils are predominantly loams ranging from silt loam to gravels loam typically with low permeability (Appendix A-Figure 5, soils from 2009 USDA-NRCS).

An alluvial fan has formed where Coal Creek exits the slopes of Lyman Hill and enters the Skagit Valley. The alluvial fan has what is interpreted to be two terraced surfaces of different ages (Appendix A-Figure 6). The older (higher) alluvial fan terrace appears to have been truncated by lateral migration of the Skagit River and is currently interpreted to be inactive with an age we estimate at mid to late Holocene. The gradient change resulting from erosion of this alluvial fan by the Skagit River shortened the stream length and triggered incision, which led to the development of a lower and active alluvial fan entrenched into the older alluvial fan terrace. The younger alluvial fan is currently much smaller than the historic alluvial likely was.

The alluvial fan is hypothesized to be a composite alluvial fan created by both floodwaters and debris flows; however, no trenching of the fan has ben conducted to confirm this hypothesis. The alluvial fan transitions into the Skagit Valley alluvial floodplain.

Background on Natural Hazards and Alluvial Fan Risks

Many natural hazards exist within the study area. These hazards include, but are not limited to:

- landslide hazards (including debris flows);
- flooding hazards;
- volcanic hazards (including lahars); and
- seismic hazards.

The purpose of this study was not to assess the natural hazards (the source of danger) or the risks (the probability of occurrence and the consequences) within the study area. However, it should be noted that many of these hazards could impact the infrastructure and community located on the alluvial fan and Skagit Valley, and that in some cases the combined high recurrence interval and potential consequences of some hazards create potentially high risk.

In particular, we learned through historic research that debris flows from the upper watershed occur with fairly high frequency and we saw evidence of fairly large debris flows occurring within the watershed. Large debris flows have the potential to carry significant debris (rocks, logs, sediment) long distances with velocities that can damage or destroy infrastructure and

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property (homes, cars). Debris impact and burial can create potentially lethal conditions to those caught in the path of a debris flow (Photo 1).

Diagram 1: Smith Creek, Whatcom County Washington following a debris flow in 1983.
Photo from Bellingham Herald.

Typically, discharges from debris flows are significantly larger than clear-water or even rain-on-snow flood flows. Debris flows include not only water but a large portion of sediment adding to the volume and therefore discharge. The empirical equation:

$$Q_P = (V_{max}/50)^{0.87}$$ [where Q_P is the peak discharge (m^3/s) and V is the total debris flow volume (m^3)]

was derived for bouldery to muddy debris flows in southwestern British Columbia (Jakob, 1996). Applying this equation to a small Coal Creek debris flow delivering a sediment volume of 3000 yd^3 (2200 m^3) in a single event would result in a debris flow peak discharge of 1000 cfs (30 m^3/s). This figure is 4 times higher than the estimated 100-year return period flood flow of 250 cfs.

A detailed debris flow analysis was completed on the Jones Creek alluvial fan near the town of Acme in Whatcom County. The basin geology, elevation and size is comparable to that of Coal Creek. A debris flow in 1983 delivered 33,000 cubic yards of sediment and resulted in a peak discharge of 7,800 cfs where the 100-year return period clear water flood is calculated to be 310 cfs. Analysis of the alluvial fan stratigraphy revealed that much larger debris flows had occurred frequently throughout the past 7,000 years and indicated that the 1983 event was approximately a 50 to 100 year return interval event. Therefore, debris flows, while infrequent, create substantially higher peak discharges and can deliver large quantities of sediment.

Frequency of debris flows and magnitude is controlled by watershed characteristics and hydroclimatic conditions. Watersheds with abundant amounts of stored sediment and debris are more responsive to hydroclimatic events, especially high intensity rainfall, long periods of antecedent moisture, and rain-on-snow, and these watersheds can respond with a wide range of debris flow magnitudes. These basins do not need the recharge period between large events because a single, massive event is not capable of removing all of the stored sediment, therefore the frequency of large events can be higher. Coal Creek has a virtually limitless amount of sediment stored in its upper watershed. Previous regionally proximate studies by Orme (1989, 1990), deLaChapelle (2000), and Jakob et al (2004) have measured return periods

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in the Late Holocene. Generally, those analyses found that very large, regionally significant debris flows had a recurrence interval of approximately 500 years and that major events had a recurrence interval of approximately 50 years.

Development on alluvial fans is particularly susceptible to debris flow hazards and loss of life and property damage from debris flows occurs frequently in a global scale. In Japan, an estimated 90 people per year die from debris flow events (VanDine, 1985), and several catastrophic events in South America have killed several tens of thousands of people (1985 Armero, Columbia, about 21,000 deaths; 1999 Vargas Venezuela, about 30,000 deaths).

Under state legislation enacted in 1990, alluvial fans fall under the critical areas classification of the Washington State Growth Management Act (GMA) as geologically hazardous areas [WAC 365-190-080(4)(d)(viii)]. Alluvial fan development is regulated by ordinance (Chapter 14.24) in Skagit County.

2.1.4 Current Land Use

Approximately 84% of the basin is currently covered by forests of varying stand age. Basin ownership currently includes both state and private forestry parcels. Forest harvesting practices have occurred in the watershed over the past century, but basin harvests peaked in the 1960s and 1970s and have subsided considerably since that period. A period of increased mass wasting was observed in the 1970s through early 1990s and was attributed to the forest practices that occurred in the 1960s and 70s (DNR, 1994). Coal Creek is currently crossed by only a few actively maintained forestry roads; however, several relict forestry roads and an old railway trestle cross the upper watershed.

2.1.5 Infrastructure

For this analysis, infrastructure is defined as technical structures that support society, including roads, water supply, power grid, telecommunications, trails, and sediment basins.

Coal Creek is crossed by several forestry/telecommunication access roads in its upper watershed and by State Route 20 and Minkler Road on its alluvial fan (Appendix A-Figure 7). Several other crossings (roads and trails) occur downstream of Minkler Road. Historic flooding of the road systems as well as scour at the State Route 20 Bridge has occurred.

A sediment basin maintained by Skagit County is located just south of Minkler Rd. on Coal Creek. The sediment basin was constructed in 1985 to address flooding exacerbated by sedimentation of the channel. The sediment trap has been maintained periodically, most recently in September 2010. Historic costs to maintain the State Route 20 Bridge and Minkler Road Bridge and sediment trap are unavailable. Approximately 3,500 cubic yards of sediment was removed for approximately $7,800 in the 2010 sediment removal.

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2.2 Background Reports

2.2.1 Hansen Watershed Administrative Unit Report (DNR, 1994)

The Washington Department of Natural Resources (DNR) initiated a Level 1 watershed analysis in the Hansen Watershed Administrative Unit (WAU) in 1994. The Hansen WAU includes the following drainages:

- Hansen Creek;
- Coal Creek;
- Wiseman Creek;
- Tank/Childs Creek; and
- Jones Creek.

The Hansen WAU was selected as a priority based on present/future fisheries values, reduction of fish habitat productivity and the likelihood of continued high levels of forest practice activities.

Land-Use History

A land-use history included in the WAU indicates that railroad logging of the Skagit River floodplain and lower terraces began in the late 1800's, with the first logging of the lower slopes in the WAU starting in about 1905. Much of the area had been logged by 1940, apart from the highest elevations in the watersheds. By this time, agriculture was the dominant land-use on the floodplain and low terraces. Upper elevations in the watersheds were harvested in the 1960's and 1970's.

Mass Wasting

Shallow-rapid landslides and debris torrents are the dominant mass wasting processes in the Hansen WAU, accounting for nearly 95% of the inventoried failures. Other processes included sporadic deep-seated landslides, gullying, and stream-channel destabilization. In addition, large-scale ancient failures involving bedrock and/or till were identified in middle to upper elevations of the watersheds. The assessment identified forestry activities as being associated with many of the landslides included in the mass wasting inventory.

The mass wasting module identified three major mapping units in Coal Creek associated with mass wasting:

a. Inner gorges;
b. Concave/convergent topography; and
c. Hillslopes > 65%

A mass wasting inventory was conducted using historical air photographs. Mass wasting events in Coal Creek are summarized in the following table.

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Table 2: Mass wasting inventory for Coal Creek (from Hansen WAU, 1994).

Year	Description
1943, 1948, 1956	No documented mass wasting events in Coal Creek
1965 (approx.)	1. Shallow-rapid landslide/debris; elevation: 850 ft; source area: inner gorge, 50-year old forest, parent material: till; sediment delivered to watercourse.
1978 (approx.)	1. Shallow-rapid landslide/debris; elevation: 3,050 ft; source area: road on planar 60% slope, parent material: till/phyllite; sediment delivered to watercourse. Fill/sidecast failure. 2. Shallow-rapid landslide/debris torrent; elevation: 3,400 ft; source area: logged area on headwall, parent material: phyllite; sediment delivered to watercourse. Transformed into debris torrent and ran for 800 ft. 3. Shallow-rapid landslide/debris; elevation: 3,300 ft; source area: road on headwall, parent material: phyllite; did not connect with watercourse. 4. Shallow-rapid landslide/debris; elevation: 3,100 ft; source area: road on headwall, parent material: phyllite; did not connect with watercourse.
1983	1. Shallow-rapid landslide/debris torrent; elevation: 1,150 ft; source area: incised channel in recently logged area, parent material: till/phyllite; sediment delivered to watercourse. Debris torrent ran for 800 ft and connected with another torrent. 2. Shallow-rapid landslide/debris torrent; elevation: 1,150 ft; source area: incised channel in recently logged area, parent material: till/phyllite; sediment delivered to watercourse. Debris torrent ran for 1000 ft and connected with another torrent and ran a further 400 ft before entering Coal Creek. 3. Shallow-rapid landslide/debris torrent; elevation: 1,900 ft; source area: inner gorge in 50-year old forest, parent material: till/phyllite; sediment delivered to watercourse. Several small failures became a debris torrent that ran for 15,000 ft.
1984-1991	1. Shallow-rapid landslide/debris; elevation: 450 ft; source area: inner gorge in logged area, parent material: till; sediment delivered to watercourse. 2. Shallow-rapid landslide/debris; elevation: 550 ft; source area: inner gorge in logged area, parent material: till; sediment delivered to watercourse. 3. Shallow-rapid landslide/debris; elevation: 1,600 ft; source area: incised channel in 50-year old forest, parent material: till/phyllite; sediment delivered to watercourse. About 300 ft of channel destabilized. 4. Shallow-rapid landslide/debris; elevation: 2,200 ft; source area: incised channel in 50-year old forest, parent material: till/phyllite; sediment delivered to watercourse. About 400 ft of channel destabilized. 5. Shallow-rapid landslide/debris; elevation: 2,700 ft; source area: incised channel in 30-year old forest, parent material: till/phyllite; sediment delivered to watercourse. 6. Shallow-rapid landslide/debris; elevation: 3,500 ft; source area: road on headwall, parent material: phyllite; sediment possibly delivered to watercourse.
Note: Adapted from Form A-1 from Hansen WAU (DNR, 1994).	

As Table 2 indicates, there have been at least 14 landslides in the Coal Creek watershed, most of which delivered sediment to Coal Creek or its tributaries. It is also evident that landslide activity increased following forestry activities in the watershed. At least some of the 1983 mass wasting activity was likely triggered by a severe storm that occurred Jan. 9-10, 1983.

2.2.2 Coal Creek Minkler Road Sediment Basin Performance Review & Recommended Refinements (nhc, 2008)

This report was commissioned by Skagit County Department of Public Works in order to review the performance of the Minkler Road sediment basin. The report summarizes an engineering

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review of the sediment basin and includes recommended modifications to the basin to improve its reliability.

Sediment Delivery

An average sediment delivery rate was estimated for the Minkler Road sediment basin based on maintenance records from 1985 to 2005. These data are reproduced in the table below.

Table 3: Sediment Delivery Volumes and Rates (from nhc, 2008)

Period (years)	Estimate of Total Volume of Sediment Deposited Within Basin (yd^3)	Estimate of Average Annual Volume of Sediment Deposited within the Basin (yd^3/year)
1985 to 1991	21,000	3,500
1991 to 1996	15,000	3,000
1996 to 2005	30,000	3,300
	TOTAL = 66,000	**AVERAGE = 3,150**

The average sediment delivery rate to the basin is about 3,150 yd^3/year, although moderate to severe floods may deliver 2 to 3 times that volume in one event (nhc, 2008). Based on 4 grain-size samples, nhc reports that the sediment composition in the basin is an equal mix of sand and gravel with a small percentage (about 6%) of silt and clay-sized particles. Coarser sediment tends to accumulate near the bridge (cobble and larger gravel).

Basin Performance

The hydraulic performance of the basin was evaluated by developing a one-dimensional hydraulic model (HEC-RAS) of the sediment basin. The model was based on 2007 topographic survey. Instantaneous peak flows were estimated for Coal Creek based on USGS regional regression equations. Modeled flood profiles suggested that the Minkler Road Bridge could convey the estimated 2- and 10-year return period floods, but not larger events. In addition, the model cannot represent sediment deposition during flood events (i.e. the bed is fixed), which might lead to additional flooding issues even for the 2-year and 10-year return period floods.

NHC also identified a propensity for the channel to deposit sediment starting at the Minkler Road Bridge due to a sudden widening of the channel and decrease in gradient.

Recommendations

Channel modifications were recommended in order to reduce deposition at Minkler Road bridge, as summarized below:

- Reduce effective width of Minkler Road Bridge waterway.
- Reduce channel width downstream of Minkler Road Bridge.
- Re-grade channel invert and floor of sediment basin and remove peninsula access road.
- Do not remove existing concrete weir at downstream end of sediment basin.

It is understood that most of the recommendations have been implemented by Skagit County as of September 2010.

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2.3 Desktop Analysis and Field Visit

2.3.1 Reach Characterization

A longitudinal profile and characterization of Coal Creek was developed by NHC (2008).

