GEOMORPHIC HAZARDS AND RISKS ASSESSMENT AND ALTERNATIVES ANALYSIS

SOUTH FORK SNOQUALMIE RIVER
CIRCLE RIVER RANCH NEIGHBORHOOD

Prepared for
King County
Water and Land Resources Division
River and Floodplain Management Section

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

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Prepared for
King County Water and Land Resources Division
River and Floodplain Management Section
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INTRODUCTION

Several properties within the Circle River Ranch neighborhood located just outside the City of North Bend have begun to experience channel changes along a right bank side channel of the South Fork of the Snoqualmie River (South Fork). According to property owners, the banks of the side channel have eroded significantly, and the channel has expanded in the last 3 years (P. Hibbert, personal communication, August 17, 2011). King County maintains a flood protection facility (the Circle River Ranch Revetment) that extends approximately 362 feet along the right bank of the South Fork immediately downstream of this side channel. In order to better understand the geomorphic hazards and risks facing the Circle River Ranch neighborhood, the County contracted with Herrera Environmental Consultants (Herrera) to conduct a geomorphic hazards and risks assessment and to develop possible alternatives to address the identified hazards and risks.

The 2006 King County Flood Hazard Management Plan highlights the risks to the properties in the Circle River Ranch neighborhood. The Plan identifies a number of objectives and actions aimed at reducing flood risks in and near the cities of Snoqualmie and North Bend (King County 2006). These actions include implementing both structural and non-structural projects and elevating and acquiring properties in flood-prone areas to reduce property losses and public exposure. This report further discusses these possible risk-reduction measures.

Study Area

The study area is along the South Fork Snoqualmie River, near its confluence with the North and Middle forks of the Snoqualmie River (Figure 1). The project reach evaluated in this study includes the lower 2 River Miles (RM) of the South Fork, with a particular focus on the right bank side channel (hereafter referred to as the *side channel*) upstream of the Circle River Ranch Revetment. For distinction from the South Fork side channels and the main stem of the Snoqualmie River, the main channel of the South Fork is hereafter referred to as the *main channel*. The lower 1.5 RMs of the project reach are in unincorporated King County, and the upper 0.5 RM is in the City of North Bend. The Circle River Ranch neighborhood includes single-family residences constructed along the right bank of the South Fork main channel and side channel upstream of the County's revetment. The left bank of the channel is undeveloped.

Scope

The scope of Herrera's study included a literature review, field investigation, identification of geomorphic hazards, the development of four potential alternatives that would reduce the identified risks, and the consolidation of these findings in a report. This report draws heavily on a channel migration study performed for the Three-Forks Area by Perkins (1996) and also uses more recent aerial photography and lidar datasets to corroborate observations of recent channel change. No statistical analyses were performed to predict a timeline for

Legend

- River or stream
- Highway
- Park

Figure 1. Vicinity map for the Circle River Ranch Geomorphic Hazards Assessment and Alternatives Analysis project.

N

0 0.25 0.5 1 Miles

HERRERA

Aerial: King County (2009)

K:\Projects\10-04731-000\Project\alternatives\vicinity_map.mxd future geomorphic changes; however, geomorphic hazards and risks are tied to established recurrence intervals and magnitudes of flow events. The hazard and risk reduction alternatives and the alternative evaluation criteria were developed in close collaboration with the County. Although the alternatives assessment does not rank or compare alternatives against one another, it describes each alternative's effectiveness according to selected performance, impact, and implementation criteria.

GEOMORPHIC ASSESSMENT

Introduction

This section presents a geomorphic assessment of the lower 2 RMs of the South Fork, with a particular focus on the side channel adjacent to the Circle River Ranch neighborhood. This neighborhood is located along the eastern edge of the South Fork from approximately RM 1.35 to RM 1.65 and is in the vicinity of the Circle River Ranch Revetment. This geomorphic assessment documents recent and historical conditions based upon available literature, aerial photographs and lidar data, personal interviews with property owners, and field observations completed during an August 16 and 17, 2011, field reconnaissance. This geomorphic assessment documents geomorphic hazards in the vicinity of the Circle River Ranch Revetment (Figure 2). The findings from this geomorphic assessment were used to develop the risk reduction alternatives discussed later in this report.

Geomorphic Setting

Located above Snoqualmie Falls in the Upper Snoqualmie River Valley, the South Fork is the smallest of the three forks of the Snoqualmie River system, with a total tributary area of 85 square miles (Bethel 2004). The river has an ample supply of sediment from its mountainous headwaters in the Denny Creek and Snoqualmie Pass areas. The project reach is located on a composite alluvial fan formed from the deposition of hundreds of feet of alluvium by the three forks of the Snoqualmie River. The gradient upstream of the project reach ranges from 0.3 to 0.4 percent in the leveed section through the City of North Bend and decreases downstream through the project reach to 0.17 percent between RM 1.0 and 2.0 and 0.14 percent in the lowest mile of the South Fork (Perkins 1996). Sediment deposition is also occurring downstream of the leveed due to the reduction in the channel gradient and in response to the cessation of gravel removal operations. Backwater flooding from the main stem Snoqualmie River provides an additional mechanism for coarse and fine sediment deposition in the lower mile of the South Fork (Booth et al. 1991; Perkins 1996; Bethel 2004).

The project reach is located in one of the most dynamic river reaches in the entire Snoqualmie River basin. Perkins' (1996) calculations demonstrated that the project reach between RM 1 and RM 2 had some of the highest channel migration rates in the three forks of the Snoqualmie River. The average channel migration rate for this reach between 1942 and 1961 prior to significant levee and revetment (what Perkins refers to as the "pre-armor" period), was 6.5 feet per year. Following bank armoring, levee construction, and gravel removal in the period 1961 to 1993 (the "post-armor" period), the average channel migration rate declined to 3.6 feet per year (Perkins 1996). In the same time periods, the channel migration rates between RM 0 and RM 1 are lower, averaging 1.6 and 0.5 feet per year, respectively (Perkins 1996). Figure 2 illustrates the historical channel locations within the study reach.

Perkins (1996) states that gravel removal beginning in the mid-1960s through the early 1990s is the likely cause for a decline in channel migration rates. Booth et al. (1991) estimated that the 62,000 cubic yards of gravel removed from the South Fork between 1964 and 1966 to construct the levees between North Bend and Interstate 90 represented approximately 15 years of bedload sediment flux

It is noted that the pre-armor channel migration rates include the rapid and extensive meander migration that occurred during the 1959 flood, which peaked at approximately 13,000 cubic feet per second (cfs) and corresponded to a 50-year recurrence interval flow [Perkins 1996; King County 2011a]). The 1959 flood was the largest flood on the South Fork between 1942 and 1993 and is attributed by Perkins (1996) to causing a maximum bank migration distance of 280 feet near RM 1.7 during that single event.

Three of the four cutoff avulsions Perkins (1996) observed between RM 0 and RM 1.0 on the South Fork occurred during periods including moderate to large floods (20- to 30-year statistical recurrence). However, Perkins (1996) also noted that rapid channel migration was evident within portions of the project reach even when floods were relatively small (5- to 10-year statistical recurrence).

Influence of Historical Channel and Floodplain Modifications on Geomorphic Process

Although the project reach is relatively free of physical modifications such as levees and revetments (less than 3.5 percent of the lower 2 miles of the South Fork have revetment facilities [Perkins 1996]), the geomorphic processes driving its response and migration potential have been indirectly influenced by nearby levees, revetments, riparian forest clearing, floodplain development and gravel removal operations. The Circle River Ranch Revetment was constructed around 1966 (Perkins 1996) and, since that time, both banks of the river adjacent to the revetment have been relatively stable (Figure 2). The South Fork channel upstream and downstream of the revetment has actively migrated and exhibits relatively large meander bends with amplitudes as large as 800 feet.

The levees upstream of RM 2.0 were constructed on both banks during the 1960s using sediment removed from the gravel bars (King County 2011a). In addition to reducing flood risks during relatively small flood events, the levees disconnected the river from potential sediment storage areas within the floodplain. As a result, approximately half of the coarse sediment load that once deposited across a broad area of the adjacent floodplain is instead deposited within the active channel between the levees.

Subsequent to the construction of the levees, frequent sediment removal operations, mainly via gravel bar scalping, occurred in the leveed reaches into the early 1990s, limiting the amount of coarse sediment load delivered to the project reach. An evaluation by King County (2011a) of bar topography between 1995 and 2006, after significant gravel removal efforts ceased, indicated that approximately 2,700 cubic yards of gravel was deposited per year within the leveed reach of the South Fork. As other studies (Dunne 1984; Booth et al. 1991) have suggested, this volume represents approximately half of the total coarse sediment volume delivered to the leveed reach, indicating that the remaining half is conveyed

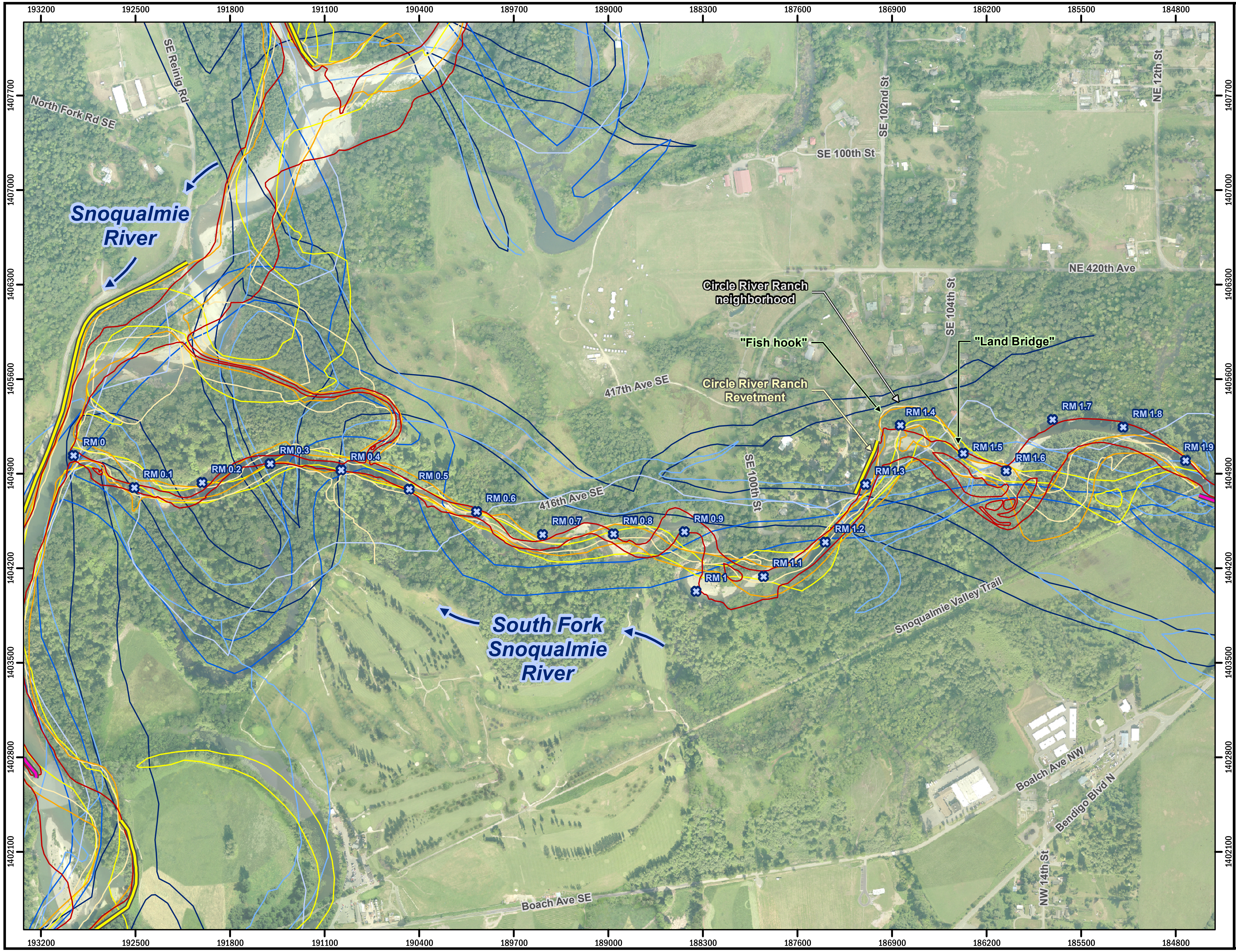

Figure 2.
Project reach overview and historical channel locations.

Legend

- River mile
- Levee
- Revetment
- Flow direction

Historic channel (Perkins, 1996)

- 1865-1881
- Pre-1911
- 1913
- 1921
- 1942
- 1958
- 1961-1964
- 1993

N

0 350 700 1,400 Feet

HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)
Aerial: King County, 2009

Produced By: GIS ( )
Project: \\sea-file03\gis-k\Projects\10-04731-000\Project\alternatives\historic_channel.mxd (7/30/2012)

downstream to the project reach. Based on the results of these previous studies, it is estimated that up to approximately 2,700 cubic yards of coarse sediment has deposited in the project reach on an average annual basis since cessation of gravel removal activities.

Mapped Flooding and Channel Migration Hazards

The Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) (FEMA 2005) included updated flood inundation areas for the project reach. The recurrence interval flow rates for the South Fork as reported in the 2005 FIS are presented in Table 1 (corresponding to USGS gage 12144000). As shown in Figure B-1 of Attachment B, over half of the properties in the Circle River Ranch neighborhood are within the 100-year floodplain, and a portion of all right bank properties along the river are located within the 100-year floodway (the portion of the floodplain with the deepest and fastest flow). Channel migration hazard mapping was adopted by the King County Department of Development and Environmental Services in 1999. Most properties in the Circle River Ranch neighborhood are mapped as severe or moderate channel migration hazard areas (King County 1999, Figure B-2).

Table 1. Peak Recurrence Interval Flows for the South Fork Snoqualmie River, Corresponding to USGS Gage 12144000 and Reported in FEMA (2005).

Recurrence Interval (years)	Flow (cfs)
10	9,000
50	13,000
100	15,000
500	19,700

cfs – cubic feet per second

Field Observations

Findings from the field reconnaissance on August 16 and 17, 2011, are presented in relation to RMs from the upstream limit of the surveyed project reach (RM 1.9) to the downstream limit (RM 0.2) along the South Fork. General sub-reach geomorphologic characteristics are presented according to the Montgomery and Buffington (1997) classification system. Observed changes were noted in channel and bar positions relative to the 2009 aerial imagery (King County 2009), the 2010 lidar (King County 2010), and the channel alignments mapped by Perkins (1996). Field notes and photo point locations are included in Attachment A. Photographs are provided on an attached compact disc.

RM 1.9 to 1.7

The right bank shows signs of slow bank erosion in this sub-reach, with trees falling in or leaning over the river. The left bank gravel bar is vegetated with young willow trees and is accreting to the east (toward the right bank) along with the migration of the main channel to the east (see the *Aerial Photo and Lidar Analysis* section below for an average rate of bank position change per year). The channel is confined by the right bank floodplain, which has a high elevation relative to the downstream sub-reach.

RM 1.7 to 1.6

Main Channel South Fork

Several trees are leaning over the right bank of the main channel as a result of relatively slow but progressive channel migration to the east. These trees could fall into the channel and result in several possible outcomes discussed below in the *Geomorphic Hazards and Risk* section.

A riffle extends diagonally across the entire main channel at the side channel inlet. Large woody debris (LWD) has accumulated on the right bank of the main channel downstream of the side channel inlet and functions as an apex logjam that armors the right bank and deflects flow into the side channel. There is a long pool on the right bank side of the main channel, between the riffle and the LWD. Downstream of the side channel inlet, approximately 80 feet of lateral meander migration has occurred in the main channel since 1993 based on a comparison of channel alignments mapped by Perkins (1996) (Figure 2).

Silver Creek Overflow Channel

Silver Creek, described by Perkins (1996) as a cross-floodplain channel from the Middle Fork Snoqualmie River, enters the South Fork on the right bank about 100 feet upstream of the side channel. The mouth of Silver Creek is mostly blocked by a high sand bar that likely formed in the backwater of the South Fork. There is a pool along the right bank of the South Fork in front of the mouth of Silver Creek.

Left Bank Side Channel

The left bank side channel inlet is elevated above the main channel and has been filling with sand and gravel. This left bank side channel coincides with the location occupied by the main channel in the 1990s (see Figure 2). Although this former main channel is filling with sand, the channel conveys flow during bankfull or greater floods and at low flow the outlet remains connected to the main channel downstream at RM 1.45.

RM 1.6 to 1.5

The main channel in this sub-reach is migrating to the west, as evidenced by recent left bank erosion. A gravel point bar is growing from the right bank and filling in part of the former channel. Observations of trees leaning over the gravel bar from the right bank and a review of aerial photographs indicate that gravel is now depositing where the channel was formerly migrating to the east and eroding the right bank. There is a 5-foot-wide strip of island referred to as the “land bridge” (M. Ruebel and R. Rose, personal communication, August 16, 2011) that separates the right bank of the main channel from the side channel at approximately RM 1.48. The “land bridge” appears to overtop annually; the top of the “land bridge” was measured approximately 4.0 feet above the low-flow water surface elevation (corresponding to approximately 85 cfs on August 17, 2011 [USGS 2011]).

RM 1.5 to 1.35

Meander migration in this sub-reach appears to be limited by the Circle River Ranch Revetment and additional heavy loose riprap and large rounded cobbles placed along the main channel right bank and adjacent to house number 10125 (Figure B-2, Attachment B, King County 2011b). Although the ad hoc bank armor adjacent to house number 10125 is not part of the revetment facility (see Field Map notes on Sheets 2 and 9 in Attachment A), it functions together with the revetment to encourage the main channel to make a 90-degree turn to the west. This sharp bend has induced the formation of a deep scour pool at the upstream end of the revetment. The steep riffle extending approximately 0.4 mile upstream of the pool is an area of temporary sediment deposition and storage.

The right bank immediately upstream of the revetment and adjacent to the scour pool has likely experienced recent erosion, as the bank line is set back into the floodplain a distance of about 20 to 30 feet and appears unprotected. Close visual inspection of the bank was precluded by the deep scour pool and yard waste covering the bank. There is a large log protruding from the top of the right bank down to the toe in front of the debris.

RM 1.35 to 1.15

This sub-reach is a low-gradient glide between long riffles in adjoining reaches and is also influenced by the Circle River Ranch Revetment, located along the right bank between approximately RM 1.28 and 1.35. Because as-built information for the Circle River Ranch Revetment is unavailable, it is unknown how deeply the riprap extends below the toe. The visible portion of the revetment appeared to be in a stable and good condition. This sub-reach has remained stable since construction of the Circle River Ranch Revetment, which has simplified the hydraulics along the right bank and restricted the possibility for meander migration to the north.

RM 1.15 to 1.05

This sub-reach is composed of steep riffles, gravel bars, and an anastomosing channel for approximately 0.1 mile. This reach appears to be an area of temporary sediment deposition and storage.

RM 1.05 to 0.8

This sub-reach is characterized by highly sinuous pool-riffle morphology, active channel migration, and wood recruitment. Consequently, the pools in this sub-reach are generally deeper than the pools upstream. Relative to the upstream sub-reaches, this sub-reach is characterized by increased percentage of sand content on the bars and in the pools and a generally decreasing grain size on bars. However, the bars are still gravel-dominated, and large cobble is present in the larger riffles.

