RISK ASSESSMENT AND RECOMMENDED ACTIONS

TIMBERLANE VILLAGE

King County
Department of Natural Resources and Parks
Water and Land Resources Division

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Timberlane Village

Prepared for

King County

Department of Natural Resources and Parks
Water and Land Resources Division
River and Floodplain Management Section
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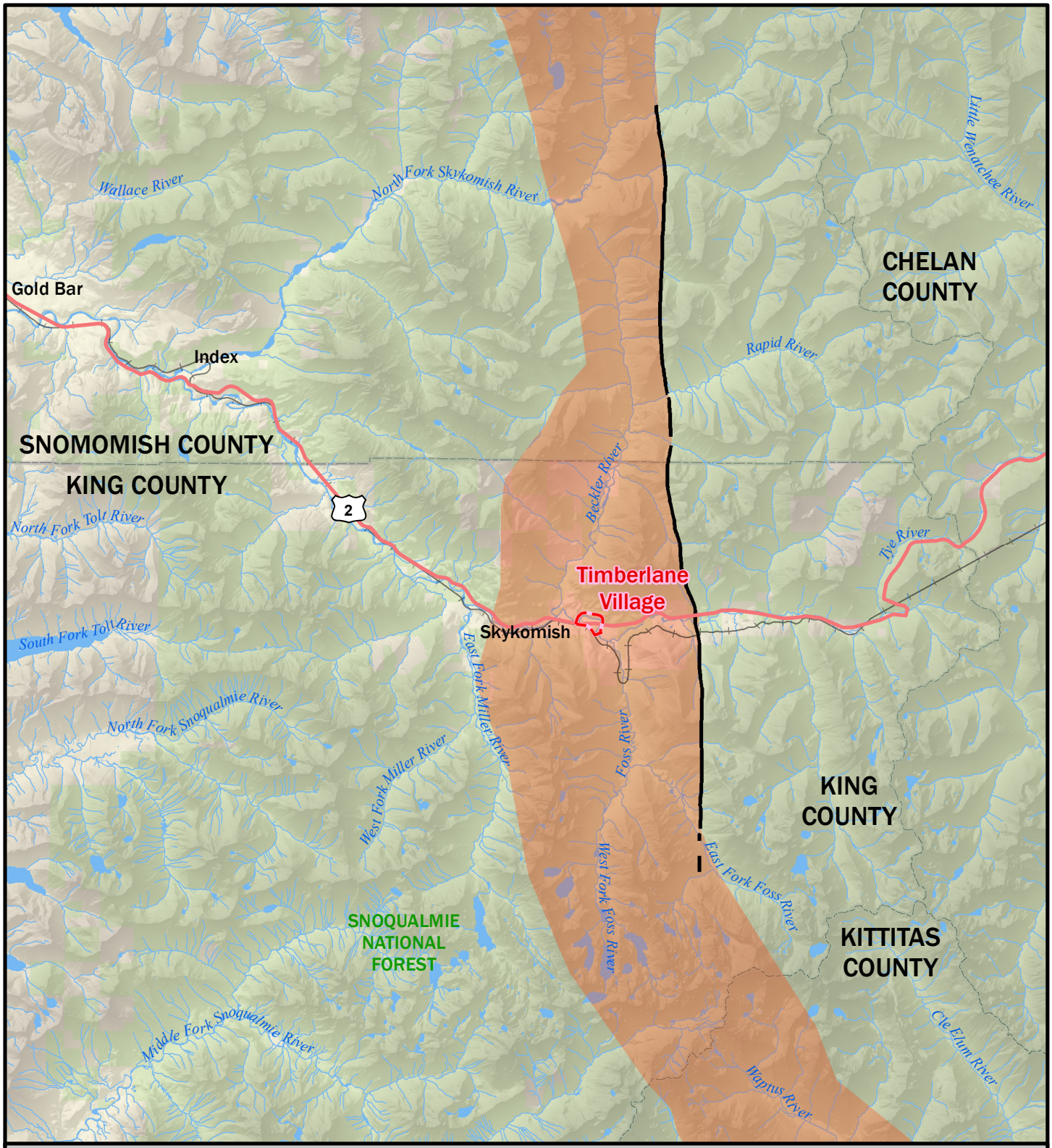
INTRODUCTION

Timberlane Village is a community of private residences located 1.5 miles east of the Town of Skykomish on US Highway 2 (US-2) in unincorporated King County. It is bounded to the north, west, and east by the South Fork Skykomish River (the South Fork) and is known to be vulnerable to erosion and flood hazards. In 2009, King County (the County) acquired five parcels of land in this community, including three with residential structures that were demolished in 2012. While the structures have been removed, these parcels include a nearly vertical, constructed rock revetment along approximately 300 feet of the riverbank, hereafter referred to as the revetment at river mile (RM) 18.5. This revetment is failing due its over steepened condition and exposure to significant hydraulic forces in recent years. A companion report identifies geomorphic and flooding hazards in and adjacent to Timberlane Village and describes the relative severity of each hazard with respect to estimated frequency of recurrence and confidence associated with the estimate (Appendix A).

This document presents a risk assessment and recommended management actions for two categories of response: 1) structural actions at the County owned parcels, and 2) non-structural mitigation actions in other areas of Timberlane Village. The discussion of structural actions at the County owned parcels includes an analysis of alternatives for future management of the revetment at RM 18.5, and specific recommended actions for the revetment. The discussion of risk management in other areas of Timberlane Village prioritizes non-structural actions (particularly acquisition of properties at risk).

The study area includes the channel, banks, floodplain, and hillslopes along the South Fork between approximately RM 17.9 and RM 19.2 (Figure 1). Figure 2 illustrates many of the landmarks that are discussed later in this document.



Legend

- Study Area
- Evergreen Fault
- Straight Creek Fault Zone
- Highway
- Railroad
- County

Figure 1.
Timberlane Village Study Area Vicinity Map.

N

0 2 4 8 Miles

King County

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Prepared for King County by Herrera
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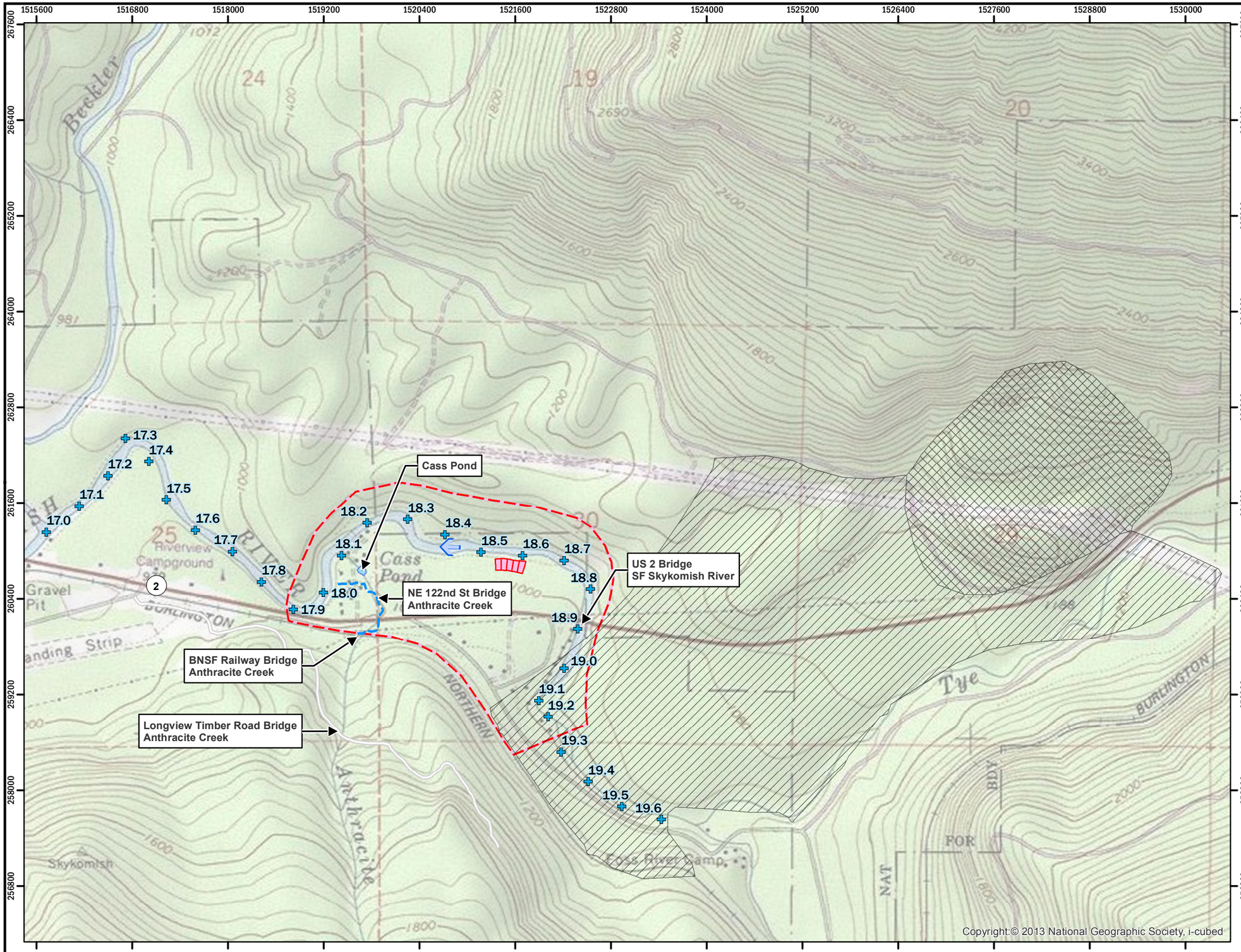

Figure 2.
Timberlane Village Study Area, Site Map.

Legend

- Study Area
- County-Owned Parcels
- SF Skykomish River Miles
- Anthracite Creek (2011 Alignment)

Geologic Units Based on 1:100,000 Scale Mapping by USGS (2005)

- Recent Landslide Deposit
- Rock Avalance Deposits

Note:
The actual limits of the Beckler Peak Rock Avalanche may deviate from the extents mapped in the geological map because of scale constraints, particularly with regards to outlying spray boulders at the fringes of the rock avalanche deposit.

N

0 600 1,200 2,400 ft

King County

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

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METHODOLOGY

Risk Assessment

The hazards described in Appendix A were used as the basis for determining risks in the study area. Risk was assessed using criteria established by the King County Flood Control District. The basis for these criteria is the 2006 King County Flood Hazard Management Plan policies related to flood risk hierarchy (G-2) and project prioritization (PROJ-1) (King County 2006). The intensity of flooding and the potential for it to cause bodily harm or extensive property damage was assessed using "deep and fast" flow guidelines from the US Bureau of Reclamation (1988). Where a hazard is correlated to flooding, the area at risk is considered to include only those areas exposed to flooding, as modeled and described in Appendix A. However, where channel migration hazards exist, it is assumed that areas further from the active channel that currently do not flood may be at risk. Channel migration rates were not estimated directly in this study, but the sizes of corresponding risk zones were approximated assuming that the largest historical erosion rates observed in the aerial photographic record (approximately 5 feet per year) may occur over the course of the next 10 years (thus 50 feet in ten years). This amounted to a 50-foot offset from the channel bank in areas where channel migration is a risk as observed in the most recent aerial photograph. However, a 100-foot offset from the channel bank was assumed at the revetment at RM 18.5 to account for potential failure of the revetment, which is approximately 20 to 30 feet thick with a comparable amount of fill behind it (and thus 100-feet in total). The larger offset from RM 18.5 merges with the 50-foot offset at the downstream end of the revetment. Note there is a separate effort underway by King County to delineate Channel Migration Hazard Zones (CMZ) along the South Fork Skykomish including Timberlane Village. The work contained in this report is intended to inform capital actions and hazard mitigation, but is not a regulatory CMZ map.

King County is also in process of updating landslide hazard mapping countywide which will inform future management and regulatory actions. The updated landslide hazard mapping will consider hazards originating outside the Timberlane project area described in this report (see Beckler Peak Rockslide discussion in Appendix A).

Risk Management

Risk can be managed with structural and non-structural (e.g., land acquisition) mitigation actions. Structural actions evaluated in this study focused on the channel migration hazard near the right bank bar at RM 18.5. Non-structural actions were considered for other areas in Timberlane Village where risks to human safety and developed property are documented in this report.

Structural actions were considered only for the revetment at RM 18.5 because of King County's existing property interest and the compromised condition of the revetment

inherited during the property acquisition. Non-structural risk mitigation was applied to other areas of the neighborhood.

Three alternatives were considered regarding future management of risks associated with the revetment at RM 18.5 based upon discussions with County staff. They included 1) no constructed action, 2) removal of the revetment, and 3) replacement of the revetment with a bank protection design that enhances aquatic and riparian habitat while adequately preventing bank erosion.

The County has determined that repair of the existing revetment cannot be considered for several reasons. Primarily, vertical rock revetments are not consistent with several policies and design guidelines used by King County, including the 2013, 2006, and 1993 *King County Flood Hazard Management Plans*, the *Guidelines for Bank Stabilization Projects* (King County 1993), and the *Integrated Streambank Protection Guidelines* (Washington State Aquatic Habitat Guidelines Program 2002). Additionally, the feasibility and permitability of repairing the revetment is questionable. If the applicable County, state, and federal permits were secured for a repair, it is expected that they would collectively require costly mitigation measures to offset adverse environmental impacts of the repaired rock revetment.

In addition to the structural actions considered for managing risks at the revetment at RM 18.5, non-structural actions were considered for other areas in Timberlane Village where risks to human safety and developed property are large. Non-structural mitigation strategies, including acquisition and demolition of at risk structures, permanently removes infrastructure from hazardous areas where structural mitigation is not appropriate or cost-effective.

RISK ASSESSMENT

Risks in the study area are distributed in ten zones. The zones are mapped in Figure 3. The zones are different from the geomorphic reaches described in Appendix A for two reasons. First, risks are associated with infrastructure and human exposure to physical hazards, while the geomorphic reaches relate only to physical hazards. In addition, because risks relate to human infrastructure, the risk zones are confined to areas predominantly on the floodplain, while the geomorphic reaches are based on riverine characteristics and processes and are mostly present in the active channel. Despite these differences, the risk zones were defined based upon the physical processes responsible for the dominant hazard in each zone. Even though there is a low-level risk to any development in the study area from a major rock avalanche on Beckler Peak or large-scale slumping of the hillslopes above the right bank (facing downstream), only those zones where significant risk is present within the next 100 years are mapped in Figure 3 and discussed below.

The risks are categorized as moderate, high, severe, and extreme. For this study, a moderate risk is defined as one that has the potential to manifest over relatively long time frames (in the next 100 years). A high risk is one that has the potential to manifest over much shorter timeframes (in the next 30 years). Severe risks could manifest themselves in less than 10 years. An extreme risk is one that has the potential to manifest in the next flood event (i.e., 50 percent annual chance of exceedance).

1 - Tye River Road

Primary hazard: *slope instability*

The Tye River Road risk zone (Zone 1 on Figure 3) is along the left bank of the South Fork upstream of the US-2 Bridge to RM 19.15. It does not include the top of the bank, which is generally stable. Properties along Tye River Road in this area were originally developed with seasonal cabins prior to the construction of most of Timberlane Village. Structures associated with these properties are on a high bank, and are generally not exposed to the slope instability hazard. However, landscaping and other appurtenances on the bank slope are at risk. Because slope instability is not evolving quickly and most of the risk is associated with appurtenances and not structures, the risk to structures in this risk zone at this point in time is deemed moderate. Additionally, channel migration due to changes in sediment or wood deposition in this reach is not currently a problem; therefore, risk to structures is not expected to occur in the near future.

2 - Lower US-2

Primary hazard: *flooding*

The Lower US-2 risk zone (Zone 2 on Figure 3) is defined by a point bar on the left bank downstream of the US-2 Bridge from RM 18.66 to RM 18.88. The point bar slopes gently from the bank toward the active channel. The landward edge of the bar is well defined throughout its length by a subtle bank that rises to a similar ground surface elevation as the most

upstream terrace of Timberlane Village. There are no built structures in risk Zone 2, though the properties in this zone are developed on the terrace landward of the point bar. Flooding from the South Fork periodically occurs on these parcels but does not reach the elevation of the structures. Flow velocities can be high in this area, but channel migration potential is limited due to the presence of bank armoring at the US-2 Bridge crossing. The only physical driver for channel migration in this zone would be failure of the large unstable slope on the right bank forcing the channel to erode into the left bank. Slope-failure-induced channel migration is considered to have less than a 10 percent annual chance of exceedance (or stated differently, such a failure would probably have a recurrence interval of 10 years or more). However, this slope-failure hazard, and changes in river planform that could be induced by slide deposits in the existing river channel, could initiate more pronounced flooding hazards to existing structures within the next 30 years. Therefore, the risk to structures in this zone is considered high.

3 - Left Bank Revetment

Primary hazard: *channel migration*

The Left Bank Revetment risk zone (Zone 3 on Figure 3) is on the left bank between RM 18.53 and RM 18.66. The channel migration manifest by bank erosion risk emanates from the influence of a long bar on the opposite (right) bank. This risk zone includes the parcels acquired by the County and three privately owned properties upstream of the county parcels, each of which has been improved with homes and other structures. The river bank in this zone is high and generally competent, but it is steep. The high bank prevents floodwater from spreading landward (south) in this area, but is vulnerable to toe erosion that could induce a bank failure. This risk of bank failure is mitigated somewhat by the presence of a private revetment at RM 18.62 and the revetment at RM 18.5. The river is currently directed toward the left bank by the large right bank bar as described in Appendix A. The locus of erosion is currently directed downstream of the existing developed properties (at the upstream end of the zone). However, the extent of development on the privately owned parcels and the unrelenting direction of channel migration (towards the south) poses severe risks of property damage and risks to human safety in this zone. Compounding this risk are the hazards associated with failure of the revetment at RM 18.5.

4 - Right Bank Hillside Upstream of the US-2 Bridge

Primary hazards: *slope instability, channel migration*

This risk zone (Zone 4 on Figure 3) spans up the hillslopes above the right bank of the South Fork from RM 19.03 upstream of the US-2 Bridge to the bridge itself. Although this entire zone is undeveloped, there are two large privately held properties. These two properties are accessible and one of them has a residence built away from the river's edge, but the risk zone only includes the steep areas of those parcels near the river. The hillside is extremely unstable in this zone, as evidenced by overturned mature vegetation near the headwall of the scarp (see Appendix A for details). The risk is considered severe in this zone because of the likelihood of continued slumping and the potential for development. There is also a small risk of another flank collapse of Beckler Peak, which could impact this zone. This type of rockslide event has an unknown probability of occurrence, but is likely greater than a 1000-year recurrence interval.