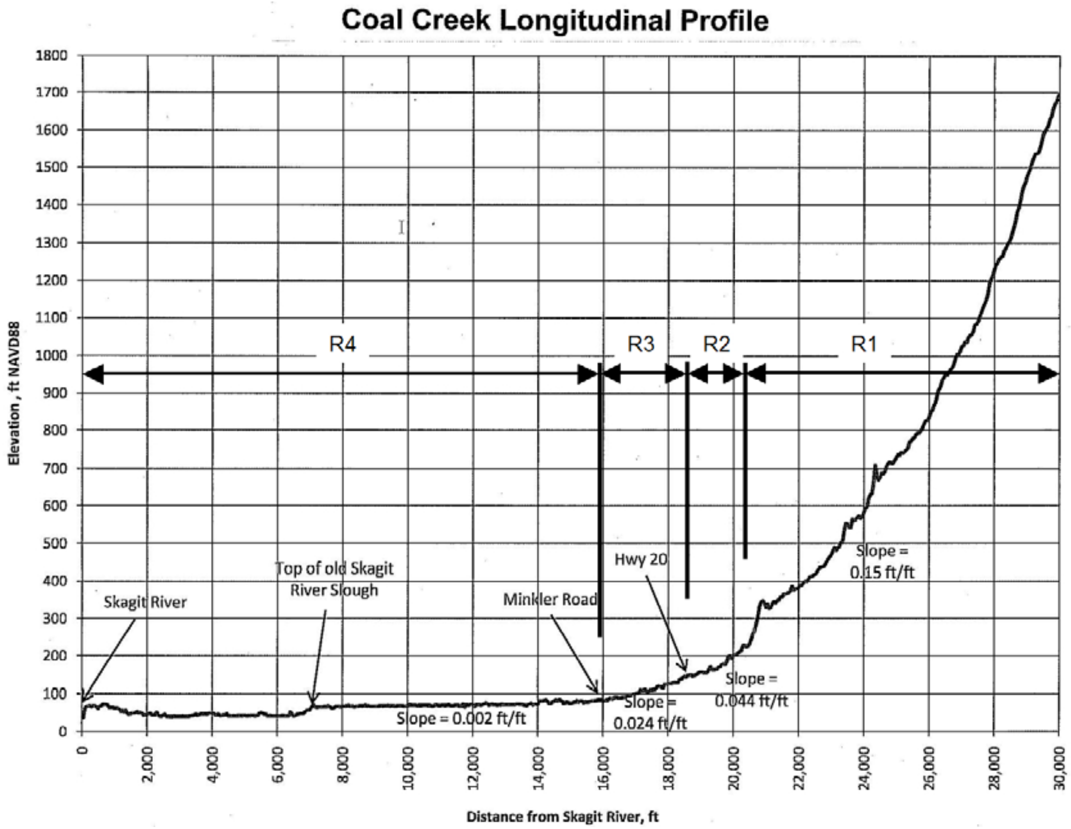

Diagram 2: Coal Creek Longitudinal Profile (modified from nhc, 2008)

Coal Creek has been divided into four characteristic reaches that are described below.

Reach 1 encompasses the entire upper Coal Creek basin to the fish passage barrier below the logging road bridge, with an average gradient of 0.15 ft/ft.

Reach 2 extends from approximately the fish passage barrier below the logging road bridge to State Route 20. This reach is about 2,000 feet in length and has an average gradient of 0.044 ft/ft.

Reach 3 extends from State Route 20 to Minkler Road. This reach is the active part of the alluvial fan and is a depositional reach. The creek bed material consists of a wide range of sediment sizes, from sand and smaller to large cobbles. The reach average gradient is much steeper than Reach 1, increasing to 0.024 ft/ft.

Reach 4, the lowest reach, begins at the confluence of Coal Creek with the Skagit River and extends to the sediment basin just south of Minkler Road. The creek gradient in this reach is extremely low (average slope about 0.002 ft/ft), as it flows across the Skagit Valley floodplain.

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The sediment basin is located within Reach 4, at the downstream-most limit of the Coal Creek alluvial fan where it transitions onto the Skagit River floodplain. The sediment basin also functions to moderate the creek gradient by arresting downstream transport of bedload sediment into the lower reach.

2.3.2 Air Photo and LIDAR Observations

Sediment sources and watershed and channel morphology were investigated using 2007 DNR air photos, 2004, 2005, and 2009 USDA orthophotos and LiDAR elevation data.

A review of 2007 air photos shows different vegetation types occurring throughout the watershed. Some of the observed variation may be the result of past logging activities, but most of the variation in vegetation types is likely related to unstable slopes and the presence of water (perennial seeps, shallow ground water, and wetlands) because of their spatial distribution. The 2009 USDA orthophotos did not reveal any massive scars from mass wasting events, nor did the 2008 stereophoto graphs (WSDOT) that we assessed. Oblique 2008 Pictometry images did reveal some destabilized slopes, but image coverage was limited.

We observed numerous and expansive scarps and sag features on the USGS 2006 LiDAR data set, located within the Vashon Stade glacial deposits. We interpret that there are two prominent deep-seated landslide basins within the watershed and that many secondary slope instability landforms exist. Cross sections and profiles were extracted from the LiDAR in each of these slides (west slide and east slide) (Appendix A-Figure 8 and Figure 9). The east slide basin (Appendix A-Figure 9) appears older and more material seems to have been evacuated from this basin, leaving a concave profile and cross-section. The debris runout from this slide appears to have disrupted and disturbed the channel network and parallel rill-type channel morphology through the slide debris can be observed on the LiDAR. We interpret that the stream channels in this reach are actively incising into this deposit.

The west landslide basin (Appendix A-Figure 9) appears to be more recent and less mature as demonstrated by a more convex cross section and profile. We interpret that the west landslide mass moves intermittently, possibly as a translational slide evolving into a flow in its lower reaches, and that it may migrate either as a slow creep or intermittently. The headscarp of the west slide shows close to a hundred feet of vertical displacement as measured from the LiDAR, and air photography revealed that the scarp was vegetated (and recently logged). Occasional damage to the forestry road (John Gold, personal communication) suggests that minor movement of the slide mass occurs periodically.

The material from the east and west landslide basins does not appear to have reached the valley bottom en masse; rather it appears to have deposited mid-basin. Observations suggest that the slide mass has forced the creek toward the opposite (southeast) bank. This has caused considerable erosion and destabilized the slopes that the creek has been forced against.

The erosion and destabilized slopes in this area are interpreted to be the largest source of sediment being delivered to Coal Creek at this point in time, based on observations made from air photo and LiDAR analysis. Storm events and debris flows may periodically bring in larger sediment quantities, but the on-going contribution of sediment from the erosion and

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destabilized slopes reaching the upper parts of the basin appears to contribute sediment regularly. The steep and extensive stream incision is evidence that it has been a long-term, on-going occurrence.

2.3.3 Field Observations

Physical field inspection of Coal Creek watershed between the Minkler Road sediment trap and the upper watershed was conducted to characterize the channel and sediment conditions. Field visits were conducted on August 18, 2010, and September 21-22, 2010. Field observations are recorded in Appendix D, and are summarized below by reach.

Reach 1(a): Upper Watershed to Chuckanut Canyon (Darrington Phyllite)

We observed that sediment throughout this reach is being recruited by the stream and that instream storage of sediment is virtually unlimited. Evidence of slope instability, both deep-seated and shallow, was widespread and in many instances, very recent and occasionally still active.

While sediment contribution was evident throughout the basin, more pronounced sediment delivery from several landslide point sources was observed in the area we interpret as the landslide toe/lateral migration of the channel based on LiDAR (see Section 2.3.1). One reach in particular had many hundred continuous feet of unstable slope on both sides of the channel that were delivering significant quantities of sediment from oversteepened, high stream banks. The creek banks are largely unvegetated and were observed to be unraveling into the stream during our field visit.

We estimate that sediment sources in this reach are delivering thousands of cubic yards of sediment per year to the creek, and that more sediment is being delivered to the channel than is being transported downstream during a normal annual range of clear-water discharges. A convex "bulge" in the stream profile supports this hypothesis. The bulge is interpreted to be a deposit of material built-up in the channel due to sediment supply exceeding the transport rate.

We observed that in-stream wood deposited naturally is effectively storing large quantities of sediment, the volume of which is unknown, but likely significant. It is anticipated that this sediment may become transportable during large discharge events or debris flows (which might destabilize the wood), or as the wood rots.

The unstable stream and slope conditions create situations in which the potential for debris flows is likely high.

Additional observations include:

- The slide mass contained protruding wood debris.
- The scarp area of the west slide basin was vegetated with 50- to 60-year old trees.
- Old growth stumps were located on the interpreted slide runout deposit from the east slide basin. The stumps showed spring-board notches and were likely harvested in the early 1900's and exported by the relict railway we observed. Assuming these stumps are

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approximately 500 years in age, plus the time since they were felled, the landslide runout occurred at least 500 years before present.

Reach 1(b): Chuckanut Canyon to SR 20 Bridge (Chuckanut Formation and Glacial Sediment)

This reach is characterized by abundant poorly-sorted and weakly armored in-channel sediment dominated by Darrington Phyllite provenance. Outside of the wetted perimeter, bed armoring was lacking and abundant loose deposits of phyllite were prevalent. There is little evidence of bank erosion in this reach, although an unstable slope approximately 1000 feet upstream of State Route 20 Bridge does contribute some sediment to the system but relative to the contributions upstream, these volumes are minimal.

Several debris dam/sediment wedges consisting of several thousand cubic yards of sediment were observed. In addition, we observed evidence that minor shallow-rapid failures (volumes approximately 10-50 yd^3 per event) had occurred in the recent past. Evidence of episodic debris flows is found throughout the reach with numerous large boulders deposited in the channel. Boulder sizes ranged from 3 to 6 ft on average (1-2 m) with a maximum diameter exceeding 12 ft (4 m). Boulder size and number increased with distance upstream. Cross sections of sediment deposits showed inverse sorting, which is consistent with debris flow deposits. Boulder lithologies were predominantly granites (glacial erratics) and Chuckanut sandstone. Frequency of debris flows is unknown, but we estimate that the most recent event of significant size occurred approximately 15 years ago based on tree growth on the depositional terrace.

The lack of strong channel armoring in this reach suggests that the creek is in this reach transport-limited (i.e. that the supply of sediment is greater than the creek's ability to transport it). The grain size distribution is consistent with sediment sizes from the Minkler Road sediment trap (estimated at 0.5" - 4" diameter b-axis), although a greater fraction of larger material is also evident in the channel. Larger debris flows have deposited in this reach, forming terraces just below the Chuckanut Canyon. The sediment source in this reach is primarily the abundant in-channel sediment deposits with minor episodic inputs from adjacent hillslopes.

Reach 2: Fish passage barrier (below logging road bridge) to SR 20 Bridge

We observed that this reach acts primarily as a transport reach with gradients and confinement sufficient enough to pass most sediment. Older forested terraces well above the channel and ordinary high water and large diameter boulder lag within the channel suggest that this reach is occasionally impacted by very large debris flow events. Some minor erosion of glacial sediments and alluvial sediment banks by lateral erosion and evidence of some sediment contribution by mass wasting was observed locally.

Reach 3: SR 20 Bridge to Minkler Road (modern, active alluvial fan reach)

The modern, active Coal Creek alluvial fan is a fairly low gradient alluvial fan. This is not uncommon in streams that have Darrington Phyllite geology in the upper basin. The phyllite tends to have a finer matrix which affects viscosity and results in lower gradient alluvial fans (personal observations, Jones and McCarty Creeks). The surface of the alluvial fan shows evidence of past events. We did not perform a subsurface exploration nor assess the alluvial fan surface beyond the stream. We understand that WSDOT has had to repair the SR20 Bridge from

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scour. It is not uncommon for alluvial fans to go through periods of incision in between intervals of deposition (personal observation, Canyon Creek).

Reach 4: Minkler Road to Skagit River

This reach was not necessarily within the scope of assessing sediment input. This reach is low gradient and does receive fine grained and suspended sediment loads that pass through the alluvial fan reach and Minkler sediment trap. Sediment deposition is not the primary driver of channel morphology in this reach.

Summary

The chronic deposition of bedload sediment that the County has observed at the Minkler Road sediment trap results from the abundant sediment sources in the upper watershed. Sediment sources include widespread mass wasting, incision of streambed sediments and recruitment of poorly consolidated colluvium that unravels into the channel as banks are undercut. Much of the colluvium in the upper watershed (Reach 1) is part of a landslide mass, which continues to deform as a slow-creep flow that may intermittently change velocity or move more abruptly under certain conditions. The evidence of debris flows observed in the field and documented in the WAU indicates that sediment delivery to Coal Creek may also occur in episodic large pulses.

The sediment supply from the upper watershed of Coal Creek is essentially unlimited, meaning that sediment transport in the creek is limited only by the available stream power (a function of discharge and gradient). Periodically, debris flows transport greater quantities of material. Debris flows have reached at least as far as the logging road bridge and significant flows likely reach the alluvial fan.

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3 Sediment Budget

As identified in Section 2, the sediment supply to Coal Creek is high and cannot be traced to one or a few discrete point sources. The sediment transported and deposited in the lower reaches of the creek is a function of the transport capacity of the creek, rather than being limited by the supply of available material. In light of this finding, the best estimate of a sediment budget for the creek will come from the maintenance records of the Minkler Road sediment basin as well as the upstream reach extending from Minkler Road to SR 20.

nhc (2008) has previously estimated the average deposition rate in the sediment basin to be about 3,150 yd^3/year. This figure is based on removal records for the basin itself. It is understood that additional dredging was performed in the channel upstream of Minkler Road. Skagit County did not have records of volumes removed upstream of Minkler Road, therefore the actual average rates may be slightly higher. On a year-by-year basis, rates may fluctuate and infrequent debris flows may produce significantly more sediment in a short period of time. The average deposition rate is equivalent to several feet of deposition over the entire area of the sediment basin (2010 footprint).

The average sediment transport rate should be viewed as a lower-bound estimate since a certain portion of the sediment carried by the creek will likely be transported past the basin and deposited downstream (fine-grained and suspended load sediments). In addition, it should be understood that sediment transport is highly dependent on discharge and that large floods may result in transport rates that are significantly higher than average.

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4 Fish Habitat Assessment

A habitat and large woody debris assessment of the alluvial fan and sediment trap reach of Coal Creek was conducted to inform future sediment management strategies and possible restoration efforts, using the Timber-Fish-Wildlife monitoring protocol (Pleus et al. 1999; Schuett-Hames et al. 1999). The complete habitat assessment is presented in Appendix C.