A comparison of the existing channel location to historic locations (Perkins 1996) and recent lidar data and aerial photography since 2002 (King County 2002, 2010, 2011b, Attachment C) indicates that the channel in this sub-reach began to lengthen in 1993, potentially in response to the reduction in gravel removal activities after levee construction in the 1960s.

RM 0.8 to 0.2 (downstream end of survey)

This sub-reach is characterized by pool-riffle morphology, with decreasing sinuosity and physical complexity in the downstream direction. Although this sub-reach is likely within a transitional zone between gravel- and sand-dominated substrate, the majority of the channel substrate and bar deposits are dominated by sandy gravel, with just one sand-dominated dune-ripple feature located between approximately RM 0.35 and RM 0.45. The meander bend between RM 0.6 and RM 0.7 is actively eroding and widening into the left bank, where the bank material is mostly sand. Overall, there are relatively minor amounts of LWD in this sub-reach, but where present, LWD is associated with localized grade-controls and deeper pools.

The portion of this sub-reach between RM 0.4 and RM 0.2 is mapped as a severe channel migration area associated with the main stem Snoqualmie River (King County 1999, Attachment B).

Circle River Ranch Side Channel, RM 1.35 to 1.65

The side channel is characterized by plane bed morphology with a gravel substrate and pools associated with minor meander bends, eroding banks, and LWD. The bankfull widths at the fairly straight portions of the channel are around 40 feet. Bankfull depths range between 4 and 7 feet.

The side channel is experiencing bank erosion and expansion to accommodate increased flows. Bank toe scour, exposed roots, and sloughing banks are prevalent throughout the side channel. Small woody debris and gravel deposits have accumulated behind fallen trees and on top of the left bank at the entrance to the side channel. Approximately 200 feet downstream of the side channel inlet, the right bank has migrated and recruited several large trees to the channel. It appears that high flows in 2010 or 2011 have further scoured out the bank around the root balls of the fallen trees and formed downstream pools.

The Hibbert Property

A fairly straight riffle, with a few small pools and pieces of LWD, connects the large pool near the entrance of the side channel with a large pool located at the first major bend, near the "land bridge" and adjacent to the Hibbert property (house number 41524, Figure B-2). The highest rates of recent channel migration and widening occur where the side channel has an almost 90-degree bend to the right. The active channel widths range between 70 and 110 feet in this location, and pool depths are up to 4 feet in front of the "land bridge." The left bank at the "land bridge" is almost entirely composed of sand, with some clay, and there is no deep-rooting vegetation remaining to resist further bank erosion. The pool in front of the "land bridge" also has mostly sandy substrate. According to Peter Hibbert, the left bank at the "land bridge" has eroded 10 to 15 feet, and the right bank in front of his property has eroded 20 to 30 feet in the last 3 years (P. Hibbert, personal communication, August 17, 2011). These banks were vertical and approximately 8 feet high at the time of the site visit. Mr. Hibbert pointed out a location approximately 75 feet downstream of his house where the side channel had widened by 7 to 8 feet and undercut the bank to recruit several large trees into the channel. Mr. Hibbert stated that up until 2008 or 2009, the side channel would occasionally dry up in the summertime; currently summer flows seem to be approximately evenly split between the main channel and the side channel (P. Hibbert, personal communication, August 17, 2011).

Downstream of Mr. Hibbert's property, the side channel width and depth are fairly uniform, with toe scour throughout, vertical banks, and localized bank sloughing around undercut trees that have fallen into the side channel. The bed material is consistently gravel with cobble, and the banks are mostly sand with clay.

The "Fish Hook"

At its downstream end, the side channel makes a hairpin turn to the left referred to as the "fish hook" (Figure A-1). Here the channel is widening to the north, on the right bank of the bend. At the "fish hook," the side channel has incised down to a clay layer. The right bank is undercut and has been armored with riprap (one-man and smaller rock size). At the confluence with the main channel, the right bank of the side channel comes to a point that has been armored with large cobble and riprap placed along the bank. The side channel is approximately 3.5 feet deep in front of the riprap. There is a slight backwater into the side channel from the main channel. The island that separates the side channel from the main channel at this location is characterized by sandy substrate and is covered by Japanese knotweed.

Lidar maps clearly indicate a relic cross-floodplain channel that occupies low ground in the floodplain between 416th Avenue SE and SE 100th Street (see Attachments A and C). This relic floodplain channel and low point were not evaluated by Perkins (1996) for enlargement potential; however it is mapped by Perkins as having been occupied by the South Fork in the 1865-1881 period. This area is frequently inundated during flood events (M. Ruebel, King County, personal communication, August 16, 2011). This area was further inspected during the site visit on August 17, 2011. There is a small swale running between the properties (house numbers 10125 and 10131, Attachment B) located just north of the "fish hook" that could convey overbank floodwater from the side channel toward the drainage ditches along the 416th Avenue SE roadway. Although the swale intersects drainage ditches at the roadway, the lidar indicates that this relic floodplain channel has the potential to direct flow north across 416th Avenue SE towards SE 100th Street (Attachment B).

Aerial Photo and Lidar Analysis

Historic South Fork channel locations, as well as aerial photographs and lidar data covering the time period between 2002 and 2010 were provided by King County (King County 2002, 2010, 2011b). These datasets were evaluated and compared to mapped floodplain (FEMA 2005) and channel migration hazard areas (Perkins 1996) to assess potential topographic or geomorphic changes that might be associated with erosion hazards or flood risks.

Figure B-1 illustrate the 100-year floodplain, floodway, and the channel migration hazard areas in the project reach. Figure B-2 shows the channel migration hazard areas and the construction dates of houses within the Circle River Ranch neighborhood. Several homes were built within moderate and severe channel migration hazard areas following adoption of these hazard areas by King County in 1999 (King County 1999, 2006).

A review of the historical channel alignments from the Perkins (1996) study (Figure 2) indicates that the sub-reaches adjacent to the Circle River Ranch Revetment have been fairly stable since the revetment was constructed in the 1960s. Prior to construction of the Circle River Ranch Revetment, the main channel meander of the South Fork between RM 1.5 and RM 1.4 had been migrating in the downstream direction.

The historic channel alignments (Figure 2) also indicate that the lower portion of the side channel (downstream of the “land bridge”) was occupied by the main channel of the South Fork between 1942 and 1961. The side channel upstream of the “land bridge,” was occupied by the main channel of the South Fork as early as 1921 (Perkins 1996). The widening of the side channel near the Hibbert property, near the intersection of these two historic channel alignments, might reflect the different erodibility of sediments that filled in the 1921 channel from the sediments that filled in the 1961 channel.

Comparison of the 2002 and 2010 lidar data with the aerial photography for 2002, 2005, 2007, 2009, and 2010 (see Attachment C figures) was completed to note any channel changes during this time period. Aside from the 2010 aerial photography, vegetation in the aerial photos makes it difficult to note distinct features in the side channel. However, features in the main channel were easily observed in these photos. When compared to the 1993 channel position (Figure 2), the lidar and aerial photos from 2002 to 2010 (Attachment C) indicate that the main channel from RM 1.4 to 1.7 migrated in the direction of the right bank. In 1993, the left bank side channel was active and may have conveyed as much flow as the main channel, based on the relative channel width evident in the historic channel alignment (Perkins 1996). Between 2002 and 2005, it appears that aggradation in the main channel downstream of the side channel inlet began to limit the amount of flow accessing the left bank side channel. By 2007, after the 2006 flood of record (approximately 13,600 cfs, or about a 50-year recurrence event [King County 2011a]), the left bank side channel was mostly plugged with sediment. Significant erosion had occurred at the “land bridge” and at the right bank in front of the Hibbert property (house number 41524, Figure B-2). The 2009 and 2010 aerial photography show continued gravel bar deposition in the main channel, increased flow splitting into the side channel, and increased local widening and erosion in the side channel.

Changes to the active position of the main channel of the South Fork as indicated in comparing the 2002 and 2010 aerial photos and lidar with the previous (1993) channel delineation (Perkins 1996) were used to estimate average rates of bank or channel change over time. This analysis shows that the left bank gravel bar increased in area from about 0.35 acre in 2002 to about 1.62 acres in 2010 and has slowly blocked the left bank side channel between RM 1.6 and RM 1.7. Due to interference of bank vegetation in both the aerial photo and lidar datasets, changes to the side channel position were only noted at easily observable locations such as the side channel inlet and the portion of the side channel adjacent to the “land bridge.” Between 2002 and 2010, the width of the side channel entrance widened by approximately 40 feet. The width of the side channel near the “land bridge” expanded 50 to 60 feet. Table 2 presents the corresponding average annual rates of bank position change for these locations.

Table 2. Average Annual Change of Bank Position Based on 1993 to 2010 Aerial Photos and Historic Channel Alignment Comparison for the Main Channel South Fork and Side Channel in the Circle River Ranch Neighborhood Vicinity.	
Location	**Average Rate of Change (feet/year)**
Right bank of main channel South Fork upstream of inlet to side channel (RM 1.8 to 1.65)	4
Side channel at inlet (total of both banks, RM 1.65)	5
Side channel at the "land bridge" (total of both banks, RM 1.5)	7

Geomorphic Hazards and Risks

This section highlights potential geomorphic hazards and risks in the vicinity of the Circle River Ranch Revetment and neighborhood with consideration of recent changes as well as the potential for future changes and risks identified by Perkins (1996). This section is not an update of the channel migration hazard area mapping completed by Perkins (1996). Geomorphic hazards are defined relative to established recurrence intervals and flow event magnitudes.

Primary Drivers of Geomorphic Hazards

The primary drivers for geomorphic hazards within the project reach are identified as follows:

- A relatively high natural and historical rate of channel migration during both the "pre-armor" and "post-armor" periods (documented by Perkins [1996]) when compared to other reaches in the three forks of the Snoqualmie River
- A channel that is mostly unconstrained by physical modifications such as levees and revetments that would otherwise further constrain geomorphic processes
- Potential for future channel aggradation due to the cessation of gravel removal operations upstream
- Continued aggradation of the left bank side channel and the main channel as in recent years, unless the main channel is "captured" by the left bank side channel due to continued migration to the west near RM 1.55
- Continued aggradation of the left bank portion of the floodplain and the main channel upstream of RM 1.6 encouraging lateral migration towards the right bank
- Potential for increased flow in the side channel or avulsion into the side channel in response to main channel aggradation and meander migration toward the right bank
- Continued channel enlargement of the side channel depending on the percentage of total flow captured by the side channel due to the processes described above
- High potential for locally recruited wood to remain within the project reach and contribute to existing log jams that could either block flow from or encourage flow toward the side channel

- Continued development of the right bank point bar between RM 1.6 and RM 1.5 that would increase the flow angle of the main channel towards the "land bridge," and increase the likelihood of erosion at the "land bridge"

This report makes the following four assumptions when discussing geomorphic hazards in the project reach:

- Coarse sediment supply to the project reach will remain constant at current levels (King County 2011a).
- Flood hazards in the project reach will remain constant at current levels.
- LWD loading will remain constant at current levels.
- No additional actions will be taken to reduce geomorphic hazards.

Geomorphic Hazard and Risk Zones

The geomorphic hazard and risk zones relative to the Circle River Ranch Revetment and neighborhood are shown in Figure 3 and defined in Table B-1 (Attachment B). Given the recent channel changes observed and documented in the previous sections, an emphasis was placed on geomorphic hazards that could be experienced within the next 15 years. Thus a "high hazard zone" is defined as an area that is likely to be occupied by the main channel in the next 5 years. A "medium hazard zone" is defined as an area likely to be occupied by the main channel South Fork in the next 10 to 15 years.

Risk is defined as the intersection of a hazard zone with a house, outbuilding, or revetment, with the assumption that such impacts represent a threat to public safety. The greatest risks identified included structural damage or property loss along several residential properties due to bank erosion resulting from a channel avulsion or channel migration into the side channel. The geomorphic hazards and risks are subdivided into zones corresponding to RMs and are discussed below.

Zone 1 – Main Channel Right Bank (RM 1.8 to 1.65)

This zone is susceptible to continued right bank erosion and tree recruitment as the main channel continues to migrate toward the right (east) bank. The estimated high hazard width is 20 feet based on an average annual change of the right bank position of 4 feet per year (*Aerial Photo and Lidar Analysis*, Table 2), over a 5-year period. The medium hazard width of 40 feet is based on the same rate of bank position change, 4 feet per year (Table 2), over a 10-year period.

The continued migration of the main channel to the east will likely increase the proportion of flow entering the (right bank) side channel. Upstream trees leaning from the right bank could fall into the main channel and result in several outcomes. The trees could be mobilized downstream and block the side channel inlet. This may temporarily reduce flow entering the side channel, but scour around the blockage could also widen the side channel inlet more. Trees recruited to the main channel as a result of channel migration into the right bank could also be mobilized past the side channel and accumulate on the logjam on the right bank near

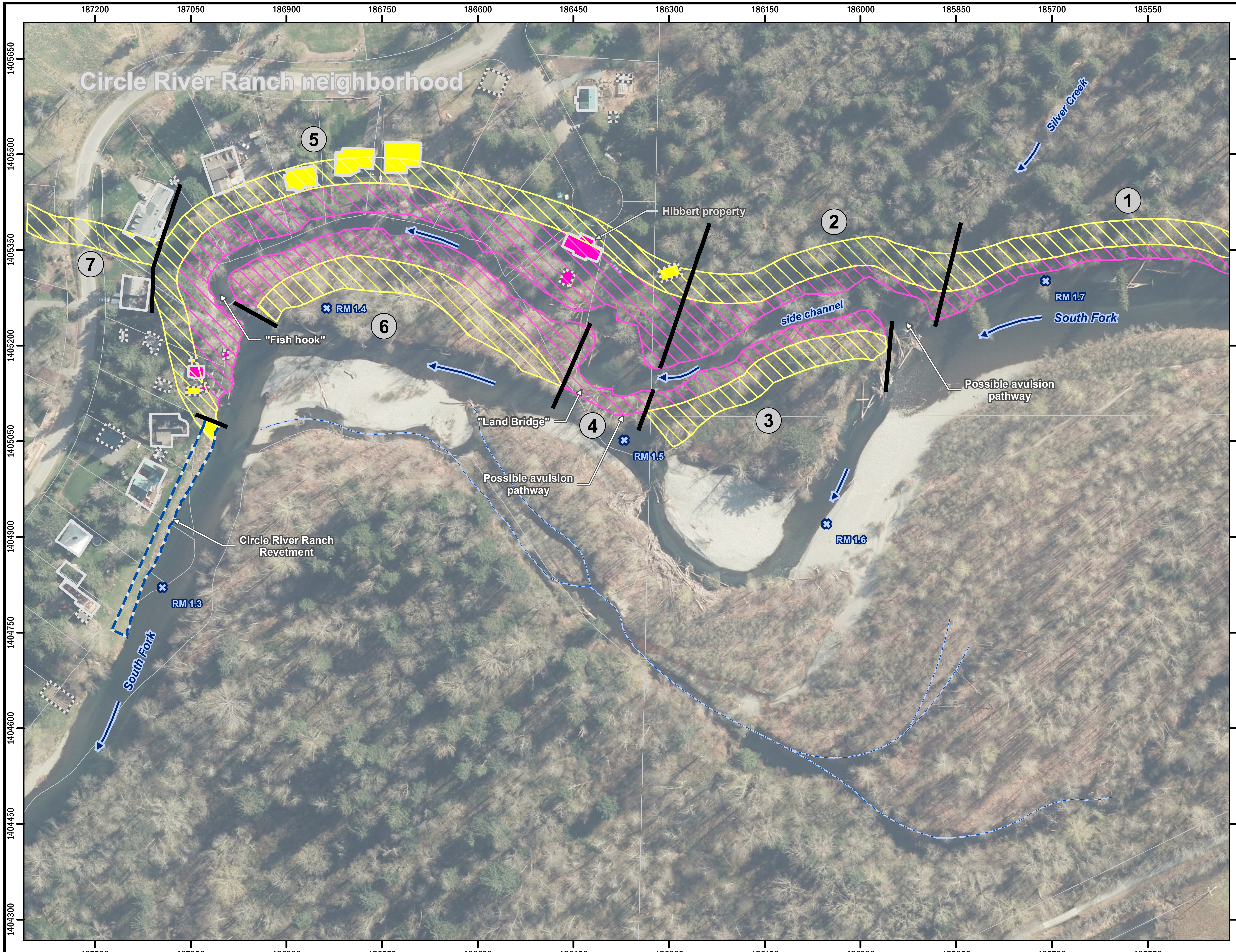

Figure 3.
Geomorphic Hazard and Risk in the Circle River Ranch neighborhood vicinity, South Fork Snoqualmie River.

Legend

Geomorphic hazards

- High hazard (potential for channel occupation in next 5 years)
- Medium hazard (potential for channel occupation in next 10 to 15 years)

Geomorphic risks

- High risk (intersection of high hazard with house, outbuilding, or revetment)
- Medium risk (intersection of medium hazard with house, outbuilding, or revetment)
- 6 Geomorphic hazard zone
- River mile
- Flow direction
- Existing left bank side channel
- House
- Outbuilding
- Facility
- Parcel

N

0 75 150 300 Feet

HERRERA

Aerial: King County, 2010
Coordinates: NAD83 HARN StatePlane Washington North (Feet)

Produced By: GIS ( )
Project: \\sea-file03\gis-k\Projects\10-04731-000\Project\alternatives\geomorphic_flooding_risk.mxd (7/19/2012)

RM 1.65. The increased wood loading at RM 1.65 could induce sediment aggradation upstream of this point and increase flow to both of the side channels.

Silver Creek Overflow Channel

Because the Middle Fork is higher on the composite alluvial fan than the South Fork, there is a possibility that the Middle Fork could avulse across the floodplain to the South Fork during a very large flood as discussed by Perkins (1996). However, this study does not reevaluate the avulsion potential of the Middle Fork into the South Fork via Silver Creek, and the enlargement potential of Silver Creek is not factored into the hazard and risk zones defined in this report.

Zones 2 and 3 – Side Channel Upstream of the "Land Bridge" (RM 1.65 to 1.5)

Zones 2 and 3 represent the right and left banks, respectively, of the upstream portion of the side channel. Both banks are susceptible to continued bank erosion and channel migration, consistent with the average annual rates of change reported in Table 2 for the right bank of the main channel (4 feet per year) and the side channel inlet (5 feet per year). The high hazard widths of 20 feet and 25 feet for Zones 2 and 3, respectively, correspond to these average annual rates of bank position change over a 5-year period.

The medium hazard widths for Zones 2 and 3 (47.5 feet and 42.5 feet, respectively) correspond to a partial avulsion capturing 75 percent of the South Fork flow (see Table B-1). This avulsion could occur at the inlet of the side channel during a small-magnitude (bankfull) or greater flood event, especially if gravel and LWD deposition in the main channel continue to encourage more flow into the side channel. A partial avulsion could cause tens of feet of increased bank erosion along the entire side channel length through this reach. Although there is no infrastructure at risk within Zones 2 and 3, an avulsion through the side channel inlet could cause property damage and loss to all properties along the side channel as discussed below. A full avulsion, not considered in this analysis, could cause the side channel to expand up to 90 feet wide (approximately equivalent to the current bankfull width of the main channel upstream).