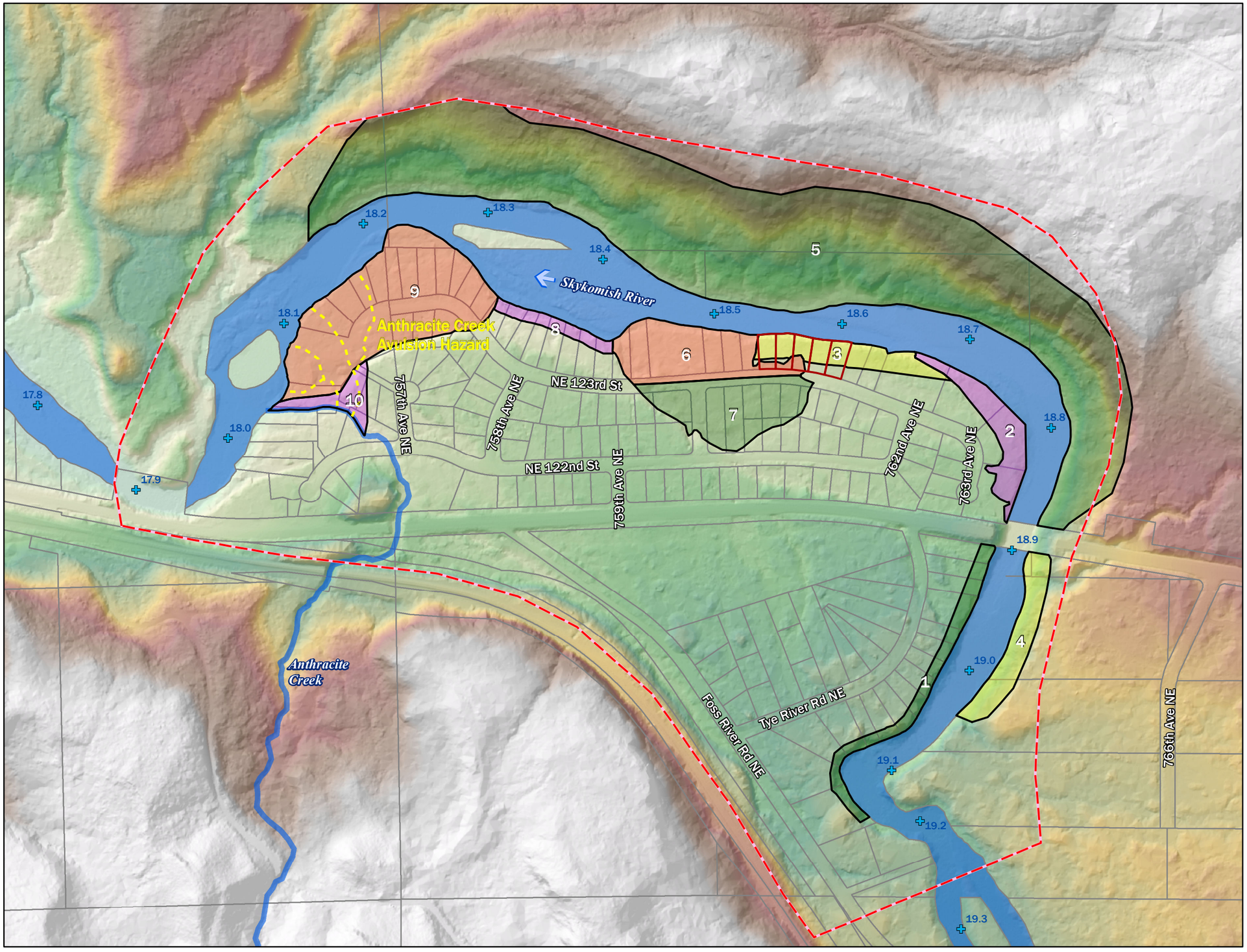


Figure 3.
Risk Zones in the Timberlane Village Study Area.

Legend

- Study Area
- SF Skykomish River Mile
- County-Owned Parcel
- Parcel

Risk

- Moderate
- High
- Severe
- Extreme

Region

1. Tye River Road
2. Lower US-2
3. Left Bank Revetment
4. Right Bank Hillside Upstream of the US-2 Bridge
5. Right Bank Hillside Downstream of the US-2 Bridge
6. Inner Meander Bend
7. Outer Meander Bend
8. Upper Side Channel
9. Left Bank Point Bar
10. Anthracite Creek

N

0 200 400 800 ft

King County

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

King County, Hillshade (2011)
Prepared for King County by Herrera

Produced By: GIS
Project: K:\Projects\Y2010\10-04766-034\Project\Risk_Assessment\risk_area.mxd (7/8/2014)

5 - Right Bank Hillside Downstream of the US-2 Bridge

Primary hazards: *slope instability, channel migration*

This risk zone (Zone 5 on Figure 3) spans up the hillslopes above the right bank of the South Fork from the US-2 Bridge to RM 18.2. Although this entire zone is undeveloped, there are two large, privately held and undeveloped properties between RM 18.4 and RM 18.7. These two properties are in-holdings that have no road access. In fact, the properties are on slopes that are difficult to traverse on foot. The hillside is extremely unstable in this zone, as evidenced by a lack of mature coniferous vegetation and slumps visible on historical aerial photographs that have displaced portions of the river channel. It is likely that the ongoing nature of the slope instability makes development impossible. The risk is considered moderate in this zone because of the lack of existing (and possible) development.

6 - Inner Meander Bend

Primary hazards: *flooding, channel migration*

The Inner Meander Bend risk zone (Zone 6 on Figure 3) is a low-lying area in the north-central portion of Timberlane Village, along the left bank the South Fork. The zone is bounded to the south by NE 123rd Street. It has one home within it, but it is otherwise undeveloped. The home is separated from the South Fork by a sloping rock revetment. The remainder of the zone contains three privately owned, undeveloped parcels and a large parcel that is community space (i.e., owned by the Timberlane Village homeowner's association).

Although there is uncertainty regarding the extents of flood inundation due to limitations and assumptions in the hydraulic model in this location (described in Appendix A), the low lying ground surface in this zone and the vegetation characteristics suggest that floodwater inundation occurs frequently, possibly as often as during the 50 percent annual chance exceedance flood (2-year recurrence event). The hydraulic model indicates that flood flow depths can be up to three feet in the 1 percent annual chance exceedance flood in this area (100-year recurrence event), with the greatest depths in the portion of this zone at the downstream end in areas that are currently undeveloped.

In addition to the flood inundation hazard, there is also a channel migration hazard. The entire zone is within the channel in historical aerial photographs of the South Fork and the presence of an unstable, constantly slumping hillslope on the opposite (right) bank mean that the river channel could potentially be pushed southward into this zone in the near future. The presence of a home and other potentially developable parcels, coupled with the frequency and depth of floodwater inundation and channel migration hazard, makes the risks in this zone extreme.

7 - Outer Meander Bend

Primary hazard: *flooding*

This zone is numbered 7 on Figure 3, and is separated from the Inner Meander Bend zone to the north by NE 123rd Street. A meander bend of the South Fork once extended well south of NE 123rd Street in this area (i.e., in the 1914 survey: USGS 1914). The hydraulic model results (Appendix A) indicate that deep (up to 5 feet) of inundation is possible throughout the

depression that coincides with the location of the former channel. The road is constructed on a fill prism that would limit flood waters from entering the depression, however there are culverts that cross under the road allowing some inundation. The limited one-dimensional hydraulic model did not explicitly simulate flow across the roadway or in the culverts. Flow depths over the road are generally less than 1 foot, indicating that it is likely an impediment to flooding south of the road. Despite these limitations, the model indicates the entire zone would be inundated in the 1 percent annual chance exceedance flood (100-year recurrence event), consistent with the FEMA 100-year floodplain maps. There is only one residence in this zone, but there are several homes on the edge of the zone that may incur minor inundation damage from a large (e.g., 1 percent annual chance of exceedance; 100-year recurrence) flood event. The damage would be due to slack water inundation, without deep and/or fast characteristics.

The NE 123rd Street road prism also serves to reduce the likelihood of erosion, at least in the near term (less than 10 years). Therefore, the channel migration hazard to the properties south of NE 123rd Street in this zone is considered negligible. Combined with the slack water characteristics of the flooding, the risk in this area is moderate.

8 - Upper Side Channel

Primary hazard: *channel migration*

This zone is comprised of a bank slightly higher than the 1 percent annual chance of exceedance (100-year recurrence) event that forms the left edge of an active side channel of the South Fork between RM 18.32 and RM 18.42 (Zone 8 on Figure 3). The entire length of the bank is armored, and there are six homes on these properties near the edge of the bank. In the 1980s, the South Fork main channel thalweg was located immediately adjacent to the bank, which was likely the motivation to construct the revetment. Subsequently, the channel thalweg migrated north, leaving a large vegetated island between the thalweg and the developed parcels along the side channel. While the vegetation on the island is generally immature, deciduous and somewhat regularly inundated, it is extremely dense. The island acts as a significant roughness element, and is rapidly accumulating sediment reinforcing the bifurcation of flow. Despite the current separation between the main channel and the revetment, the hydraulic modeling suggests that high flow velocities are possible adjacent to the revetment during floods, indicating that it is possible for the main channel to reoccupy its 1980 location. The left bank is high enough to not be overtopped, even in the 1 percent annual chance of exceedance flood (i.e., 100-year recurrence event). Therefore, the only risk is due to the main stem river flow re-occupying the side channel and causing damage or destruction of the existing revetment. The risk in this zone is considered high because if the side channel were to become the thalweg, there would be a significant risk of damage to those properties currently protected by the revetment.

9 - Left Bank Point Bar

Primary hazards: *flooding, channel migration, Anthracite Creek avulsion*

Zone 9 (Figure 3) consists of two low inset terraces that define a point bar on the left bank of the South Fork between RM 18.35 and RM 18.05. Both terraces slope downward in the downstream direction (southwest) resulting in the downstream ends being at the lowest

elevation. The lower terrace is inundated in the 50 percent annual chance of exceedance flood (i.e., 2-year recurrence event), and likely even during typical high water flows (e.g., above 30,000 cubic feet per second at Gold Bar), evidenced by the noticeable ground disturbance and lack of established riparian vegetation. Flow velocities are expected to be high and inundation depths relatively deep in this low terrace area, even during the 50 percent annual chance of exceedance flood event. There is no development on the lower terrace. There is a revetment along the bank that separates the lower terrace from the upper more developed terrace.

The upper terrace is inundated less frequently, but the hydraulic modeling indicates that nearly all of it would be inundated in a 1 percent annual chance of exceedance flood (i.e., 100-year recurrence event). The upper terrace has been developed extensively compared to other parts of Timberlane Village, with 10 homes along NE 123rd Street. The hazards here are due to the combination of floodwater inundation and the potential for erosion to quickly carve channels in response to concentrated overbank flow originating near the upstream end of the bar. The model indicates inundation at the upstream end of the terraces in the 50 percent annual chance exceedance event. Flow over the upstream end of the terraces (in the area just downstream of risk Zone 8), if it were to occur, could easily form new erosion channels as the flow connects with the main channel downstream to the west. This physical process is a common mechanism for channel formation in steep mountainous rivers such as the South Fork. Figure 4 shows a freshly cut, similarly formed, channel in an analogous point bar from the Carbon River in Washington.

Figure 4. Flood Damage from Channel Initiation through a Point Bar on the Carbon River, Pierce County, Washington.

In addition to the damage that could be wrought in a single large flood event, there exists a general trend of channel migration landward, towards the development in this zone. Sediment deposition in this area is likely contributing to the channel migration visible in aerial photographs and to the greater inundation simulated in the hydraulic model relative to the FEMA 100-year floodplain maps. Although the left bank area most susceptible to erosion hazards has a privately owned revetment, continual engagement of the revetment with river flow will gradually wear it away, requiring maintenance of the facility to ensure that it remains functional. There are also areas where no revetment currently exists. Though these areas are at less risk of being eroded due to the current alignment of the active channel, the potential for a change in the alignment of the river and therefore erosive attack in the future is significant.

As described in Appendix A, there is also an avulsion hazard in Zone 9 from Anthracite Creek. The avulsion pathway through this zone is highly uncertain due to the relatively flat topography and highly dynamic nature of alluvial fans. The entire Zone 9 is considered at risk, except for the most upstream end.

Due to these overlapping hazards combined with the dense development, and the probability of occurrence within the next 10 years, the risk in this zone is considered extreme.

10 - Anthracite Creek

Primary hazard: *Anthracite Creek avulsion*

Zone 10 (Figure 3) includes part of the Anthracite Creek alluvial fan that is prone to an avulsion from the creek, but not prone to inundation during South Fork flooding. As discussed in Appendix A, avulsion is likely to occur in this area, but it may require a significant amount of time (more than 10 years) or external influence (i.e., reconfiguration of the US-2 crossing of Anthracite Creek). There are no homes in this zone, although there are several privately owned and undeveloped parcels, and remnant, decaying infrastructure from the Cass Pond Resort (mostly old masonry walls, fill, and culverts). The probable pathway of avulsion is also uncertain in this zone. Since the probability of occurrence is likely less than 10 percent per year under current conditions (i.e., an event that would be expected to occur less often than once every 10 years), but could change over time, the risk in this zone is considered high.

MANAGEMENT ACTIONS

Management actions to address the risks described in the previous section are separated into two types: specific structural actions related to the revetment at RM 18.5 on County property and non-structural actions related to those zones that are identified as having extreme or severe risk. Management actions that the County and others should consider are discussed in that order.

Structural Actions Related to Revetment at RM 18.5

Three alternative actions were considered to address the failing revetment at RM 18.5. In addition to the discussion and graphics below, construction cost estimates (for the alternatives involving new construction) are provided in Appendix B.

Alternative #1 – Monitoring But No Constructed Action

The simplest alternative is to construct nothing. However, if this alternative is selected, it is recommended that the revetment be monitored closely because the revetment is at risk of eroding or collapsing into the river. It is most likely inevitable that over time the structure will fail in part. A large collapse occurred within the last year (where approximately 20 feet have failed), which might contribute to erosion of private property immediately adjacent to the County owned parcels (both upstream and downstream from the revetment). Most recent reconnaissance by County staff revealed that erosion of this failed portion is expanding, albeit slowly.

As mentioned in Appendix A and earlier in this document, the most significant hazard in this reach of the river is channel migration. Herrera staff visited the site in late 2012 and found the revetment intact, but County staff have observed settling of material on the landward side of the revetment. More recent reconnaissance found a 20-foot section of the revetment had slumped into the river, but there was not significant erosion of fill behind (landward of) the revetment and the slump did not trigger any additional bank erosion. The parcels acquired by the County are not at risk due to flooding and will continue to be that way as long as the revetment at RM 18.5 remains intact. Adjacent properties (i.e., those residences upstream and downstream of Zone 3 in the general vicinity of the County property) are at some risk of flooding but doing nothing will not increase that risk. Doing nothing also would not improve the poor habitat character of the armored bank.

Monitoring should include an assessment of the erosion of the portion of the revetment that has already slumped into the river. Questions to be investigated include:

- Is there erosion of the alluvium behind the failed rock?
- Is there deposition in front of the failed bank?
- Is there large woody debris accumulating in the failed area?

These questions will inform the degree of bank erosion hazard associated with leaving the revetment alone. If there is significant deposition in the channel and large woody debris in the failed area, it means that the bank may heal itself through forming a natural levee in the area. If the failed bank continues to erode, it means that the bank will likely migrate further south (landward) over time.

The upstream and downstream ends of the revetment are the most critical elements for the continued protection of adjacent landowners, with the upstream (east) end being more important than the downstream (west) end; further explanation is provided in the discussion of Alternative #2 below. As long as the ends of the revetment remain intact there is little increased channel migration hazard to adjacent landowners from erosion of the revetment on the County-acquired properties.

However, if the upstream and downstream ends of the revetment fail, there will be increased risk to adjacent residences. On the upstream (east) side, two homes are quite close to the end of the revetment. It is likely that erosion and inundation will increase risk to these structures, after failure of the revetment. On the downstream end of the revetment, there is a 200-foot distance between the end of the revetment and the nearest residence. The buffer is heavily vegetated, undeveloped, and low-lying. While eventually the river could migrate and increase risk to this residence, it will likely take much longer to manifest itself and in general be less severe than at the upstream end.

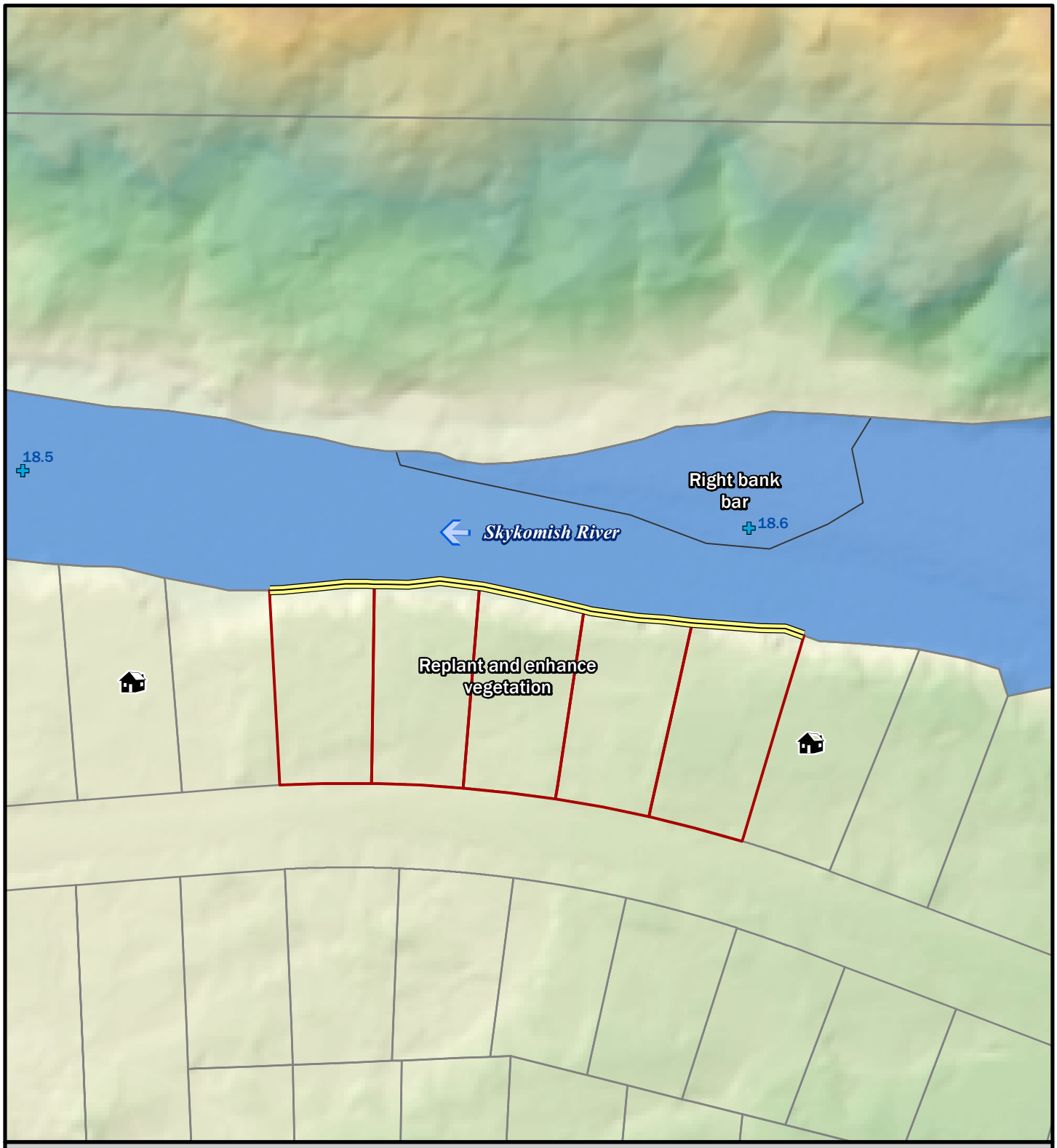
One simple way to mitigate some of the channel migration hazard that has increased due to slumping of a portion of the existing revetment would be to plant the top of the bank. Very little woody vegetation exists at the top of the revetment. Although it is possible that much of the planted bank could be eroded away in the near future, it is also possible that, if the vegetation could mature sufficiently, the vegetation would act as a natural barrier to future channel migration in the direction of Timberlane Village. Survival of any revegetation on the river banks and landward areas may require some component of communication and information provided to the community as to its benefits and importance.

Over the long term, aquatic habitat conditions near the revetment would degrade slowly relative to existing conditions, which are already marginal for salmonids. If portions of the revetment slump and fall into the river, the quarry rock would also diminish habitat value in the channel bed.

As this alternative does not include constructed actions, no permits would be required for implementation and no construction cost estimate was generated.

Alternative #2 – Revetment Removal

Removing the revetment (Figure 5) would allow the steep bank to erode and rebuild a more natural sloping, vegetated bank. Expansion of the active channel width would have minor flood reduction benefits to adjacent properties over time. Restoring the bank would also improve channel edge habitat and possibly allow for the accumulation of large woody debris. This would be a benefit to fish, including endangered salmonids, and several other aquatic species.



Legend

- SF Skykomish River Mile
- House location
- Existing Revetment to be Removed
- County-Owned Parcel
- Parcel

Figure 5.
Conceptual Design of Alternative #2 - Revetment Removal, Timberlane Village, Skykomish, Washington.