The habitat assessment was conducted on July 27th and 18th, 2010 and covered approximately 5,000 linear feet of channel beginning approximately 330 ft (100 m) downstream of the Minkler Road sediment trap and extending to approximately 2,500 ft (760 m) upstream of the State Route 20 Bridge (Appendix C-Figure 1). The habitat survey ended at a major fish passage barrier (6 m high falls), which marks the upstream extent of usable habitat by anadromous fish.

The assessment was conducted in two phases:

1) identification and measurements of all habitat units, and
2) survey of large woody debris (LWD), spawning habitat, and stream slope.

Several instream characteristics were measured for each habitat unit including: type, length, width, pool depths, bank vegetation, canopy cover, and sediment type. Transects of channel cross-sections were measured every 20 habitat units and bankfull width and depth, wetted width and depth, Wolman Pebble Counts, and latitude/longitude were characterized and recorded. Transects were located both by handheld GPS and by using a hip chain. The data collected in the survey is identified by reach as defined by the upper and lower transect. The survey results were entered into a database with associated polyline for use in GIS.

Fish Habitat Summary

Diverse instream and riparian conditions were identified in the surveyed reach of Coal Creek. The canopy and riparian vegetation were largely intact along most of the creek, providing shade that can mitigate high stream temperatures. Several reaches, especially downstream of the sediment trap and upstream of the State Route 20 Bridge, could provide good to excellent spawning and rearing habitat for salmon. Active sediment recruitment to the surveyed reach was evident at a few notably eroded banks upstream of State Route 20 and along some parts of the channelized/straightened reaches just upstream of Minkler Road.

Instream sediment below the Coal Creek sediment trap, (Habitat Reach A), was primarily composed of gravels and small cobbles creating an armored layer with a high percent of embeddedness (the degree of saturation of interstitial spaces by sediment (Waters, 1995)). The gradient was lower along this reach than the other reaches measured in this study. Few pieces of LWD in the stream or within the bankfull area were identified downstream of the sediment trap. Many small schools of Coho salmon were observed within the 1985 sediment trap footprint downstream of the current sediment management area and upstream of the lower concrete weir.

Upstream of Minkler Road (Habitat Reaches B – F), the stream was often highly channelized and composed mostly of riffle habitats. Habitat diversity was low, with limited pools and/or cascades. The sediment size was generally larger than downstream of the sediment basin

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(cobbles and gravels), but was consistently embedded with fines. Fewer fish were observed in these reaches than downstream of the sediment pond.

Upstream of SR 20, the sediment size, gradient, number of pieces of LWD, and number of habitat units per unit length of channel increased (Habitat Reaches G – K). Instream habitat included diverse habitat sub-units such as falls, cascades, and plunge pools. Although the sediment size increased and included boulders and bedrock, the sediment still contained fines and was 34% - 55% embedded in these reaches. The bankfull channel was often wider than the current stream channel and contained piles of easily mobilized gravels and cobbles and smaller LWD.

Conclusion

The most habitat impaired reach is between SR 20 and Minkler Road. Lack of channel complexity and substrate embeddeness were the primary conditions responsible for creating low habitat value in this reach. Habitat conditions upstream of SR 20 and downstream of Minkler Road were less impaired with more diverse habitat conditions and thus the habitat value is higher.

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5 Alternatives Identification and Analysis

A number of management alternatives have been developed for Coal Creek. In general, it is assumed that the intended objective of Skagit County is to manage on-going deposition in Coal Creek with the goal of avoiding flooding at Minkler Road. Sediment management alternatives are summarized below. One additional management alternative is provided in section 5.2, which deals with management of larger events such as potential debris flows. Summarized planning level cost are presented in Table 5-1.

5.1 Sediment Management Alternatives

Eight sediment management alternatives are described below.

1) No Action

If Skagit County were to cease managing sediment in Coal Creek, the Minkler Road basin would eventually fill in to the point that overbank flooding at or near the bridge would result. Therefore, this option is not likely to be acceptable to the County.

2) Stabilization of Upper Watershed Sediment Sources

The WDFW has suggested the possibility of building log-jam/boulder structures in the upper watershed to retain sediment in the upper watershed. These sorts of features form naturally in Coal Creek and were observed during fieldwork. The structures essentially form a low weir in the channel, which allows material to deposit on the upstream side, leading to the formation of sediment 'wedges' in the channel.

Although log-jam/boulder structures do form naturally in Coal Creek and act to retain sediment in the channel, ultimately the logs will gradually rot and compromise the stability of the structure. It is therefore likely that the structure will fail eventually, and release the impounded sediment. Since a failure is more likely to occur under high flow conditions (when forces exerted on the structure will be greatest), the sediment that is released will have a high likelihood of being mobilized and moved down the system. Although it is not possible to predict, such failures might result in larger-scale destabilization of the streambed.

Given the likely eventual failure of these structures, there are legal implications for the County if the structures are man-made rather than forming naturally. For this reason, this option is not likely to be acceptable to the County.

3) Relocate Sediment Basin

The reach of creek downstream of Minkler Road has been identified as good to excellent spawning and rearing habitat for salmon. In comparison, the reach upstream of SR20 is somewhat lower value habitat for spawning and rearing. One option might be to relocate the sediment basin further upstream to near the fan apex, so that ongoing management activities are located in a lower habitat value reach. As well as halting (or dramatically minimizing) disturbance to the reach of channel downstream of Minkler Road, this would also greatly reduce the need for channel dredging between SR20 and Minkler Road.

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The creek profile shows a notable break at the SR20 Bridge (Figure 2), which suggests that sediment deposition would begin to occur naturally at this location. Interestingly, the SR20 Bridge has historically had scour issues. This suggests that material may accumulate transiently at the fan apex, and then be mobilized downstream as sediment supply declines (e.g. during a period of lower flows).

In order to relocate the basin, space would need to be provided to widen the channel and provide an area for material to deposit and accumulate. This may be difficult in the vicinity of SR20 as there is private property on both banks of the creek upstream and downstream of the highway. The basin would need to be sized based on the County's proposed schedule of maintenance, as well as with consideration of likely sediment delivery. A relatively greater volume of sediment may be expected as this location, since the basin would be capturing sediment that would otherwise have deposited in the reach between SR20 and Minkler Road, as well as sediment that would have deposited in the Minkler Road basin. In addition, on-going monitoring of the basin and the downstream reaches would be prudent, to assess the response of downstream reaches to the interruption of sediment supply.

4) Modify Existing Maintenance Strategy

Historically, sediment has been removed from the Minkler Road Basin at least five times since 1985, including two recent channel removals in 2009 and 2010. The removals prior to 2009 were fairly spread out over time, were relatively large (15,000 yd^3 to 30,000 yd^3), and involved disturbance of a relatively large area within the basin. The 2009 and 2010 removals were significantly smaller (approximately 3,000 yd^3) and impacted a smaller footprint. In addition, the County or private entities have dredged the channel between SR20 and Minkler Road. It is not known how frequently this was done, nor were the volumes quantified.

The historic maintenance strategy can be considered to be of two strategies; a "less-frequent but large disturbance" approach, and a "more frequent but smaller disturbance" approach. The impacts of each have not been fully quantified, but the more frequent, smaller disturbance approach is currently the one favored by WDFW as specified in the 2009 HPA. This option may have slightly higher associated costs for the County (given the increased mobilization/ demobilization costs of conducting annual removals), but this is likely minimal.

5) Infrastructure Abandonment

By removing the bridge at Minkler Road, the County would essentially have eliminated the flooding concern at the bridge. Overbank flooding that might result from sediment accumulation in the channel could conceivably be considered to be a natural process that may alleviate some of the County's responsibility. For this analysis, we evaluated the travel times for bridge removal given four scenarios (Appendix A-Figure 11). However, given that the area on both banks of the creek is inhabited and that once infrastructure is removed it is extremely costly to reinstall it, bridge removal is not a viable option from the County's perspective.

6) Infrastructure Improvements

The Minkler Road Bridge currently has about 3 to 4 ft freeboard above the bed following the 2010 sediment removal. When the creek was surveyed in 2007, the freeboard was approximately 2.5 ft (nhc, 2008). As identified by nhc, modeling indicated that at the time of survey, the bridge could convey the estimated 2-year and 10-year return period floods but nothing greater. Since the sediment management activities in the creek are driven by a need to manage flooding at Minkler Road, one option is to raise the bridge in order to improve flow conveyance.

The bridge would need to be re-designed to the appropriate return period flood profile, and would include an allowance for sedimentation in addition to freeboard. As well as greatly reducing the frequency with which sediment management would have to be performed in the creek, raising the bridge would also make it much more practical to manage sediment in the immediate vicinity of the bridge since it is currently impossible to access the sediment deposited under the bridge using a machine.

7) Create Setback Levees

The sedimentation in Coal Creek is aggravated by the fact that the creek is constrained within narrow levees, which do not allow for natural alluvial fan processes to occur. By confining deposition to within the existing creek channel, the rate of aggradation is increased artificially and translated downstream to the Minkler Road area. By setting back the levees, the creek would be allowed to overflow its banks and deposit material on the alluvial fan floodplain. This would provide a much larger area for storage of material, as well as dramatically increasing the flood conveyance. This option has been implemented at nearby Hansen Creek.

The primary disadvantage to this option is that a very large amount of private property acquisition is required in order to be able to set back the levees from the creek. It might be possible to apply this concept in a limited fashion in the reach immediately downstream of SR 20 on the left bank (east of the creek) where impacts do not include structures. For this analysis we created two conceptual setback levee alignments to evaluate potential storage areas and costs (Appendix A-Figure 12). The primary cost differences are related to real estate purchases. Maintenance of levees would be necessary over time, and in addition to constructing a new left bank setback levee, improvements to the existing right bank levee may be needed. Maintenance of the existing stockpiles levees are, in theory, necessary under the existing management and yet the levees have not required much maintenance in the past years, therefore maintenance of new or improved levees could be infrequent.

8) Forestry Land Use Management

The upper watershed consists of commercial forestry properties. Forest practices are regulated by the Department of Natural Resources. Forestry harvests in the watershed appear to have peaked in the 1960’s and 1970’s. In recent years, the Timber Fish and Wildlife program has led to forest practice rules which are much more stringent than past rules and forest practices in areas with unstable slopes now require more scrutiny (Class IV Specials). As such, the County has the ability to provide comment to forest applications.

Much of the watershed has not been harvested within the past few decades, so in theory, basin hydrology is recovering as is root strength when compared to the post 1970’s watershed conditions. The recent harvests we did observe had been replanted per regulatory prescription. Areas we observed that were unvegetated and had exposed soils adjacent to the creek would be challenging to stabilize with plantings due to the rate of creek and slope movement and the

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depth at which movements were occurring. We observed many older established trees tipped or disturbed by recent slope movements. Tree root strength takes years to establish and typically extends only to depths of 6 feet (2 meters) or less; therefore it is less effective at stabilizing larger mass wasting occurrences, and scientific literature has not definitively linked deep-seated landslide activity to logging activities.

5.2 Hazard Mitigation Alternatives

Another option is presented below, which deals with both sediment management from fluvial processes as well as addressing the debris flow hazard.

9) Debris Basin

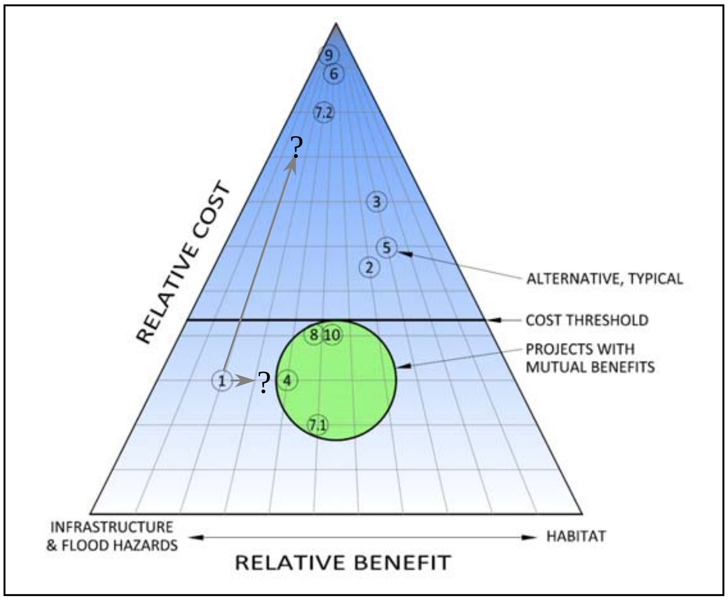
Constructing a large debris basin can be used as a tool to manage both sediment and debris flow hazards. The costs of these facilities are significant and were beyond the scope of the problem addressed in this analysis. The alluvial fan risk is unknown and it is likely that the cost of the structure is outside of Skagit County's ability, therefore this alternative was not assessed further at this time.

10) Land Use Regulations

Land use regulations aimed at addressing geologic hazards on alluvial fans are already being implemented through the Critical Areas Ordinance. Management of risk by reducing the consequences through land use is a cost effective and meaningful management strategy. Where development is to occur, requiring the development to mitigate for the hazards is another way to manage risk.

5.3 Alternatives Analysis

The eight sediment management alternatives were considered for their ability to meet the objectives and fit within the fiscal abilities of Skagit County. In general, we observed that some alternatives provide benefits to only one objective. For example, an alternative that focuses exclusively on management of sediment may not address any of the fisheries objectives. Conversely, an alternative that focuses only on habitat may not adequately address the sediment issues. The alternative or alternatives that best meet more than one objective are ones with mutual benefits and offer some degree of compromise between conflicting objectives.



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Of these alternatives that provided mutual benefits, we identified options that were financially viable given our understanding of Skagit County's resources. Table 5-1 shows the planning level costs of each alternative. For Alternative 7 (setback levees), two planning level costs were generated for two conceptual alignments (Appendix A-Figure12) in order to provide a range of cost potential since no levee alignment has been defined.