Zone 4 – the "Land Bridge" (RM 1.5)

The growing gravel point bar upstream of RM 1.5 along the right bank of the main channel is increasing the approach angle of the main channel increasing erosion of the "land bridge." Due to the sandy soil and lack of vegetation, a bankfull flood may be adequate to breach the "land bridge." Such a breach could result in a partial avulsion of the South Fork into the downstream half of the side channel (1942-1961 channel alignment). Thus, the high geomorphic hazard zone width at the "land bridge" is defined as the bankfull width for the South Fork.

Zone 5 and 6 – Side Channel Downstream of the "Land Bridge" (RM 1.5 to 1.35)

As indicated above, it is likely that following the next several bankfull events, a connection between the South Fork and the side channel will form at the "land bridge". When this occurs, it is possible that most of the flow in the South Fork would reoccupy the 1942-1961 river alignment. A partial or full avulsion into the side channel could lead to channel widening in the side channel downstream, as shown in Figure 3.

Based on historical bifurcated channel alignments observed along the South Fork from Perkins (1996) and from the aerial photographic record (King County 2009, 2011b), the high hazard width (approximately 47.5 feet) for Zones 5 and 6 assumes that a partial avulsion occurs, corresponding to 75 percent of the flow (thus 75 percent of the bankfull width), and that the banks continue to erode and migrate over a 5-year period consistent with the average annual rates of change (4 feet per year) referenced for the main channel (Table 2). The medium hazard widths of 40 feet correspond to the main channel average annual rate of bank position change (4 feet per year) over a 10-year period. Zones 5 and 6 have the same high hazard and medium hazard widths, assuming the main channel is equally likely to migrate in either direction.

The geomorphic hazard widths in Zone 5 correspond to substantial risks in the Circle River Ranch neighborhood. The high hazard width for Zone 5 intercepts the house and an outbuilding on the Hibbert property as well as an outbuilding at house number 10119. The medium hazard width for Zone 5 intercepts another outbuilding near the Hibbert property as well as three more houses (house numbers 10235, 10227, and 10219), another outbuilding at house number 10119, and the upstream portion of the Circle River Ranch Revetment near house number 10113. Zone 5 also risks loss of the ad-hoc riprap placed upstream of the Circle River Ranch Revetment. There is also a risk that the main channel flow will continue to migrate and flank the revetment (i.e., begin eroding the back side of the revetment) if the river migrates to the north through the upstream residential properties (see Figure 3). The log jutting out from the right bank here may act like a weir, initially causing bank erosion along the unprotected bank and toe as the channel widens in this area.

Zone 7 – North of the "Fish Hook" (RM 1.4)

An upstream avulsion (in Zones 2-6) could result in the enlargement of the floodplain channel located to the north of the "fish hook" and increase the risk to adjacent properties along the alignment of the swale described previously. The hazard zone width at the "fish hook" assumes the existing swale to the north has the potential to expand up to the bankfull width of the existing side channel (40 feet).

RM 1.35 to 1.15

As described above and illustrated in Figure 3, there is a risk of erosion occurring at the upstream end of the Circle River Ranch Revetment if the "fish hook" enlarges or migrates to the north. If this occurs, erosion at the upstream end of the revetment could compromise the integrity and effectiveness of the facility.

RM 1.15 to 0.2 (downstream end of survey)

Geomorphic processes in this reach are unlikely to pose risks to the Circle River Ranch neighborhood. Because much of this sub-reach lies within natural areas with large riparian buffers, channel migration does not pose an imminent risk to residential properties or infrastructure.

Discussion of Geomorphic Hazards and Risks

In general, the zones of high and medium geomorphic hazards identified in this study coincide with areas previously delineated as within the severe channel migration hazard area (Attachment B). In addition, the entire project reach and adjacent properties of the Circle River Ranch neighborhood lie within the 100-year floodplain of the South Fork, and much of it is within the floodway; thus, adjacent low-lying, over-bank areas in the floodplain are likely to be inundated by any over-bank flooding (Attachment B).The main channel is likely to avulse into a high or medium geomorphic hazard zone near the Circle River Ranch neighborhood given the presence of both a side channel and historical river channels that the main channel could reoccupy (Figure 2).

If decreased channel migration from the 1960s to 1990s is due to gravel removal activities upstream, the cessation of gravel removal activities will likely trigger an increase in future channel migration potential similar to the “pre-armor” migration rates measured by Perkins (1996). Additionally, channel migration rates depend on the frequency and magnitude of future flood events.

Field observations for this study, channel migration rates noted during the last decade, and the migration hazards noted by Perkins (1996) collectively indicate that the South Fork has the potential to occupy the estimated high or medium geomorphic hazard zones (Figure 3), and potentially the full right-bank extent of the severe channel migration hazard area during the next significant flow event. If this type of avulsion or migration were to occur, emergency response measures would likely be required to limit significant property and infrastructure damage. These geomorphic risks could be reduced or prevented if proactive measures are taken. The following section describes alternatives for mitigating the geomorphic hazards and risks.

ALTERNATIVES ASSESSMENT

Purpose and Scope

This alternatives assessment identifies four potential alternatives that would reduce the hazards and risks documented in the geomorphic assessment above. This section provides detailed descriptions and concept figures for the four alternatives, defines evaluation criteria, and describes the anticipated effectiveness of each alternative. This section also discusses the anticipated geomorphic response to each alternative with respect to reducing the identified risk. This report does not make recommendations for implementation of any particular alternative over another.

Alternatives Development and Assessment Methodology

Several alternatives were developed to address the identified hazards and reduce risks to properties located along the east side of the side channel within the high and medium geomorphic hazard zones. Assessment criteria were developed to qualitatively describe four alternatives that made it through an initial screening process. The assessment criteria are organized into three categories: performance, impact, and implementation. The methodology for the development and assessment of alternatives is presented in Attachment D.

Alternatives Description and Evaluation Results

The four alternatives evaluated are listed in Table 3 and are described below. Each alternative's probable geomorphic response, performance, impacts, and implementation complexity are summarized below. Figures showing the locations and extent of each alternative are included in Attachment E. Representative photographs of risk reduction measures are included in Attachment F. A matrix summarizing each alternative with respect to each evaluation criterion is included in Table G-1 in Attachment G. Planning-level estimates of construction costs for each of the four alternatives are included in Attachment H.

Alternative 1

Description

Alternative 1 includes the acquisition of five properties with residential structures in the South Fork floodplain and along the side channel that are located within either the high and/or medium geomorphic hazard zones (Figure E-1, Attachment E). This alternative would include the removal of all infrastructure from the properties including houses, outbuildings, fences, paving, and utilities. Following demolition of the existing infrastructure, the site and river bank would be planted with native vegetation to re-establish riparian zone conditions.

No bank protection or other risk-reduction measures would be installed on the five acquired properties or any other properties along the side channel.

Table 3. Summary of Risk Reduction Alternatives Chosen for Evaluation.

Alternative	Description
1	Acquire five properties situated along the side channel, each with buildings located within either high or medium hazard zones; remove all infrastructure on those properties and restore the land to riparian zone conditions.
2	Install a continuous bioengineered bank protection system along the right bank of the downstream half of the side channel.
3	Install large logs to roughen the side channel inlet and protect the Silver Creek overflow channel outlet, install multiple bank deflector and apex (mid-channel) type engineered logjams (ELJs) in the South Fork main channel immediately upstream and downstream of the inlet, and excavate a new channel through the floodplain at RM 1.55 to convey flow from the main channel to the left bank side channel.
4	Install multiple bank deflector and apex ELJs in the South Fork main channel between the Snoqualmie Valley Trail bridge at RM 1.95 and RM 1.7 and construct four new channels between RM 1.9 and RM 1.6 to convey flow from the main channel across the left bank floodplain and into existing relic side channels.

Anticipated Geomorphic Response

The geomorphic response to Alternative 1 would be the same as under existing conditions. Removal of the residential infrastructure and planting with native vegetation would have a negligible effect on the avulsion and bank erosion hazards over the next 10 to 15 years.

General Summary of Criteria Evaluation

The significant findings with respect to the performance, impact, and implementation evaluation criterion for Alternative 1 are summarized below.

Performance

Alternative 1 would eliminate the risk to the acquired properties by removing the infrastructure and restoring the land to a natural area. However, the existing erosion hazard along all properties adjacent to the side channel would not change because no additional measures would be taken to reduce the likelihood of bank erosion. The results of the geomorphic hazard assessment, which evaluated risks over a 15-year period, indicate that channel migration after this time frame could place three to four additional homes in the vicinity of the “fish hook” at risk.

Impact

Alternative 1 would result in no change in the existing hazards to recreational users of the river. The alternative would provide a net benefit to riparian and aquatic habitat and vegetation by restoring important ecosystem composition, structure, and functions. Short-term impacts related to demolition and revegetation would not require mitigation per applicable environmental regulations due to the self-mitigating nature of this alternative. No increase in the regulatory 100-year base flood elevations would result from Alternative 1.

Implementation

Implementation would be relatively simple and would require relatively few permits. Total cost to implement Alternative 1, including property acquisition, demolition and removal of infrastructure, and revegetation, is estimated to be $2,550,000 (in 2012 dollars).

Alternative 2

Description

Alternative 2 includes installation of a bioengineered bank protection system along approximately 1,150 linear feet of the right bank of the downstream half of the side channel (Figure E-1, Attachment E). Two types of systems were considered in this evaluation to provide a range of probable construction costs and effectiveness in reducing hazards and risks: 1) a log cribwall structure and 2) reconstruction of the right bank using reinforced soil lifts.

The upstream 150 feet of the log cribwall would project landward to the southeast from the bank at the southernmost boundary of the Hibbert property and would be completely buried to counter flanking to the east by the upstream side channel. To counter potential flanking of the upstream end of the soil lifts option, large riprap would be buried in a trench along the upstream-most 150 feet of the bank. From the southernmost boundary of the Hibbert property, both systems would extend downstream approximately 1,000 feet around the “fish hook” and would tie into the upstream end of the King County Circle River Ranch Revetment.

Anticipated Geomorphic Response

The hydraulic roughness provided by a log cribwall or well-vegetated soil lifts would reduce water velocities along the right bank relative to the existing bank conditions. If additional flow is introduced to the side channel (either from increased flow at the side channel inlet or from an avulsion at the “land bridge”), widening of the side channel by means of bank erosion would occur on the opposite (left) bank of the side channel. Trees recruited from the left bank of the side channel could form a logjam and divert flow either into the cribwall or vegetated soil lifts (possibly resulting in needed repairs to damaged sections) or toward the left bank, away from the cribwall or soil lifts.

General Summary of Criteria Evaluation

The significant findings with respect to the performance, impact, and implementation evaluation criteria for Alternative 2 are summarized below.

Performance

A continuous log cribwall would significantly reduce the existing risks to landward properties by limiting further channel migration toward the Circle River Ranch neighborhood during the anticipated 50-year design life of the structure. During the plant establishment period, reinforced soil lifts may only provide moderate protection against bank erosion, and the anticipated 20-year design life of the soil lifts would provide less long-term protection than a cribwall. As vegetation is established on the soil lifts, the effectiveness in reducing erosion hazards and risks would increase. If a shorter segment of log cribwall or soil lifts were constructed along a single property instead of continuous bank protection along the entire side channel, bank erosion and channel migration hazards along adjacent, unprotected properties might increase.

Both the log cribwall option and the reinforced soil lifts option would require maintenance to replace loose logs or re-plant areas with inadequate plant establishment.

Impact

Both options under this alternative would enhance existing aquatic and riparian habitat conditions in the side channel by utilizing natural materials to provide bank stability and to establishment riparian vegetation. The base of the cribwall option would improve fish habitat along the bank by providing cover. The log cribwall would pose increased hazards to recreational users of the river due to woody debris extending from the bank. The reinforced soil lifts option would have a minimal to negligible impact on recreational users. A log cribwall could increase the regulatory 100-year base flood elevations along its length and extending upstream of it. The reinforced soil lifts option could be constructed flush with the existing bank line without placing fill and could, thereby, avoid any changes in the regulatory 100-year base flood elevations.

Implementation

Construction would be moderately to highly complex and would require a range of local, state, and federal permits. The estimated construction cost for the reinforced soil lifts option is $560,000, which equates to approximately $500 per linear foot for the 1,150 feet of bank protection system installed. The estimated construction cost for the log cribwall option is $1,160,000, which equates to approximately $1,000 per linear foot for the 1,150 feet of bank protection system installed.

Alternative 3

Description

Alternative 3 includes installing eight ELJs, four of them apex (mid-channel) ELJs, and four of them medium-sized bank deflector ELJs in the main channel of the South Fork from approximately RM 1.72 downstream to RM 1.55 (Figure E-2, Attachment E). It is assumed that each ELJ would be composed of approximately 20 logs, with each log 30 to 50 feet long and 2 to 3 feet in diameter, and most of them having intact rootwads. All ELJs would incorporate vertical timber piles to secure the logs, and they would be designed and constructed with an anchoring system to be structurally stable for the anticipated scour conditions and the hydraulic forces exerted during the 100-year recurrence flow. Large logs would be placed in the side channel inlet to augment the existing LWD that has accumulated there. A few vertical timber piles would also be placed in the side channel inlet to prevent the large logs from moving downstream and to help collect debris. Additional large logs would be installed into the right bank of the Silver Creek overflow channel outlet and into the right bank of the main channel between the second bank deflector ELJ and the inlet to the side channel. A new channel would be excavated between the left bank of the main channel at RM 1.55 and the left bank side channel. The channel is assumed to be approximately 200 feet long, 75 feet wide, and average roughly 3 feet deep. The new channel would be activated when main channel flows are equal to and greater than the winter base flow, reducing the amount of sediment accumulating at the inlet.

Anticipated Geomorphic Response

It is expected that the upstream bank ELJs would deflect flow toward the left bank and reduce flow velocities along the right bank, thereby inducing sediment deposition in the downstream wake of the ELJs and in the vicinity of the side channel inlet. The left bank gravel bar across from the side channel inlet would likely erode. Increasing the roughness of the right bank and the existing main channel with ELJs downstream of the side channel inlet would be expected to deflect flow into the new floodplain channel and induce sediment deposition in the existing channel between RM 1.6 and RM 1.5. The existing main channel between RM 1.55 and RM 1.45 would likely fill with sediment and become vegetated over time. Smaller side channels would likely remain in this sub-reach.

The existing left bank side channel downstream of the new floodplain channel would likely widen and become the new main channel. Floodplain trees would be recruited from this channel and transported downstream during initial channel widening, which would occur primarily on the left bank of this reach. The recruited trees would likely be transported downstream of the Circle River Ranch Revetment or be deposited on the left bank across from the revetment. Young trees recruited from the left bank as the channel widens would likely accumulate on the apex ELJs and be transported downstream.

General Summary of Criteria Evaluation

The significant findings with respect to the performance, impact, and implementation evaluation criteria for Alternative 3 are summarized below.

Performance

The ELJs and LWD placement would be highly effective at reducing the amount of flow entering the (right bank) side channel and moderately to highly effective at reducing the likelihood of an avulsion through the area of the “land bridge”. The effectiveness of the ELJs in deflecting flow to the west depends on the degree of sediment deposition in the wake of the ELJs and the spacing of the ELJs to inhibit flow between the structures. An ELJ spacing of less than one bankfull width would significantly reduce the likelihood of an avulsion between structures. The ELJs and large logs could provide up to 50 years of service with minimal to no maintenance. The new floodplain channel could provide the same service life depending on the geomorphic response of the channel.

Impact

Alternative 3 would significantly enhance aquatic habitat in the project reach. The proposed ELJs could pose increased hazards to recreational users of the river. Existing aquatic and riparian habitat would not be degraded and should not require any environmental mitigation to offset construction-related impacts. Alternative 3 would likely locally increase the regulatory 100-year base flood elevations

Implementation

Construction would be moderately to highly complex and would require a range of local, state, and federal permits. The estimated construction cost for Alternative 3 is $1,140,000.

Alternative 4

Description

Alternative 4 includes installing five ELJs in the South Fork main channel between the Snoqualmie Valley Trail bridge at RM 1.95 and the mouth of the Silver Creek overflow channel at RM 1.75 (Figure E-2, Attachment E). One medium and two large bank deflector ELJs would be situated along the right bank, with two apex ELJs situated mid-channel. The upstream-most ELJ would be located roughly 350 feet downstream of the Snoqualmie Valley Trail bridge at RM 1.85, and the downstream-most ELJ would be located roughly 250 feet upstream of the side channel inlet at RM 1.7. All ELJs would incorporate vertical timber piles to secure the logs, and they would be designed and constructed to withstand scour and the hydraulic forces for flows up to the 100-year recurrence flow.

Four new channels would be excavated between the left bank of the main channel and relic left bank floodplain side channels. Inlets for the new channels would be spaced roughly 200 to 300 feet apart along the left bank of the main channel. The new channels would be approximately 20 feet wide and 6 feet deep, and would vary in length from approximately 550 to 800 feet. The new channels would be activated when main channel flows are equal to and greater than the winter base flow so that they would be frequently activated, reducing the likelihood of sediment accumulating at the inlet.

Anticipated Geomorphic Response

The upstream bank ELJs would cause the main channel to widen on the left bank and deposit sediment in the wake of the ELJs on the right bank. The new left bank side channels would enlarge and deepen during overbank flooding, thereby conveying increasingly more flow away from the main channel. The inlets to these new side channels may fill with sediment and become disconnected from the main channel during low flows. The combination of the added hydraulic roughness from the proposed ELJs and the loss of sediment transport capacity as flow is lost to the new side channels would promote sediment deposition in the main channel upstream of the (right bank) side channel inlet. This would increase the likelihood of an avulsion into the relic channels to the west, away from the Circle River Ranch neighborhood. Downstream of RM 1.8, sediment would be expected to fill the channel between the two apex

ELJs and the right bank. This area would become vegetated within a few years. A side channel may remain in this area east of the apex ELJs.

General Summary of Criteria Evaluation

The significant findings with respect to the performance, impact, and implementation evaluation criteria for Alternative 4 are summarized below.

Performance

Sediment deposition induced by Alternative 4 upstream of the side channel inlet would temporarily reduce future aggradation at the gravel bar in the main channel that is currently responsible for deflecting flow into the side channel. Alternative 4 would be effective at reducing the erosion and avulsion hazards in the short-term, but it would become less effective as the sediment storage capacity of the Alternative 4 area (main channel upstream of the side channel inlet) is reached and sediment conveyance to the side channel area is restored. An avulsion to the west into relic channels would be highly effective at reducing short-term avulsion and erosion hazards in the Circle River Ranch neighborhood.

ELJs could provide up to 50 years of service with minimal to no maintenance. The constructed side channels could provide the same service life, depending on the geomorphic response of the system (for example, how quickly they fill with sediment).

Impact

Alternative 4 would significantly enhance aquatic habitat in the project reach. ELJs could pose increased safety hazards to recreational users of the river. Existing aquatic and riparian habitat would not be degraded and should not require any environmental mitigation to offset construction-related impacts. Alternative 4 would likely increase the regulatory 100-year base flood elevations in the area of ELJ placements and extending upstream.