N

0 50 100 200 Feet

King County

King County, Hillshade (2011)
Prepared for King County by Herrera

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Because the left bank would be allowed to erode under this alternative, it is expected that the channel would migrate southward. Downstream bank erosion (to the west) would be hindered by the remnants of a former channel (seen in the Water Supply Bulletin in Appendix 1 of Appendix A) that is low and well vegetated, which separates the existing revetment from a home approximately 200 feet away. Channel migration would be slow because overbank flooding will be dispersed due to the low elevation of the bank and its orientation perpendicular to the main channel flow. The mature vegetation will also slow erosion via roughness and root cohesion. The home, which is currently at risk due to flooding, also has a rock revetment on the riverbank north of the house. Removing the revetment at RM 18.5 would result in a negligible increase in the channel migration hazard to this downstream home and would result in slightly reduced floodwater depths due to expansion of the channel width. However, increased channel migration and flooding would be expected on the undeveloped parcel immediately to the west of the County-acquired land. This could be moderated by the acquisition of the two parcels to the west of the existing County properties.

To the east of the parcels acquired by the County, there are three privately owned parcels each with a home. The home on the parcel immediately east of the County parcels is not protected by a revetment, yet it has been indirectly protected by the revetment at RM 18.5 and a neighbor's revetment to the east. Removal of the revetment at RM 18.5 could increase channel migration in the direction of this home. The home is somewhat set back from the river and it may take many years for the river to endanger the home, but it is likely that bank migration will eventually push the active river edge closer to the house.

The primary challenge during construction to remove the revetment would be isolation of the work area to protect water quality in the river. The river flow adjacent to the existing revetment is fast moving and deep, even during low flow conditions. Standard methods of work area isolation (e.g., bulk bags) could be difficult to use in the deep channel. Sheet piles could be used to isolate the work area, but their installation (via impact hammer) could cause significant noise impacts to resident fish. Several strategies that could be implemented (ideally in combination) to mitigate offsite water quality degradation are described below.

- Acquire a variance to extend the mixing zone downstream. The Skykomish River basin, unlike some other montane river basins in western Washington, does not contain a volcano or large glaciers. Without natural sources of fine sediment in the water, summertime turbidity levels in the river are quite low. This means that even small bank disturbances can notably increase turbidity. It is hypothesized that full stream-wide dilution of a turbidity plume would require at least two riffles to be achieved. The standard 300-foot-long riverine mixing zone that the Washington State Department of Ecology frequently authorizes for construction projects may not be sufficient to dilute turbidity from the project, particularly if partial isolation methods (silt curtains) are not used.

- Use a silt curtain to partially isolate the work area. Silt curtains are often used in areas where water depth precludes effective use of bulk bags. They are not as effective at isolating the work area, however. Using a silt curtain in the swift current typical along the left bank at RM 18.5 would be challenging, but would be far less

expensive and more protective of the environment than sheet pile or some other cofferdam-type isolation device.

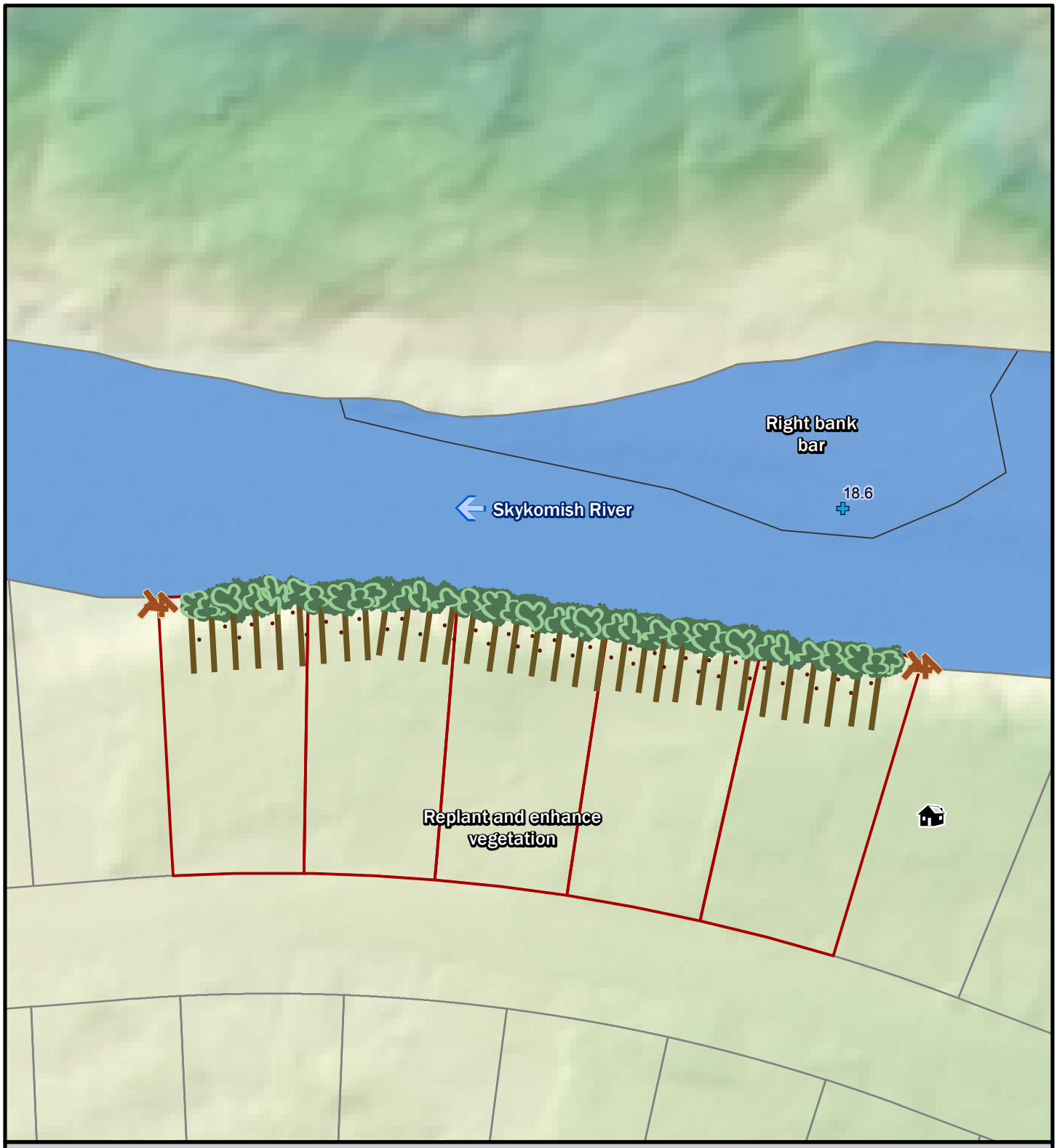
- Remove only the upper portion of the revetment. It may not be necessary (or even practical) to remove all of the rock in the revetment to yield significant habitat gains. Riprap extends at least several feet below low-water level in the channel at the toe of the revetment, if not down to the bottom of the scour pool that has formed at the base of the revetment (more than 10 feet below low water surface elevations). Even removal to the low-water elevation would allow flood flows to attack the bank and initiate the formation of a more natural riverbank. A bar would likely form around the remaining revetment, but channel migration would be allowed to continue, producing high quality edge habitat. This strategy would avoid working in the water, therefore greatly reducing the potential for turbidity problems. The construction contract could be written to stipulate that work on the lowest part of the revetment be reserved for times when water levels at the Snohomish County flow gage at Skykomish are below a certain level (e.g., 4 feet above the gage datum).

Permitting the revetment removal should be straightforward, despite construction impacts, because its removal would restore natural bank conditions and improve habitat on the County-owned parcels, even if the lower portion of the revetment is left remaining. The bank should be planted under this alternative as an added mitigation action to slow channel migration and to further improve habitat.

Alternative #3 – Revetment Replacement

Replacing the rock revetment with a bioengineered revetment would protect the County-acquired parcels from erosion, while enhancing aquatic and riparian habitat. A replacement facility could indirectly protect adjacent homeowners by preventing erosion for the long term at either end where it ties into the existing bank. If designed to resist the anticipated hydraulic forces and toe scour during flood events, the biorevetment would deflect the river's energy away from the left bank, though this effect would be slight because the denuded right bank bar on the opposite side of the channel from the existing revetment has coarsened to the point where it is not erodible/mobile. Therefore, the offsite impacts of this alternative would be minimal. The structure could be designed to prevent water surface elevation increases in surrounding channel and floodplain areas during flood events, thereby preventing offsite flood impacts.

A conceptual configuration for this alternative is shown in Figure 6. It entails constructing a log crib wall for the length of the existing revetment. The logs and the cover they provide would create refuge for fish, which is absent under existing conditions. Native riparian plantings atop the log crib structure should be included for added habitat improvement. Because of the coarse-grained composition of the alluvium in the area, without further geotechnical exploration, it is assumed that steel piles would be required to secure the larger "key" logs to form a solid foundation for the crib wall, as it may not be feasible to drive timber piles to the necessary depth in the native subsurface material.



Legend

- SF Skykomish River Miles
- Log Jam
- House location
- County-Owned Parcels
- Parcels
- Log Crib

Figure 6. Conceptual Design of Alternative #3- Revetment Replacement, Timberlane Village, Skykomish, Washington.

N

0 35 70 140

Feet

King County

King County, Hillshade (2011)
Prepared for King County by Herrera

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Like Alternative #2, the primary construction challenge with this alternative would be work-site isolation. Even though there would be significantly more ground disturbance, work-site isolation should not be significantly more difficult compared to Alternative #2 because the length of the work area would be nearly identical and the new crib wall would not extend farther out into the channel. Strategies to protect water quality during construction would be the same as described for Alternative #2. Access for construction is otherwise straightforward and there is adequate area available on the existing parcels to stage equipment and materials for removal of the existing rock revetment and placement of the new crib wall structure.

Permitting the construction would not be simple, even though it would enhance habitat relative to existing conditions. The new structure would keep the bank relatively straight (in plan view) and restrict the area of floodplain evolution and associated riparian vegetation growth (i.e., habitat conditions in the future would not be equivalent to the removal alternative). Because flow would entrain generally parallel to the structure, accumulation of large woody debris on it over time would be minimal, and thus its aquatic habitat value years into the future would likely be similar to conditions immediately after construction. Potential pile driving impacts to fish, even if the piles were driven into dry earth, would also have to be addressed because of the proximity of the project to endangered salmonid habitat.

Recommended Non-Structural Actions in Areas of Extreme Risk

Two risk zones were classified as extreme. They are quite different in terms of both their current land use and the nature of the hazards that contribute to risks. Zone 6 - Inner Meander Bend (Figure 3) is mostly undeveloped and is primarily at risk from relatively deep, but slow moving, inundation from the South Fork. It has one permanent structure. It is also prone to channel migration, but this hazard is not particularly significant. Zone 9 - Left Bank Point Bar (Figure 3) is developed with at least twelve residences and a section of NE 123rd Street. Zone 9 is susceptible to a range of flood and erosion hazards, some of which are significant and highly probable as described previously.

Even though the hazards and land use are distinct in these two zones, both areas should be targets for acquisition and removal of the homes and other related structures, though for different reasons. The rationale for acquisition of parcels within Zone 6 (Inner Meander Bend), is that most of the zone is undeveloped and has relatively good habitat conditions. These undeveloped properties are low-lying, within the FEMA 100-year floodplain, and almost entirely in the floodway, which limits their development potential given prevailing County, state and federal regulations. The lone parcel that is developed in this zone is surrounded by low areas that flood regularly and has relatively high quality habitat. Removal of the revetment at RM 18.5 (discussed above) would require consideration of the developed parcel in Zone 6. Therefore acquisition of the developed Zone 6 parcel would help with implementation of the revetment removal. The developed parcel has a revetment, which could be removed if it was acquired. The removal of the isolated revetment on the developed Zone 6 parcel would bring significant ecological lift and would not endanger adjacent properties. Therefore, the relatively low cost property acquisition strategy would allow for the floodplain to be fully connected and the habitat value to be maximized. Finally, acquisition would create an opportunity for addressing the change in downstream risk resulting from removal of the revetment at RM 18.5.

In the case of the Zone 9 - Left Bank Point Bar, the rationale for acquisition is that risk is related to multiple significant hazards and there is no reasonable structural solution to protect the development at risk. In addition to the flooding (inundation) hazard due to the land surface being low, there is a risk of channel formation through this risk zone due to high-velocity overbank flow from both the South Fork and Anthracite Creek. Protection of the homes and related development in this zone from the combined hazards would likely be extremely expensive, would not provide certain hazard mitigation, and would require significant long-term maintenance costs and level of effort. Reconstruction and expansion of the existing revetment would reduce bank erosion; however, the multiple hazards including channel migration, deep-fast flooding and possible avulsion of Anthracite Creek through the area would still be present. On the other hand, acquisition could allow for the removal of the existing private revetment and improve habitat functions in this dynamic area.

Recommended Non-Structural Actions in Areas of Severe Risk

Two zones exhibit severe risk. The first of these zones is Zone 3 - Left Bank Revetment. Most (five) of the parcels in this zone have already been acquired by the County including the revetment at RM 18.5, which is at risk to failure. Failure could endanger adjacent residences within the zone and in Zone 6 depending on the mode of failure and the subsequent response of the river. This is discussed at length in the previous sections describing structural actions at the revetment.

Within Zone 3, there are three parcels with structures upstream of the parcels already acquired by the County. Acquisition priority progressively drops moving upstream (to the east) of the parcels acquired by the County. The nearest parcel does not have a revetment, but the home is set back from the river, though it is still at some risk considering the potential failure of the revetment at RM 18.5 and future bank migration. The next home upstream is much closer to the riverbank, but is protected from channel migration by a revetment. The most upstream parcel has a home on the edge of the risk zone, which is protected from channel migration, the dominant hazard, by a thick band of vegetation. This upstream home is at much lower risk, though changes to the downstream parcels could heighten that risk over time (e.g., by removal of the single revetment immediately to the west if that private property were purchased by the County). Acquisition of all of these parcels could ease the structural actions taken on the County properties and remove the risk from these existing structures. Furthermore, acquisition of the middle parcel could enable the removal of its revetment, but it would have to be completed in a coordinated action as this revetment indirectly protects homes on either side of it.

The other zone at severe risk is Zone 4 – Right Bank Hillside Upstream of the US-2 Bridge. The primary hazard is slope instability. The bank along the South Fork in this zone is unstable. Runout of future failures are not expected to be an issue based on the size of existing slumps. The zone is predominantly undeveloped, though one of the privately owned parcels upstream of the US-2 Bridge does have a residence on it sited away from the area at risk. The residence is situated far enough away from the risk zone such that protection, from either acquisition or other structural means, is not necessary at this time.

The other privately owned parcel is not developed. It is also an acquisition target. Here, development potential is high because of good access and plenty of buildable flat ground amidst the debris of the Beckler Peak Rock Avalanche. Moreover, while the parcel is large enough to accommodate development far from the risk zone, the speed at which the slope instability is moving eastwards and the desire for a home to have a view of the river means the potential for constructing a structure within the risk zone cannot be underestimated. Finally, the parcel has mature vegetation along the river that could support conservation of this high quality habitat.

SUMMARY OF FINDINGS

The following statements can be made based upon the results of the analysis discussed herein:

- The areas at greatest risk due to flooding and erosion hazards in Timberlane Village occur in Zone 9 - Left Bank Point Bar, in the vicinity of South Fork RM 18.05 to RM 18.33, which contains most of the developed properties on the west end of NE 123rd Street, and in Zone 6 - Inner Meander Bend just downstream of the parcels acquired by the County, which consists of a low-lying area vulnerable to frequent flooding in the north-central portion of the development.
- If the revetment at RM 18.5 is left as is, consistent, targeted monitoring should be conducted to determine if any portions of the revetment are being compromised by erosion and slumps. If monitoring finds that some or the entire revetment is collapsing and thereafter failing to prevent bank erosion, management action could be planned with adequate time to mitigate the risk to neighboring landowners.
- The pure removal alternative (Alternative #2) would be attractive, if adjacent properties at risk were acquired.
- The revetment replacement alternative (Alternative #3) would be quite expensive relative to the benefits that could be achieved and limited number of developed properties protected with the action.
- The recommended action for areas of severe and extreme risk (see Figure 3) is property acquisition to permanently remove residential structures from areas exhibiting multiple and significant hazards.

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APPENDIX A

Geomorphic Process and Flood Hazard Assessment

GEOMORPHIC PROCESS AND FLOOD HAZARD ASSESSMENT

TIMBERLANE VILLAGE

Prepared for
King County
Department of Natural Resources
and Parks

Prepared by
Herrera Environmental Consultants, Inc.

GEOMORPHIC PROCESS AND FLOOD HAZARD ASSESSMENT

TIMBERLANE VILLAGE

Prepared for
King County
Department of Natural Resources and Parks
Water and Land Resources Division
River and Floodplain Management Section
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June 19, 2014

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INTRODUCTION

Timberlane Village is a community of private residences located 1.5 miles east of the Town of Skykomish on US Highway 2 (US-2). It is bounded to the north, west and east by the South Fork Skykomish River (the South Fork) and is known to be vulnerable to erosion and flood hazards. In 2009, King County (the County) acquired five parcels of land in this community, including three with residential structures that were demolished in 2012. While the structures have been removed, these parcels include a nearly vertical, constructed rock revetment along approximately 300 feet of the riverbank, hereafter referred to as the revetment at river mile (RM) 18.5. The constructed rock revetment is failing due to its oversteepened construction and exposure to significant hydraulic forces in recent years. This report identifies geomorphic and flooding hazards in the neighborhood and documents the relative severity of each hazard with respect to frequency of recurrence and confidence associated with the estimate. The documentation of hazards will assist with a delineation of risk and will guide future County actions in the area.

This report focuses exclusively on geomorphic and flood hazards and their relative recurrence intervals. The nature and severity of these flooding and geomorphic hazards is also clearly identified with respect to potential effects on structures, developable land and infrastructure in Timberlane Village. The report to which this document is appended incorporates this analysis with a description of risks, future management alternatives, and recommendations, including priorities for non-structural actions (particularly acquisition of properties at risk) and potential structural actions on property currently owned by the County.