Of the eight alternatives we identified, we found that the setback levee alternative used in combination with the frequent but small footprint sediment removal offered the greatest mutual benefits to Skagit County and the stakeholders. These combined alternatives provide:

1. flood hazard benefits by being able to contain larger flood events and sediment discharges,
2. sediment storage on the floodplain so that less sediment is transported downstream to the Minkler Road sediment basin, therefore decreasing maintenance volumes and possibly frequency,
3. increased natural processes in the most impaired habitat within the assessment area of Coal Creek
4. potential for restoration opportunities such as engineered log jams and riparian planting

In addition to pursuing the active management strategies described above, passive management strategies should be part of the overall management strategy. While management of sediment in the upper watershed does not appear to be a feasible alternative given the scale and degree of long-term instability; supporting and encouraging conservative forest practices in order to reduce the potential impacts is an action that Skagit County could pursue by working with upland land owners. On the alluvial fan, Skagit County can continue to administer the Critical Areas Ordinance and try to minimize risk on the alluvial fan through regulatory controls. Future development proposals on the alluvial fan should consider the hazards and risks that are present and mitigate accordingly.

Through the implementation of any management strategy for a dynamic system, adaptations may be needed as changes to the system, or the regulatory environment, occur. At such time, alternatives currently excluded as not feasible, may become feasible, or alternatives not identified may be needed. Given the ability to look forward in the short-term, changes to sediment removals is one project element that will need ongoing adjustments. In addition, evaluating habitat conditions will also need frequent consideration. Pursuing a monitoring program and periodic review of management practices should be part of the overall management strategy.

TABLE 4: Summarized Planning Level Costs

Alternative Description / Assumptions	*Qty.*		*Cost per Unit*			*Extended Planning Level Cost Estimate*
1 - No Action						
Flooding and road closures and damages					$	Unknown
2 - Stabilization of Upper Watershed Sediment Sources						
2.1 Log-jam/boulder structures in upper water shed	100	$	4,000	EACH	$	400,000
2.2 Engineering, permitting, and construction management	1	$	20,000	LS	$	20,000
Alternative Subtotal					**$**	**420,000**
3 - Relocate Sediment Basin						
3.1 Property acquisition (approx. 12 Acres)	12	$	5,000	ACRE	$	60,000
3.2 Grade Control Structures (Soldier pile wall and wood lagging) construction	1000	$	475	LF	$	475,000
Engineering and permitting	1	$	25,000	LS	$	25,000
3.3 Continued maintenance costs	10	$	3,000	YEAR	$	30,000
Alternative Subtotal					**$**	**590,000**
4 - Modify Existing Maintenance Strategy						
4.1 More frequent dredging and material handing (3,000 CY per year for 10 years)	30000	$	8	CY	$	240,000
Alternative Subtotal					**$**	**240,000**
5 - Infrastructure Abandonment						
5.1 Minkler Road bridge removal & road closure, traffic barricade / signage construction	1	$	350,000	LS	$	350,000
5.2 Engineering, permitting, and construction management	1	$	50,000	LS	$	50,000
Alternative Subtotal					**$**	**400,000**
6 - Infrastructure Improvements						
6.1 Raise Minkler Road bridge 4-ft in elevation and increase span to 100-ft. Bridge abutments and adjacent Minkler Roadway reconstruction.	1	$	2,500,000	LS	$	2,500,000
6.2 Right of acquisition if necessary	1	$	50,000	LS	$	50,000
6.3 Engineering, permitting, and construction management	1	$	150,000	LS	$	150,000
Alternative Subtotal					**$**	**2,700,000**
7 - Setback Levees						
Levee Alignment Option 1 (200-ft east offset from Coal Ck.)						
7.1 Levee Construction	2700	$	41	LF	$	110,700
7.2 Engineering, survey, permitting	1	$	40,000	LS	$	40,000
7.3 Property or easement acquisition (County Assessor market values / acre)	10	$	5,000	ACRE	$	50,000
Alternative Subtotal					**$**	**200,700**
Levee Alignment Option 2 (1200-ft east offset from Coal Ck.)						
7.1 Levee Construction	2500	$	41	LF	$	102,500
7.2 Engineering, survey, permitting	1	$	40,000	LS	$	40,000
7.3 Property / easement acquisition (County Assessor market values)	1	$	1,000,000	LS	$	1,000,000
Alternative Subtotal					**$**	**1,142,500**
8 - Forestry Land Use Management						
8.1 Follow FPA rules (DNR)					$	**0**

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6 Summary and Recommendations

6.1 Summary

The key points in this reports are summarized as follows:

Coal Creek

1. The upper watershed of Coal Creek is steep and on unstable geology.
2. Mass wasting, stream incision, and erosion contribute virtually unlimited sediment supply to Coal Creek.
3. Approximately 3,100 cubic yards of bedload sediment per year on average is delivered to the alluvial fan and deposited in the Minkler Road sediment basin area.
4. Sediment volumes in excess of this as driven by flooding or debris flows can occur and are anticipated.
5. Bedload sediment contributes to rapid channel bed aggradation in the Minkler Road reach and results in reduced channel capacity and exacerbates flooding.

Management

1. Skagit County Public Works constructed the Minkler Road sediment basin in 1985 and has conducted sediment removals in order to reduce damages to Minkler Road and private properties.
2. Environmental permitting objectives have changed over this time and in 2009 a HPA permit condition required a re-evaluation of management the strategy and consideration of alternatives.
3. A watershed-scale analysis that considered sediment sources, sediment transport, sediment deposition, and fish habitat was conducted and 10 alternatives were developed.
4. A planning-level alternatives analysis was conducted to determine which alternatives best met the objectives of Skagit County and the stakeholders.
5. Integration of two alternatives implemented concurrently appear to best address the overall project objectives: setback levees and sediment removals downstream of Minkler Road.

6.2 Recommendations

It is recommended that Skagit County consider the following management strategy to best address the overall project objectives:

1. Work with property owners to identify potential voluntary property acquisition for a setback levee
2. Use the outcome of this to define a setback levee alignment
3. Work with the stakeholders to develop and evaluate the setback levee design and seek potential funding sources and strategies to enable project implementation

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4. Continue frequent and small impact area sediment removals downstream of Minkler Road consistent with the 2009 HPA requirements
5. Consider land-use regulations or other risk reduction measures to address the Coal Creek alluvial fan hazards
6. Implement a monitoring and adaptive management program.

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Appendix A

Figures

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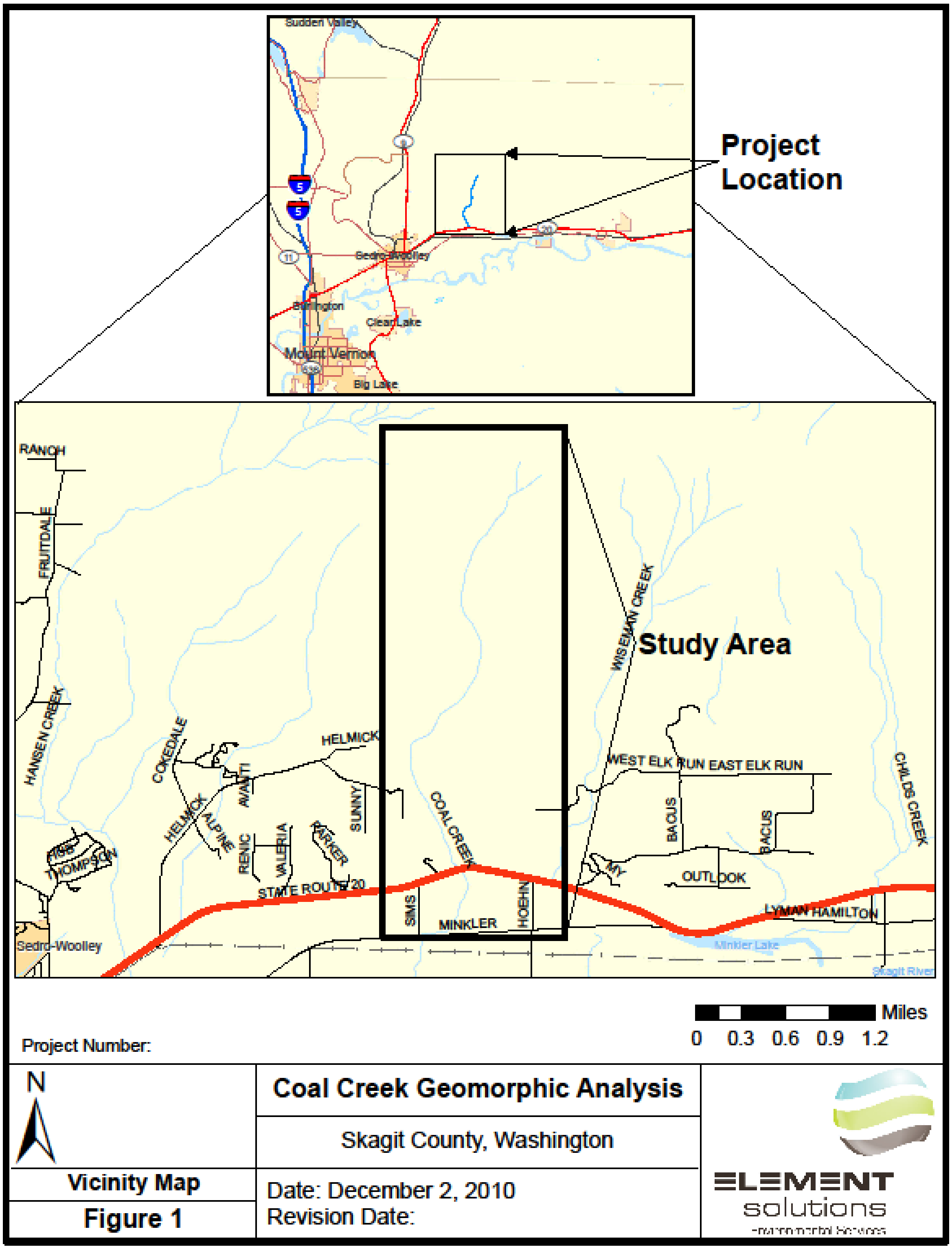

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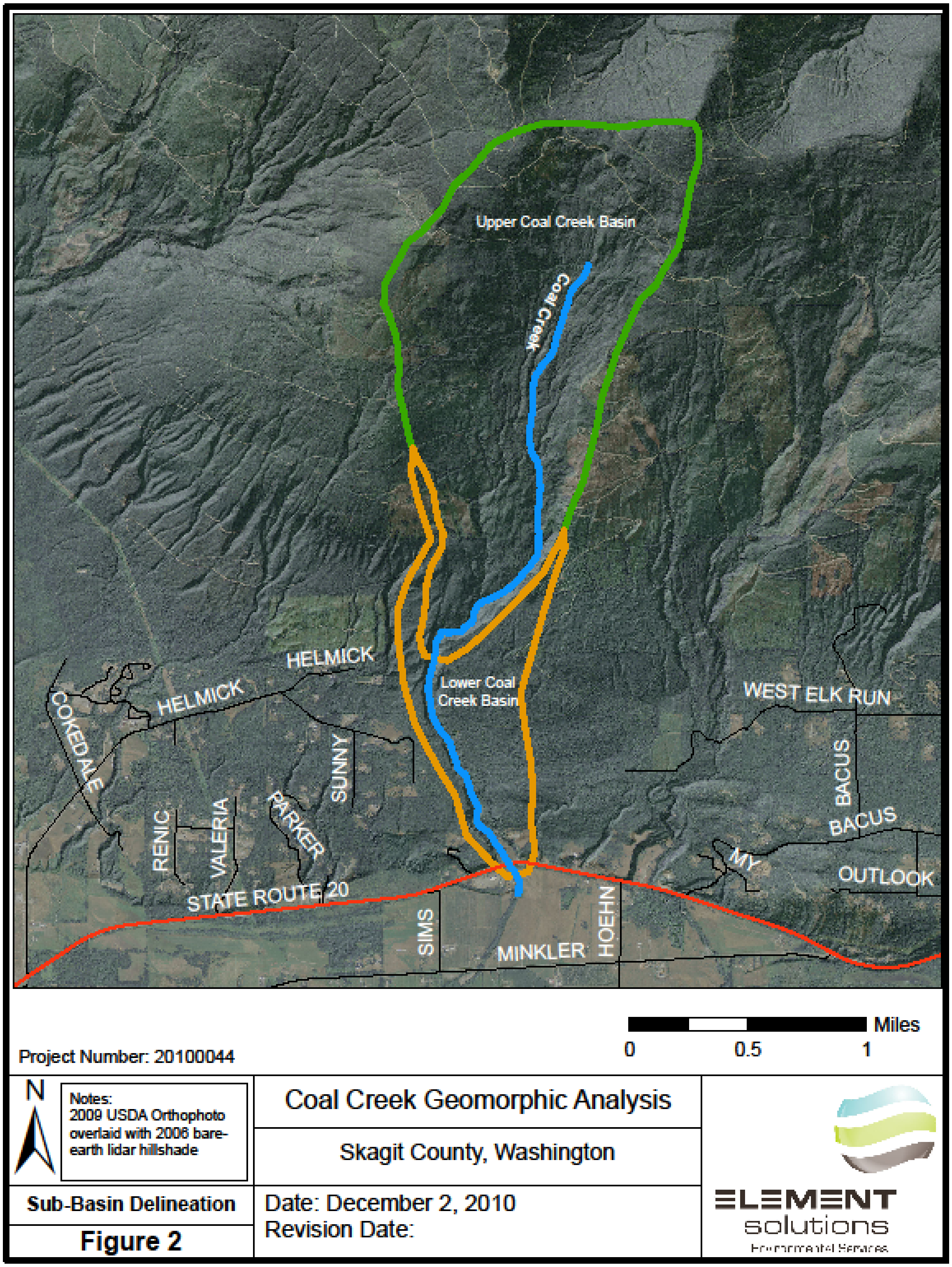