Implementation

Construction would be moderately to highly complex and require a range of local, state and federal permits. The estimated construction cost for Alternative 4 is $1,250,000.

Discussion

In general, the level of risk reduction provided by the four alternatives presented herein is commensurate with the estimated construction cost. Alternative 1 (acquisition of the five properties at greatest risk) is the most expensive alternative. This alternative would provide the greatest reduction in risk by eliminating the risk for the acquired properties. It would continue to eliminate future risks if additional properties are acquired later. As currently defined, Alternative 1 does not reduce the risk to the adjacent properties that would not be acquired. The log cribwall option for Alternative 2 is intermediate in cost and could be expected to reliably reduce risks to properties over the design life of the structure (approximately 50 years), provided regular inspection and maintenance are performed as necessary. The process-based measures proposed in Alternatives 3 and 4 are comparable in cost to Alternative 2 and provide a moderate to high degree of confidence that they would reduce risks to properties over the design life of the structures (approximately 50 years). Although the four alternatives have been described and evaluated individually in this study, it may be desirable to combine some elements of two or more alternatives to develop an alternative with a specific focus or risk-reduction goal.

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ATTACHMENT A

Field Observations

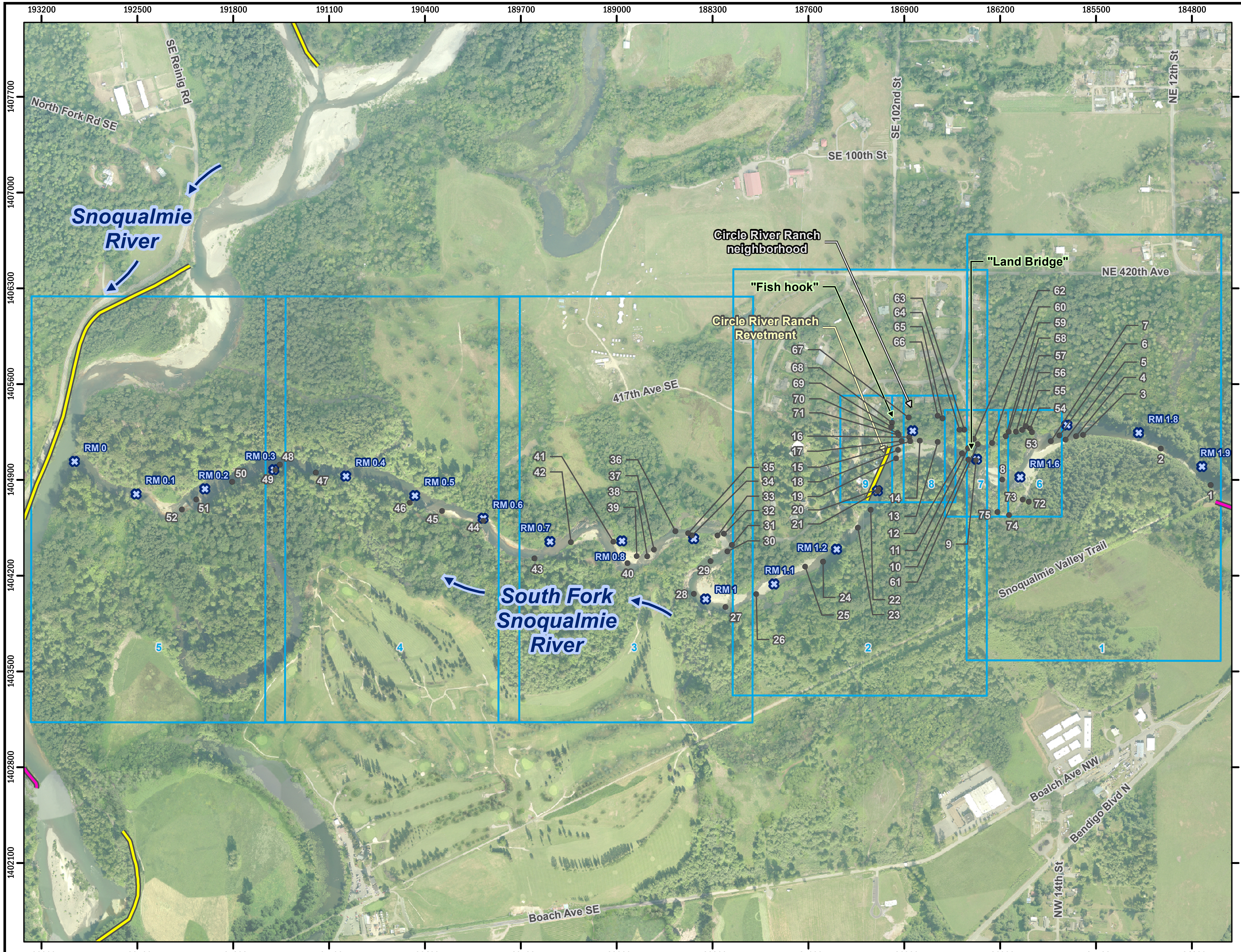


Figure A-1.
Field map overview and photo point locations.

HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)
Aerial: King County, 2009

Produced By: GIS ()
Project: K:\Projects\10-04731-000\Project\alternatives\photo_point.mxd (7/19/2012)

Table A-1. South Fork Snoqualmie River, Circle River Ranch Neighborhood, Geomorphic Hazards and Risks Assessment Photographic Log.

Photo Point	Photo Range	Photo Description
1	326, 6283-6286	South Fork Main Stem RM 1.9 – RM 1.7
2	327-330	South Fork Main Stem RM 1.9 – RM 1.7
3	331-333	South Fork Main Stem RM 1.9 – RM 1.7
4	334-335, 6288-6293	South Fork Main Stem RM 1.9 – RM 1.7
5	336	South Fork Main Stem RM 1.7 – RM 1.6
6	337-345, 350-352, 6294-6297	South Fork Main Stem RM 1.7 – RM 1.6
7	6308-6317, 346-348, 353-358, 6298-6305, 6318-6321	South Fork Main Stem RM 1.7 – RM 1.6
8	359-369, 6306	South Fork Main Stem RM 1.6 – RM 1.5
9	242-245, 370-374	South Fork Main Stem RM 1.5 – RM 1.4
10	235	South Fork Main Stem RM 1.5 – RM 1.4
11	236-237	South Fork Main Stem RM 1.5 – RM 1.4
12	375-379	South Fork Main Stem RM 1.5 – RM 1.4
13	384-387	South Fork Main Stem RM 1.5 – RM 1.4
14	389	South Fork Main Stem RM 1.5 – RM 1.4
15	390	South Fork Main Stem RM 1.4 – RM 1.15
16	388	South Fork Main Stem RM 1.4 – RM 1.15
17	392-397, 399-400	South Fork Main Stem RM 1.4 – RM 1.15
18	248-253, 401-411	South Fork Main Stem RM 1.4 – RM 1.15
19	412-413	South Fork Main Stem RM 1.4 – RM 1.15
20	414-422	South Fork Main Stem RM 1.4 – RM 1.15
21	423--426	South Fork Main Stem RM 1.4 – RM 1.15
22	427-435	South Fork Main Stem RM 1.4 – RM 1.15
23	436-437	South Fork Main Stem RM 1.4 – RM 1.15
24	441-450	South Fork Main Stem RM 1.4 – RM 1.15

Table A-1. South Fork Snoqualmie River, Circle River Ranch Neighborhood, Geomorphic Hazards and Risks Assessment Photographic Log.

Photo Point	Photo Range	Photo Description
25	254	South Fork Main Stem RM 1.4 – RM 1.15
26	451-456	South Fork Main Stem RM 1.15 – RM 1.05
27	457-459	South Fork Main Stem RM 1.4 – RM 1.15
28	460-461	South Fork Main Stem RM 1.4 – RM 1.15
29	462-465	South Fork Main Stem RM 1.4 – RM 1.15
30	466-467	South Fork Main Stem RM 1.05 – RM 0.8
31	468-474	South Fork Main Stem RM 1.4 – RM 1.15
32	475-479	South Fork Main Stem RM 1.4 – RM 1.15
33	257-258, 480-481	South Fork Main Stem RM 1.4 – RM 1.15
34	259	South Fork Main Stem RM 1.4 – RM 1.15
35	482-483	South Fork Main Stem RM 1.4 – RM 1.15
36	484-485	South Fork Main Stem RM 1.4 – RM 1.15
37	260	South Fork Main Stem RM 1.4 – RM 1.15
38	486-487	South Fork Main Stem RM 1.4 – RM 1.15
39	488-489	South Fork Main Stem RM 1.4 – RM 1.15
40	490	South Fork Main Stem RM 1.4 – RM 1.15
41	261-262, 491-494	South Fork Main Stem RM 0.8 – RM 0.2
42	6567-6580	South Fork Main Stem RM 1.4 – RM 1.15
43	6555-6566	South Fork Main Stem RM 1.4 – RM 1.15
44	6547-6554	South Fork Main Stem RM 1.4 – RM 1.15
45	6531-6545	South Fork Main Stem RM 1.4 – RM 1.15
46	6526-6530	South Fork Main Stem RM 1.4 – RM 1.15
47	6475-6480	South Fork Main Stem RM 1.4 – RM 1.15
48	6481-6486	South Fork Main Stem RM 1.4 – RM 1.15
49	6487-6494	South Fork Main Stem RM 1.4 – RM 1.15
50	6495-6500	South Fork Main Stem RM 1.4 – RM 1.15
51	6501-6514	South Fork Main Stem RM 1.4 – RM 1.15
52	6515-6525	South Fork Main Stem RM 1.4 – RM 1.15
53	6338	South Fork Main Stem RM 1.4 – RM 1.15
54	6322-6337	Right Bank Side Channel adjacent to the Circle River Ranch Neighborhood (the "Side Channel") RM 1.65 – RM 1.35

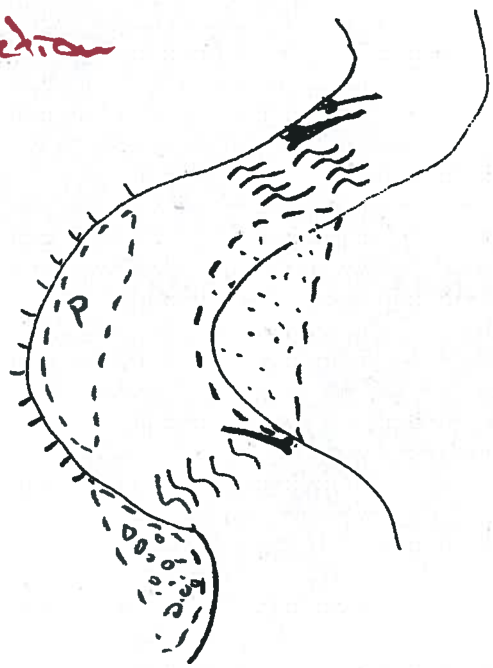
Table A-1. South Fork Snoqualmie River, Circle River Ranch Neighborhood, Geomorphic Hazards and Risks Assessment Photographic Log.		
Photo Point	**Photo Range**	**Photo Description**
55	6347-6354, 6251-6258	Side Channel RM 1.65 – RM 1.35
56	6339-6346	Side Channel RM 1.65 – RM 1.35
57	6355-6359	Side Channel RM 1.65 – RM 1.35
58	6360-6361	Side Channel RM 1.65 – RM 1.35
59	6362-6364	Side Channel RM 1.65 – RM 1.35
60	6365-6367	Side Channel RM 1.65 – RM 1.35
61	6373-6377	Side Channel RM 1.65 – RM 1.35
62	6378-6385, 6237-6240, 6368-6372	Side Channel RM 1.65 – RM 1.35
63	6392-6395, 6241-6250	Side Channel RM 1.65 – RM 1.35
64	6396-6399	Side Channel RM 1.65 – RM 1.35
65	6403-6408	Side Channel RM 1.65 – RM 1.35
66	6400-6402	Side Channel RM 1.65 – RM 1.35
67	6409-6414	Side Channel RM 1.65 – RM 1.35
68	6415-6422	Side Channel RM 1.65 – RM 1.35
69	6423-6432, 6259-6270	Side Channel RM 1.65 – RM 1.35
70	6433-6441	Side Channel RM 1.65 – RM 1.35
71	6442-6448	Side Channel RM 1.65 – RM 1.35
72	496-497	LB side channel RM 1.6 – RM 1.45
73	498-499	LB side channel RM 1.6 – RM 1.45
74	500-501	LB side channel RM 1.6 – RM 1.45
75	232-234, 502-503, 263-265	LB side channel RM 1.6 – RM 1.45
N/A	6232-6235, 6281-6282	Photos taken from the Snoqualmie Valley Trail bridge at RM 1.95
N/A	6453-6454, 6262, 6464	Photos taken of the swale/ditch along 416th near house address 10125 and 10131; location of historic 1865 channel, and potential overflow channel/avulsion location
N/A	6271-6275	Photos taken from Circle River Ranch revetment facility along the right bank, near RM 1.3

- RM 1.7 — River mile
- Pool
- Riffle
- Sand bar
- Gravel bar
- Eroding bank
- Large woody debris
- Beaver dam
- Riprap
- Road
- Property boundary
- log weir
- Flow direction

Co = cobble
G = gravel
S = Sand
M = Silt
Cl = Clay

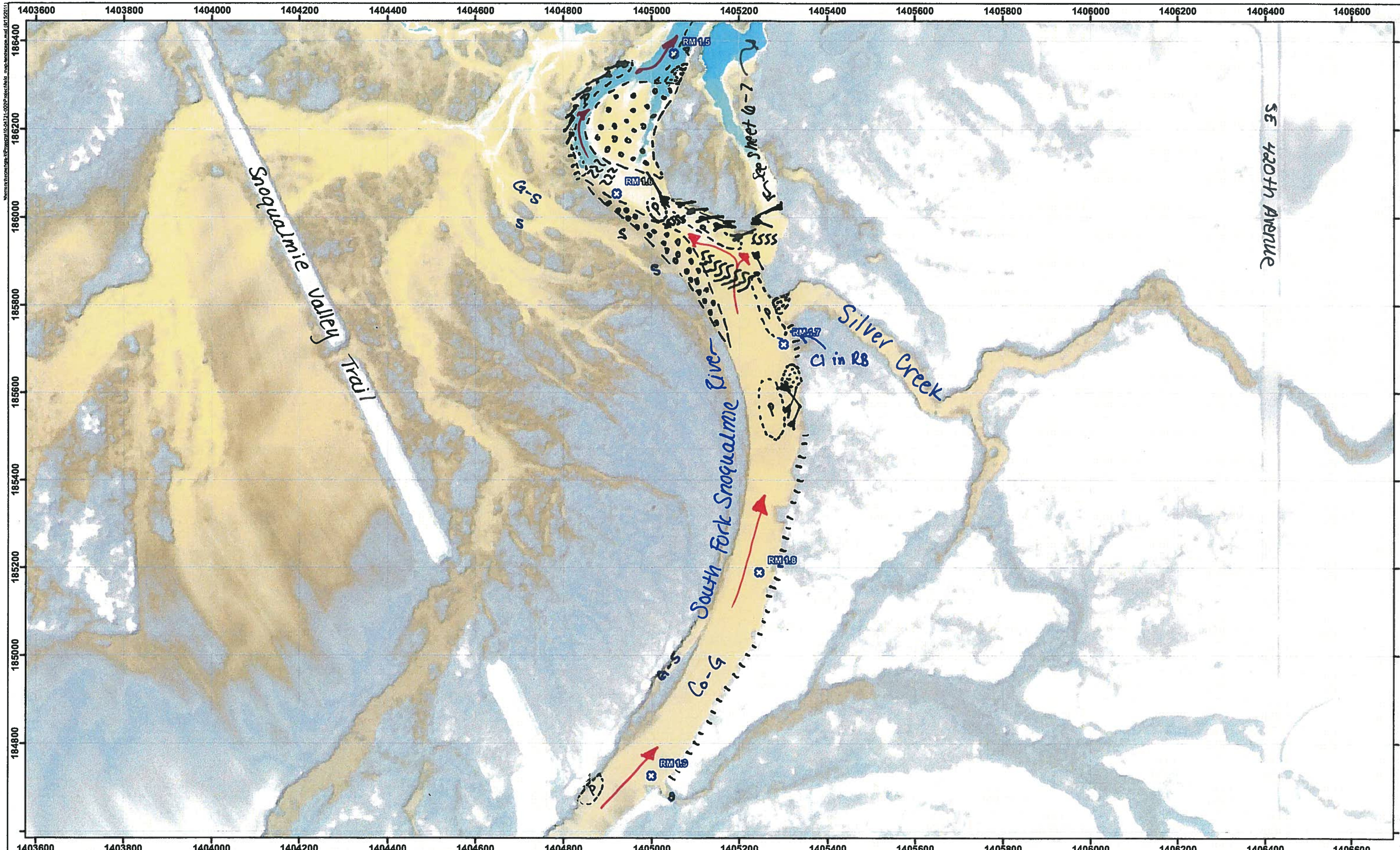
G - S

G: dominant substrate
S: subdominant



EXAMPLE

Circle River Ranch Field Map Legend



Sheet 1.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

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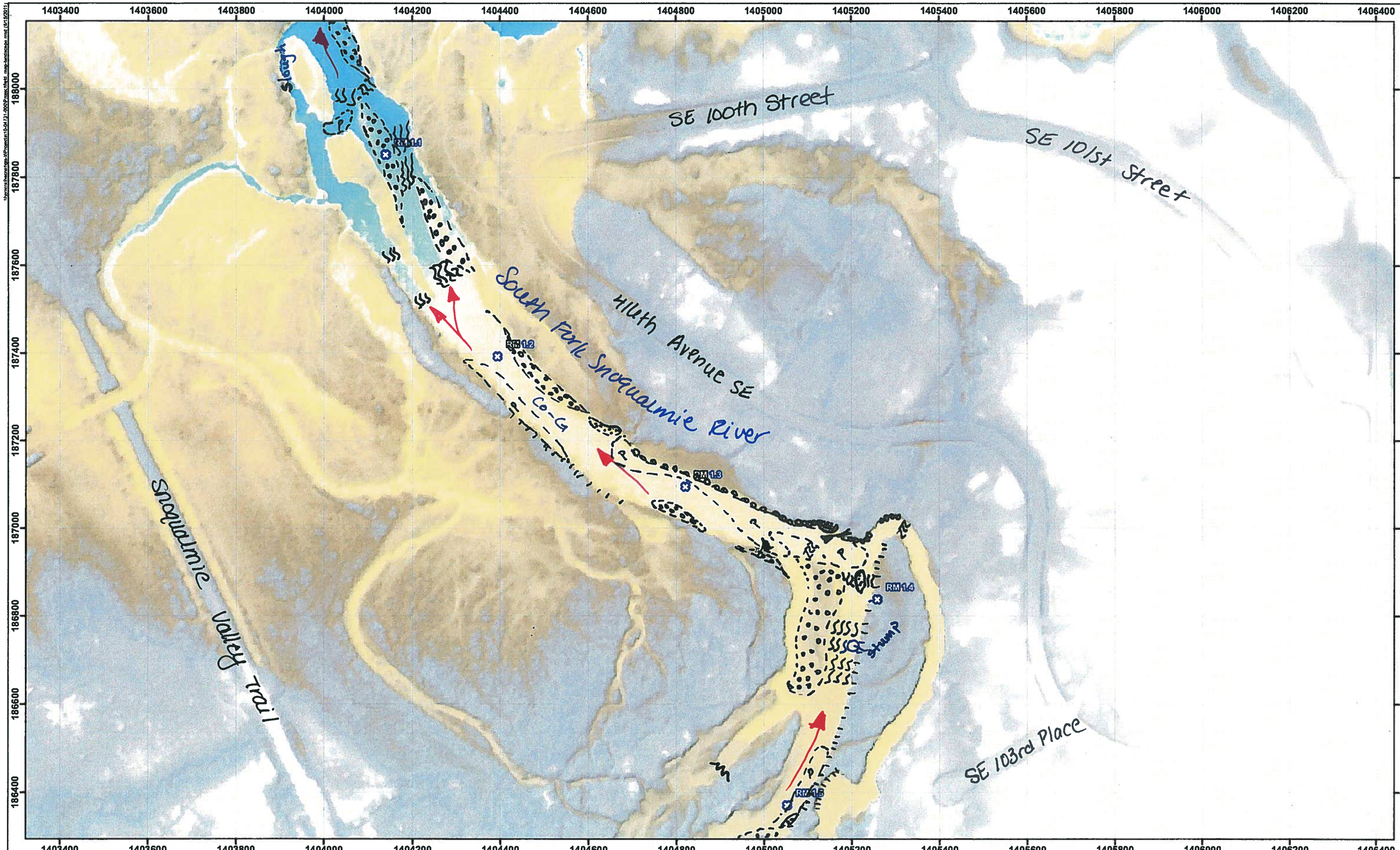