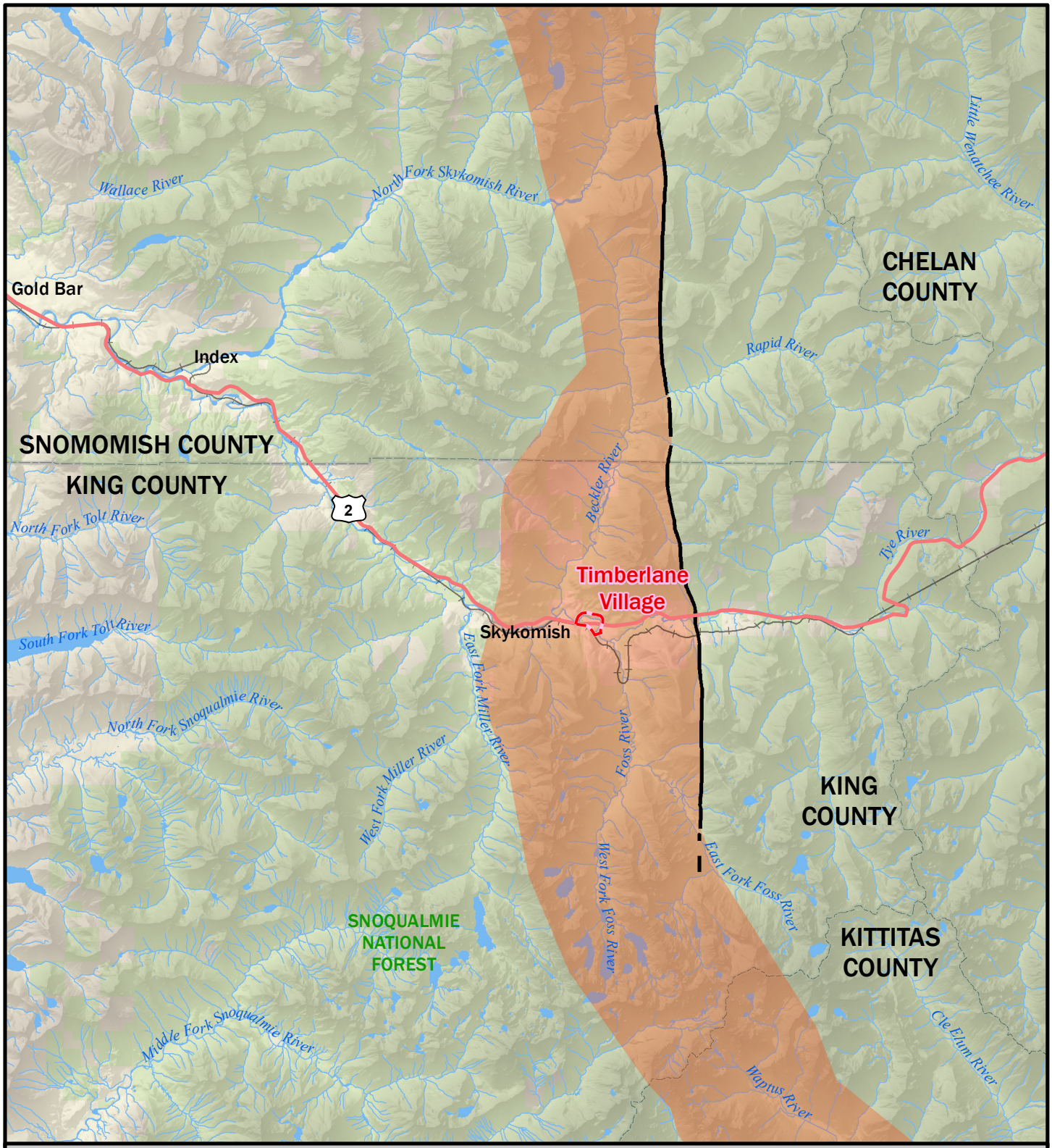
Note there are separate efforts underway by King County to update landslide hazard maps Countywide and to delineate Channel Migration Hazard Zones (CMZ) along the South Fork Skykomish including Timberlane Village. The updates to the landslide hazard maps will include hazards originating outside the project area such as the Beckler Peak Rock Avalanche described below.

Study Area Limits

The study area includes the channel, banks, floodplain and hillslopes along the South Fork between approximately RM 17.9 and RM 19.2 (Figure 1). This study includes an assessment of the one major tributary to the South Fork in this area, Anthracite Creek. Anthracite Creek was examined from the BNSF Railway Bridge to its confluence with the South Fork.

Geologic Setting

Timberlane Village is located midway into a large gorge that defines what some have called the Upper Skykomish Valley in the central Cascade Mountains of Washington State. It is accessed via US Highway 2 (US-2) and a series of small, mostly unpaved roads. The study area contains mildly undulating topography where it is not dissected by the South Fork. The undulations are associated with a variety of past geomorphic and geologic processes including



Legend

- Study Area
- Evergreen Fault
- Straight Creek Fault Zone
- Highway
- Railroad
- County

Figure 1.
Timberlane Village Study Area Vicinity Map.

N

0 2 4 8 Miles

King County

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Prepared for King County by Herrera
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historical South Fork (alluvial) sediment deposition, the Beckler Peak Rock Avalanche, and the Anthracite Creek Alluvial Fan. Anthracite Creek is the primary tributary to the South Fork in the area.

Timberlane Village is in a geologically active area. As such, a range of geologic processes could induce risk to human activities and infrastructure. All geophysical hazards known to have occurred in the last 10,000 years were considered in this analysis, though emphasis was placed on those hazards that could reasonably be expected to recur in the next 10 to 100 years. They include: flooding (damage or destruction of property from inundation and/or high flow velocity) in the South Fork, channel migration and erosion along the South Fork, alluvial fan deposition and channel migration along Anthracite Creek, and landslides varying in magnitude from small surface slumps capable of diverting some portion of the river flow to wholesale flank collapses of neighboring mountains.

Because the area is geologically active, it is possible that other hazards could emerge within 100 years that could pose risks within the study area, particularly as they relate to faulting and slipping within the large and deep Straight Creek Fault Zone (of which the Evergreen Fault Zone is the primary surface expression). Timberlane Village is in the middle of the Evergreen Fault Zone. The Evergreen Fault (i.e., the dominant, most obvious surface strand of the spatially complex Straight Creek Fault Zone) is mapped 2 miles east of the study area. It is classified as a Class B fault by the US Geological Survey (USGS). This means that there is evidence of Quaternary (recent) deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C (i.e., a relict fault), but not strong enough to assign it to Class A (i.e., a fault that has been active in modern time, like the San Andreas Fault in California or the Seattle Fault that bisects the city of Seattle) (USGS 2013). Given the lack of information about modern ruptures of the Evergreen Fault Zone and the Straight Creek Fault Zone in general, earthquake hazards were not considered in this analysis.

Historic Setting

The Upper Skykomish Valley, particularly the relatively flat areas in the vicinity of the modern day Town of Skykomish, was first visited seasonally by the Skykomish Tribe, now a part of the Tulalip Tribes, thousands of years ago. European settlement in the area began following the construction of the Great Northern (now BNSF) railway in the early 1890s (Carlson 2009). Construction of the railway was the first significant permanent development in the study area. Sometime shortly after 1902, an original (likely unpaved) road was constructed near the railway alignment. The current alignment of US-2 through the study area is slightly different than the original road alignment, but the old alignment can still be seen in places and is evident in both the 1944 and 1956 aerial photographs (Appendix 1). The old road alignment more closely followed the railway, extending through the current Timberlane Village development to the north and along the current alignment of Foss River Road to the south (Figure 2). From the 1944 aerial photograph (Appendix 1), it appears that current road alignment was constructed in the late 1930s, along with the existing US-2 Bridge.

The road facilitated much of the development in the study area. The first major phase of development was associated with Cass Pond Resort at the west end of the study area. It is unclear when the resort opened, but pictures collected by the Skykomish Historical Society indicate that the resort was accepting guests in the early 1920s. The 1902 USGS topographic map (USGS 1902) does not show any sign of development at the resort site. As late as 1965, there was no development in what later became Timberlane Village, aside from the resort and a collection of structures at the west end (USGS 1965). The 1965 topographic map indicates the presence of cabins along Tye River Road NE on the opposite (south) side of present-day US-2 from Timberlane Village.

The first appearance of the remainder of the road network within Timberlane Village is in the 1970 aerial photograph (Appendix 1). Most of the existing homes in the study area were constructed between 1970 and the present, with a few homes added between each set of available aerial photographs. Although resolution of earlier historical photographs is not sufficient to determine when the revetment on the County acquired properties was constructed, it is clear from the most recent, higher resolution photographs that the structure was in place in the late 1990s.

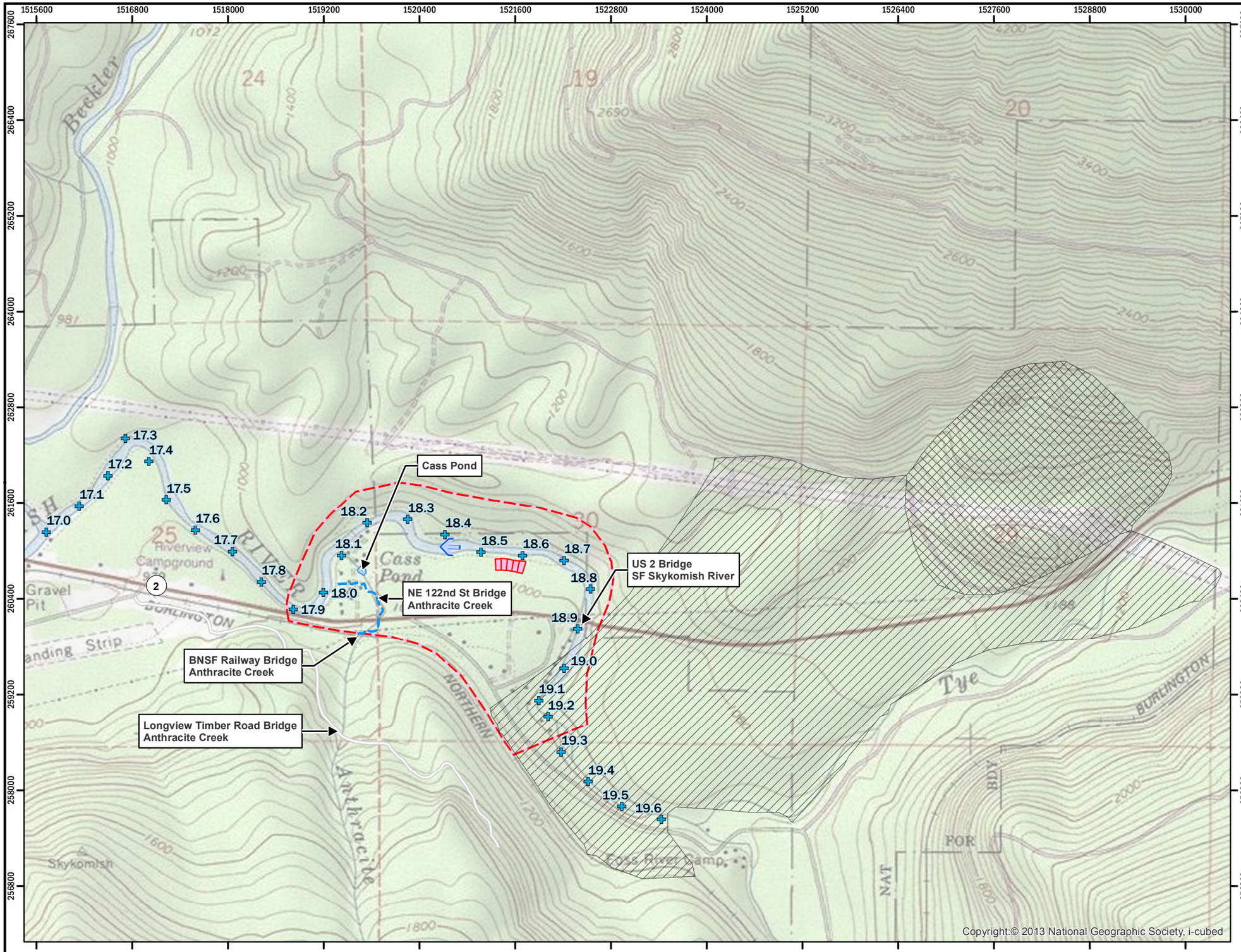

Figure 2.
Timberlane Village Study Area, Site Map.

Legend

- Study Area
- County-Owned Parcels
- SF Skykomish River Miles
- Anthracite Creek (2011 Alignment)

Geologic Units Based on 1:100,000 Scale Mapping by USGS (2005)

- Recent Landslide Deposit
- Rock Avalance Deposits

Note:
The actual limits of the Beckler Peak Rock Avalanche may deviate from the extents mapped in the geological map because of scale constraints, particularly with regards to outlying spray boulders at the fringes of the rock avalanche deposit.

N

0 600 1,200 2,400 ft

King County

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Prepared for King County by Herrera

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METHODOLOGY

Geomorphic Process Assessment

Existing Data

An important source of information regarding the geomorphology of the study area is the geologic map and accompanying documentation of Tabor et al. (1993). The General Land Office (GLO) map was also examined (GLO 1897). As many others have found, the quality of the GLO maps can vary significantly. From comparison with the geologic map (e.g., the location of intact Beckler Peak Rock Avalanche deposits), it is clear that away from the section lines, the alignment of the South Fork in the GLO map is in error. Therefore, the GLO map was only used as a qualitative historical document and then only when describing features close to section lines, such as the mid-channel island near the mouth of Anthracite Creek that is discussed repeatedly in this report.

The USGS presents a profile survey of the South Fork in a Water-Supply Paper (USGS 1914) that provides an alternative to the GLO map and a somewhat more accurate record of the geomorphic conditions in the study area prior to the aerial photographic record. It was used as the principal source of pre-aerial-photograph information for the study area.

Aerial photographs were made available by the County (photos before 1998, Appendix 1) and were also obtained from Google Earth™ (photos taken after 1998). Lidar is also available for the study area, with data collected in 2002 and 2011. The lidar data is discussed at length below in regards to the topographic information used for hydraulic modeling.

A report completed by the County (King County 2005) that collected and presented information on past channel locations but was not a channel migration analysis was consulted and informed the reach scale analysis described below. Note there is a separate effort underway by King County to delineate Channel Migration Hazard Zones (CMZ) along the South Fork Skykomish including Timberlane Village. The work contained in this report is intended to inform capital actions and hazard mitigation and not develop CMZ regulatory maps.

Field Reconnaissance

Two site visits were conducted by Herrera staff to observe geomorphic conditions, the first on August 13, 2013, and the second on August 16, 2013. The upland and riparian portions of the five County-owned parcels were explored in the first site visit. This visit also included a walk up Anthracite Creek from its confluence to the NE 122nd Street Bridge. The second site visit focused on observing the South Fork below the ordinary high water mark between RM 17.9 and RM 19.2. Anthracite Creek was examined during this visit, between the BNSF Railway bridge and the NE 122nd Street Bridge. The second site visit also included a trip to the younger Beckler Peak landslide (on top of the older Beckler Peak Rock Avalanche) and to the Longview Timber private road crossing on Anthracite Creek one-half mile upstream from the BNSF Railway bridge.

Flood Hazard Assessment

The flood hazard assessment maps and describes characteristics of flood waters based upon the site visits and the results of the hydraulic modeling described below.

Existing Data

Current Federal Emergency Management Agency (FEMA) maps of the South Fork floodplain (i.e., Flood Insurance Rate Maps [FIRMs]) are based upon a HEC-2 hydraulic model developed by King County Rivers Section in 1994 (King County 1995). This one-dimensional model has the same theoretical basis (i.e., governing equations) as the HEC-RAS hydraulic model developed for this study, as described further below. However, the cross-section data input to the older model came from topographic survey that was collected at the time of the mapping effort. The aerial photograph record indicates that the river channel has changed significantly between 1994 and the present. Therefore, a new hydraulic model was developed using the US Army Corps of Engineers' HEC-RAS program to account for the geomorphic changes that have occurred in the last 30 years.

There have been two lidar data collection efforts in the study area and vicinity in the recent past. The first lidar data collected in 2002 were found to be inadequate to provide the resolution required for this study. Lidar data collected in 2011 are of much higher quality and were thus used as the basis for defining channel and floodplain areas above the ordinary high water mark of the South Fork in the HEC-RAS model, as well as for providing existing topographic information for the geomorphic analysis.

Bathymetric Survey

Because lidar data cannot capture channel bathymetry below the water level at the time it was collected, new bathymetric data were collected for this study to serve as the basis for defining the river channel below the ordinary high water level in the HEC-RAS model. Channel bed and bank elevations were determined using a laser level correlated to selected flat, cleared (free of vegetation) points in the lidar data. The horizontal position of data points collected with the laser level was determined using a hand-held Global Positioning System (GPS) device. As a result, the horizontal error in the location of the sections is accurate to approximately 20 feet. Absolute vertical error is approximately 0.1 foot. However, repeatability of the vertical measurements is less than this due to the rough landscape and selection of survey locations. Because the sections were collected by hydraulic modelers, and not licensed surveyors, survey locations were selected such that they minimize errors in the calculation of conveyance (i.e., locations were selected at grade breaks). A total of nine bathymetric cross-sections were collected on August 16, 21, and 28, 2013, through the study area.

Hydraulic Modeling

HEC-RAS version 4.1.0 was used to model the hydraulic characteristics in the study area. Hydrologic input to the model was determined from the stage (water level) record collected at the South Fork Skykomish flow gage located at the 5th Street Bridge in Skykomish between 1999 and the present(for a 14-year period of record: Snohomish County 2013). Recorded annual peak stages (water surface elevations) at this gage were converted to annual peak

flow rate using a rating curve developed by Herrera (2013a), and Log Pierson III flow frequency analysis (US Army Corps of Engineers 1982) was used to develop a flood frequency curve for the gage (Appendix 2). South Fork flow rates at the gage were scaled by basin area to remove the contribution of the Beckler River basin, generating flood frequency values for the study area (Table 1). Herrera (2013a) documented that the hydrology of the portion of the South Fork basin east of the Skykomish flow gage, of which the study area is a part, is significantly different than in western portions of the basin. The earlier study showed that the largest floods in the entire basin are driven primarily from extremely large flood events in the western tributary basins (e.g., the Miller River basin), while eastern basins support more base flow (i.e., the western basins are "flashier" than their eastern counterparts). This means that within the study area, extreme (hazardous) flows are not as large as basin area relationships using flow data from the USGS Skykomish River near Gold Bar gage would indicate.

The magnitude of the flood events are larger than the flood study used to construct the existing FEMA maps (as mapped in Figure 3), particularly for the more frequent flood events (King County 1995: Table 1). The increase in the size of events described in this study likely reflects ongoing climate change and the slow conversion of the upper South Fork from a snowmelt-dominated to a fall-runoff-dominated river (Elsner et al. 2010; Pelto 2011).

Table 1. Flood Frequency Values for the South Fork in the Study Area.

Annual Chance of Exceedance (%)	50	10	4	2	1
Estimated Flow Rate (cfs)	14,370	20,400	23,100	24,800	26,800
1995 Flood Study (cfs)		12,600		19,400	22,800

As noted above, the geometry of the hydraulic model cross-sections was constructed from the new bathymetric data merged with upland extents from the 2011 lidar. The model cross-sections all extend well above the 1% annual chance exceedance flood elevation.

The model was not calibrated due to the lack of calibration data, such as recorded high water marks at the site or at nearby locations. However, HEC-RAS is an established river modeling tool used in some form by numerous federal, state, and local agencies for more than 25 years that can be used by a modeler with skill and knowledge to provide reasonable estimates of flood depths in the study area under a range of flows. To check the accuracy of the model results presented in this report, it is recommended that high water marks be noted in the study area during the next large flood event (similar to the flood events that occurred in November 2006 and January 2009), and used in combination with coincident flow measurements at the South Fork Skykomish gage to determine if model input parameter adjustments are warranted.

Aquatic Habitat Conditions Assessment

Aquatic habitat conditions were observed anecdotally as a secondary consideration during the site visits in August 2013. Based on a very limited number of observations, it was found that fish use was extensive in certain areas and not in others. In addition, several obvious habitat impairments (such as stray garbage and debris in the active channel) were observed.