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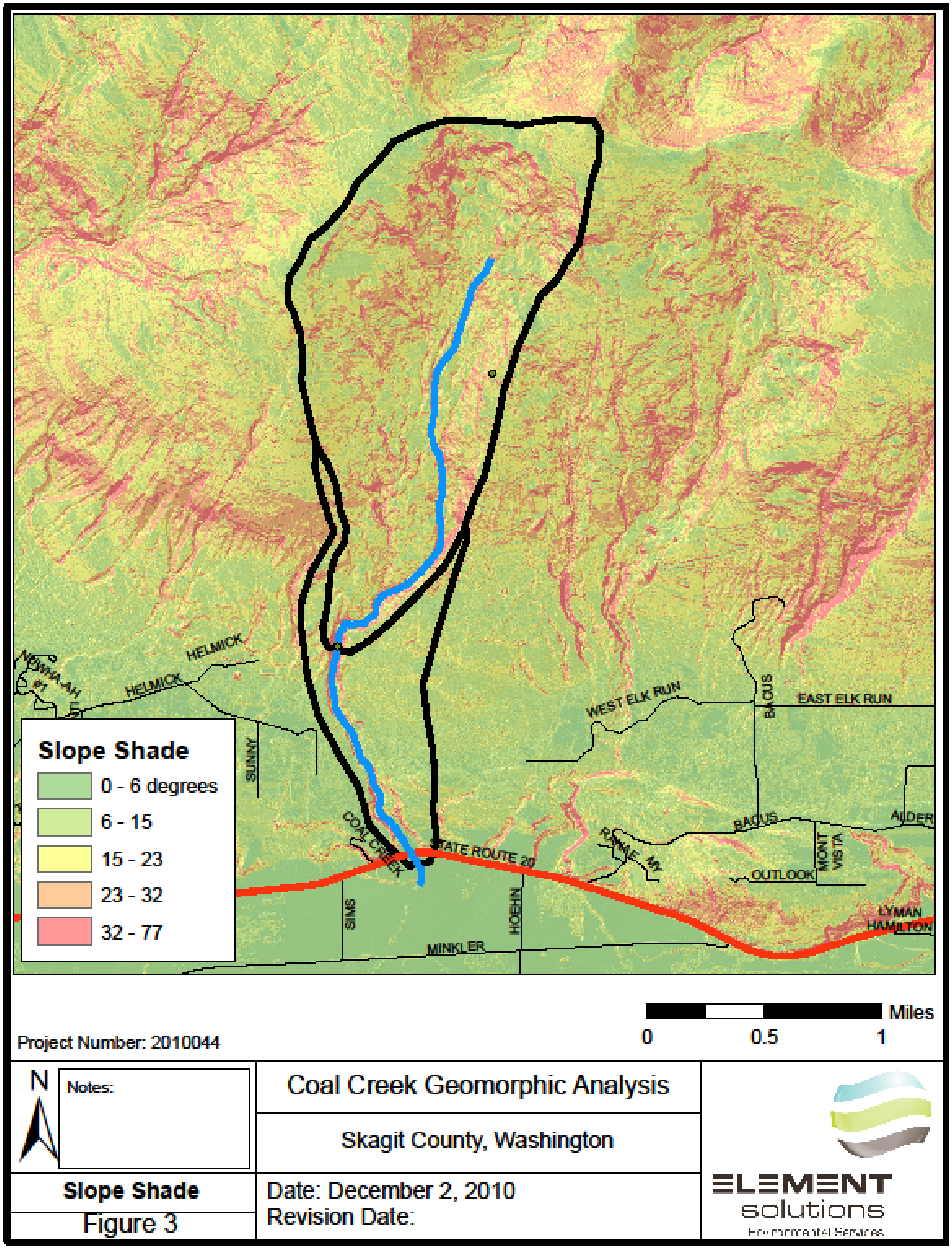

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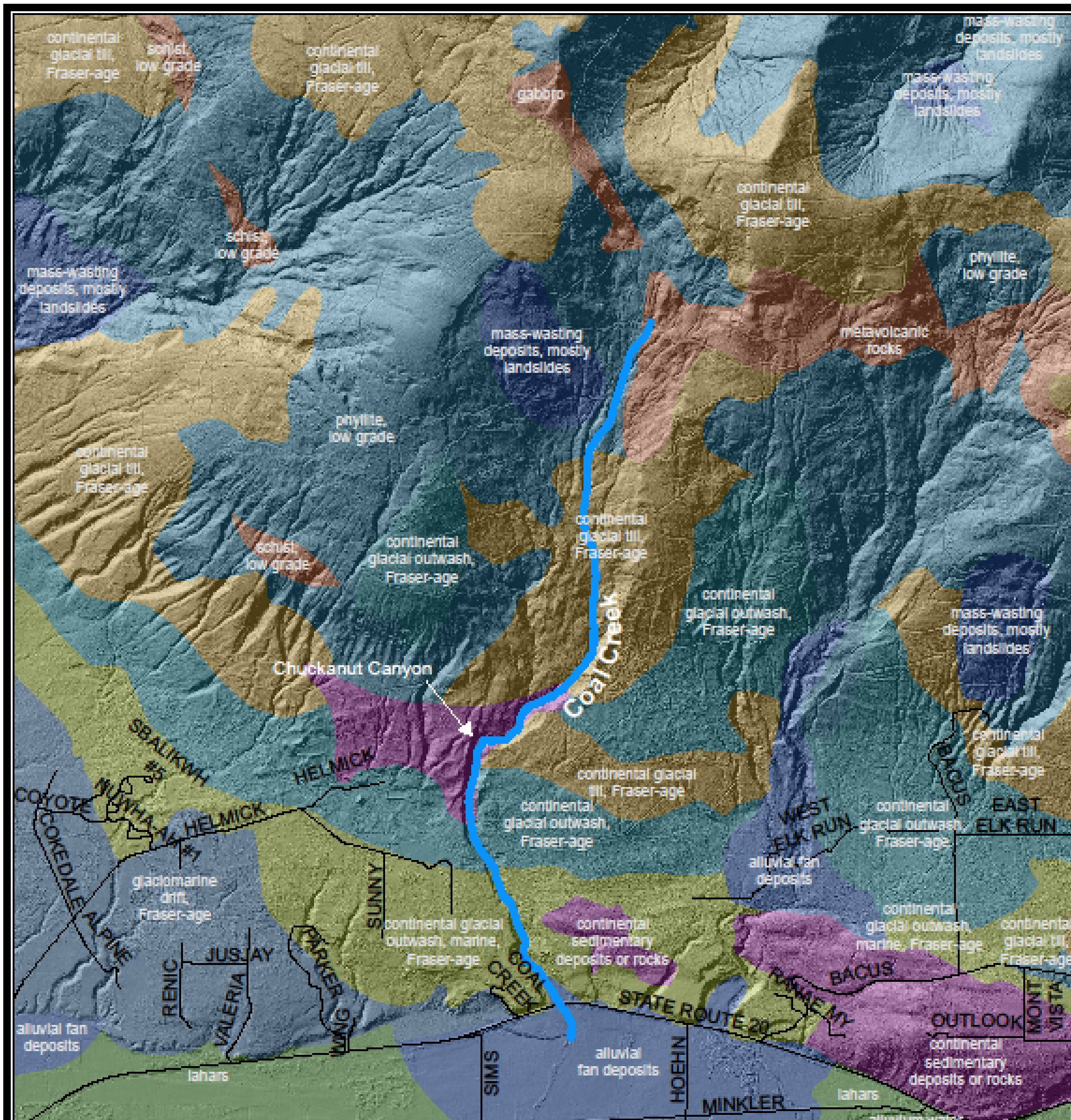

Project Number: 2010044

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Coal Creek Geomorphic Analysis

Skagit County, Washington

Geology

Figure 4

Date: December 2, 2010
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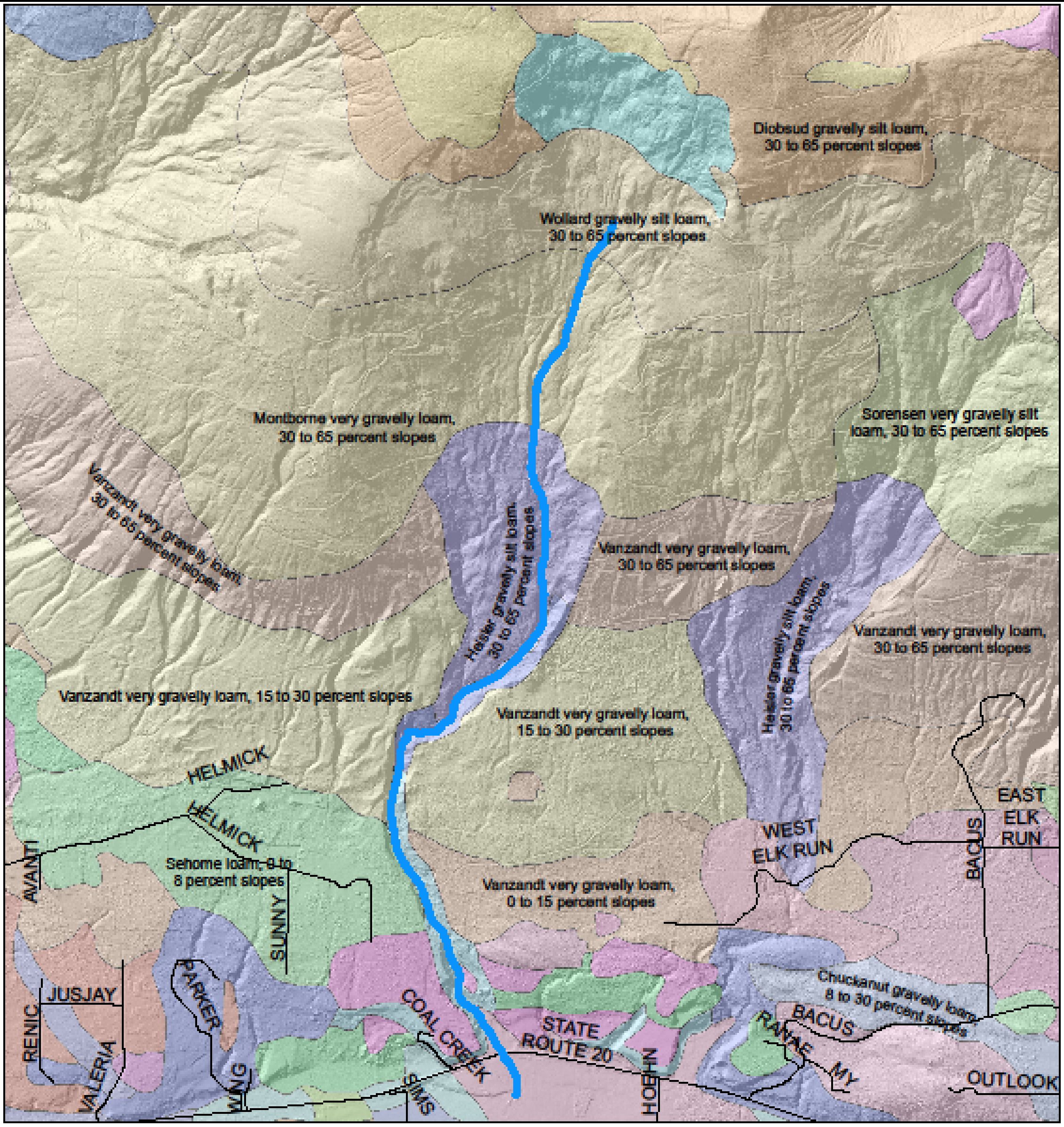

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Notes:

Coal Creek Geomorphic Analysis

Skagit County, Washington

Soils Map

Figure 5

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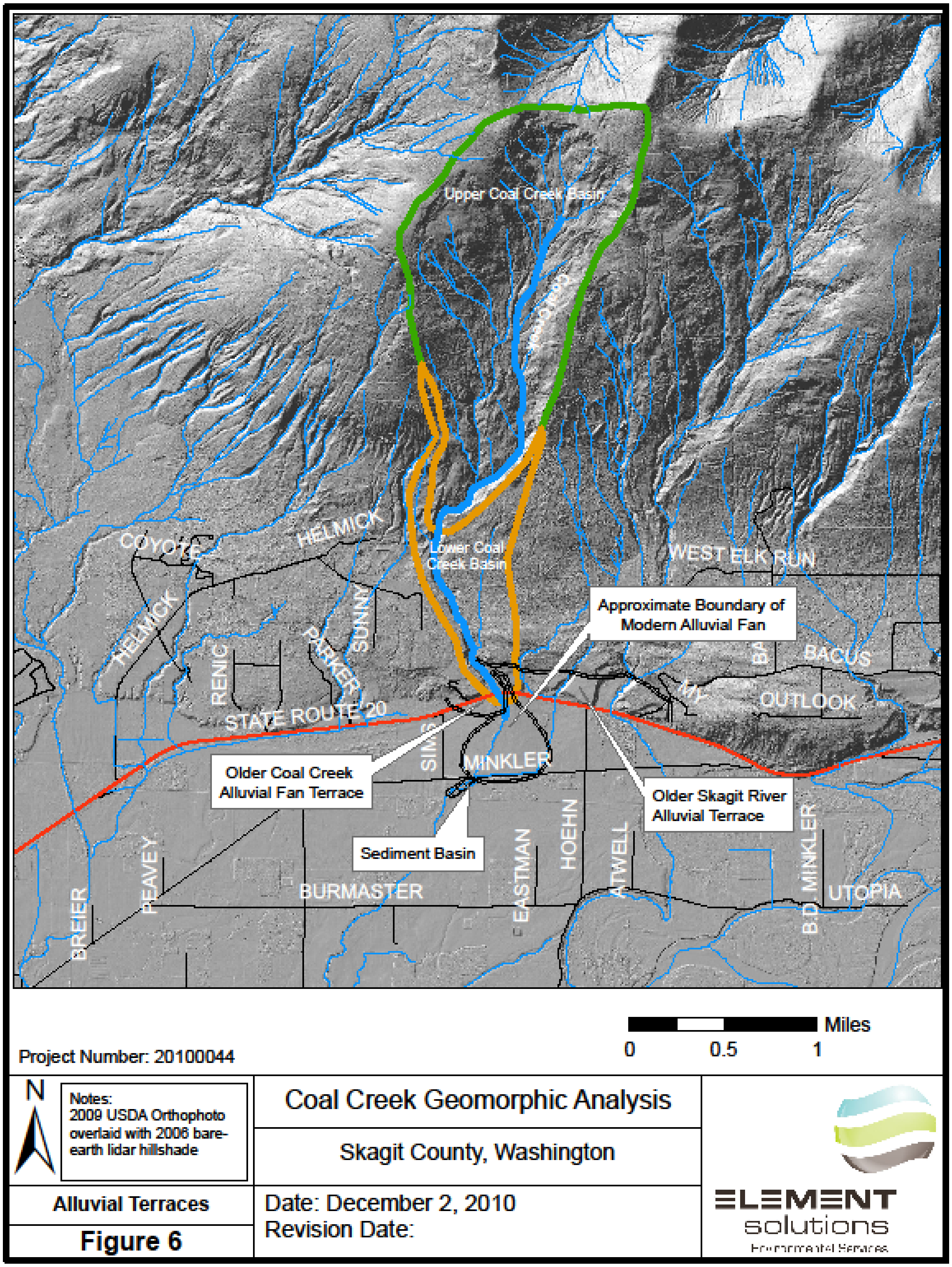