Sheet 2.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

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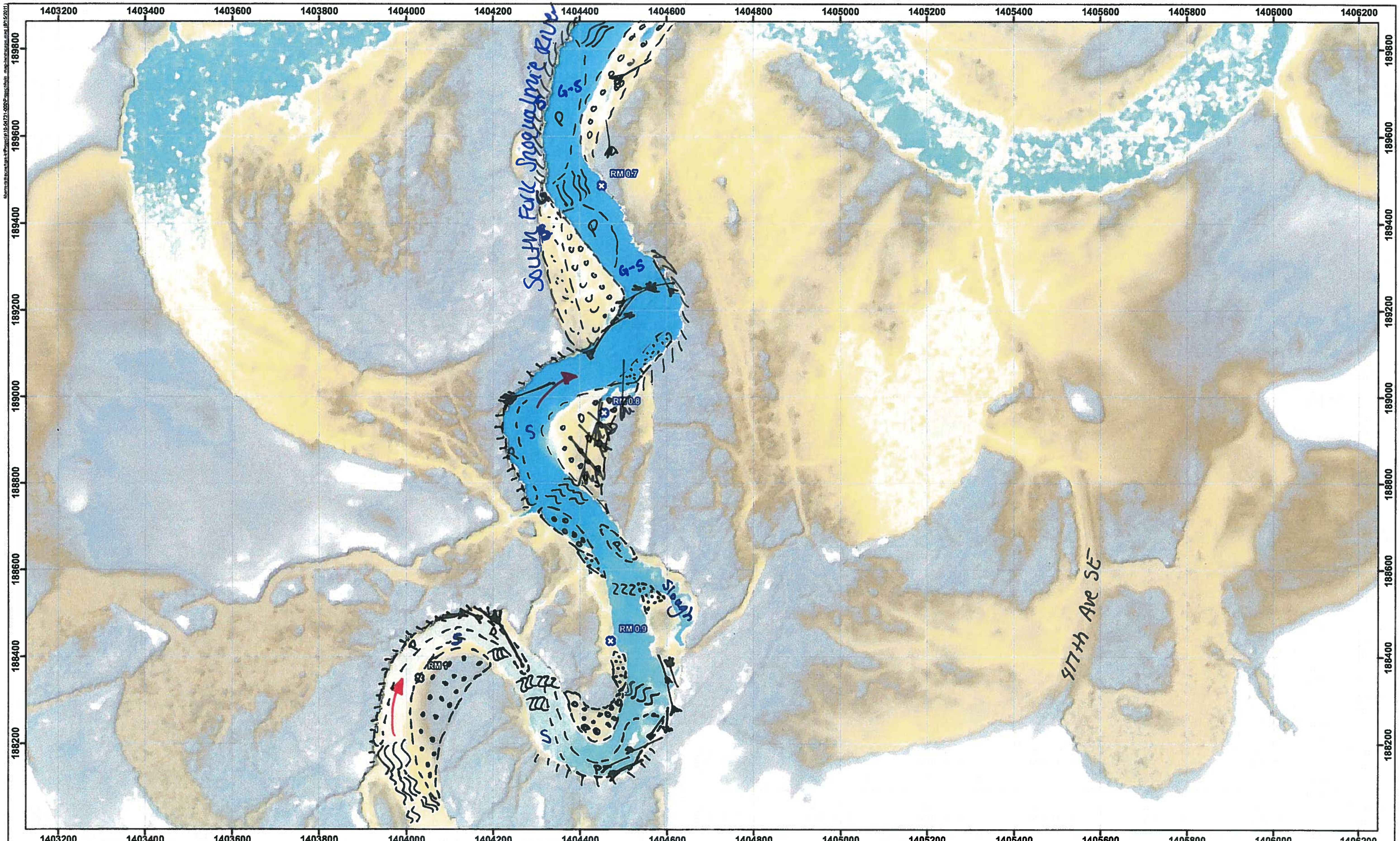

Sheet 3.

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LiDAR: King County, 2010

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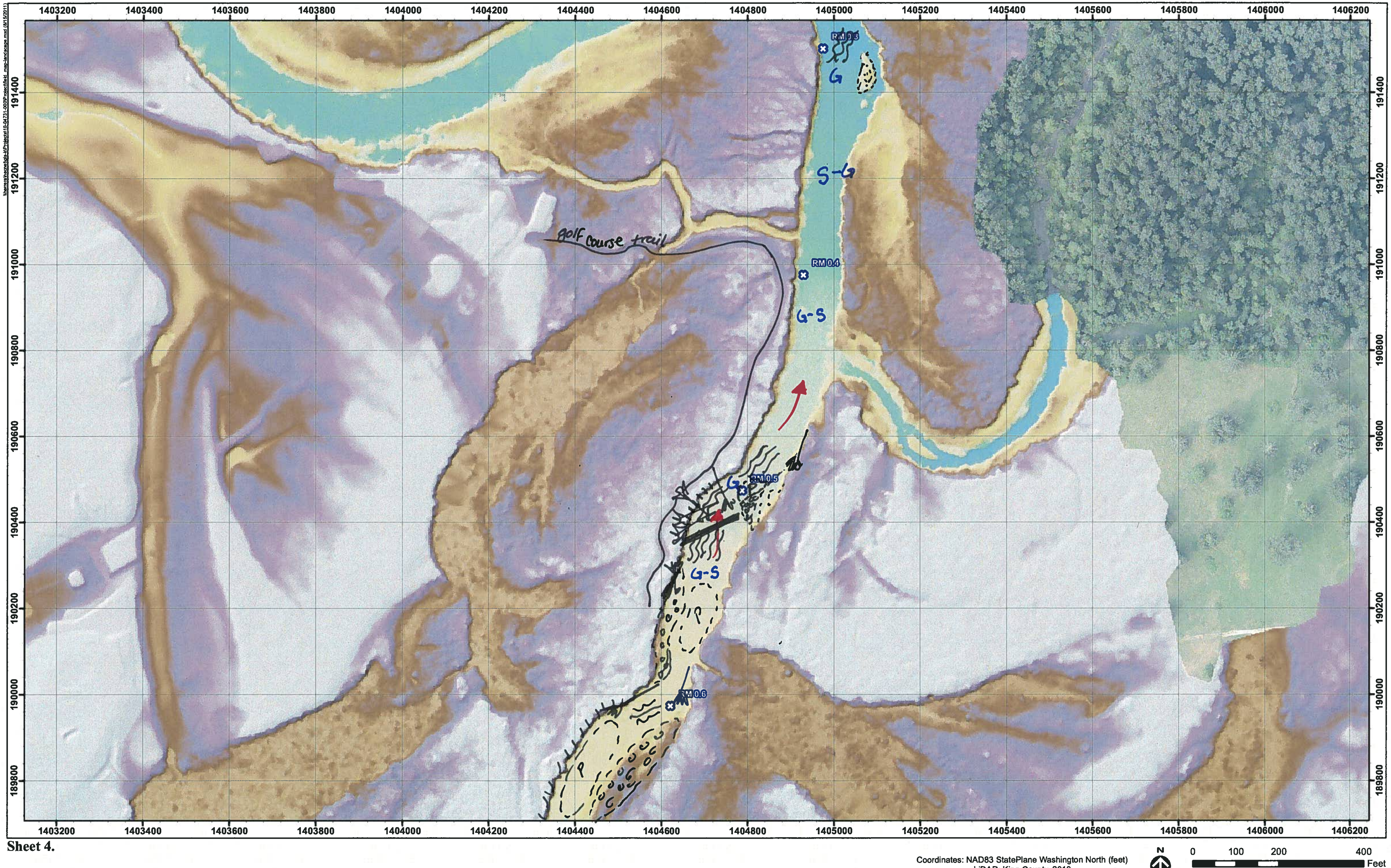


golf course trail
RM 0.3
RM 0.4
RM 0.5
RM 0.6
G
S-G
G-S
G
G-S
Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010
N
0 100 200 400
Feet

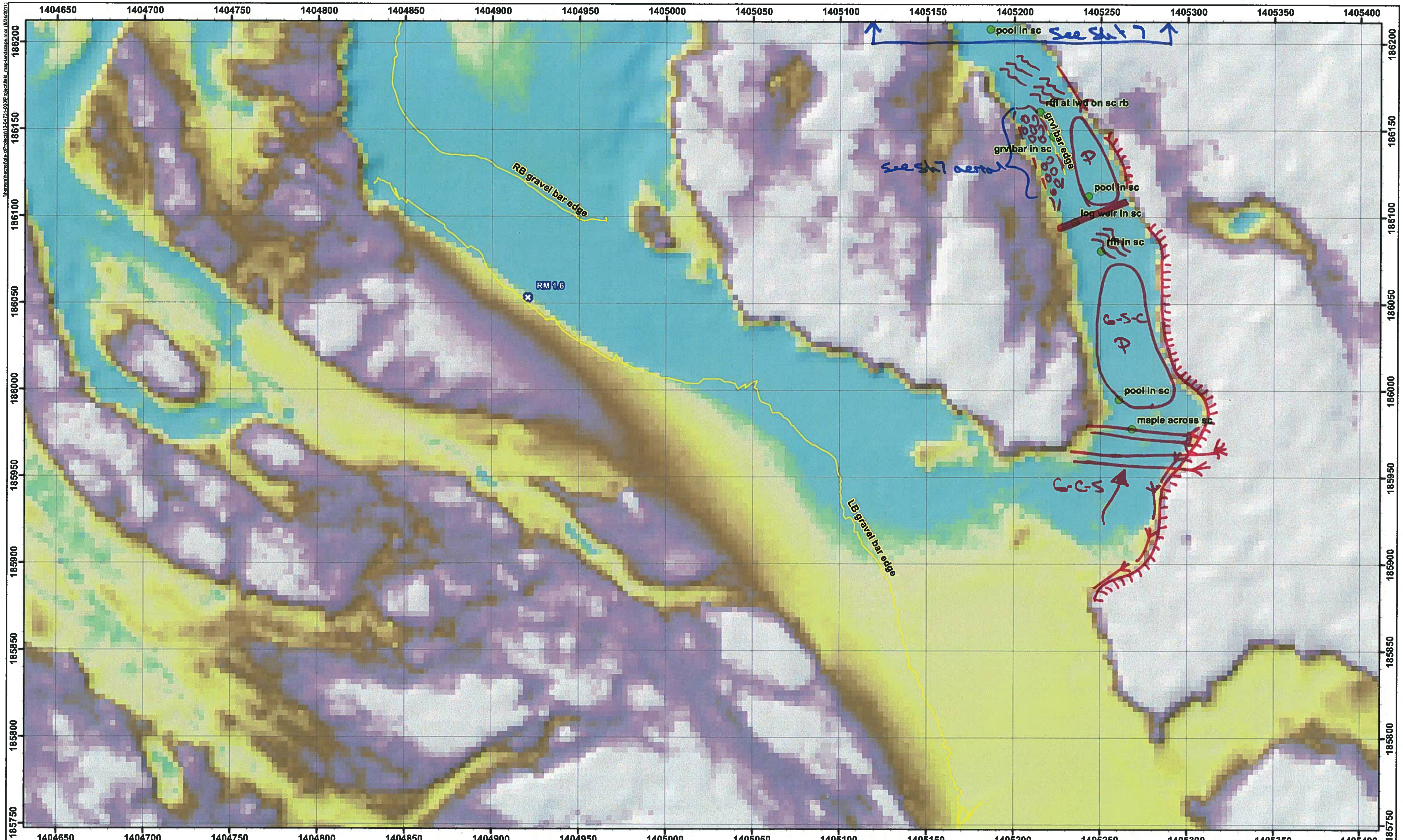
Sheet 4.

Sheet 5.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

N

0 100 200 400 Feet



Sheet 6.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

N

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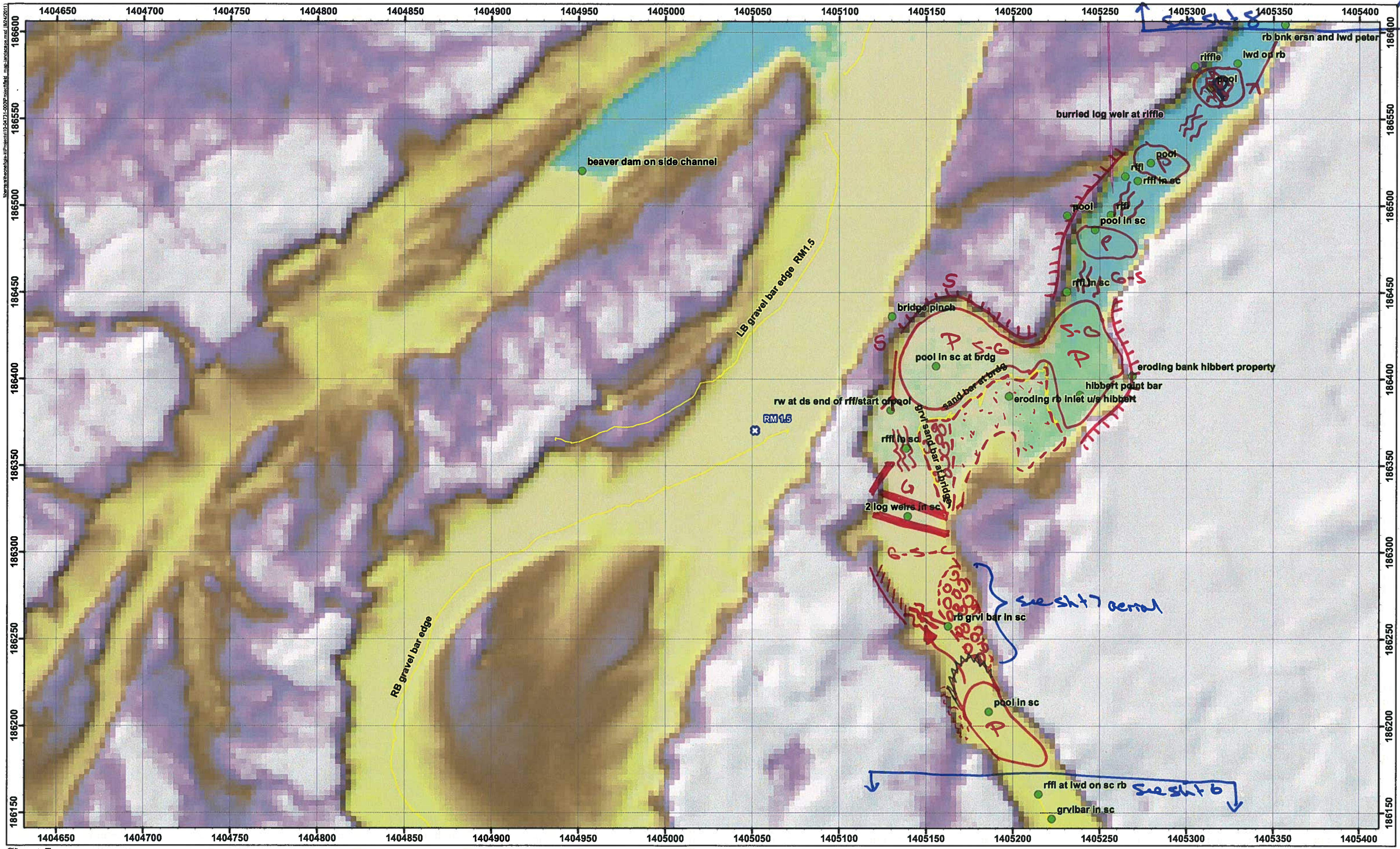
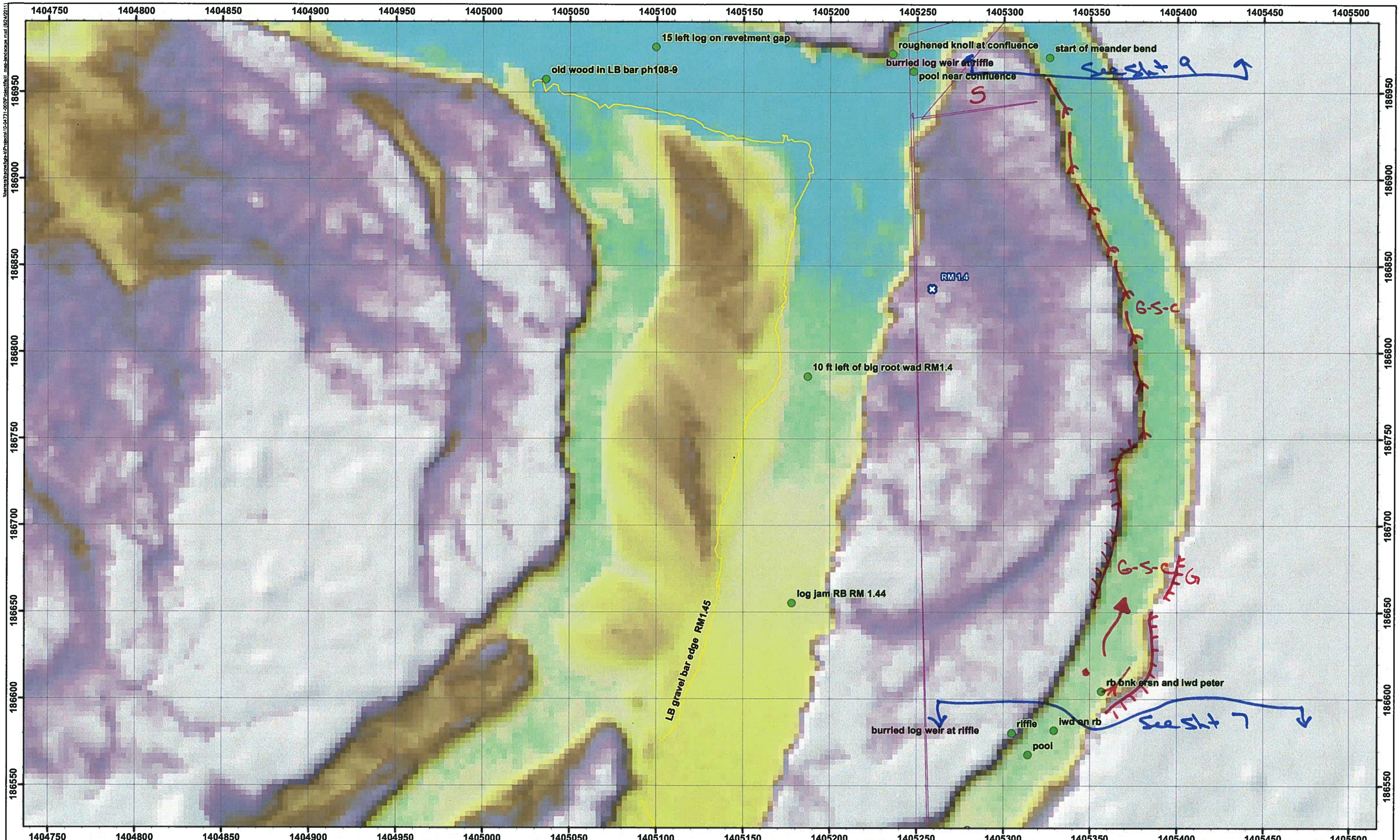


Sheet 7.