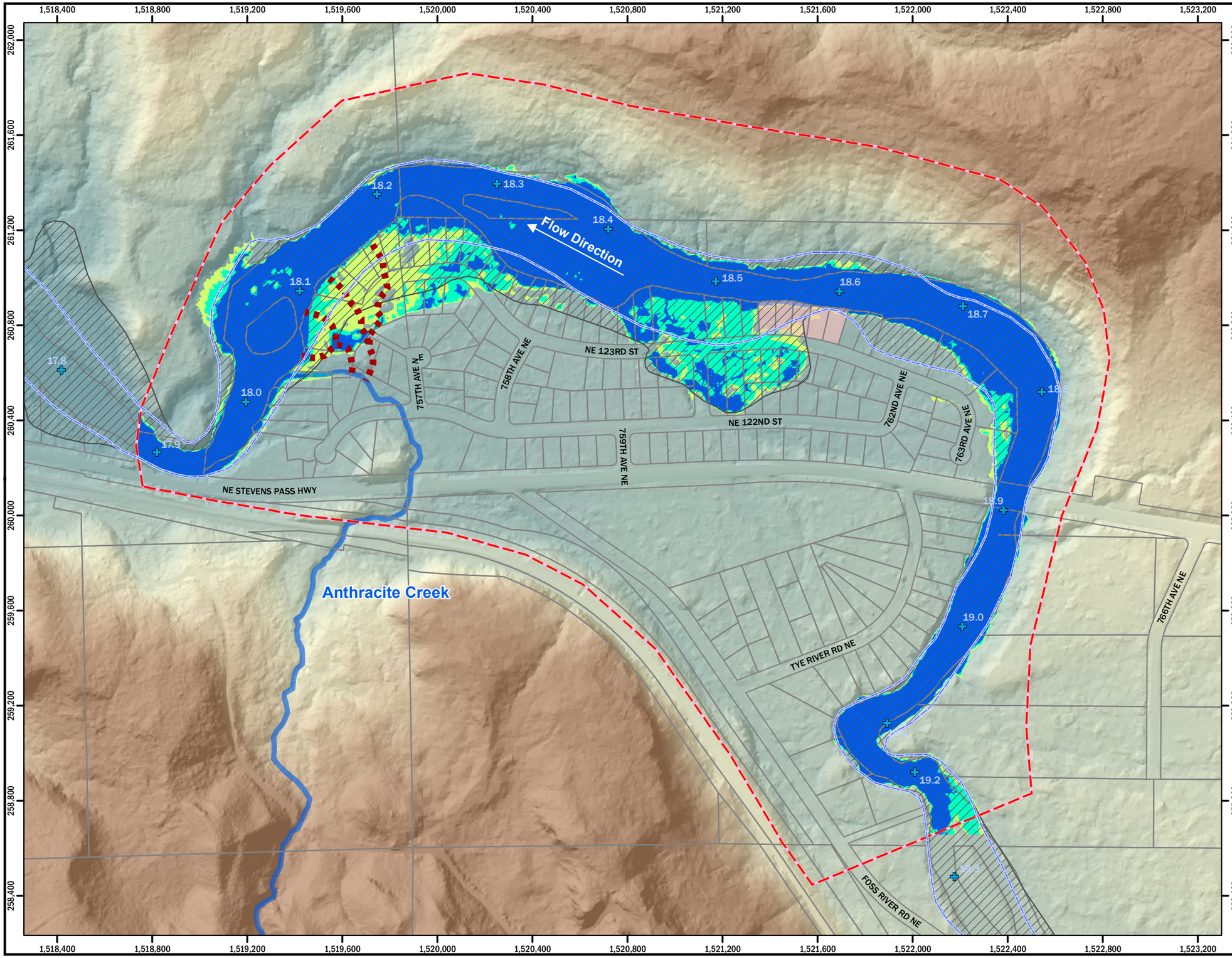

Figure 3.
Modeled Flood Inundation Extents,
Timberlane Village,
Skykomish, Washington.

Legend

- Study Area
- SF Skykomish River Mile
- Parcel
- County-Owned Parcel
- FEMA Floodplain
- FEMA Floodway
- Anthracite Creek Potential Avulsion Pathway

Modeled Inundation Extent

- 50% Annual Exceedence
- 10% Annual Exceedence
- 01% Annual Exceedence

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County, Hillshade (2011)

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RESULTS

General Findings

There are several physical processes that interact to cause geomorphic change and produce flood hazards in the study area. The geomorphic processes are grouped below, along with a brief qualitative description of their scale and recurrence. Even though there are separate physical processes that produce hazards, nearly all of them relate directly or indirectly to river channel migration. Channel migration is very minor at the upstream end of the study area, but increases progressively in the downstream direction, with its greatest extent occurring just upstream of the bedrock constriction that defines the downstream end of the study area. Historical geologic events have had a direct influence on the locations and extents of channel migration and channel constriction in the study area.

Flood Hazards

Figure 3 presents the modeled inundation extents for a range of flood flows in the study area, along with the floodplain as mapped by FEMA (FEMA 1998). As can be seen in the figure, flooding is most pronounced at the west (downstream) end of the study area. Because the channel is migrating towards developed property near the left bank bend at the west end of the study area (see specific reach discussion in the next section), it is likely that flooding there will worsen over time. Another key flooding concern is the inundation immediately downstream of the County-acquired property. Flooding is predicted to be extensive where the main channel was once present (USGS 1914, Appendix 1). Some of this predicted flooding may be inaccurate because this area is in between cross-sections in the HEC-RAS model, and HEC-RAS does explicitly model flow in a two-dimensional sense. For a detailed discussion of this predicted inundation, see the reach-scale findings sections below. The model results also indicate that no development will be flooded upstream of the US-2 bridge, even in the 1 percent annual chance exceedance event.

As can be seen in Figure 3, predicted inundation during the 1 percent annual chance exceedance event closely resembles the FEMA 100-year floodplain. There are three areas of minor differences. The first two are near RM 18.4 and RM 18.65 on the left bank (Figure 3). These areas are high banks that are within the FEMA 100-year (1 percent annual chance exceedance) floodplain. The model produced for this study does not predict inundation over the top of these high banks. The difference is likely due to the King County HEC-2 modeling having insufficient cross section coverage in this area. Both of these areas are in between cross sections where the banks are lower, meaning that the HEC-2 model projected water flow through areas where the banks are higher, yielding erroneous inundation predictions. The HEC-2 study was based on a 4' contour interval topographic map leading to less precise inundation mapping than the current effort. The third minor difference is that the model produced for this study shows expanded flooding of the left bank point bar between RM 18.1 and 18.3. This expansion of flooding is likely due to geomorphic changes and sediment

deposition that have occurred in this reach in the last 30 years since the FEMA modeling was done.

Figure 4 illustrates the areas where hazards are greatest for deep and/or fast flows, as described by the US Bureau of Reclamation (1988). As mentioned in this guidance document, the broad classification scheme defines a gradation of hazard depending on approximately the product of the velocity and depth. Like the modeled inundation shown in Figure 3, the two prime areas of deep and/or fast flow hazards are located downstream of the County acquisition near RM 18.5 in what was formerly a meander bend according to the map presented in USGS (1914), and on the left bank point bar at the north end of the former Cass Pond Resort in between RM 18.1 and 18.3. Also similar to the predicted flood inundation, the deep and fast flow hazards are greater in the left bank point bar area than near RM 18.5. The high hazard areas in the former meander bend are due only to flood flow depth in the abandoned meander channel. Inundation with slow-moving water is predicted throughout this area. The splotchy yellow and orange areas shown in Figure 4 in the left bank point bar at its upstream end near RM 18.3 indicate that fast flows may initiate anywhere in this area, as the flows interact with the structures (homes) in this area and deform the bed. The model resolution is also higher in the left bank point bar area, enabling greater confidence in the model results, as compared to the former meander bend. It is important to mention that structures are not explicitly in the model (i.e., the lidar "bare earth surface" typically removes structures), even though they may locally increase flow velocities, particularly in the left bank point bar area.

Geomorphic Hazards

Mainstem River Channel Migration

The most significant geologic or geomorphic hazard that occurs over shorter time scales (less than 10 years) is channel migration. Although the South Fork channel alignment has been relatively stable through most of the study area during the period of photographic record (1944 to the present, Herrera 2013b), there are signs of channel migration since 1944.

In the study area, the South Fork channel is bounded upstream and downstream by erosion resistant features: the Beckler Peak Rock Avalanche at the upstream end (Figure 2), and sandstone bedrock at the downstream end (near RM 18.0). At these end points, channel migration is expected to be close to zero over shorter time scales. Near the downstream limit of the study area the stream bed elevation is set in sandstone bedrock. This bedrock is exposed on both banks, though fill from the construction of US-2 is also covered by riprap in places, further confining the channel and fixing the alignment of the river in place. The upstream end of the study area is confined by large blocks from the Beckler Peak Rock Avalanche. Although not strictly bedrock, and not particularly competent (i.e., resistant to chemical weathering and abrasion), the large 15-foot clasts are immobile and function effectively like a bedrock channel, as has been demonstrated elsewhere in the Cascades (Brummer and Montgomery 2006).

In between the hard points, channel migration can be significant, up to several feet per year. Migration occurs to the greatest extent upstream of the sandstone bedrock control (RM 18.0) and diminishes to essentially nothing near the US-2 Bridge (RM 18.9). Some combination of

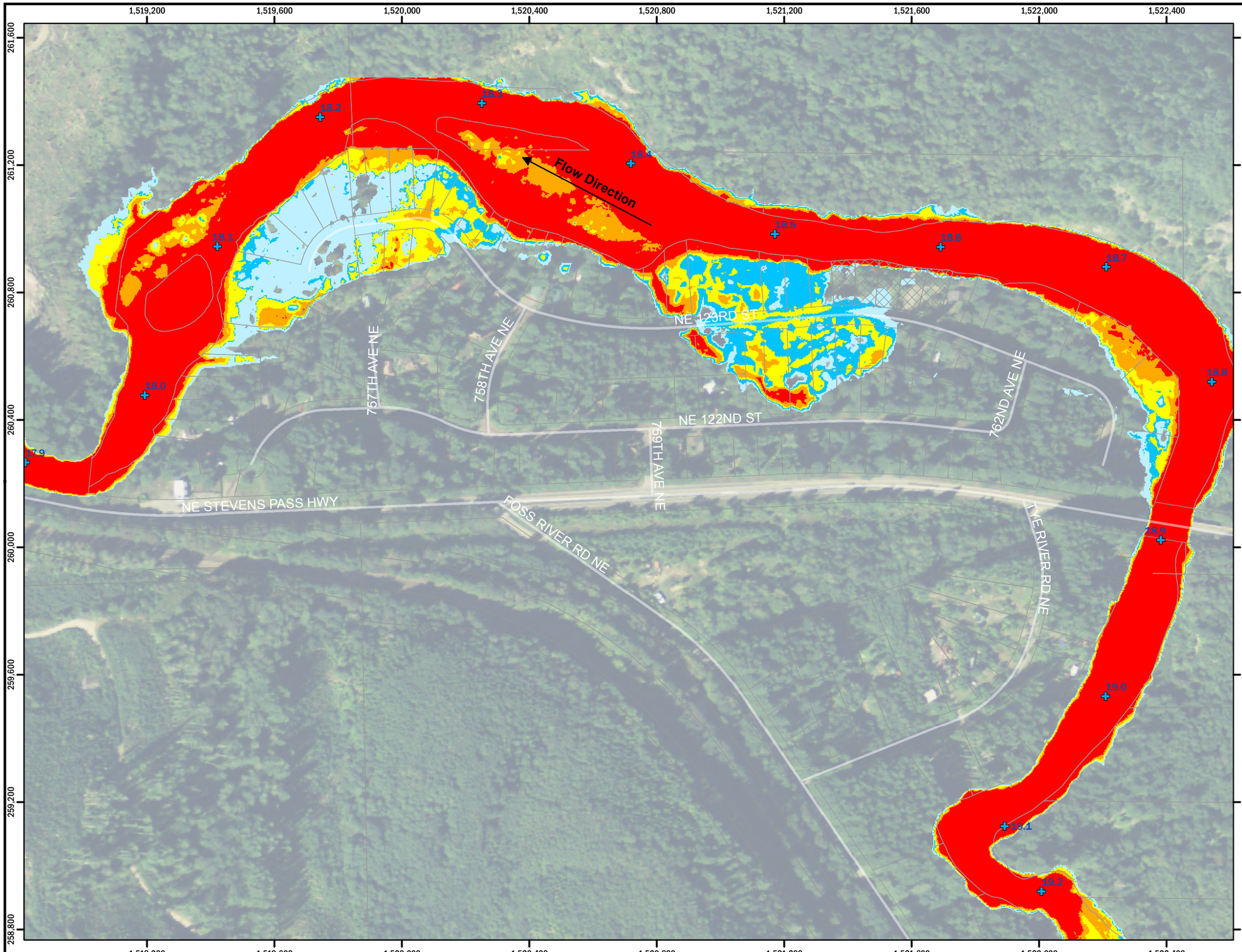

Figure 4.
Modeled Depth and Velocity Flood Hazards, Timberlane Village, Skykomish, Washington.

Legend

- SF Skykomish River Mile
- Parcel
- County-Owned Parcel

Deep and/or Fast Flowing Water

- 50% Annual Exceedence
- 10% Annual Exceedence
- 01% Annual Exceedence

Inundation Extents (flows not deep or fast)

- 10% Annual Exceedence
- 01% Annual Exceedence

N

0 150 300 600 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: USDA, Aerial (2013)

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the relatively recent constriction of the channel by the US-2 road prism at RM 17.9 or an incomplete equilibration of the channel elevation profile to the downstream sandstone bedrock control appears to have caused sediment deposition to be greatest immediately upstream of the sandstone bedrock constriction. This trend is also evident in the channel profile. Increased sediment deposition corresponds to increased channel migration. Other geomorphic change (i.e., activity of bank landslides, vegetation changes, etc.) similarly trends from more to less moving from downstream to upstream in the study area.

Landslides and River Avulsion

There are four active landslide areas that border the river within the study area (Figure 5). Three of these landslide complexes are downstream of the US-2 Bridge (RM 18.9) and are all on the right bank. They are comprised of sediment laid down as a part of deltas and other lacustrine deposits formed at the edges of glacial Lake Skykomish. These were identified by Herrera (2013b) and can be seen to change and evolve throughout the aerial photographic record. The beds in these complexes all dip eastward at an angle of about 3 percent. The inclination of the beds is likely due to some combination of glacial rebound and tectonic deformation associated with the Straight Creek Fault Zone. The two western landslide complexes near RM 18.2 to RM 18.4 appear to be more active currently because of recent channel migration into the toes of the slopes.

A fourth active landslide complex, which was not mapped by Herrera (2013b), occurs primarily in Beckler Peak Rock Avalanche material upstream of US-2 (RM 18.9 to RM 19.0), though the base of the slide appears to contain significant volumes of glaciodeltaic sediment. Inspection of the top of the slide indicates that the slide is actively, but slowly, expanding eastward, as found from recently fallen trees and fresh landslide scarp deposits at the headwall of the slide.

In addition, two potential landslides were identified in the lidar mapping within the study area, one above the right bank upstream of RM 18.8 and the other above the right bank at RM 18.1 (shown as relict slide on Figure 5), but on-site evidence was not found to confirm that these features are indeed landslides. It is possible that both of these features were slides, but much older than the four active ones described above.

Although the vegetation in the landslide areas appears to change (i.e., vegetation appears and disappears) on an annual basis, there is no evidence in the aerial photographic record (dating back to 1944) of large slides capable of shifting the river outside of its primary channel. The lack of channel migration directly from landslide activity suggests that the hazard is not as significant as might be expected in other settings where landslides have occurred close to a river (e.g., the Hazel slide on the Stillaguamish River or the 2001 slide downstream of the former Elliott Bridge on the Cedar River). This is particularly true for the active landslide upstream of US-2 in Beckler Peak Rock Avalanche material, where the higher (left) bank precludes migration of the river westward into developed areas. However, the potential for channel migration due to landslides is not negligible, and should be considered in addition to the channel migration hazards associated with sediment deposition described above, which are much more predictable and demonstrate a clear spatial trend throughout the study area.

Anthracite Creek Alluvial Fan Deposition

Much of the land surface under the western third of the Timberlane Village development formed over the last several thousand years in association with the Anthracite Creek Alluvial Fan (Figure 5). The floodplain surface is higher in this fan deposit than it is elsewhere in the development, and is thus not as susceptible to flooding from the South Fork. However, there is a possibility that Anthracite Creek will avulse through the relatively unconsolidated fan deposits, as frequently occurs on alluvial fans. The creek channel is incised immediately above its confluence with the South Fork near RM 18.0, and also upstream of the NE 122nd Street Bridge between US-2 and the confluence with the South Fork. There are clear indications of channelization (i.e., placed rock surrounding a straight channel that has subsequently incised) immediately above the confluence and in the vicinity of US-2 and the BNSF Railway. There is also a large spoils pile north of US-2, possibly the result of historical channel dredging operations, that prevents westward migration of the channel. However, there is a small reach of the creek downstream of the NE 122nd Street Bridge, in the vicinity of a bank-left bend (i.e., about 100 to 200 yards downstream of the NE 122nd Street Bridge), where avulsion could occur. Avulsion would be most probable towards the right bank and through the homes and private property at the west end of NE 123rd Street (Figures 3 and 5). In fact, Cass Pond may have once been one of these avulsion pathways or a former channel.

Ongoing sedimentation downstream of the NE 122nd Street Bridge within the channel will tend to increase avulsion potential over time, particularly if the sediment currently being sequestered upstream of the US-2 Bridge is ever transported through that currently constricted crossing. Avulsion is a natural process by which an alluvial fan distributes sediment throughout its surface. Sediment builds up in one location where the primary channel is located for some time until the stream avulses and fills lower areas that had previously been abandoned. The Anthracite Creek Alluvial Fan (Figure 5) has been constrained within the historical photographic record (since 1944) to its current alignment. Over time, sediment will eventually build up high enough for the creek to overtop its right bank to areas north and east. However, it is unlikely that avulsion would occur in the next 10 years because it is apparent that sediment from Anthracite Creek is being actively sequestered above US-2, starving the alluvial fan of sediment. The avulsion hazard could significantly increase due to reengagement (and mobilization) of this stored sediment if the stream were allowed to migrate or incise due to changes in the geometry and/or operation of the US-2 crossing. This hazard could also increase if and when the sediment storage capacity in the channel upstream of US-2 is exceeded, allowing more sediment to move past the US-2 crossing and deposit downstream of the NE 122nd Street Bridge. Despite relative starvation of the alluvial fan by the US-2 crossing of the creek, over longer time periods (100 years or more), avulsion is inevitable in this area unless prevented through direct intervention (e.g., dredging, levee construction).

Beckler Peak Rockslides

The most unusual aspect of the study area is the Beckler Peak Rock Avalanche (Figure 2). The main Beckler Peak Rock Avalanche occurred sometime between 3,500 and 450 years before present (Tabor et al. 1993). It completely filled the South Fork valley between the eastern edge of the study area in the vicinity of RM 19.0 upstream to RM 21.2 on the Tye River. However, that was not the most recent large rockslide event in the area. Another distinct

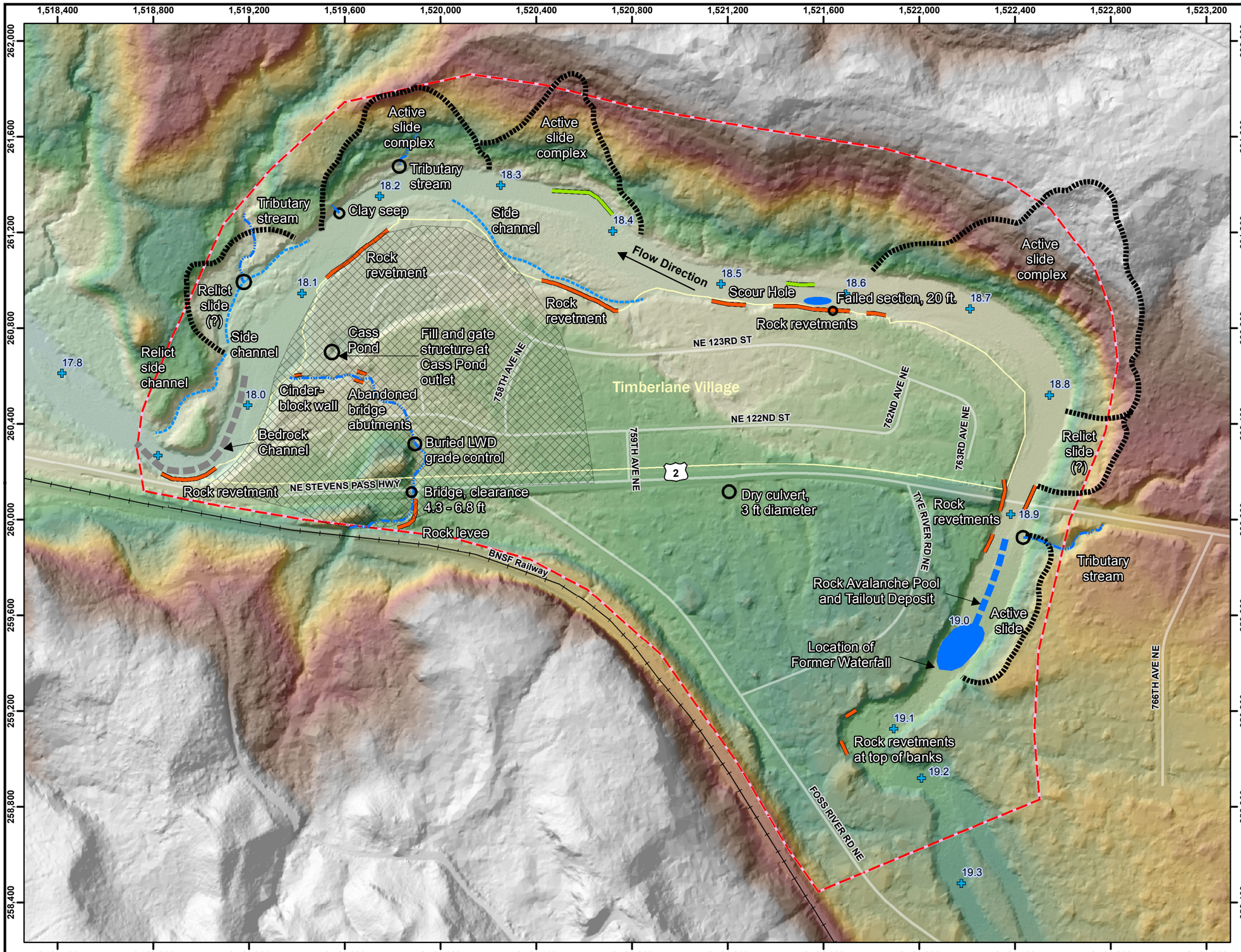

Figure 5.
Existing Geomorphic Conditions,
Timberlane Village,
Skykomish, Washington.