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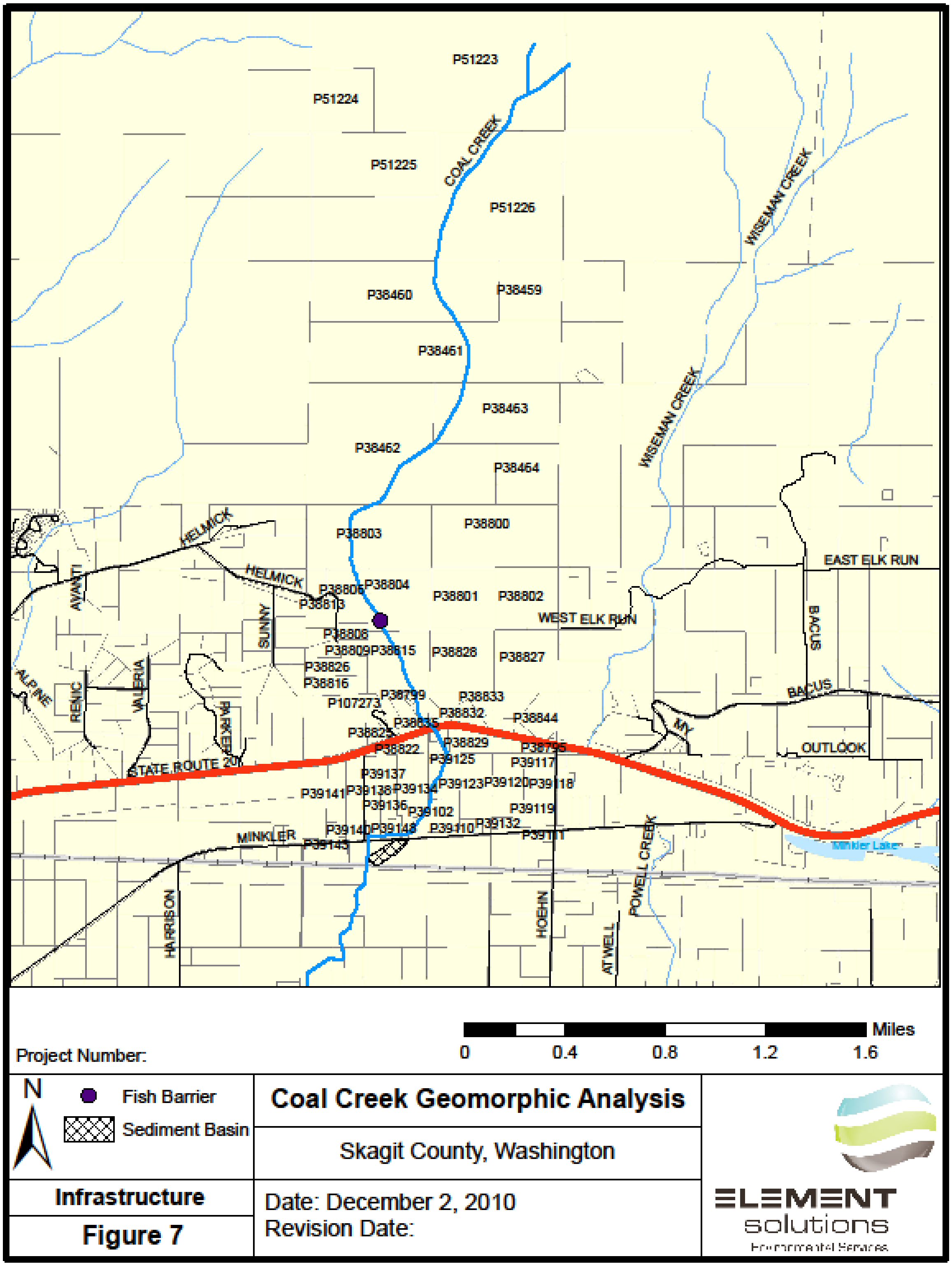

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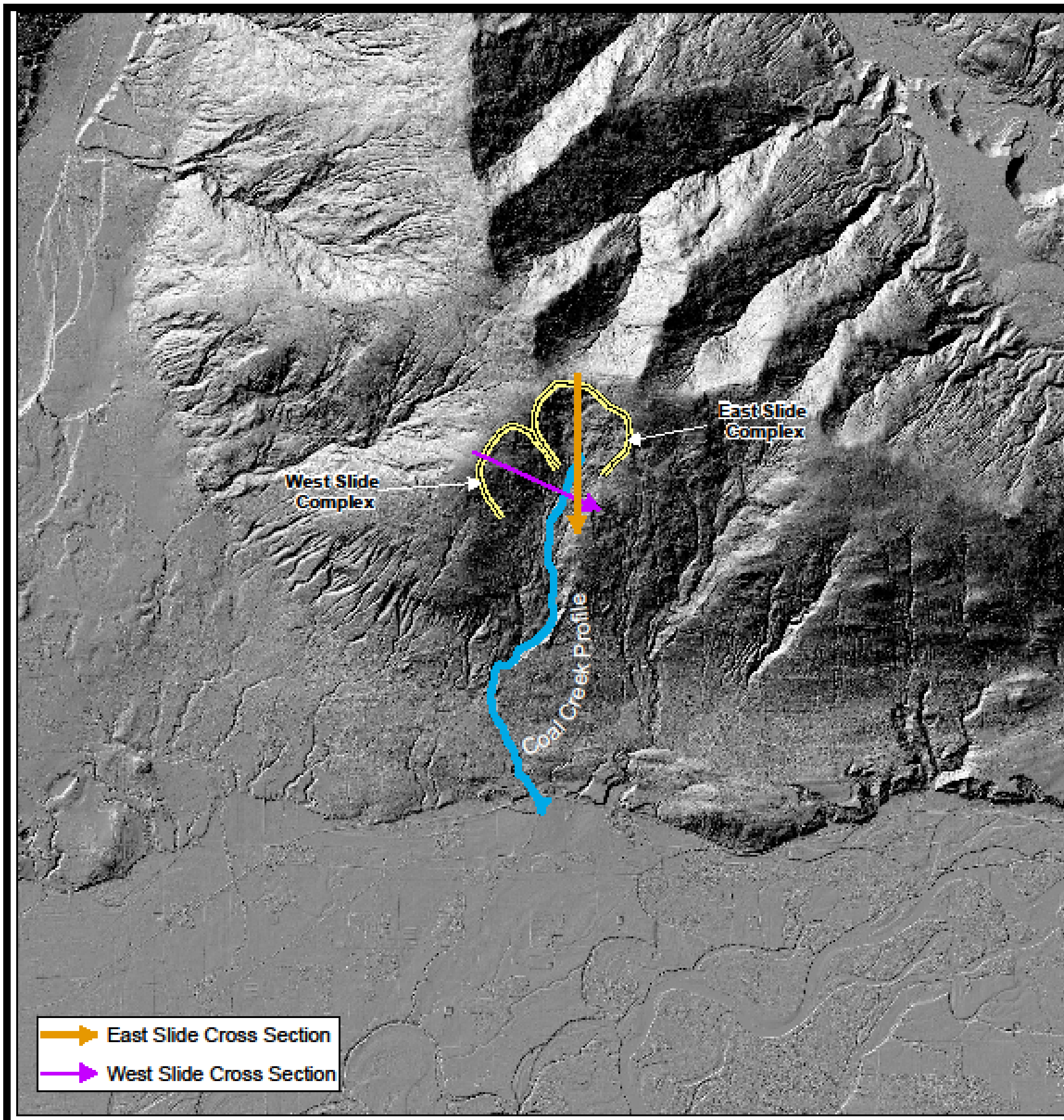

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Coal Creek Geomorphic Analysis

Skagit County, Washington

Profile Locations

Figure 8

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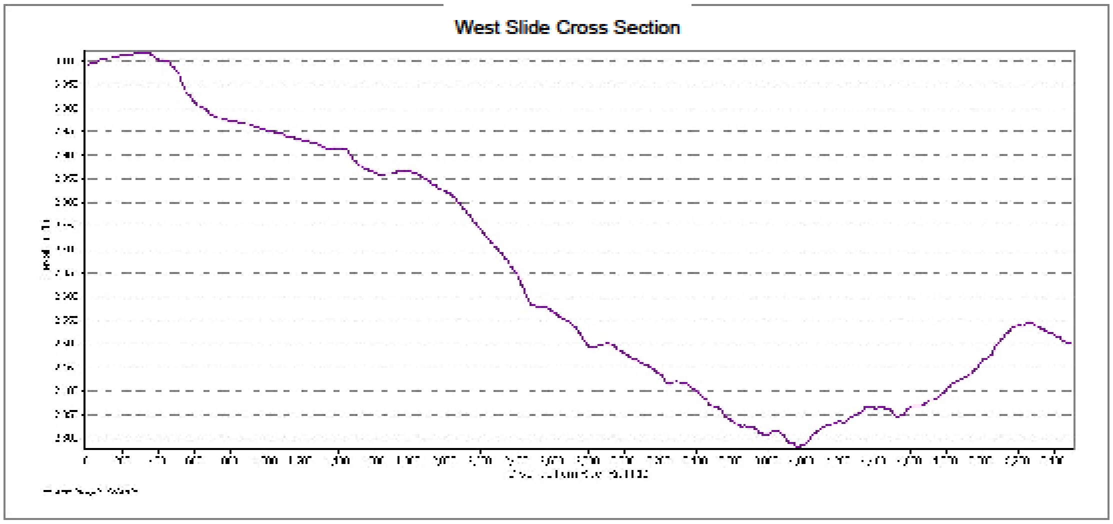

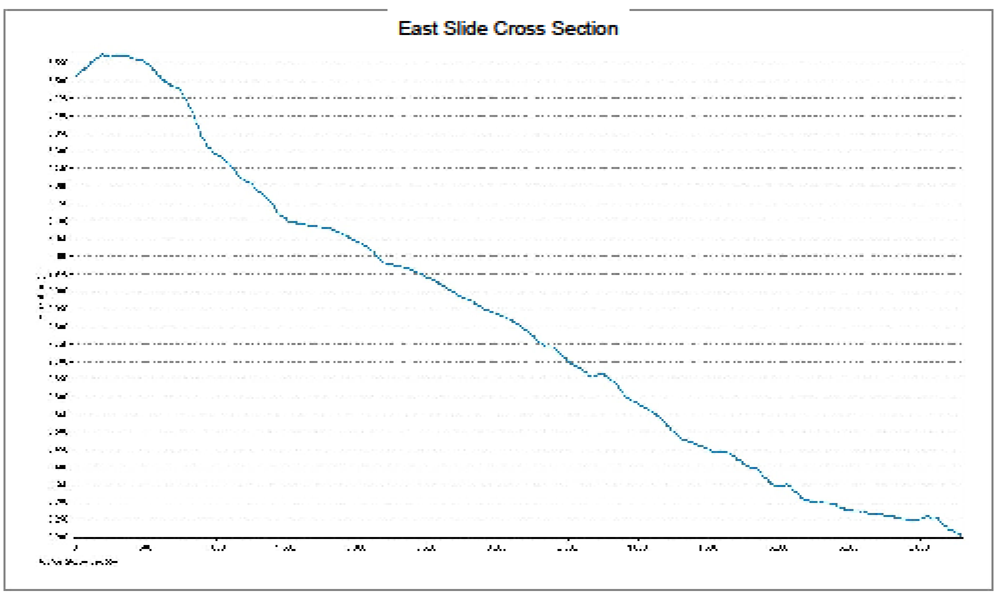

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	Coal Creek Geomorphic Analysis	ELEMENT solutions Environmental Services
	Skagit County, Washington	
Cross Sections	Date: December 2, 2010	
Figure 9	Revision Date:	