N 0 25 50 100 Feet

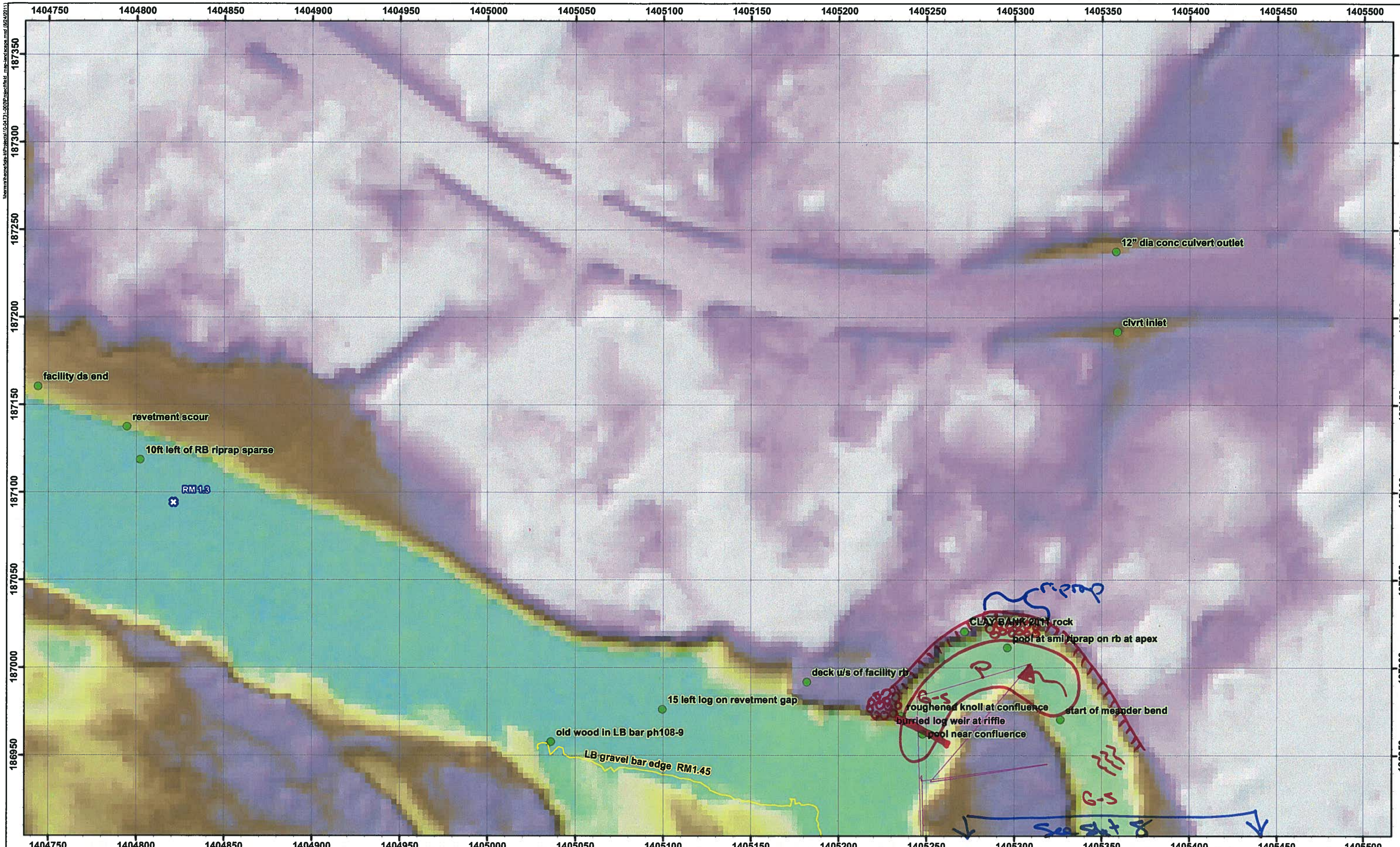
Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010



Sheet 8.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

N 0 25 50 100 Feet



Sheet 9.

Coordinates: NAD83 StatePlane Washington North (feet)
LiDAR: King County, 2010

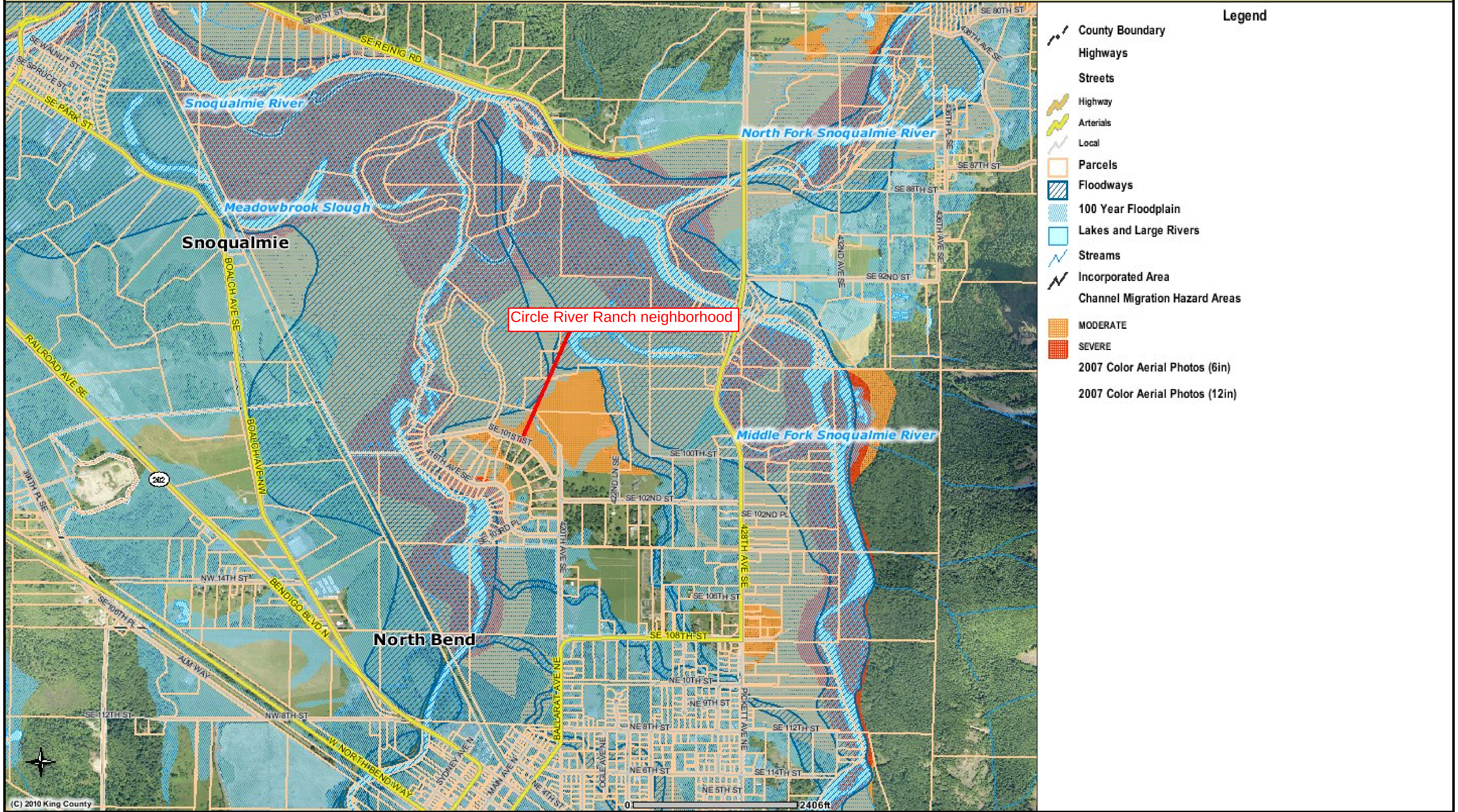
N

0 25 50 100 Feet

ATTACHMENT B

Flood and Channel Migration Hazard Information

Figure B-1. Mapped SFS Floodplain and Channel Migration Hazard Areas.

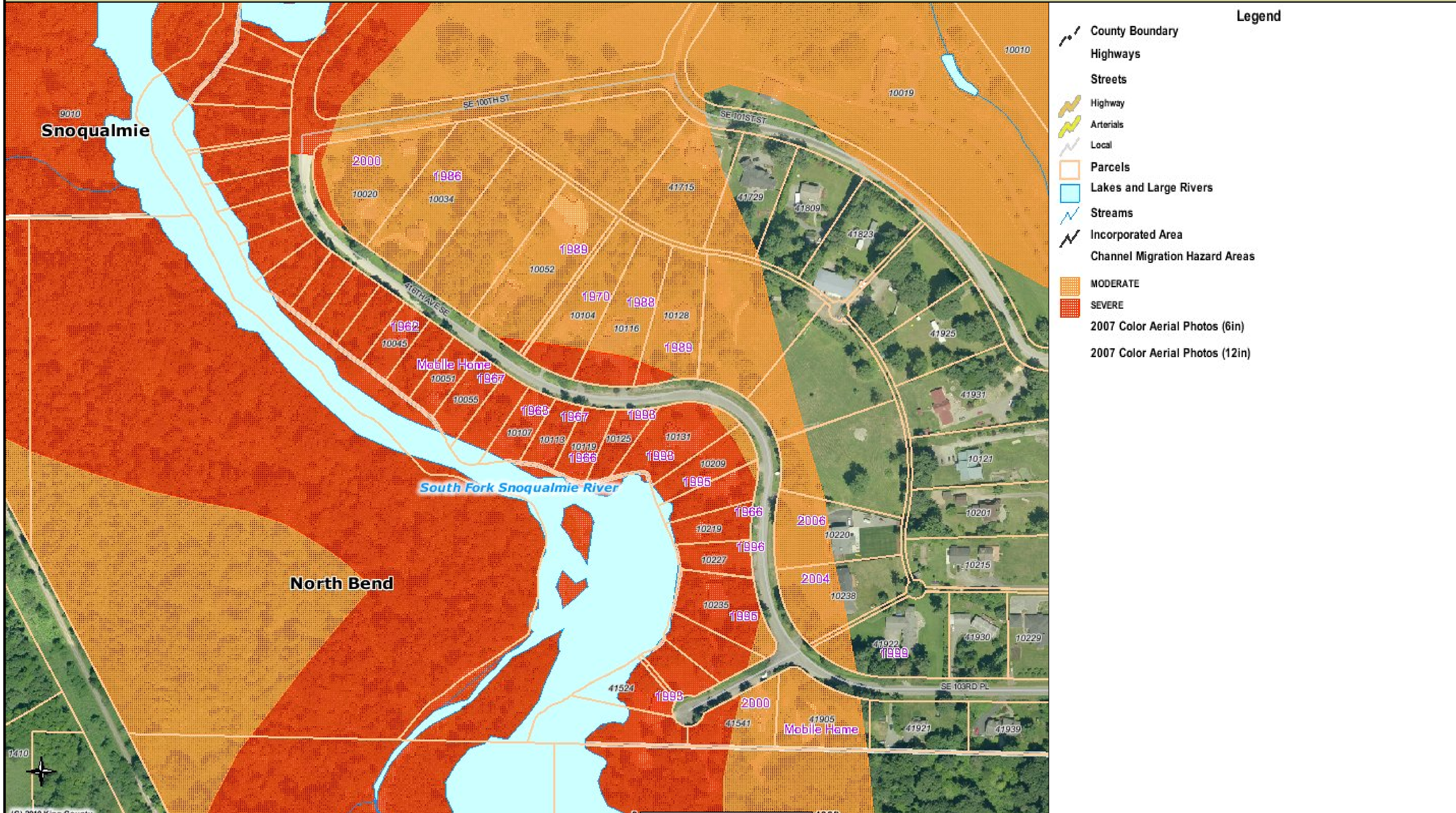


COMMENTS: Sources:

Date: 8/31/2011 Source: King County iMAP - Hydrographic Information (http://www.metrokc.gov/GIS/iMAP)

King County

Figure B-2. Circle River Ranch Properties.



COMMENTS: Sources: Perkins 1996, FEMA 2005

Date: 8/31/2011 Source: King County iMAP - Hydrographic Information (http://www.metrokc.gov/GIS/iMAP)

King County

Table B-1. Description of Assumptions and References Supporting Figure 3, Geomorphic Risks in the Circle River Ranch Neighborhood Vicinity, South Fork Snoqualmie River.

Geomorphic Hazard Zone [a]	Geographic Location	Figure Item	Width (ft)	Description and Documentation for Width Calculation
General Figure Definitions				
NA	Circle River Ranch Neighborhood	Houses and Buildings	NA	Based on the 2010 and 2011 aerial photography and the parcel boundaries provided by County.
NA	Entire Figure	High Hazard zone	varies	Greater than 50% probability that the channel will occupy this area in the next 5 years. Erosion likelihood resulting from a 5-year recurrence interval flow, in the next 5 years, if no action is taken.
		Medium Hazard zone	varies	Greater than 50% probability that the channel will occupy this area in the next 10 to 15 years. Erosion likelihood resulting from a 10- to 15-year recurrence interval flow, in the next 10 to 15 years, if no action is taken.
NA	Entire Figure	High Risk zone	varies	Intersection of the "High Hazard" with a house, outbuilding, or King County Facility.
		Medium Risk zone	varies	Intersection of the "Medium Hazard" with a house, outbuilding, or King County Facility.
NA	Riverside boundary	High Hazard zone	NA	Corresponds to the respective bank edge of the main channel or side channel as delineated from 2010 aerial photography and 2010 lidar data provided by the County.
		Medium Hazard zone	NA	Corresponds to the outer edge of the "High Hazard" zone.
Geomorphic Hazard Zone Definitions [b]				
1	Main channel right bank, upstream of the side channel inlet (RM 1.8 to 1.65)	High Hazard zone width	20	Average annual rate of right bank position change applied over 5-year period = 4 ft/year * 5 years.
		Medium Hazard zone width	40	Average annual rate of right bank position change applied over 10-year period = 4 ft/year * 10 years.
2	Side channel right bank, upstream of the "land bridge" (RM 1.65 to 1.5)	High Hazard zone width	20 +	Average annual rate of right bank position change applied over 5-year period = 4 ft/year * 5 years, with adjustments for radius of curvature near Hibbert property.
		Medium Hazard zone width	47.5 +	Assumes main channel partial avulsion (75% of flow) into side channel inlet, based on historical bifurcated channel alignment along the South Fork, plus average annual change of right bank position, applied over a 10-year period. Total hazard zone width is 75% of existing bankfull width (0.75*90 = 67.5 ft) minus existing bankfull width (40 ft) minus high hazard area width (20 ft) plus average right bank position change over 10 years (4*10 = 40 ft), with adjustments for radius of curvature.
3	Side channel left bank, upstream of the "land bridge" (RM 1.65 to 1.5)	High Hazard zone width	25 +	Average position change at side channel inlet applied over 5-year period = 5 ft/year * 5 years, with adjustments for radius of curvature.
		Medium Hazard zone width	42.5 +	Assumes main channel partial avulsion (75% of flow) into side channel inlet, based on historical bifurcated channel alignment along the South Fork, plus average annual change of right bank position, applied over a 10-year period. Total hazard zone width is 75% of existing bankfull width (0.75*90 = 67.5 ft) minus existing bankfull width (40 ft) minus high hazard area width (25 ft) plus average right bank position change over 10 years (4*10 = 40 ft), with adjustments for radius of curvature.
4	The "land bridge" (RM 1.5)	High Hazard zone width	90	Width equal to existing main channel bankfull width.

Table B-1. Description of Assumptions and References Supporting Figure 3, Geomorphic Risks in the Circle River Ranch Neighborhood Vicinity, South Fork Snoqualmie River.

Geomorphic Hazard Zone [a]	Geographic Location	Figure Item	Width (ft)	Description and Documentation for Width Calculation
5	Side channel right bank, downstream of the "land bridge" (RM 1.5 to 1.35)	High Hazard zone width	47.5 +	Assumes main channel partial avulsion (75% of flow) through the land bridge, based on historical bifurcated channel alignments along the South Fork, plus average annual change of right bank position, applied over a 5-year period. Total hazard zone width is 75% of existing bankfull width (0.75*90 = 67.5ft) minus existing bankfull width (40ft) plus average right bank position change over 5 years (4*5=20ft), with adjustments for radius of curvature.
		Medium Hazard zone width	40	Average annual rate of right bank position change applied over 10-year period = 4ft/year * 10 years.
6	Side channel left bank, downstream of the "land bridge" (RM 1.5 to 1.35)	High Hazard zone width	47.5 +	Assumes main channel partial avulsion (75% of flow) through the land bridge, based on historical bifurcated channel alignments along the South Fork, plus average annual change of right bank position, applied over a 5-year period. Total hazard zone width is 75% of existing bankfull width (0.75*90 = 67.5 ft) minus existing bankfull width (40 ft) plus average right bank position change over 5 years (4*5 = 20 ft), with adjustments for radius of curvature.
		Medium Hazard zone width	40	Average annual rate of right bank position change applied over 10-year period = 4 ft/year * 10 years.
7	North of the "fish hook" (RM 1.4)	Medium Hazard zone width	40	Width equal to existing side channel bankfull width.