Legend

- SF Skykomish River Miles
- Field survey point feature
- Side channel
- Tributary stream
- Anthracite Creek fan
- Slide complex

Field Surveyed Bank Features

- Armoring
- LWD
- Study area

2011 LiDAR Elevation (ft)

- High : 1200
- Low : 960

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County, Lidar (2011); King County GIS Center (2013)

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rockslide deposit is present on top of the Beckler Peak Rock Avalanche near the eastern edge of its deposit. The source rock is the same as the larger, main rock avalanche, but the morphology of the landscape indicates that the runout was far less. It is possible that this overlying deposit occurred shortly (hours to weeks) after the larger event. However, it is more likely it represented a different rockslide event because of the distinct edge that remains. Observation of the younger rockslide deposit during the recent site visit found large (6 feet in diameter) old growth cedar stumps on rockslide debris, implying an age of at least several hundred years. The relatively old age of the younger rockslide implies that both events likely predated the last millennium, further implying a return interval of major Beckler Peak rockslides on the order of at least a thousand years. It is unclear what, if any, relation the Beckler Peak Rock Avalanche has with recent stress or slippage of the Evergreen Fault Zone.

Reach-Scale Findings

To provide a greater level of detail on the geographic distribution of the geomorphic and flood hazard processes described in the previous sections, and the aquatic habitat characteristics noted in the site visits, the study area has been divided into eight reaches (Figure 6) based on prevailing geomorphic processes. Although some of the geomorphic processes in the study area operate at a much larger scale (e.g., the risk of another avalanche on the flank of Beckler Peak gradually increases to the east), most operate at a smaller reach scale and directly affect flood and erosion hazards and ecological conditions. Channel migration, which is the most common and significant geomorphic process commonly present during time periods less than 10 years, occurs at the scale of the reaches defined herein. Flood hazards and aquatic habitat conditions vary in an incremental manner such that the reach breakdown described below is helpful to understanding the level of hazards throughout the study area, and for developing specific management strategies to address the hazards. Each of these three elements (geomorphic hazards, flood hazards, and aquatic habitat) are addressed for each reach. The following discussion begins with the furthest upstream reach and progresses to the downstream limits of the study area.

Rock Avalanche

The Rock Avalanche reach (Figure 6) extends from the upstream end of the study area to a former waterfall that marks the limit of the Beckler Peak Rock Avalanche deposit in the bed of the river.

Geomorphic Conditions

The main channel in this short reach is comprised completely of Beckler Peak Rock Avalanche debris, with rocks typically greater than three feet in diameter. Vegetation clearing in developed areas on the left bank has left loose rock avalanche material prone to shallow slumping. Landscaping on the properties in this area typically includes stacked rock and other informal walls to halt slumping, which is possibly exacerbated by vegetation clearing. There are signs in undeveloped areas that the landscape is continuing to evolve towards equilibrium, particularly on the left bank where rock avalanche material is loose and actively slumping when disturbed. It is expected that gradual, albeit slow, incision into the rock avalanche debris will cause both banks of the river to be locally unstable in the future, as the slide

clasts chemically and physically weather. None of these unstable, sloping areas contain structures. The only homes on these parcels are on top of the intact, relatively flat rock avalanche deposit above the eroding sidewalls on both banks.

Flood Hazards

Flood hazards in the Rock Avalanche reach are minimal. Because the reach is incised into rock avalanche debris, all development is located well outside of even the 1 percent annual chance flood event inundation area (Figure 3). However, flow velocities, even during smaller floods, are quite high in the active channel through this reach (Figure 4).

Aquatic Habitat Conditions

Habitat conditions are limited in this reach due to the steep slope of the channel and the presence of rock avalanche debris. No fish were observed in this reach during the site visits. The deep pool immediately upstream of the rapids that dominate the reach could provide holding habitat for adult salmonids.

Upper US-2 Bridge

The Upper US-2 Bridge reach extends from the former waterfall that marks the limit of the Beckler Peak Rock Avalanche deposit in the bed of the river to the US-2 Bridge (Figure 6).

Geomorphic Conditions

This reach is dominated by the tailout deposit (i.e., a deposit in a river immediately downstream of a cascade or waterfall) in the channel from the Beckler Peak Rock Avalanche. The bar in the middle of this reach is the tailout of the scour pool that formed as the South Fork poured over the edge of the rock avalanche deposit immediately after it occurred (Figure 5). The tailout deposit is extensive and comprised primarily of sediment from upper portions of the basin, though rounded pieces of Beckler Peak Rock Avalanche debris are also common. The waterfall that existed in this reach shortly after the rock avalanche occurred is now largely inundated due to impoundment of flow by the continually growing tailout deposit. A remnant of the pool at the base of the former waterfall exists immediately downstream from the edge of the remaining rapid, at RM 19.0. The banks in this reach remain quite steep and are likely still in the process of stabilizing.

There is an active landslide complex above the right bank in this reach (Figure 5). The landslide is comprised primarily of rock avalanche debris, though some glaciodeltaic sediment exists near the landslide toe. The nature of its constituent debris distinguishes it from other landslide complexes further downstream. The scarp of the slide a few hundred feet inland (east of the river) is active and continuing to fail progressively landward (eastward), indicating that the landscape is not yet in equilibrium following the Beckler Peak Rock Avalanche. Future equilibration of the landscape (i.e., continued slumping in this area and areas adjacent to it) is expected; however, the steep, high left bank in this reach comprised of coarse, relatively stable rock avalanche debris should limit the channel migration hazard to existing structures, present at the top of the bank. Likewise, vegetative clearing of the private properties on the left bank for landscaping purposes likely compromises bank stability. Without access to private properties here, on-site examination to confirm these suppositions was not possible.

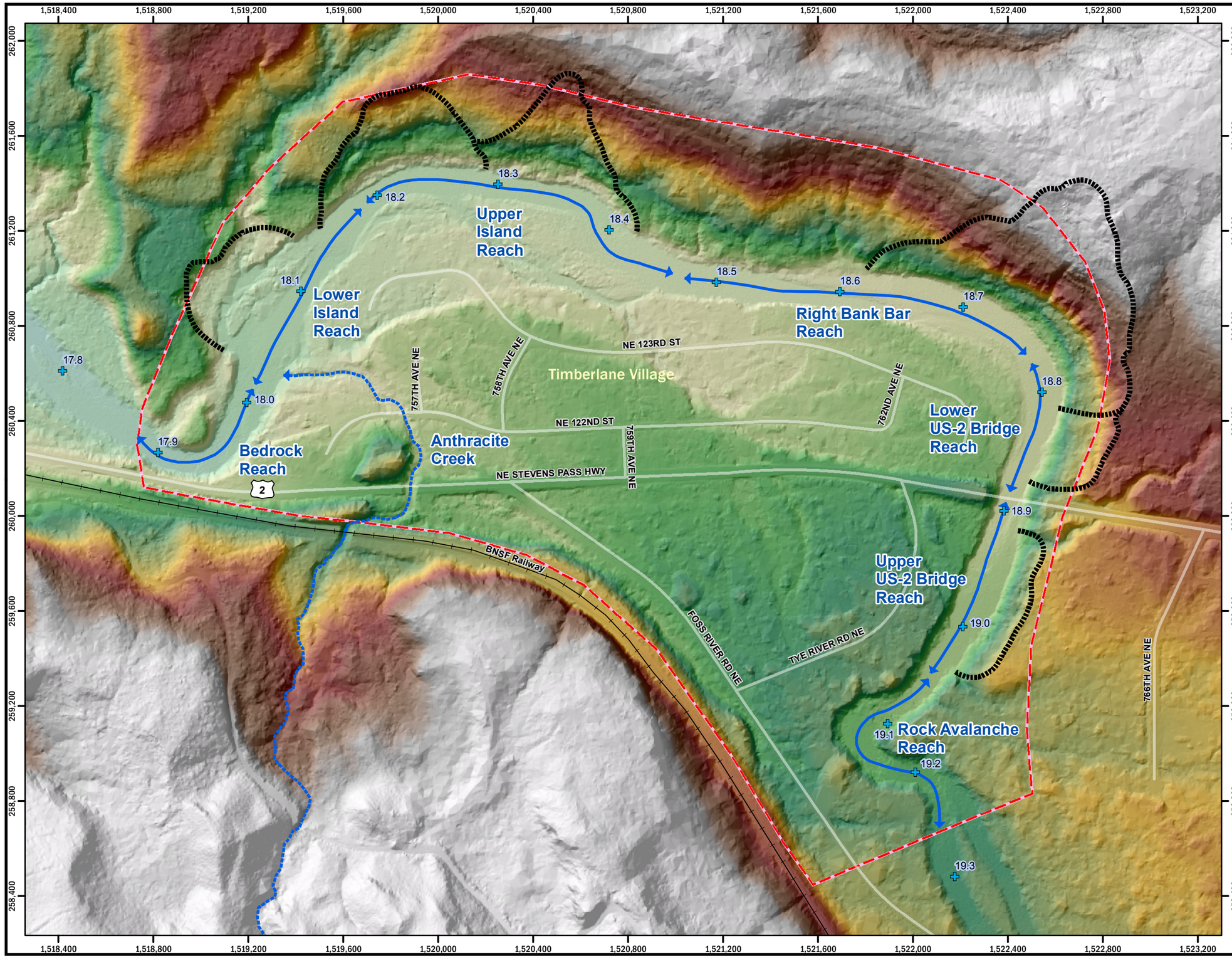

Figure 6.
Geomorphic Reaches, Timberlane Village, Skykomish, Washington.

Legend

- SF Skykomish River Miles
- South Fork Reach Extents
- Anthracite Creek
- Slide complex
- Study area

2011 LiDAR Elevation (ft)

High : 1200

Low : 960

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County, Lidar (2011); King County GIS Center (2013)

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Flood Hazards

Flood hazards in the Upper US-2 Bridge reach are minor. Because the reach is incised into Beckler Peak Rock Avalanche debris at the upstream end, and confined by the elevated US-2 roadway fill prism at the downstream end, flood flow is confined within the active channel. However, flow velocities during flood events are high within the channel.

Aquatic Habitat Conditions

Juvenile fish were observed during the site visits along the right bank in the tailout deposits, typically in association with sediment deposited at the confluence with a small tributary that enters the South Fork (Figure 5).

Lower US-2 Bridge

The Lower US-2 Bridge reach extends from the US-2 Bridge to the beginning of the right bank bar located just downstream of a major left bank point bar between RM 18.7 and RM 18.8 (Figure 6).

Geomorphic Conditions

Very little geomorphic change is evident in this reach in the historical aerial photographs. A large landslide complex exists on the right bank in this reach (Figure 5), but the material on the right bank is dominantly clay with very little coarse material, as compared to the west end of this slide complex and the other slide complexes downstream. Where the slope above the right bank has been unstable due to past landslide activity, mature vegetation has fully colonized the slope, unlike other slide areas downstream. This indicates that the right bank is relatively stable near the downstream end of this reach. The low left bank in this reach is inundated frequently and comprised of coarser (gravel, cobble and boulder) alluvium than the right bank is, but given the bridge and associated armoring upstream, channel migration is extremely slow and thus the banks are stable and vegetated. The homes above the left bank in this reach are set back from the river bank, unlike in the reaches downstream, further reducing the relative channel migration hazard to existing structures.

Flood Hazards

Flood hazards in the Lower US-2 Bridge reach are all associated with flow overtopping the left bank. Although flooding of properties bordering the river along the left bank occurs even in a 50 percent annual chance of exceedance flood (Figure 3), flow velocities are expected to be low because there is a forested riparian corridor between the homes and the river bank. Inundation and higher flow velocities will also be confined to a lower terrace between developed land and the existing bank. The higher terrace where the homes are located is above the modeled inundation elevations in the 1% annual chance of exceedance flood event.

Aquatic Habitat Conditions

Habitat conditions are marginal in this reach due to the natural confinement of the channel by clay-rich glaciodeltaic deposits and riprap associated with the US-2 embankment. No fish were observed in this reach during the site visits. The left bank bar near RM 18.8 has established vegetation and provides good off-channel and riparian habitat.

Right Bank Bar

The Right Bank Bar reach extends from RM 18.78 to RM 18.48, just upstream of the upper island in the channel within the study area.

Geomorphic Conditions

This reach is defined by a long (greater than 600 feet) bar on the right bank that extends through much of the length of the reach. The bar is evident in all of the aerial photographs dating back to 1944; however, changes since the 1990s in the meander pattern downstream have caused the bar to direct more flow southward towards the left bank near RM 18.6, possibly in relation to changing sediment supply from the right bank. The left bank is armored in three locations totaling about half the length of this reach (Figure 5), slowing bank erosion.

A large, deep scour hole at the base of the decaying revetment at RM 18.5 on the left bank (Figure 5) that once protected properties now acquired by the County could soon undermine the revetment toe in this area. However, even if this revetment is not maintained to prevent damage to it, channel migration into the left bank is likely going to continue to be slow in this reach because of the presence of large, stable rocks in the revetment and the less rapid sedimentation in this reach as compared to areas further downstream. There is low potential for landsliding above the right bank in this reach that may trigger channel migration. The landslide-induced channel migration hazard is lower in this reach than in the other reaches downstream with unstable slopes because the channel is not currently being directed strongly toward the toe of the right bank slope, even though the right bank is comprised of coarser material, and there is therefore more unstable, as compared to areas further upstream (i.e., in the Lower US-2 Bridge Reach).

Flood Hazards

Flood hazards in the Right Bank Bar reach are focused on the left bank at the downstream end of the series of revetments, in the area where an abandoned meander bend penetrated the north edge of Timberlane Village. The area of the abandoned meander bend is low in elevation, but not uniformly so. There may be hydraulic barriers (e.g., NE 123rd Street) in this area that are not resolved in the hydraulic model. As such, the model results may be of limited utility, even though the results agree well with the earlier FEMA model. Most of the modeled area of left bank floodplain inundation in this reach (Figure 3) is not developed, but there are a few homes, particularly those immediately adjacent to the river, that are expected to be inundated. These areas are already within the existing FEMA 100-year (1 percent annual chance of exceedance) floodplain. Regardless of whether these developed areas are inundated, flow velocities and depths in the floodplain are expected to be small (Figure 4).

Aquatic Habitat Conditions

Habitat conditions are marginal on the left bank in this reach due to confinement of the channel by the revetments (Figure 5). Juvenile fish were observed along the right bank in shallow vegetated areas above the bar during the site visits.

Upper Island

The Upper Island reach extends the length of a vegetated island in the river channel extending from RM 18.48 to RM 18.19 (Figure 6).

Geomorphic Conditions

The Upper Island reach is dynamic. The island, which lies between a side channel to the south and the main channel to the north, began forming in the early 1990s. Prior to that, the thalweg of the main channel ran alongside the developed properties on the left bank, with a side channel network forming intermittently on the right bank during the 1970s and 1980s. Since the last large flood event in the river (in January 2009) a thick stand of young alder trees has colonized the island, slowing flow velocities and inducing significant sediment deposition. Single flow event deposits of up to a foot in depth are common on the island. This has continued to force most of the river flow to the north at the upstream end of this reach, towards the two active right bank slide complexes shown in Figure 5, but away from development. Therefore, channel migration in this reach is currently not threatening developed property. However, this could change at any time, particularly because the channel is currently eroding the unstable right bank toe. If enough slide material falls into the river as a result of erosion undermining the right bank toe, the slide material could deflect flow toward the left bank. Slope failure capable of forcing channel migration is considered to be a low probability event.

Flood Hazards

This reach experiences extensive left bank floodplain inundation during floods. The two primary areas of inundation are at either end of the reach (Figure 3). The upstream flood inundation area, near the boundary with the Right Bank Bar reach, is not developed. Here the simulated flooding is due mainly to low velocity backwater that may be an artifact of subtle topographic features not being accurately represented in the hydraulic model. Even if the model has correctly represented flooding in this area, the hazards are low because of the low flow velocities and lack of developed property.

The left bank floodplain is developed where flooding is expected at the downstream end of the reach, based on the model results. Here flow appears to inundate a series of increasingly high point bar terraces that vary in elevation as one moves towards the left bank. Flood depths are higher and so are the flow velocities on the lowest of these terrace features, with each successive landward terrace having less depth and frequency of inundation. The model results indicate that the highest terrace will be inundated only in floods greater than or equal to the 1 percent annual chance of exceedance event. However, since bank migration is oriented toward the left bank at the downstream end of this reach, the probability for small channels to form through the left bank floodplain is high during future large flood events.

Aquatic Habitat Conditions

Juvenile fish were observed during the site visits throughout the side channel skirting the south side of the island. This side channel was the main channel prior to the 1990s. A revetment on the left bank of the side channel near RM 18.4 (see Figure 5) and developed

property in the floodplain close to the river limits riparian vegetation growth. A beehive was also encountered on the island during the site visits.

Lower Island

The Lower Island reach extends from RM 18.19 to RM 18.01 (Figure 6). A mid-channel island is present for most of that length. This reach includes the confluence with Anthracite Creek.

Geomorphic Conditions

This is the most dynamic reach in the study area and has the lowest channel slope of any other reach. Channel position has changed more in the historical photographic period (since 1944) in this reach than any other location within the study area (Appendix 1). The entire island that was present near the left bank in the aerial photographs prior to the 1970s (and possibly in the GLO map) has been nearly completely relocated to a new island that formed along the right bank, mostly within the last 20 years. This has focused flow increasingly leftward (east) toward several residences near the west end of NE 123rd Street (see Figures 3 and 4). Several of these residential properties are protected by rock revetments that encroach into the unvegetated channel, partly due to recent channel migration and bank erosion at the edge of those properties. Given the frequency with which the homes on the lowest terrace are flooded in this area (described below), it is likely that these homes will eventually be damaged or destroyed by the river if no other protective actions are taken.

In addition to channel migration as described above, there is a potential geomorphic hazard associated with an active landslide complex comprised of glaciodeltaic silt, clay and gravel above the right bank toward the upstream end of this reach (Figure 5) that influences channel migration. Though sliding has been nearly continuously occurring for at least the last 20 years, the presence of rills that dissect bedding of the parent material on that slope indicates movement is generally slow (i.e., not catastrophic). Because most of the slide blocks are relatively thin (less than 10 feet thick) they likely will not be capable of causing the river to move significantly toward the left bank if they fall into the channel.

Finally, there are no signs of a catastrophic slide event in the last 70 years that would be capable of moving the river out of its general existing alignment. Most of the channel migration in this reach is associated with deposition of alluvial bars upstream of the bedrock constriction in the lowest reach of the study area (i.e., the Downstream Bedrock reach, described below). While some of the sediment could come from the slumping material in the active slide complexes upstream of this reach, most of the sediment deposited in this reach likely comes from the Beckler Peak Rock Avalanche farther upstream and the upper basins of the rivers draining into the South Fork upstream of the study area. Therefore, although the potential for avulsion into the left bank is not negligible due to the existing, continuous landsliding in the study area, it is generally considered to be of a low probability (less than 10 percent chance of occurring in any given year).