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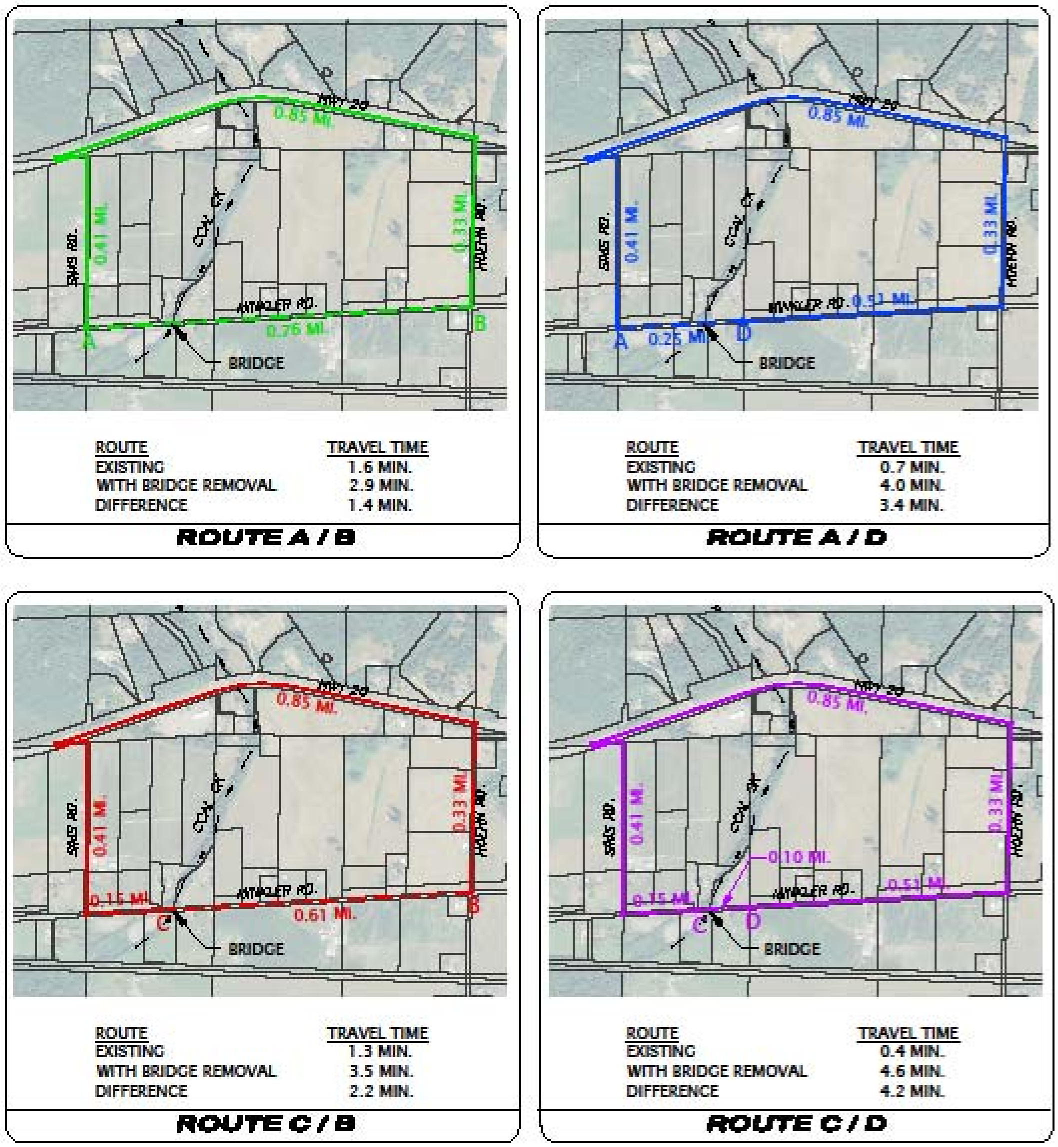

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MINKLER BRIDGE REMOVAL FEASIBILITY
ALTERNATE TRAVEL ROUTE DIAGRAM

FIGURE 10

COAL CREEK ALTERNATIVES FEASIBILITY STUDY

PROJECT No. 2010044

SKAGIT COUNTY, WASHINGTON

SHEET No. CF

PREPARED: DECEMBER 2, 2010

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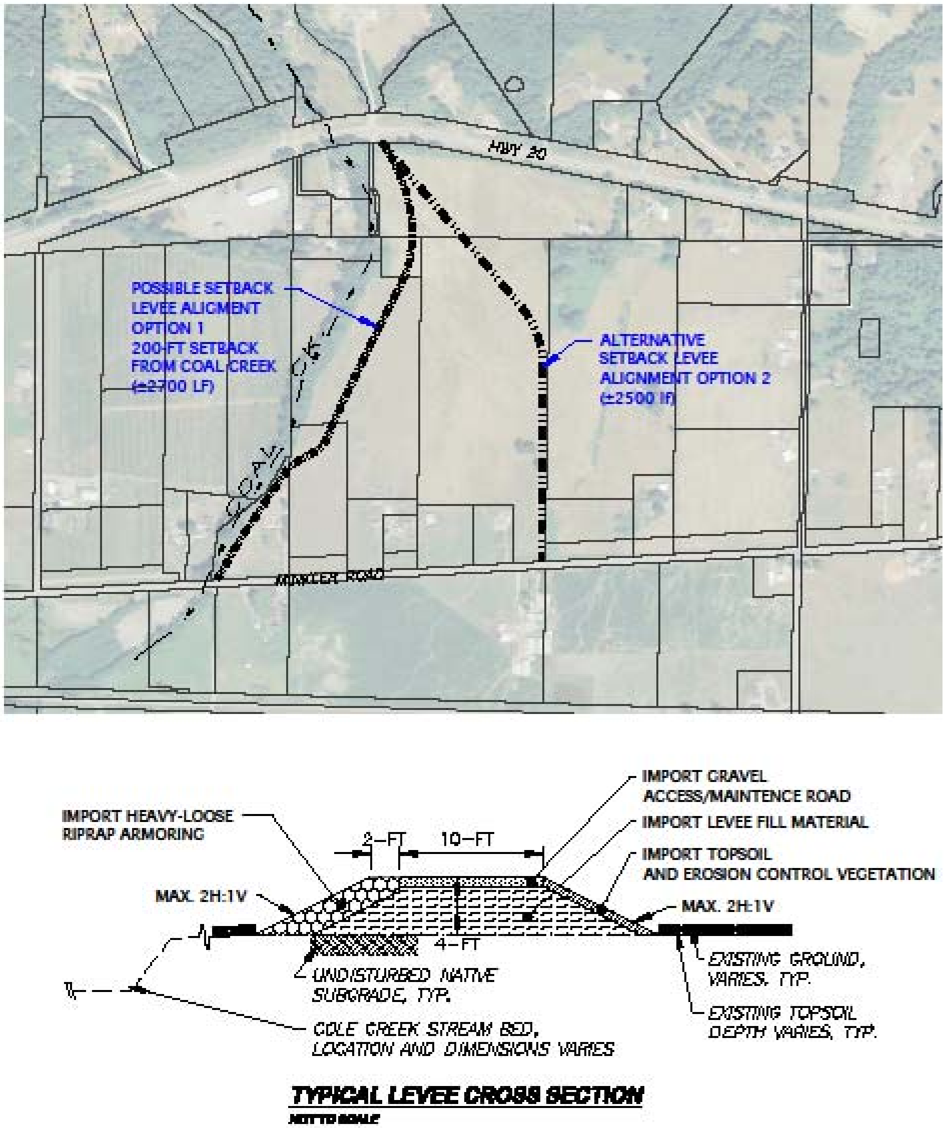

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SETBACK LEVEES CONCEPT DIAGRAM

FIGURE 11

COAL CREEK ALTERNATIVES FEASIBILITY STUDY

PROJECT No. 2010044

DRAWING No.

SKAGIT COUNTY, WASHINGTON

SHEET No. OF

PREPARED: DECEMBER 2, 2010

Appendix B

Geomorphic Assessment Desktop Methodologies

GIS Analysis
GIS was utilized to evaluate the geomorphic composition of the Coal Creek watershed. Data was obtained from multiple sources including Skagit County, the USDA Geospatial Data Gateway, Washington Department of Natural Resources, and the Puget Sound LiDAR Consortium.

Step 1: Sub-basin Delineation/Area Calculation

Coal Creek is located with the WRIA 3 watershed. However, no sub-basin delineation exists on the scale of the Coal Creek Basin. Using the DNR geology shapefile and USDA-NRCS soil layer, two sub-basins were digitized in the Coal Creek Basin. Areas were calculated for each using the field calculator and were stored within the shapefile.

Step 2: Stream Flow Stats
USGS Regression Equations were used.

Step 3: Coal Creek Basin Profiles

Profiles are useful for examining the gradient of a stream for reach delineation and for basin cross-sectional analysis. Cross sections can highlight areas of potential instability through sediment accumulation or erosion and local topographical influences. Two cross sections and one profile were extracted, using the profile extraction tool, from the Coal Creek Basin using 6ft. bare-earth lidar obtained from the Puget Sound Lidar Consortium. The Coal Creek Profile was extracted from the lidar using the digitized Skagit County Coal Creek polyline. Several cross section were extracted through the active? landslides in the upper sub-basin (Figures 1 and 2 below).

Step 4: Coal Creek Basin Slope Analysis

A slope delineation was conducted for the Coal Creek Basin using the slope module in 3D Analyst from the 6-ft. bare-earth LiDAR. The slope function calculates the maximum rate of change between points, identifying areas of higher and lower degree slopes. The slope affects the overall rate of sediment/debris movement down slope. Higher degree slopes will result in an increased rate of movement down slope.

This function allowed us to identify areas within the Coal Creek Basin that might be prone to landslides and debris flows, thereby increasing the sediment contribution to Coal Creek. The output slope raster was reclassified to seven slope ranges.

Step 5: Coal Creek Basin Curvature Analysis

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The curvature module in Spatial Analyst is useful for delineating the land surface into the nine slope shape categories defined by the NRCS (Daniels, 2006). This process is valuable for identifying areas prone to slope failure as well as understanding erosion and runoff processes within a basin, which may result in increased sediment inputs to Coal Creek. The curvature module outputs three different rasters, (1) the curvature raster, which is the slope of the slope, (2) the profile curvature raster, which is the curvature of the surface in the direction of the slope, and (3) the plan curvature raster, which is the curvature of the surface perpendicular to the direction of the slope. The profile curvature describes the acceleration and deceleration of flow and the plan curvature describes the convergence and divergence of flow. Due to the high resolution of the LiDAR, the nibble function was then used on the curvature outputs to eliminate erroneous calculations. The profile and plan curvatures were overlaid and the resulting raster was reclassified based on the nine slope types described by the NRCS (Daniels, 2006).

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Appendix C

Habitat Assessment

Summarized Report
(Full report with data sheets available from Skagit County or Element Solutions)

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Habitat Assessment of Coal Creek
Skagit County, Washington

July 2010

Performed and Prepared for Element Solutions by Vasak Biodynamics LLC

Ryan Vasak M.Sc.
Michael LeMoine M.Sc.
Allison Neils M.Sc.

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Habitat Assessment

Coal Creek, a small perenial stream in western Skagit County, Washington, is a tributary to the Skagit River. The stream flows through a sediment trap in the lower reaches of an aluvial floodplain. To inform future sediment management and possible restoration efforts, we performed a habitat and large woody debris assessment of a section of Coal Creek using the Timber-Fish-Wildlife monitoring protocol (Pleus et al. 1999; Schuett-Hames et al. 1999)

On 17th and July 18th, 2010, we conducted the assessment in two phases: 1) upstream identification and measurements of all habitat unitis, and 2) downstream survey of large woody debris (LWD), spawning habitat, and stream slope. To better describe the conditions upstream and downstream of the sediment trap, we began identifying habitat units approximately 100 m downstream of the Coal Creek sediment trap. Working upstream, we measured several instream characteristics for each habitat unit including: type, length, width, pool depths, bank vegetation, canopy cover, and sediment type. Every twenty habtat units we identified transects for channel cross sections where we recorded: bankfull width and depth, wetted width and depth, Wolman Pebble Counts, and latitude/longitude. The results of the survey are separated according to reaches delinated at the upper and lower margins by each transect.

We surveyed approximatly 5000 ft of Coal creek, from below the sediment trap to ~2500 ft upstream of Highway 20, the site of a major fish barrier. The habitat survey ended at a ~6-m waterfall which marked the most upstream extent of usable habitat by anadromous fish. Along the entire distance, we omited only a short reach due to unknown landowner cooperation. The instream conditions above and below the reach were similarly chanelized and and major changes throughout the unknown reach were unlikely.

Data Summary

Over the length of our survey, we identified diverse instream and riparian conditions in Coal Creek. The canopy and riparian vegetation were largely intact along most of the stream, providing shading which can mitigate high stream temperatures. Several reaches, especially below the sediment trap and upstream of Highway 20, would provide good to excellent spawning and rearing habitat for salmon. Active sediment recruitment to Coal Creek was evident at a few notably eroded banks upstream of Highway 20 and along some parts of the chanelized/straightened reaches just above Minkler Road.

6.2.1 Instream Conditions

Instream sediment below the Coal Creek sediment trap, along Reach-A, was primarily composed of gravels and small cobbles with a high percent of embededness. The gradient was lower along these reaches than all others measured in this study. We identifed few pieces of LWD in the stream or within the bankfull area below the sediment trap. We observed many small schools of Coho salmon below the sediment trap, but above the lower impoundment.

Upstream of Minkler Road along Reaches B – F, the stream was often highly chanelized and composed mostly of riffle habitats (Picture 3). Limited pools and/or cascades decreases the habitat diversity. The sediment size was generally larger than downstream of the sediment pond, cobbles and gravels, but was consistently embeded with fines. Fewer fish were observed during

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these reaches than below the sediment pond. We observed one cattle crossing near Transect D (Picture 2).

Upstream of Highway 20, the sediment size, gradient, number of pieces of LWD, and the number of habitat units per meter increased throughout reaches G - K. The instream habitats included diverse habitat sub-units including falls, cascades, and plunge pools. Although the sediment size increased and included boulders and bedrock, the sediment was still influenced by fines and was 34% - 55% embedded in these reaches. The bankfull channel was often wider than the current stream channel and contained piles of mobilizible gravels and cobbles. The stream likely has a lot of energy at higher flows and is able to mobilize large amounts of sediment. High stream energy can remove LWD from zone-1 and zone-2, and create unstable habitat.

6.2.2 Sediment Sources

We identified two notable sediment sources upstream of Highway 20 that were actively contributing semdiment. The first source, Big Bank Incision, was on the right bank at the top of Reach-G (Picture 5). This steep bank was actively eroding likely to erosive forces of the stream and precipitation events. The large eroded section was approximately 20 m tall and 100 m long. The exposed bank, covered by gravels, pebbles, and sands, has sloughed most vegetation and soil. The top of the bank was undercut along much of the length, exposing roots and trees. Several small to medium trees have recently fallen from the right bank into and next to the stream. Historic logging was evident in the forest north and uphill from the eroded bank.

The second main sediment source exhibiting active recruitment was on the left bank in reach-H. The erosive bank was approximately 30 m long and 3-4 m high (Picture 10 and 11). The bank was steep to vertical and exhibited sloughing of riparian vegetation and along one section, the stream cut into a vertical “wall” of sediment composed mostly of gravels, sand, and clay.

6.2.3 Fish Barriers

The habitat assessment ended at a permanent fish barrier the top of Reach-K. The barrier was a narrow falls approximately 6 m tall and was backed-up and filled with gravel and sand immediately behind the falls (Picture 19). The sediment back-up and falls are affected by a log-jam in the top of the falls. Failure of the logjam could lead to sediment release.