References: Herrera 2011; King County 2002; King County 2010; King County 2011b; K. Rauscher, personal communication, September 16, 2011; Perkins 1996

NA = Not Applicable

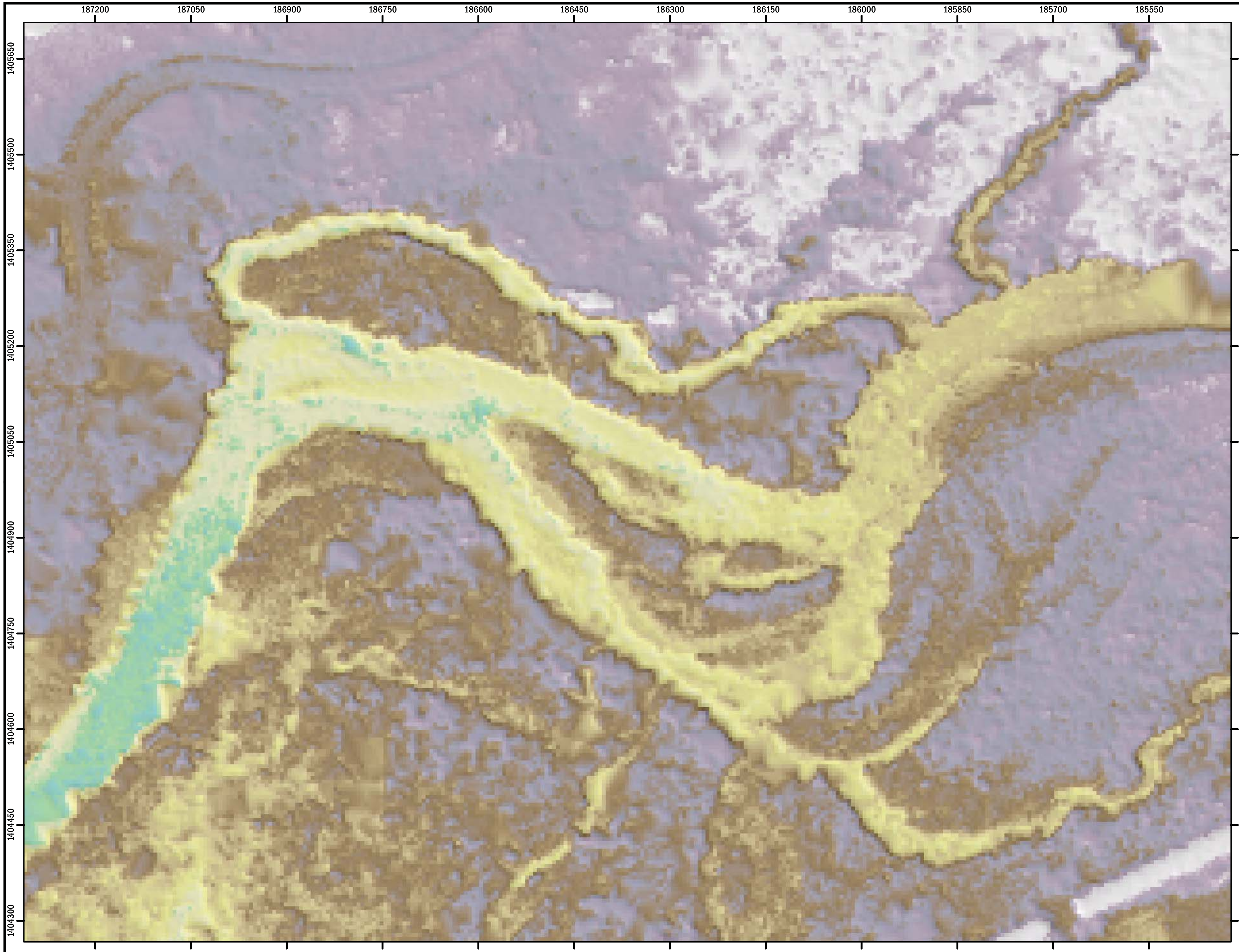
[a] Geomorphic Hazard Zone Segments correspond to segments delineated on Figure 3.

[b] Average annual change of bank position derived from 1993 and 2010 aerial photos and historic channel alignment comparison.

ATTACHMENT C

Aerial Photography and Lidar Information

Figure C-1.
2002 LiDAR at Circle River Ranch Area, South Fork Snoqualmie River.



N

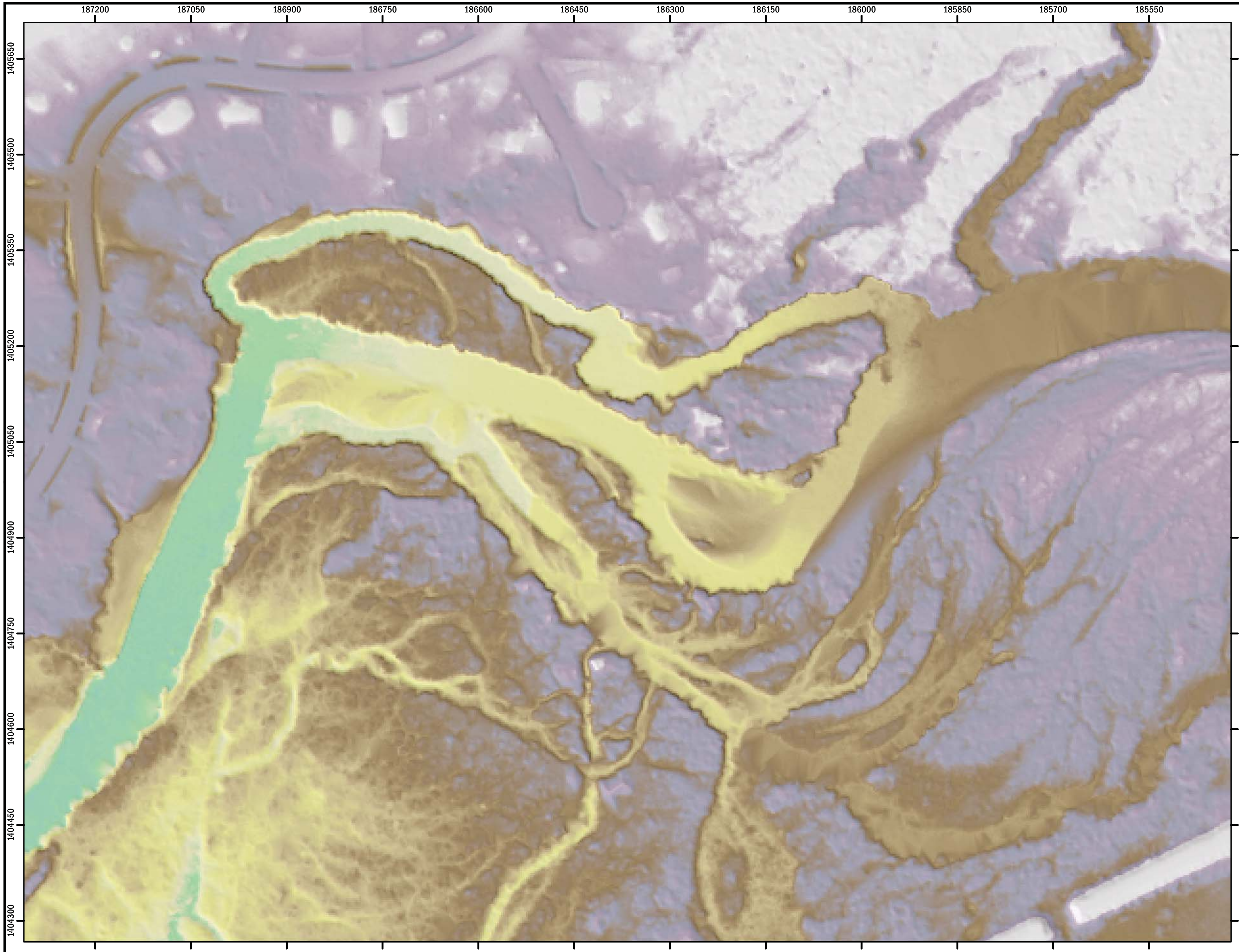
0 75 150 300
Feet

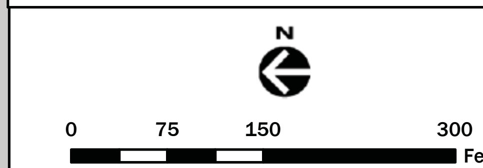
HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-2.
2010 LiDAR at Circle River Ranch Area, South Fork Snoqualmie River.





HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-3.
2002 Aerial at Circle River Ranch Area, South Fork Snoqualmie River.

HERRERA

Coordinates: NAD83 HARN StatePlane Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-4.
2005 Aerial at Circle River Ranch Area, South Fork Snoqualmie River.

N

0 75 150 300 Feet

HERRERA

Coordinates: NAD83 HARN StatePlane Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-5.
2007 Aerial at Circle River Ranch Area, South Fork Snoqualmie River.

HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-6.
2009 Aerial at Circle River Ranch Area, South Fork Snoqualmie River.

HERRERA

Coordinates: NAD83 HARN StatePlane
Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

Figure C-7.
2010 Aerial at Circle River Ranch Area, South Fork Snoqualmie River.

N

0 75 150 300 Feet

HERRERA

Coordinates: NAD83 HARN StatePlane Washington North (Feet)

Produced By: GIS ( )
Project: \\herrera\hecnet\gis-k\Projects\10-04731-000\Project\aerials_lidar-report.mxd (8/31/2011)

ATTACHMENT D

Alternatives Development and Assessment Methodology

ALTERNATIVES DEVELOPMENT AND ASSESSMENT METHODOLOGY

An alternatives assessment was performed with the objective of reducing risks in the right bank (east) floodplain along the side channel within either a high or medium geomorphic hazard zone. Alternatives were created by combining structural and/or non-structural risk-reduction measures to target either the geomorphic processes or the consequences of these processes. Main stem channel migration and sediment aggradation have increased flow in the side channel, and consequently bank erosion and channel widening in the side channel is occurring between RM 1.9 and RM 1.35 (Table D-1). During a meeting with Richelle Rose and Mark Ruebel of King County on November 1, 2011, a total of nine potential risk-reduction alternatives were discussed. During this meeting, Herrera and King County staff screened the alternatives in order to select four alternatives for Herrera to consider for further development (Table D-2). Additionally, Herrera and King County staff selected assessment criteria (Table D-3) for qualitatively comparing each alternative’s performance, impact, and implementation characteristics. This memorandum does not rank or recommend the implementation of a preferred alternative.

The following assumptions were used when developing risk-reduction measures and alternatives:

1. Existing levee conditions upstream of the project reach will not change for the design life of the alternative.
2. The coarse sediment supply to the project reach will remain consistent for the design life of the alternative
3. The project reach is not expected to experience large woody debris (LWD) loading much greater than current condition.

Descriptions of the individual risk-reduction measures and the assessment criteria are summarized below. Table D-4 provides a brief summary of the five alternatives (5, 6, 7, 8, and 9) that did not pass the initial screening exercise.

The alternatives presented in Table D-2 can be classified as non-structural or structural measures. Non-structural measures allow geomorphic processes to occur uninhibited by structural controls and reduce or eliminate risks by addressing the consequences of the identified geomorphic hazards, rather than addressing just the hazard. Alternative 1 is the only non-structural measure evaluated in this study and eliminates risk by removing structures from the hazardous areas. Alternatives 2, 3, and 4 are examples of structural measures that propose to place physical barriers in hazardous areas between the river and at risk properties. Alternatives 3 and 4 are also examples of process-based measures that seek to alter geomorphic processes (primarily sediment deposition), with the intent of shifting geomorphic hazards away from the at-risk properties to lower-risk areas of the floodplain. While all of the alternatives incorporate an understanding of the geomorphic processes into their design, the process-based alternatives are more active at the manipulation of geomorphic processes upstream of the Circle River Ranch area to reduce the hazards identified at the Circle River Ranch area.

Assessment Criteria

Herrera developed assessment criteria organized into three main categories: performance, impacts, and implementation. Specific assessment criteria within each of the three categories are summarized in Table D-3. The criteria used in this assessment are qualitative and are based on the outcomes of numerous river projects that were successfully permitted and constructed in the Puget Sound region to address geomorphic hazards and risks similar to those identified in this study for the Circle River Ranch neighborhood.

Performance

The performance criteria include metrics for evaluating the effectiveness of an alternative to reduce hazards and reduce or eliminate the risk imposed by the hazard. Performance criteria also include the anticipated design life and the monitoring and maintenance requirements during the design life.

Impacts

The impact criteria include metrics for how an alternative might pose an additional hazard to recreational users of the river. Impact criteria also include degradation of aquatic or riparian habitat and the potential for an increase in the Base Flood Elevations (BFEs) as defined for the 100-year flood.

Implementation

The implementation criteria include the likely construction complexity, permitting requirements, and planning-level cost estimates to construct the alternative. The planning-level cost estimates do not include costs for engineering or permitting, which can range from 20 to 50 percent of the construction costs for the structural measures.

Table D-1. Summary of individual hazard- and risk-reduction measures that were combined to form alternatives.

Hazard or Risk-reduction Measure	Purpose of Measure
Acquire properties with structures at risk, remove structures, and restore native vegetation at those locations	Reduce risks by removing at-risk infrastructure from the geomorphic hazard areas and to restore the natural riparian conditions of the floodplain to allow more natural channel evolution.
Armor eroding channel bank with riprap	To protect the right bank of the side channel against bank erosion and limit channel migration potential.
Bioengineered bank protection using a log cribwall structure or reinforced soil lifts.	To protect the right bank of the side channel from bank erosion using natural materials that support riparian and aquatic habitat and to prevent further channel migration toward the Circle River Ranch neighborhood. A log cribwall consists of a series of individual engineered structures, each consisting of several logs arranged in a manner to create a roughened and robust wall that prevents bank erosion. Reinforced soil lifts consist of multiple vertical soil layers, each encapsulated within either a natural or synthetic fabric material and oriented parallel to the bank and planted with native vegetation.
Side-channel inlet roughening	To prevent an avulsion through the side channel inlet by reducing flow into the upstream half of the side channel (upstream of the “bridge”) and trap floating debris. Roughening refers to placing and anchoring multiple long logs with rootwads across the inlet to resist movement when submerged and subjected to hydraulic forces.
Bank deflector and apex (mid-channel) engineered logjams (ELJs)	To collectively deflect the South Fork away from the right bank floodplain and side channel inlet, towards the left bank floodplain, and into newly constructed channels and/or existing left bank side channels. An ELJ is a large, robust engineered structure that resembles a natural stable accumulation of large logs that is installed either along a channel bank (bank deflector) or somewhere within the middle of the main stem channel (apex type). All ELJs are designed to withstand forces due to hydraulic drag, and the buoyant forces on the wood members when submerged. All ELJs are considered to be erosion-resistant hard points for the purposes of this assessment.
Channel construction	To provide a preferential pathway for conveying flow from the main stem South Fork across the left bank floodplain and into existing left bank side channels.

Table D-2. Summary of risk-reduction alternatives chosen for evaluation.	
Alternative	**Description**
1	Acquire five properties situated along the side channel, each with buildings located within either high or medium hazard zones; remove all infrastructure on those properties, and revegetate the property with native vegetation.
2	Install a continuous bioengineered bank protection system along the right bank of the downstream half of the side channel.
3	Install large logs to roughen the side channel inlet and protect the Silver Creek outlet, install multiple bank deflector and apex (mid-channel) type engineered logjams (ELJs) in the main stem South Fork immediately upstream and downstream of the inlet, and excavate a new channel through the floodplain at RM 1.55 to convey flow from the mainstem to the left bank side channel.
4	Install multiple bank deflector and apex ELJs in the main stem South Fork between the Snoqualmie Valley Trail bridge at RM 1.95 and RM 1.7 (about 250 feet upstream of the side channel inlet) and construct four side channels between RM 1.9 and RM 1.6 to convey flow from the main stem across the left bank floodplain and into existing relic side channels.

Table D-3. Summary and definitions of evaluation criteria developed to assess the five alternatives.

Evaluation Criteria		Definition
Performance	Risk prevention and/or reduction effectiveness	Degree of confidence that the alternative would prevent or reduce the likelihood of structural damage over the design life of the alternative.
	Avulsion and bank erosion prevention and/or reduction effectiveness	Degree of confidence that the alternative would prevent an avulsion and reduce the likelihood of bank erosion to the Circle River Ranch neighborhood over the design life of the alternative.
	Design life	Anticipated lifespan of the alternative with regular maintenance.
	Monitoring and maintenance requirements	Requirements for inspections and maintenance over the design life of the alternative.
Impact	Recreational safety	Degree to which the alternative and the anticipated geomorphic response would pose an increased or decreased hazard to public safety (i.e. hazards to areas accessed by the public), relative to existing conditions. This includes increased or decreased hazards to boaters, swimmers, and rafters relative to existing conditions.
	Environmental	Degree to which the alternative and the anticipated geomorphic response would degrade or improve environmental conditions (vegetation, physical channel habitat, water quality) compared to existing conditions, considering effects during construction and over the alternative's design life and the likelihood of mitigation that may be required to offset adverse environmental impacts.
	Base Flood Elevation (100-year flood)	Degree to which the alternative would cause an increase or decrease in the regulatory, 100-year base flood elevations.
Implementation	Construction complexity	The degree of construction complexity based on the number of individual work elements needed to complete construction (e.g. duration/time, earthwork within our outside of Ordinary High Water, flow diversion, dewatering, fish exclusion, staging requirements, access difficulty, traffic disruptions, phasing, and physical complexity of measure.
	Permitting Requirements	The potential difficulty or ease of obtaining all permits required for implementation of the alternative.
	Construction Costs	Total estimated planning level cost to construct the alternative.

Table D-4. Summary of additional risk-reduction alternatives considered, but not evaluated.		
Alternative	**Description**	**Reasons for not Evaluating Further**
5	Install bank protection along the side channel by placing large riprap along the segment of the right bank within individual property boundaries.	Direct and indirect adverse impacts to aquatic habitat and organisms would result and require extensive environmental mitigation that would exceed the cost of other, self-mitigating alternatives.
6	Implement a sediment management program to periodically remove accumulated sediment from the main stem South Fork channel between the Snoqualmie Valley Trail bridge at RM 1.95 and the side channel inlet at RM 1.65.	Direct and indirect adverse impacts to aquatic habitat and organisms would result and require extensive environmental mitigation. Effectiveness in addressing all geomorphic processes driving current and anticipated conditions is uncertain; therefore, effectiveness in reducing avulsion and erosion hazards and risk is uncertain. Long-term maintenance costs could exceed cost of other alternative(s) that have a higher certainty of effectiveness. Permit approval of this alternative is highly uncertain, as dredging of sediments in other river systems in the Puget Sound area has proven very difficult to permit in recent years.
7	Roughen the side channel inlet with LWD and protect the “bridge” from being breached by main stem and/or side channel flow.	The “bridge” is anticipated to be breached within the next five years, allowing the main stem and side channel flows to commingle at that point. Reconstruction and protection of the “bridge” is infeasible because more effective and justifiable means of reducing hazards and risks have been identified in the other alternatives.
8	Remove the “bridge”, construct a linear deflection structure across the side channel near the “bridge”, then install a bank protection system from the deflection structure along the right bank of the side channel upstream to the inlet.	The lack of any form of bank protection downstream of the deflection structure coupled with the questionable effectiveness of the deflection structure performance resulted in a low degree of confidence that this alternative would reduce avulsion and erosion hazards and risks.
9	Extend the King County Circle River Ranch revetment upstream along the right bank of the side channel.	Degradation of existing and future aquatic habitat conditions would result, requiring extensive onsite and possibly offsite environmental mitigation. An alternative, self-mitigating bank protection project (Alternative 3) was considered in lieu of riprap to maintain or enhance existing environmental and aesthetic conditions while providing an equivalent design life and level of protection. Permit approval of an extended riprap revetment would be onerous and uncertain, given that there are other viable alternatives to meet hazard mitigation objectives.