Flood Hazards

The Lower Island reach experiences extensive floodplain inundation on the left bank near the upstream end of the reach (Figure 3). The flood waters driving inundation come from

overbank further upstream in the Upper Island reach. Because the hydraulic model has accurate topographic resolution in this reach and the left bank floodplain connection points to the main channel are unobstructed, the accuracy of the model in this area is considered high. The model results are also generally within the existing FEMA 100-year (1 percent annual chance exceedance) floodplain. The model predicts moderate velocities and depths in the floodplain (Figures 3 and 4).

Aquatic Habitat Conditions

Instream hydraulic and structural diversity in this reach due to gravel accumulation and local wood input creates good fish habitat. Large numbers of juvenile fish were observed during the site visits in both the main channel and the wetted side channel (east of the island) in this reach. Burn piles of woody and non-woody debris were observed in the river channel and may be source of pollution to the river. The left bank revetment between RM 18.1 and RM 18.2 that protects the residences in this reach (Figure 5) encroaches on the active channel migration zone of the river and truncates the floodplain, resulting in a significant loss of riparian vegetation and ecological function.

Bedrock

The Bedrock reach extends the length of the bedrock banks that define the downstream end of the study area (Figure 6).

Geomorphic Conditions

A sandstone bedrock slope constricts this reach on the right bank. Imported riprap near US-2 and outcroppings of sandstone bedrock constrict the left bank elsewhere in the reach. The constricted channel concentrates flow energy that has resulted in a locally increased bed slope of the river. Flow velocities are perennially higher here than elsewhere in the study area, though the presence of bedrock on the banks and in the channel bed prevents erosion. Only filled areas, such as the US-2 roadside embankment, are prone to erosion and require protection to prevent it. This reach is also well beyond (west of) the Beckler Peak Rock Avalanche and the shallow landsliding of the glaciodeltaic deposits above the right bank in the reaches upstream of this area. In sum, there are limited geomorphic hazards in this reach.

Flood Hazards

Flood hazards in the Bedrock reach are minor. Because the reach is incised into steep bedrock walls, flood flows cannot overtop the banks, even in the 1 percent annual chance exceedance event (Figure 3). However, flow velocities are high in the channel, even in small flood events. These high flow velocities have caused erosion of the riprap-armored bank near US-2 (Figure 5).

Aquatic Habitat Conditions

The high flow velocities in this reach limit the extent of suitable fish holding and rearing habitat. No fry (or any fish for that matter) were observed in this reach during the site visits.

Anthracite Creek

Anthracite Creek was examined from the BNSF Railway corridor to its confluence with the South Fork in the Lower Island reach (Figure 5). This length of the creek generally defines the limits of its alluvial fan.

Geomorphic Conditions

Anthracite Creek has been modified in relation to development actions over the years. Prior to development it likely intermittently occupied most of the western third of what is now Timberlane Village, evident by the relatively higher topography here (as compared to the South Fork thalweg) than areas to the east (Figure 5). Currently, most of the sediment deposition in the creek channel appears to be focused immediately upstream of US-2, though signs of deposition are evident throughout its lower reaches downstream of the highway crossing. Significant sediment deposition is likely to continue upstream of US-2 because of unnaturally sharp turns in the channel alignment in this area. The primary geomorphic process hazard is avulsion into the right bank downstream of the NE 122nd Street Bridge as described previously, though this hazard is unlikely to occur within the next 10 years unless major changes to the US-2 crossing are made or a large sediment-producing event (debris flow) occurs in the upper Anthracite Creek basin in recently deforested areas. The US-2 crossing of Anthracite Creek is vulnerable to erosion.

Flood Hazards

Hazards associated with flooding in Anthracite Creek were not modeled and are beyond the scope of this analysis.

Aquatic Habitat Conditions

Fry were observed throughout the length of the creek examined during the site visits, though the lowest 200 feet approaching the confluence with the South Fork did not contain flow during those visits. A recent revegetation effort associated with construction of the new NE 122nd Street Bridge appears to have yielded a small number of surviving native riparian trees and shrubs. If these continue to grow they will provide shade and other benefits for fish and aquatic organisms in the creek. Fish stranding appears to be common at low flow because the creek bed becomes dry close to the confluence with the South Fork.

SUMMARY OF FINDINGS

The following statements can be made based upon the results of the analysis discussed herein:

- The greatest hazard at Timberlane Village, particularly in the near term (the next 5 to 10 years), is erosion associated with South Fork channel migration that is occurring due to alluvial processes.
- The combination of flood and erosion hazards is greatest in the Upper Island and Lower Island reaches at the northwest end of Timberlane Village. The South Fork thalweg has been forced toward existing development in the Lower Island reach in recent years. There is also a risk of landslide blocks on the opposite bank exacerbating channel migration in this direction.
- Channel migration is also occurring in the vicinity of the five parcels recently acquired by the County in the Right Bank Bar reach. Channel migration rates are relatively low in this area compared to other reaches in the study area, but erosion is ongoing and will threaten remaining private property both west and east of the County's acquisitions in the coming years.
- Small-scale, local river bank erosion appears to be occurring along the South Fork upstream of US-2 as the Beckler Peak Rock Avalanche side slopes mature. This erosion is possibly exacerbated by clearing for landscaping purposes.
- A landslide complex, apparently recently formed, was discovered along the right (east) side of the river upstream of US-2 that was not previously mapped by Tabor et al. (1993) or Herrera (2013b).
- The Anthracite Creek Alluvial Fan, a natural feature, has been significantly modified as a result of development in Timberlane Village. The greatest ongoing sediment deposition associated with the alluvial fan appears to be occurring in a sharp, man-made meander of the creek channel between the BNSF Railway and US-2 near a notable break in channel slope. If the sediment accumulating in the creek channel upstream of US-2 moves downstream into the lower reach of the creek within Timberlane Village, it could induce an avulsion to the north through developed properties near the former Cass Pond Resort. The likelihood of this occurring in the next 10 years is considered low.
- The largest flood risks in the study area are in the developed areas of the left bank floodplain in the Upper Island and Lower Island reaches. The hydraulic model prepared for this study indicates that a few of the homes in the Lower Island reach could have their foundations wetted in a 50 percent annual chance of exceedance event. In the 1 percent annual chance of exceedance flood event, the model predicts that most of the homes on the lowest terrace adjacent to the river in these reaches would have

several feet of water surrounding them. In a few locations, the model predicts that this flood water would be moving fast, increasing the hazard.

- Flood risks to infrastructure and property at and upstream of the US-2 Bridge within the study area are minimal.
- Although there are slight differences in the flood inundation predicted in the modeling performed for this study compared to the FEMA floodplain mapping study from the 1980s, there is broad agreement between the models of inundation due to the 1 percent annual chance of exceedance event.
- There is slight potential of another major rockslide from Beckler Peak that could induce significant changes in geomorphic and flooding hazards in the study area; however, the apparent return interval of this type of event is on the order of thousands of years.

Epilogue

This document was prepared prior to the tragedy that occurred in relation to the massive landslide in Oso, Washington on March 22, 2014. Because of the public awareness and the raw emotion generated by that event, a brief summary of the similarities and differences between the hazards present at Timberlane Village and at Oso is warranted. The landslide that occurred at Oso has the following similarities to the landslide hazard on the right bank of the South Fork Skykomish River at Timberlane Village:

- The sediments that comprised the Oso slide are similar in character to those on the right bank at Timberlane Village. At both locations, the sediments were laid down at the edges of glacially impounded lakes formed at the end of the last ice age (i.e., they are glaciodeltaic and glaciolacustrine in origin).
- At both locations, predominately fine-grained, lake-bottom sediments are present, however at Oso a thick layer of recessional sand overlies the fine sediments. This sandy layer is not present across from Timberlane Village. The presence of this sandy layer at Oso likely lead to groundwater concentration, mid-slope seepage, and landslide initiation.
- Recent logging occurred in the vicinity of the right bank of the river near Timberlane Village and also on the top of the hillslope that slid dramatically into the residential community across the North Fork Stillaguamish River in Oso, though at Timberlane Village the size of the deforested areas is less and the distance from the logging to probable failure planes is greater than at Oso.
- Like at Oso, one of the possible triggers for a landslide at Timberlane Village is erosion of the toe of a slope by a large river.

There are also some important differences:

- There are no known historical events in which landslides crossed the South Fork at Timberlane Village. The only known slide to cross the river into the Timberlane Village

area is the Beckler Peak Rock Avalanche, but that occurred thousands of years ago and has a completely different source and failure mechanism. At Oso, there were several documented landslides that crossed the North Fork Stillaguamish River since the valley was settled by Europeans. One of these occurred just eight years prior to the tragedy on March 22, 2014.

- The relief of unstable sediments at Timberlane Village is much lower compared with Oso. The slope that failed at Oso was 600 feet high. The slope across from Timberlane is just over 200 feet high.
- The valley floor at Timberlane has more relief and more roughness compared with the (pre-landslide) condition at Oso. These factors together mean that a landslide of similar volume and velocity would inundate a smaller area at Timberlane Village as compared with a similar event in an area like Oso.

In sum, a large landslide of the glaciodeltaic deposits bordering the South Fork capable of overrunning and burying existing homes at Timberlane Village is possible, but the probability of such an event occurring is lower than at Oso and the scale would likely be smaller than what occurred at Oso in March 2014. However, there is also a small chance of another flank collapse of Beckler Peak, but this type of event would be much rarer than the other hazards considered herein, with a recurrence interval probably on the order of 1000 years (i.e., a 0.1% chance of occurring in a given year).

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APPENDIX 1

Historic Aerial Photographs

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1897 GLO Map

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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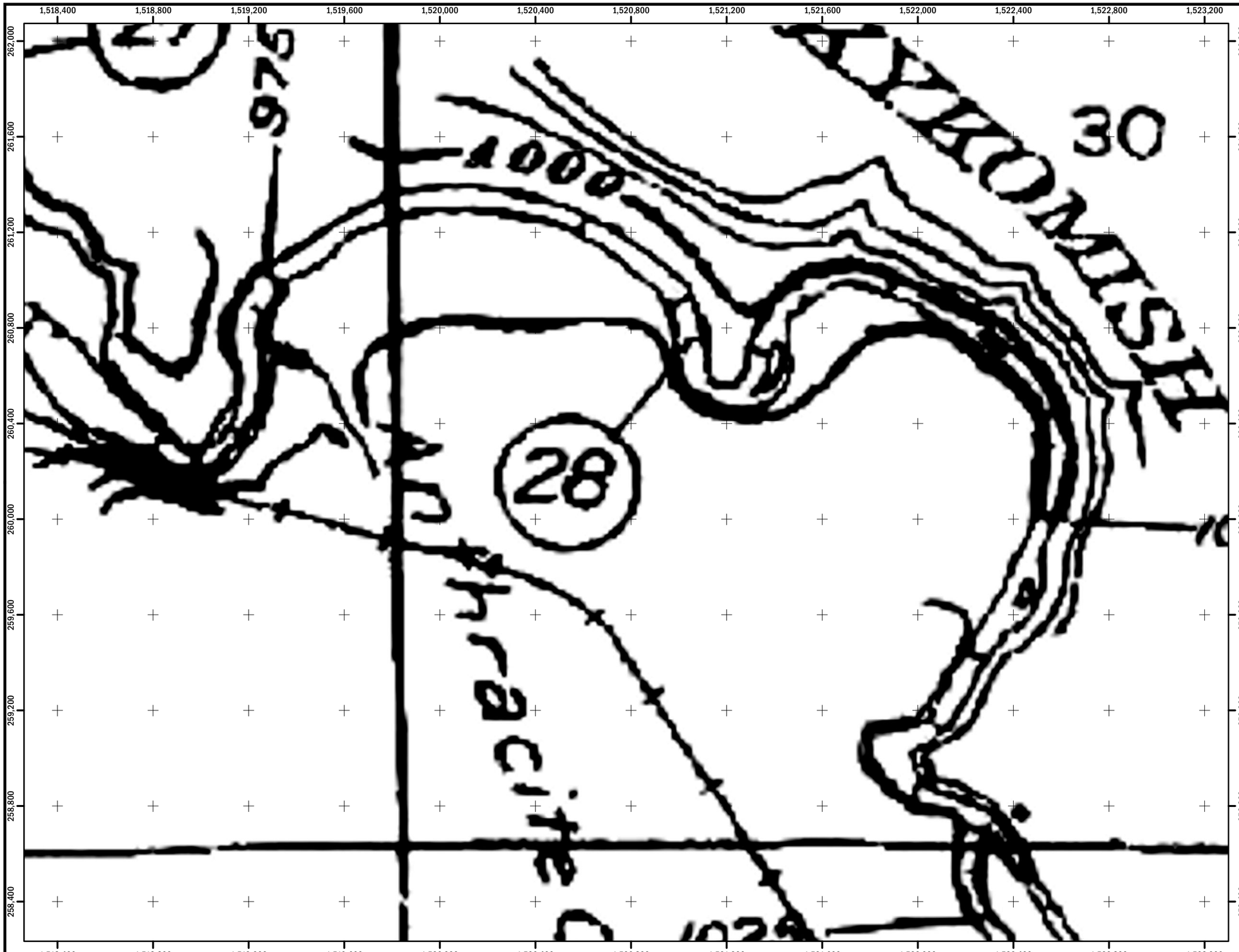

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1914 USGS Map

United States Geological Survey. 1914. Profile Surveys of Snoqualmie, Sultan, and Skykomish Rivers, Washington. Water Supply Paper 366. Plate III C.

N

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Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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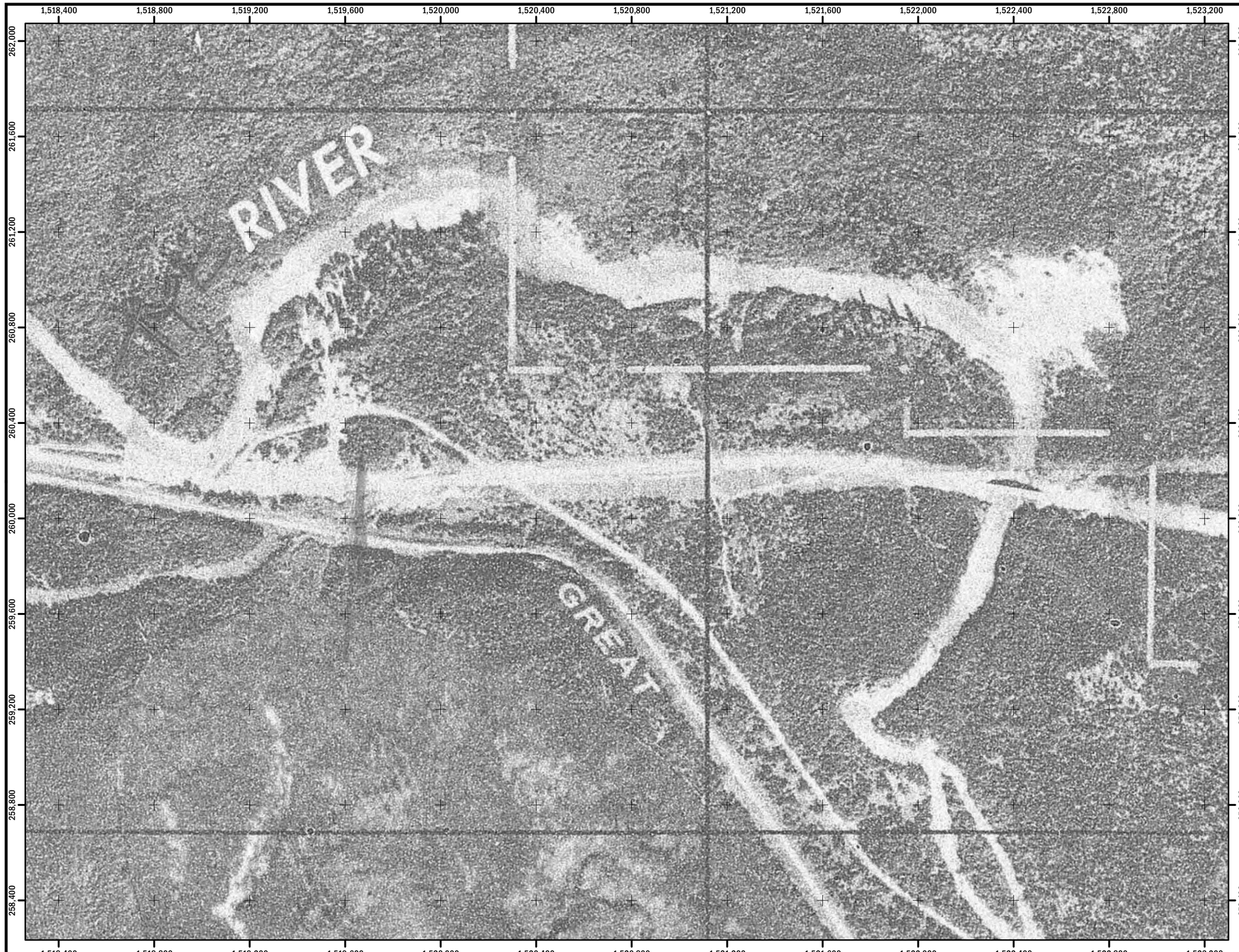

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1944 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

Produced By: GIS
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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1956 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

Produced By: GIS
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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1964 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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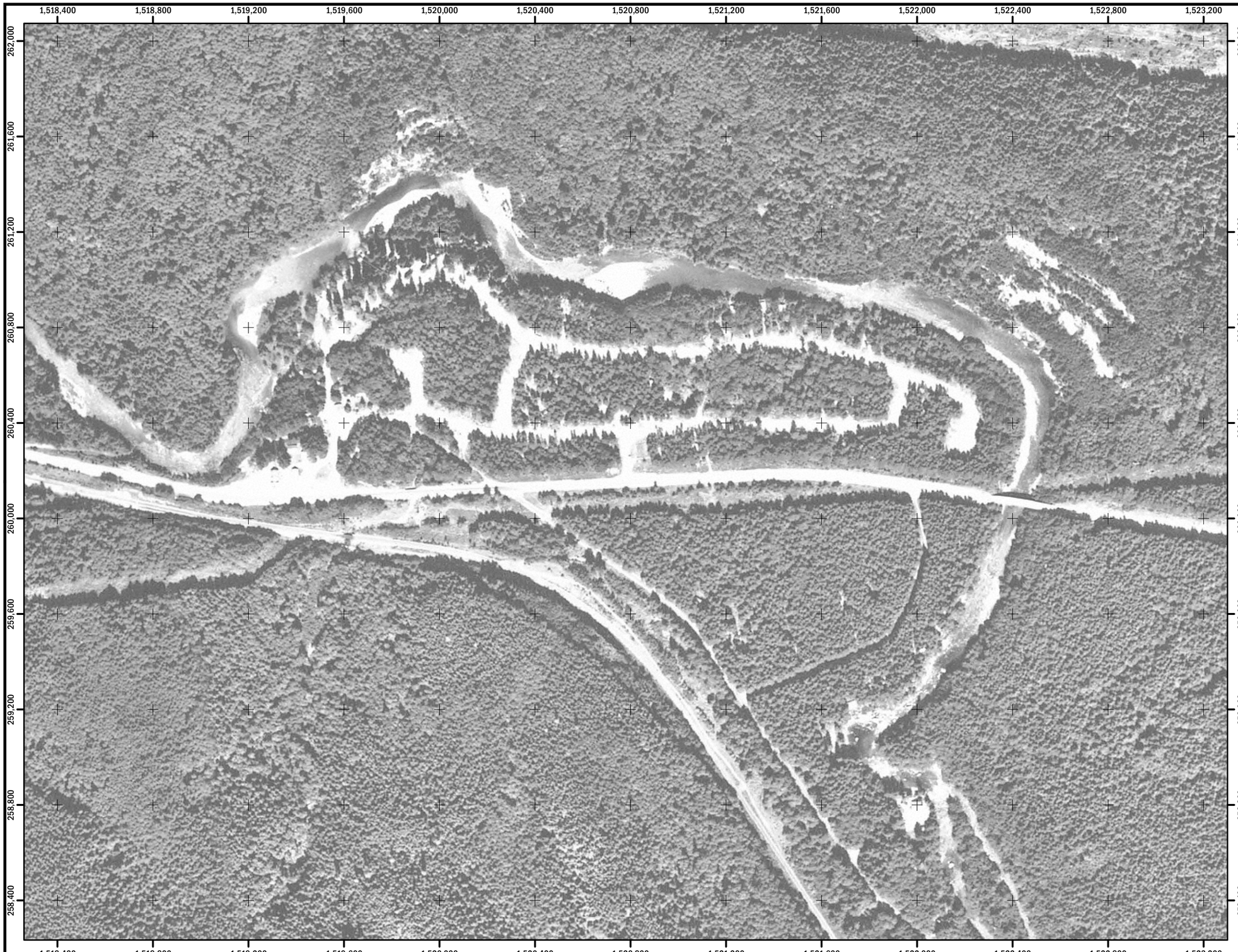