Another notable falls within Reach-I may be a barrier to fish passage at certain flows (Picture 15). Streamflow at the time of our assessment ran through a small side channel along the left bank, likely allowing fish passage.

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Pictures

Picture 1. Coal Creek in western Skagit County, Washington.

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Picture 2. Cattle crossing on Coal Creek between Minkler Road and Highway 20.

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Picture 3. Coal Creek upstream of Minkler showing channelized and straightened stream.

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Picture 4. Descent to Coal Creek via Sierra Pacific road access. Steep, densely vegetated bank with erosion, small landslides, and evidence of past logging on steep banks.

Picture 5. Large eroded bank on left-bank near entry point from road, on Mr. Lindzy's property. Active erosion and sediment recruitment including several recently fallen trees with green leaves. Bank is approximately 30 feet high and 100 feet long, with undercutting of mature trees at the top of the bank.

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Picture 6. Eroded bank looking upstream.

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Picture 7. Eroded bank looking downstream.

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Picture 8. Eroded bank – close-up of sediment showing densely layered clay.

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Picture 9. Eroded bank – looking up the hill-slope showing severe erosion and undercutting of mature vegetation.

Picture 10. Left-bank erosion upstream from large eroded bank.

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Picture 12. Left-bank erosion and sediment source exists as a tall, flat "wall" of sediment approximately 10 feet high packed with pebbles, gravels, and fines. Active sediment recruitment.

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Picture 13. Right-bank section lacks mature trees in geographic area close to steep slopes suggesting historic landslide or mass-wasting event. Upstream of large eroded bank. Total area at least 50 square meters.

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Picture 14. Petrified wood in Chuckanut Sandstone located at water level on right bank at first seasonal fish barrier falls with side channel.

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Picture 15. Downstream falls on Coal Creek acts as temporary fish barrier when side channel lacks enough water to maintain passable conditions for fishes. Side channel is evident on upper right side of image. View upstream along side channel in right image.

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Picture 16. Cobbles piled up on large-woody-debris suspended across stream (1-2 feet) suggests high stream energy during high flow events.

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Picture 17. Large-woody-debris in stream and complex cascade habitat.

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Picture 18. Narrow channel with Chuckanut Sandstone sides approximately 2 m wide with ~0.5 m falls/cascade into 1 m deep pool.

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Picture 19. Fish barrier at terminus of habitat survey. Narrow falls approximately 6 m tall. Falls and barrier may be formed by build-up of sediment associated with LWD logjam in narrows just upstream and at top of falls. Much LWD and largest logs in Coal Creek immediately downstream of falls. Largest logs show signs that they were human-felled rather than naturally fallen trees. Middle image shows build-up of sediment at immediate top of falls. Right image shows gravel sediment on right bank suggesting that sediment build-up was historically higher than current levels.

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Picture 20. Instream sediment pile (cobbles, gravels, sands) in center across to left-bank approximately 0.5 meters high at deepest point. Sediment pile is immediately upstream of Mr. Lindzy's home (visible from stream).

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Pleues, A.E., D. Schuett-Hames, and L. Bullchild. 1999. TFW monitoring protocol method manual for the habitat unit survey. Prepared for the Washington State Department of Natural Rersources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-003. DNR # 105. June.

Schuett- Hames, D., A.E. Pleus, J. Ward, M. Fox, and J. Light. 1999. TFW monitoring protocol method manual for the large woody debris survey. Prepared for the Washington State Department of Natural Rersources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-004. DNR # 106. June.

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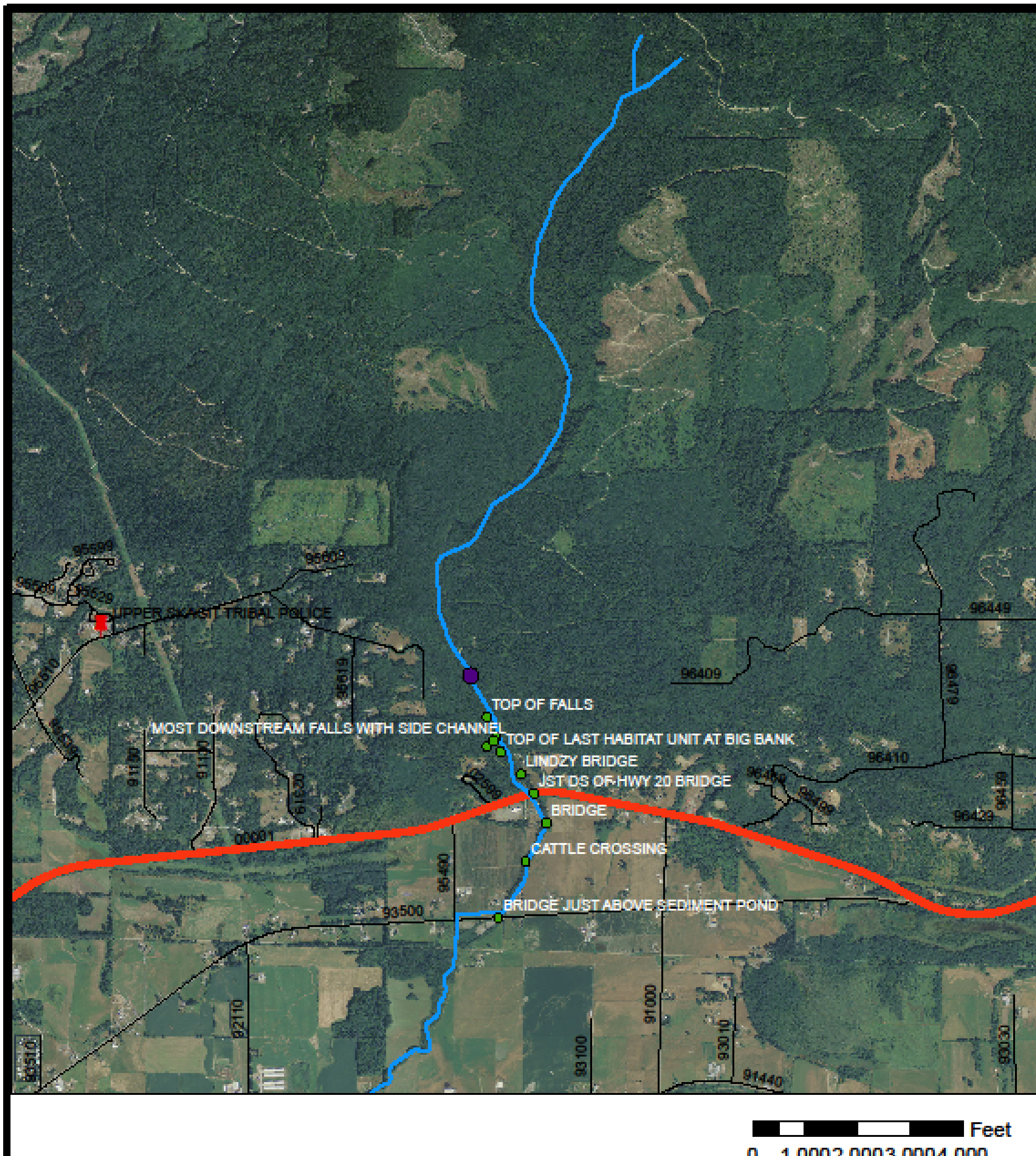

Project Number:

N	XS Locations / Fish Barrier	**Coal Creek Fish Habitat Assessment** Skagit County, Washington	ELEMENT solutions Environmental Services
Habitat Assessment		Date: December 2, 2010 Revision Date:	
Figure 1			

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Appendix D

Field Notes

Summary of Key Coal Creek Geologic Field Observations

Point	Description
046	Large sediment size (boulders 2-5 ft dia.) in channel interpreted as evidence of past debris flows. Older terraces above OHWM by 1-2 meters are interpreted as debris flow deposits as evidence by inverted sorting of sediment observed in areas of exposed cross-sections. Alluvially deposited sediment has an average B-axis diameter of 4-6 inches. Abundant fines were deposited at the OHWM from a recent high water – sediment lithology is almost entirely phyllite.
047 Photo D1	Glacial sediment outcrop – interpreted to be lodgement till (very dense and compact). Erosion of
049 Photo D2	Chuckanut sandstone bedrock boulders (rounded) up to 5 meters in diameter sitting on top of an apparent debris flow deposit.
051 Photo D3	Debris dams (LWD, boulders, sediment) estimated 10 – 50 cubic yards volume each. Qty. estimated at 30 debris dams.
052	Upstream end of Chuckanut Canyon and Chuckanut Formation – Darrington Phyllite geologic contact.
062 Photo D6	West Slide Complex (younger slide) – Head scarp and offset of continental glacial sediment and glacial morphology texture. Some bedrock exposed in scarp. A convex slope profile.
063 Photo D8	East Slide Complex (older slide) – Head scarp. Less defined offset of slide mass. Significant bedrock exposed in scarp. A zone of numerous perennial initiation points located at slope break below scarp. A concave slope profile.

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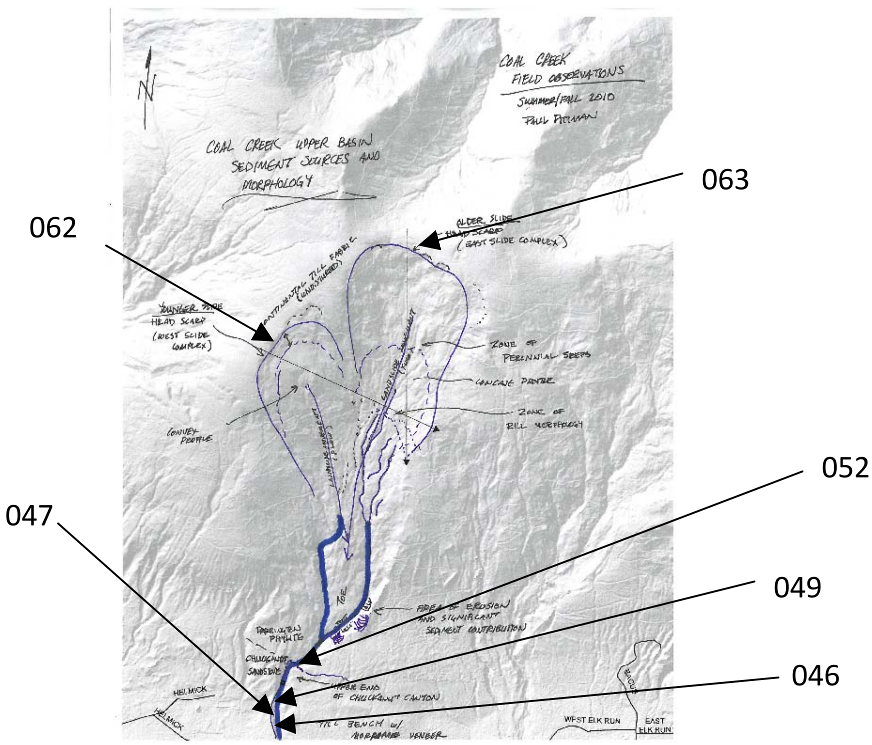
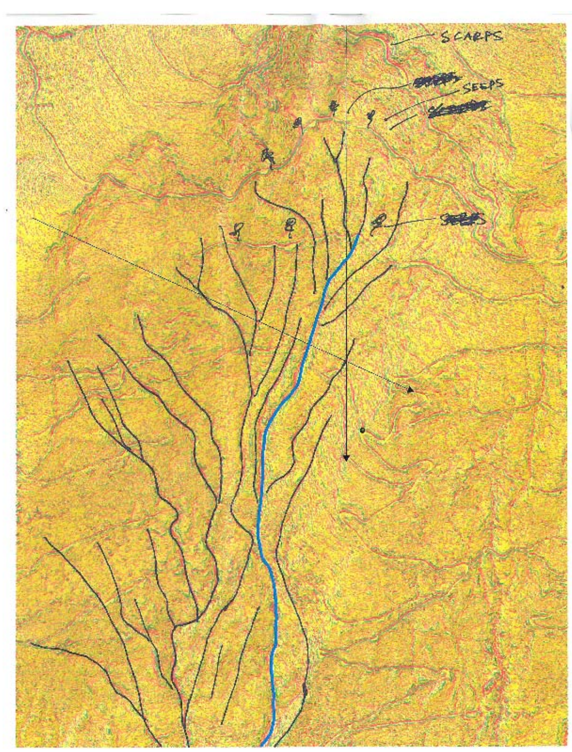


LiDAR Hillshade landslide morphology



LiDAR slope analysis with a sketch of parallel rills and perennial initiation points observed

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Field Photos

Photo D1: Glacial sediment (lodgment or basal till) exposed near the apex of the alluvial fan immediately downstream of the Chuckanut Formation canyon.

Photo D2: A large sandstone boulder sitting on top of alluvium (inversely graded) demonstrates evidence of debris flows moving through the Chuckanut Formation canyon and entering the alluvial fan area (upstream of logging road bridge and SR 20).

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Photo D3: Sediment wedge created by wood.

Photo D4: Minkler Road sediment trap (looking upstream) with the recent installation of LWD designed to maintain sediment transport through this reach and into the depositional area (following image)

Photo D5:

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Photo D6: West Slide complex head scarp

Photo D7: Darrington Phyllite geology – highly fractured and foliated metasedimentary rocks. Much of the stability issues within the Coal Creek watershed are related to the occurrence of this geologic unit.

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Photo D8: The headscarp of the East Slide complex

Photo D9: Looking down the East Slide complex.

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Photo D10: Evidence of slope stability within the Darrington Phyllite geologic unit is prolific and very recent.

Photo D11: Evidence of recent slope instability

Photo D12: Evidence of recent slope instability

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Photo D13: Virtually unlimited sediment supply results from mass wasting, channel incision, and lateral migration of Coal Creek through the unstable Darrington Phyllite geologic unit and Holocene landslide deposits.

Photo D14

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Photo D15: Virtually unlimited sediment storage within the channel.

Photo D16: The potential for larger sediment releases via debris flows is high. Debris flow magnitude and frequency was not part of this project scope, but should be considered for land use decision.

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