ATTACHMENT E

Concept Figures of Alternatives

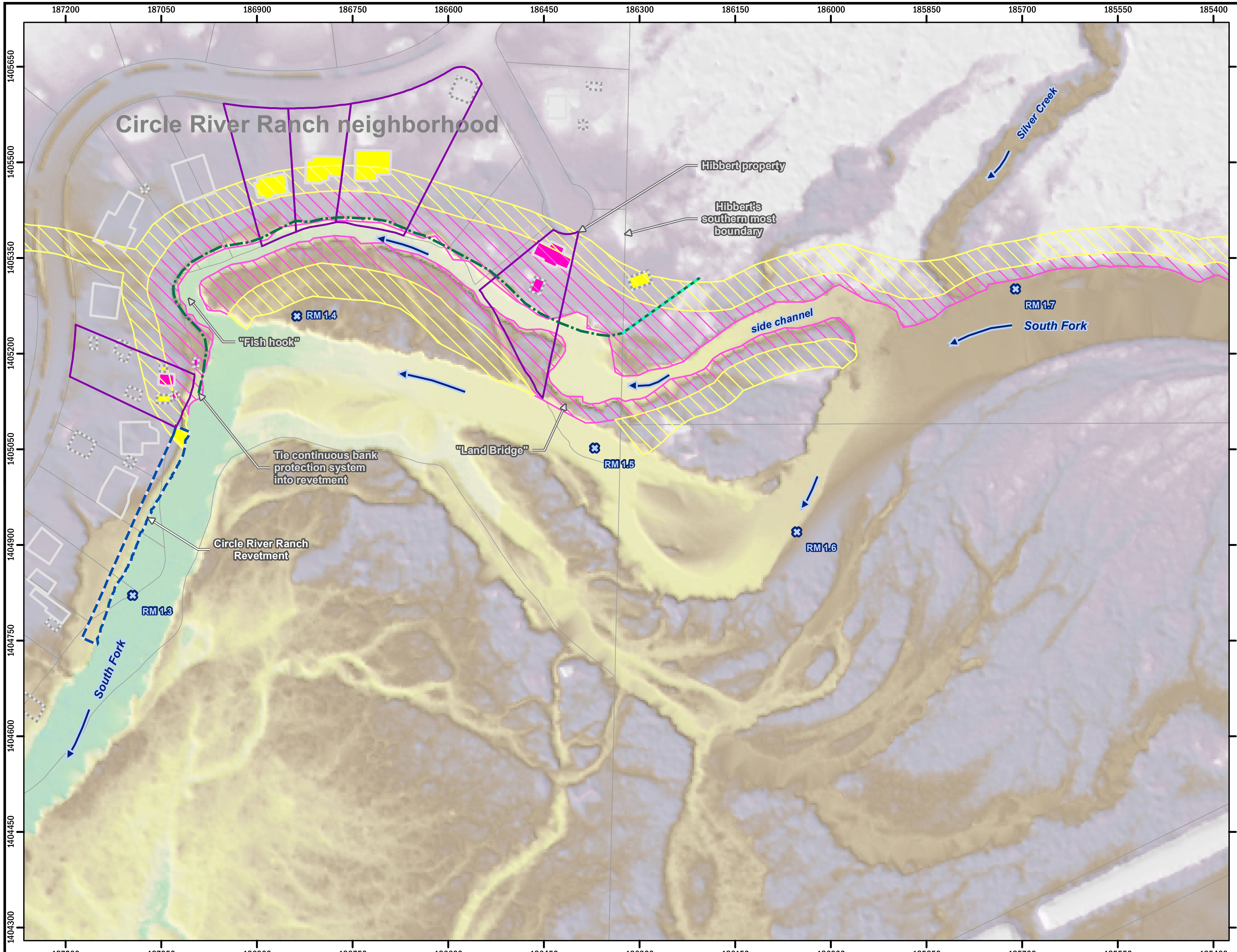


Figure E-1.
Alternatives 1 and 2 for addressing risks to the Circle River Ranch neighborhood, South Fork Snoqualmie River.

Legend

- High hazard (potential for channel occupation in next 5 years)
- Medium hazard (potential for channel occupation in next 10 to 15 years)
- High risk (intersection of high hazard with house, outbuilding, or revetment)
- Medium risk (intersection of medium hazard with house, outbuilding, or revetment)

Alternative 1

- Acquired parcel

Alternative 2

- Exposed continous bank protection system
- Buried continous bank protection system
- River mile
- Flow direction
- Facility
- Outbuilding
- House
- Parcel

N

0 75 150 300 Feet

HERRERA

Lidar: King County, 2010
Coordinates: NAD83 StatePlane Washington North (Feet)

Produced By: GIS ( )
Project: \\sea-file03\gis-k\Projects\10-04731-000\Project\alternatives\alt_1_2.mxd (7/19/2012)

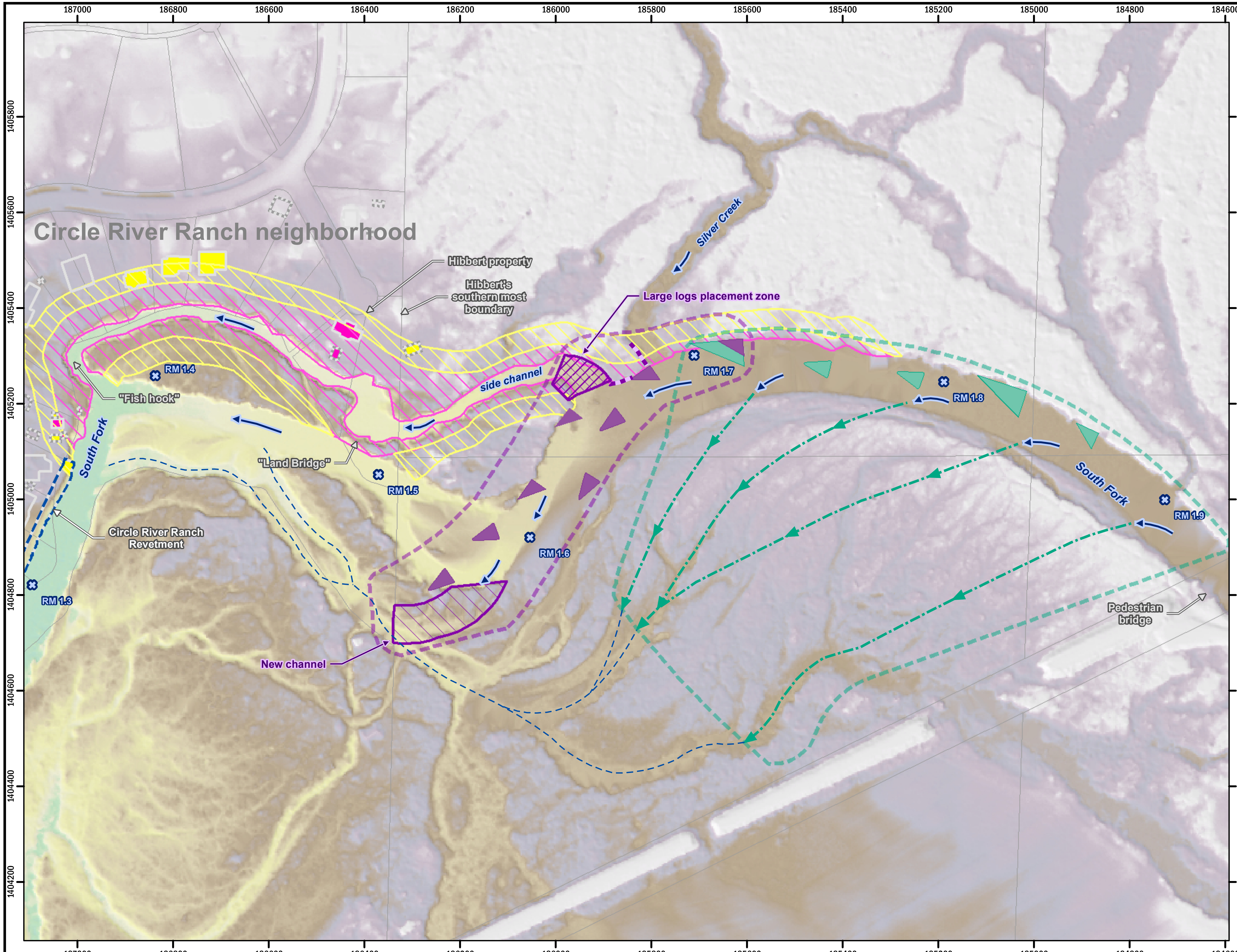


Figure E-2.
Alternatives 3 and 4 for addressing risks to the Circle River Ranch neighborhood South Fork Snoqualmie River.

Legend

- High hazard (potential for channel occupation in next 5 years)
- Medium hazard (potential for channel occupation in next 10 to 15 years)
- High risk (intersection of high hazard with house, outbuilding, or revetment)
- Medium risk (intersection of medium hazard with house, outbuilding, or revetment)
- Alternative 3 zone
- Alternative 4 zone
- Bank roughening with large logs
- New left bank channel
- Existing left bank side channel

ELJ structures

- Large deflector ELJ
- Medium deflector ELJ
- Apex ELJ

- River mile
- Flow direction
- Facility
- Outbuilding
- Parcel
- House

N

0 100 200 400 Feet

HERRERA

Lidar: King County, 2010
Coordinates: NAD83 StatePlane Washington North (Feet)

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Project: \\sea-file03\gis-k\Projects\10-04731-000\Project\alternatives\alt_3_4.mxd (7/19/2012)

ATTACHMENT F

Photographs of Constructed Risk Reduction Measures

Figure F-1. Floodplain restoration along Vasa Creek near Bellevue, Washington.

Figure F-2. Temporary riprap placement on the Mashel River near Eatonville in Pierce County, Washington, along an actively eroding bank.

Figure F-3. **Log cribwall constructed on the Mashel River near Eatonville in Pierce County, Washington along an actively eroding bank.**

Figure F-4. **Reinforced soil lifts constructed on the Touchet River near Touchet in Walla Walla County, Washington, along an actively eroding bank.**

Figure F-5. Multiple bank deflector ELJs constructed on the Touchet River in Walla Walla County, Washington, to deflect flows away from actively eroding bank and into side-channels along opposite bank. The banks between the ELJs were reconstructed using reinforced soil lifts.

Figure F-6. Large logs added to an existing natural logjam on the Mashel River near Eatonville in Pierce County, Washington, to prevent an avulsion down the side-channel behind the logjam and to trap mobile wood debris.

Figure F-7. **LWD added to roughen an exposed side-channel bank on Morse Creek near Port Angeles, Washington.**

Figure F-8. **Apex ELJ constructed at side-channel inlet on the Mashel River to deflect flows from the main stem and into the side-channel.**

Figure F-9. Side-channel at low flow conditions constructed through existing floodplain on Morse Creek.

ATTACHMENT G

Alternatives Comparison Matrix

Alternative		1	2	3	4
Project Description		Acquire the five properties with buildings located within the high or medium hazard zones. Remove all structures and utilities and plant sites with native vegetation.	Install a continuous log cribwall or reinforced soil lifts along the right bank of the downstream half of the side channel.	Roughen the side channel inlet with large wood debris (LWD), install multiple bank deflector and apex (mid-channel) type engineered logjams (ELJs) in the river from RM 1.72 to 1.55, and connect the left bank side channel to the main stem at RM 1.55.	Install multiple bank deflector and apex ELJs in the river between the pedestrian bridge at RM 1.95 and RM 1.7 and construct four side channels between RM 1.9 and RM 1.6 to convey flow to relic side channels in the left bank floodplain.
Performance	Risk Prevention and/or Reduction Effectiveness	• Eliminates risk to the acquired properties. • No change in existing risk to other properties.	• Log cribwall: Considerable reduction in risk to adjacent properties. • Soil lifts: Moderate reduction in risk to adjacent properties.	• Moderate to considerable reduction in risk to adjacent properties.	• Minor to moderate reduction in risk to adjacent properties.
	Avulsion and Bank Erosion Prevention and/or Reduction Effectiveness	• No change.	• Log cribwall: Considerable reduction in hazards. • Soil lifts: Moderate reduction in hazards.	• Moderate reduction in avulsion hazard. • Moderate to considerable reduction in erosion hazard.	• Minor change in avulsion hazard. • Minor to moderate reduction in erosion hazard.
	Design Life	• Unlimited for acquired properties.	• Log cribwall: up to 50 years. • Reinforced soil lifts: up to 20 years.	• LWD and ELJs: up to 50 years. • Floodplain channel: up to 10 years.	• ELJs: up to 50 years. • Side channels: up to 5 years.
	Monitoring and Maintenance Requirements	• Irrigation, weeding, and replanting until vegetation is established.	• Irrigation, weeding, and replanting until vegetation is established. • Annual visual inspections. • Replace damaged/ lost logs or backfill.	• Annual visual inspections for first 5 years; after bankfull (2-year) or larger floods thereafter. • Replace damaged/ lost logs or backfill. • Remove accumulated logs that pose a hazard. • Clear floodplain channel of sediment and wood.	• Annual visual inspections for first 5 years; after bankfull (2-year) or larger floods thereafter. • Replace damaged/ lost logs or backfill. • Remove accumulated logs that pose a hazard. • Clear side channels of sediment and wood.
Impact	Recreational Safety	• No change.	• Log cribwall: moderate to considerable increase in hazard to recreational users. • Soil lifts: minimal to no increase in hazard to recreational users.	• Considerable increase in hazard to recreational users.	• Considerable increase in hazard to recreational users.
	Environmental	• Improved aquatic and riparian habitat conditions due to revegetation efforts.	• Short-term, adverse impacts during construction. • Long-term improvements in aquatic and riparian habitat conditions. • Long-term loss of local wood recruitment.	• Short-term, adverse impacts during construction. • Long-term improvements in aquatic habitat conditions.	• Short-term, adverse impacts during construction. • Long-term improvements in aquatic habitat conditions.
	Base Flood Elevation (BFE, 100-year flood)	• No change in Base Flood Elevations (BFEs).	• Log cribwall: possible increase in BFEs. • Soil lifts: no change in BFEs.	• Likely increase in BFEs upstream of ELJs. • No change or slight reduction in BFEs in side channel.	• Likely increase in BFEs upstream of ELJs. • No change or slight reduction in BFEs in side channel.
Implementation	Construction Complexity	• Minimal complexity to demolish structures, remove utilities, clear and grub site, and plant with native vegetation.	• Moderate to high complexity due to in-water work, substantial earthwork, and phasing over two construction seasons.	• Moderate to high complexity due to multiple work sites, river crossings, in-water work, substantial earthwork, and phasing over two construction seasons.	• Moderate to high complexity due to multiple work sites, difficult access, in-water work, substantial earthwork, and phasing over two construction seasons.
	Permitting Requirements	• Local: KC demolition permit, Puget Sound Clean Air Agency Asbestos Demolition Notification (if applicable). • State: Ecology Section 401 Certification and NPDES permit (if > 1 acre).	• Local: CoNB SEPA compliance, Building Permit and Floodplain Development Permit, and Shoreline Substantial Development Permit. • State: HPA permit; Ecology Section 401 Certification. • Federal: Corps Section 404 Permit including compliance with Section 106 of the National Historic Preservation Act.	• Local: CoNB SEPA compliance, Building Permit and Floodplain Development Permit. • State: HPA permit; Ecology Section 401 Certification. • Federal: Corps Section 404 Permit including compliance with Section 106 of the National Historic Preservation Act.	• Local: CoNB SEPA compliance, Building Permit, and Floodplain Development Permit. • State: HPA permit; Ecology Section 401 Certification. • Federal: Corps Section 404 Permit including compliance with Section 106 of the National Historic Preservation Act.
	Construction Costs	$2,550,000	• Log cribwall: $1,160,000 • Reinforced soil lifts: $560,000	$1,140,000	$1,250,000

ATTACHMENT H

Planning Level Construction Cost Estimates

Circle River Ranch Alternatives Development and Assessment
Planning Level Construction Cost Estimate
Herrera Environmental Consultants, Inc.
February 7, 2012

			Alternative 1		Alternative 2a (Reinforced Soil Lifts Option)		Alternative 2b (Log Cribwall Option)		Alternative 3		Alternative 4	
Item Description	**Unit Cost**	**Unit**	**Qty**	**Total Price**	**Qty**	**Total Price**	**Qty**	**Total Price**	**Qty**	**Total Price**	**Qty**	**Total Price**
Purchase 5 properties	$1,545,000	LS	1	$1,545,000	---	---	---	---	---	---	---	---
Demolish/remove existing structures	$15,000	EA	5	$75,000	---	---	---	---	---	---	---	---
Site clearing	$7,000	AC	3.4	$23,673								
Site restoration (floodplain planting)	$28,000	AC	3.4	$94,691	---	---	---	---	---	---	---	---
Continuous bank protection system - soil lifts option	$250	LF	---	---	1000	$250,000	---	---	---	---	---	---
Continuous bank protection system - log cribwall option	$500	LF	---	---	---	---	1150	$575,000	---	---	---	---
Buried rock protection	$16,900	LS	---	---	1	$16,900	---	---	---	---	---	---
Large deflector ELJ	$100,000	EA	---	---	---	---	---	---	---	---	2	$200,000
Medium deflector ELJ	$60,000	EA	---	---	---	---	---	---	4	$240,000	1	$60,000
Apex ELJ	$60,000	EA	---	---	---	---	---	---	4	$240,000	2	$120,000
Floodplain channel construction	$208	LF	---	---	---	---	---	---	250	$52,083	---	---
Side channel construction	$74	LF	---	---	---	---	---	---	---	---	2750	$203,704
Bank roughening with large logs	$100	LF	---	---	---	---	---	---	150	$15,000	---	---
Large log placement in side channel inlet	$1,000	EA	---	---	---	---	---	---	---	---	25	$25,000
Construction Management	$120	HR	240	$28,800	240	$28,800	360	$43,200	480	$57,600	480	$57,600
Mobilization, clearing, TESC, water management, & access	Estimate 15% of Construction Costs (excluding property purchase)	LS	1	$33,325	1	$44,355	1	$92,730	1	$90,703	1	$99,946
Construction Subtotal		LS		$1,800,488		$340,055		$710,930		$695,386		$766,249
Contingency (+30%)		LS		$540,146		---		---		---		---
Contingency (+50%)		LS		---		$170,028		$355,465		$347,693		$383,125
Construction Subtotal Including Contingency		LS		$2,340,635		$510,083		$1,066,395		$1,043,079		$1,149,374
Sales Tax (8.6%)		LS		$201,295		$43,867		$91,710		$89,705		$98,846
Total 2012 Dollars with Contingency (Rounded to Nearest $10,000)		LS		**$2,550,000**		**$560,000**		**$1,160,000**		**$1,140,000**		**$1,250,000**