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1970 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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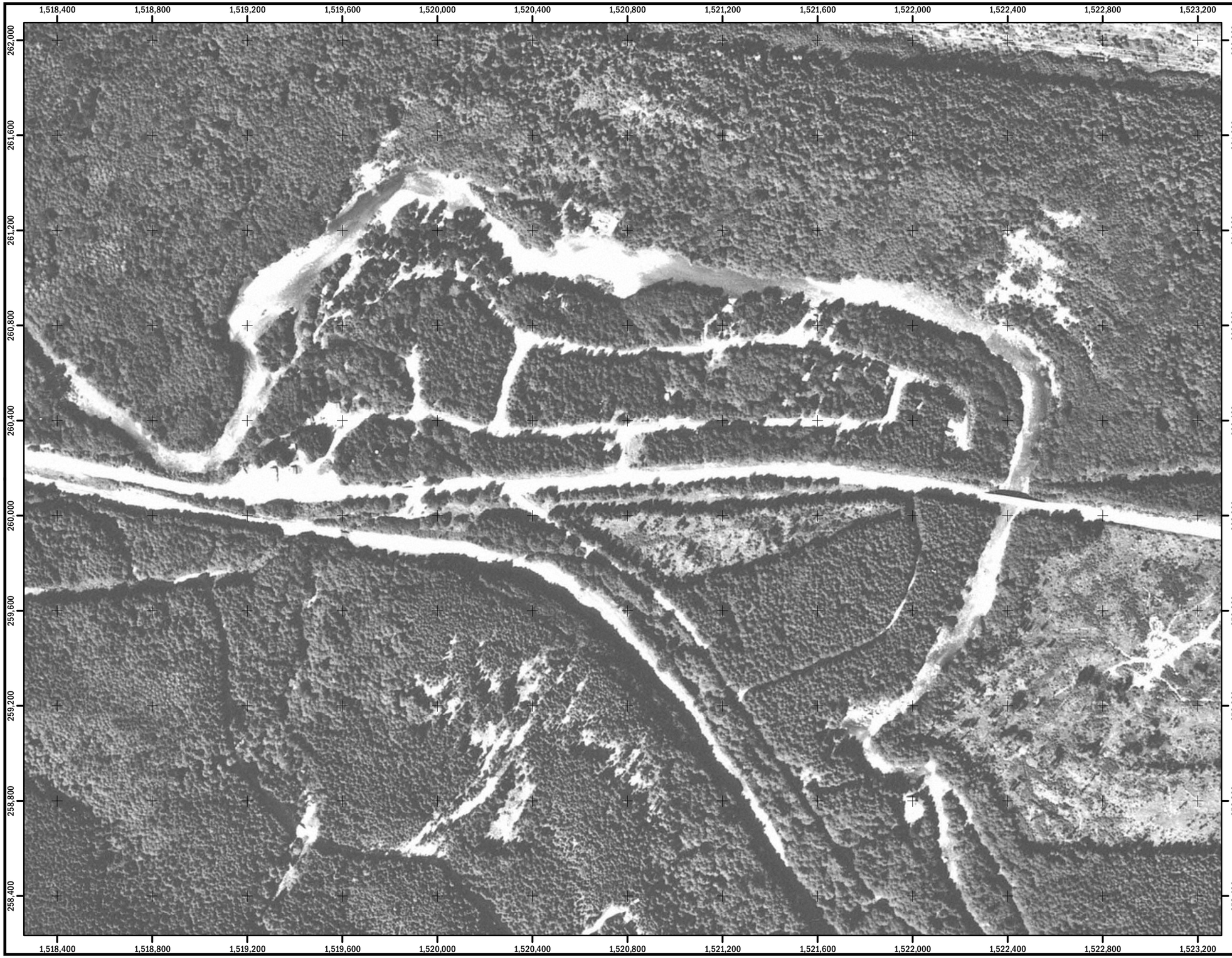

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1981 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1985 Aerial

N

0 200 400 800
ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1990 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1993 Aerial

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Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

1998 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

2006 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

Produced By: GIS
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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

2009 Aerial

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

2011 Aerial

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Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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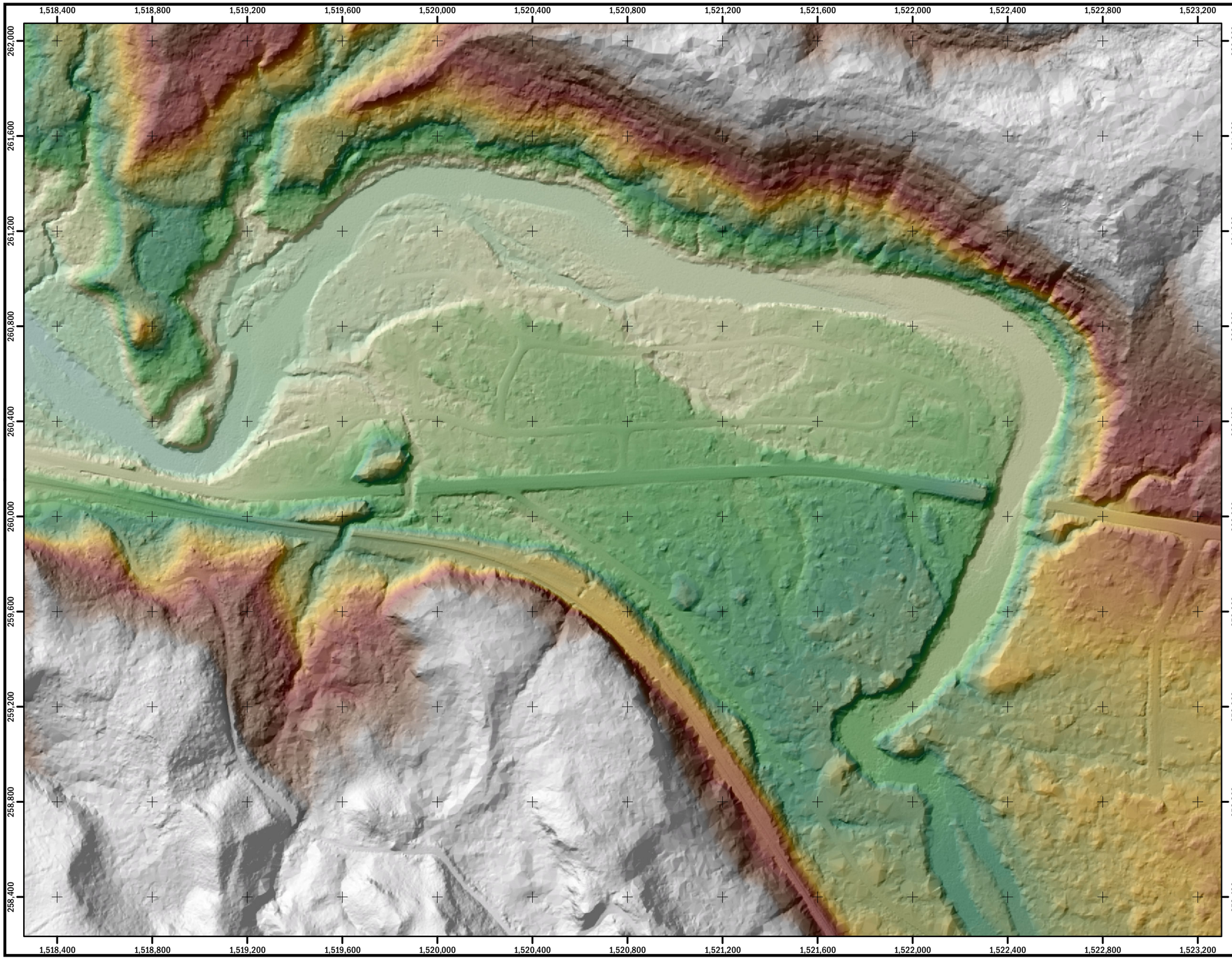

Appendix 1.
Historical Maps & Aerial Photographs
Timberlane Village,
Skykomish, Washington

2011 LIDAR Hillshade

N

0 200 400 800 ft

Coordinates: NAD 1983
Washington State Plane North FIPS 4601

Citation: King County GIS Center (2013)

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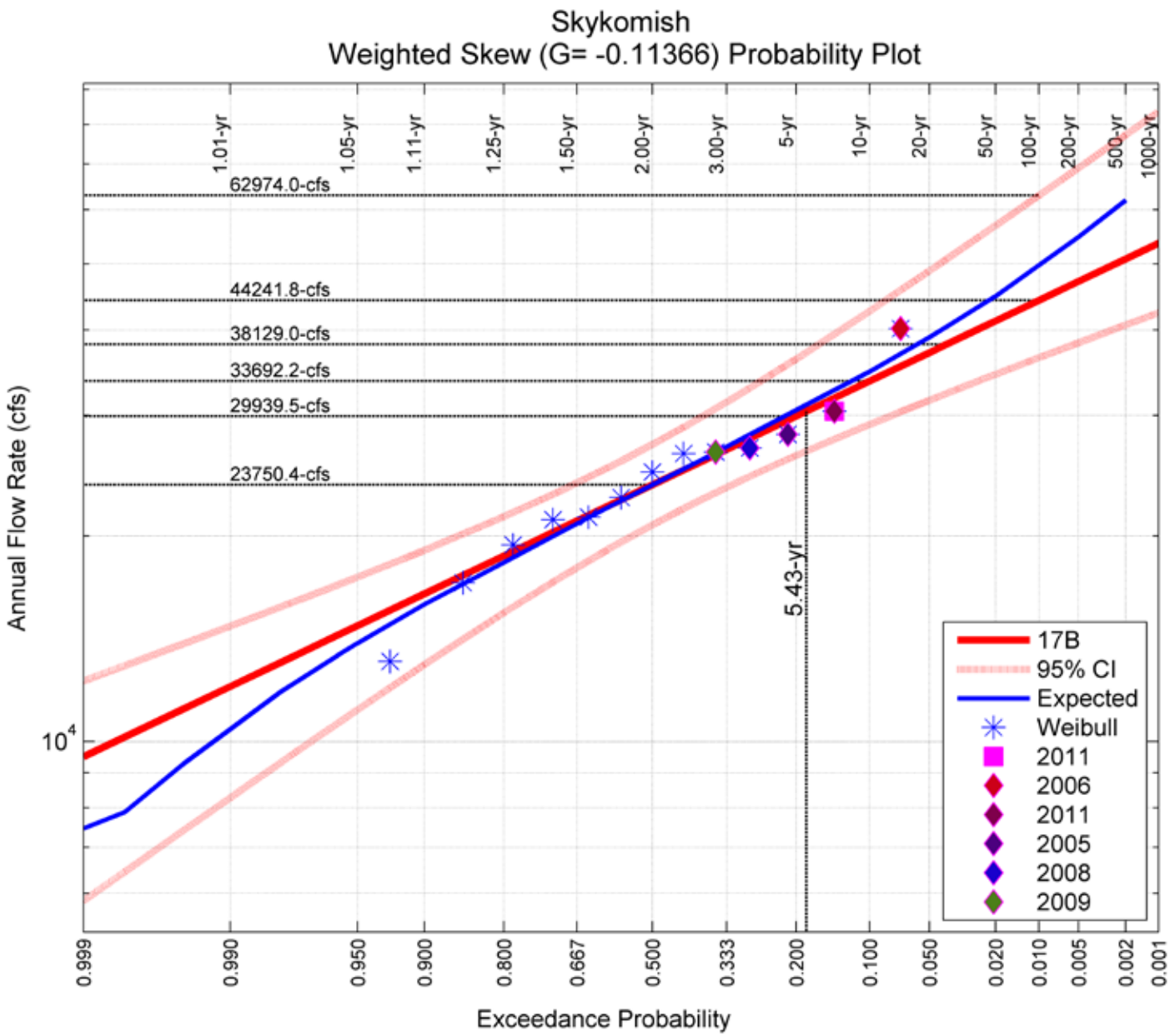
APPENDIX 2

Graphics to Support Hydraulic Modeling


Skykomish
Weighted Skew (G= -0.11366) Probability Plot
1.01-yr
1.05-yr
1.11-yr
1.25-yr
1.50-yr
2.00-yr
3.00-yr
5-yr
10-yr
20-yr
50-yr
100-yr
200-yr
500-yr
1000-yr
62974.0-cfs
44241.8-cfs
38129.0-cfs
33692.2-cfs
29939.5-cfs
23750.4-cfs
5.43-yr
Annual Flow Rate (cfs)
10^4
17B
95% CI
Expected
Weibull
2011
2006
2011
2005
2008
2009
0.999
0.990
0.950
0.900
0.800
0.667
0.500
0.333
0.200
0.100
0.050
0.020
0.010
0.005
0.002
0.001
Exceedance Probability

APPENDIX 3

Photo Log

GEOMORPHIC PROCESS AND FLOOD HAZARD ASSESSMENT – TIMBERLANE VILLAGE PHOTOGRAPHIC LOG

Photo Number	Photo Description
1	Beckler Peak Rock Avalanche Tailout Deposit with US-2 Bridge in Background
2	Beckler Rock Avalanche Debris with Beckler Peak in Background
3	Cascade in Beckler Peak Rock Avalanche Reach
4	Fry in Isolated Pool in Anthracite Creek
5	Grade Control Log in Anthracite Creek
6	Home with Private Revetment in Right Bank Bar Reach
7	Home with Revetment in Left Bank Point Bar Area
8	Home with Revetment in Right Bank Bar Reach Near RM
9	Home with Revetment on Side Channel in the Upper Island Reach
10	Homes in Left Bank Point Bar Area
11	Near Overtopping Location on US-2 Near Anthracite Creek Bridge
12	New NE 122nd Street Bridge
13	Old Bridge Abutment Near Cass Pond Resort on Anthracite Creek
14	Pool Downstream of Former Beckler Peak Rock Avalanche Waterfall
15	Refuse in Floodplain in Lower Island Reach
16	Revetment at RM 18.5 #1
17	Revetment at RM 18.5 #2
18	Right Bank Bar Looking Upstream in Right Bank Bar Reach
19	Riprap Bank at Downstream Limit of Study Area
20	Rock Revetment on Left Bank Near RM 18.93
21	Sandstone Bedrock Exposed in Bedrock Reach
22	Side Channel in Lower Island Reach
23	Unstable Right Bank in Right Bank Bar Reach
24	Unstable Right Bank in Upper US-2 Bridge Reach
25	Upstream Limit of Study Area
26	US-2 Bridge Over Anthracite Creek
27	US-2 Bridge Over South Fork

1

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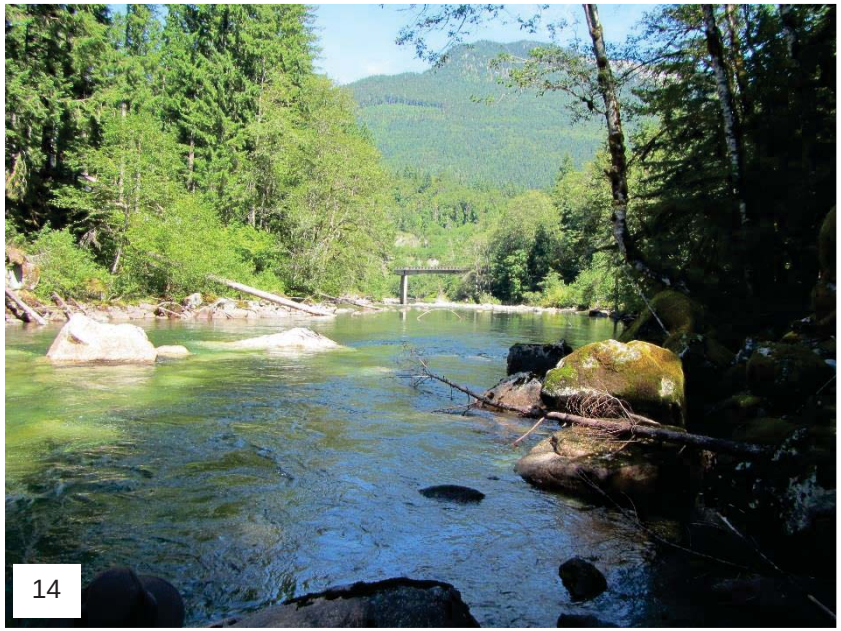

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APPENDIX B

Construction Cost Estimates

King County
South Fork Revetment at RM 18.5
Alternative #2 Revetment Removal
Conceptual Construction Cost Estimate 2/7/14

ITEM NO.	ITEM DESCRIPTION	QTY	UNIT	UNIT COST	UNIT COST	TOTAL PRICE	COMMENTS/ASSUMPTIONS
1	MOBILIZATION	1	LS	$3,290		$3,290	Mobilization is estimated at 10% of construction cost.
2	CLEARING AND GRUBBING	1	LS	$500		$500	Plants and trees removed for access to work areas.
3	REMOVAL OF ROCK STRUCTURE	273	CY	$25		$6,825	Assumes rock removal to low-water line. Structure dimensions assumed to 300'x3'x9'. Excavation cost is estimated at $12/CY. Haul distance is assumed to be ~5mi, at $2/CY/mi, and disposal is ~$3/CY. Quantity of removal is estimated from GPS estimates of extent and on-site photographs.
4	ENGINEERED LOG STRUCTURE	1	LS			$8,499	
	Excavate footprint	*27*	*CY*	*$25*	*$675*		Excavation cost is estimated at $12/CY. Haul distance is assumed to be ~5mi, at $2/CY/mi, and disposal is ~$3/CY.
	Logs	*6*	*EA*	*$1,000*	*$6,000*		Engineers estimate. Assumes placement, haul, with rootwad.
	Place reused rock	*27*	*CY*	*$12*	*$324*		Approximate size of structure is 3x3x3 yards
	Place structure	*1*	*LS*	*$1,500*	*$1,500*		1 day exacavator at $1200 + 8 hour laborer at $35/hr
5	EROSION/WATER POLLUTION CONTROL	1	LS	$12,000		$12,000	Sum of all TESC and WM items, including 400 feet of silt curtain.
6	MINOR CHANGE	1	CALC	$5,000		$5,000	Force account that may be utilized for unknown water quality mitigation measures
CONSTRUCTION TOTAL						**$36,114**	
TAX		8.6%				**$3,110**	
CONTINGENCY		30%				**$10,834**	
TOTAL W/O CONTINGENCY						**$39,224**	
TOTAL W/ CONTINGENCY						**$50,058**	

Assumptions
Reuse rock as ballast for structure
No piles are necessary to ballast structure due to reuse of revetment footing
Assumes planting will be done separately by County
Budget for grant planning only.

King County
South Fork Revetment at RM 18.5
Alternative #3 - Revetment Replacement
Conceptual Construction Cost Estimate 2/7/14

ITEM NO.	ITEM DESCRIPTION	QTY	UNIT	UNIT COST	UNIT COST	TOTAL PRICE	COMMENTS/ASSUMPTIONS
1	MOBILIZATION	1	LS	$23,020		$23,020	Mobilization is estimated at 10% of construction cost.
2	CLEARING AND GRUBBING	1	LS	$500		$500	Plants and trees removed for access to work areas.
3	EXCAVATION OF EXISTING ROCK STRUCTURE	300	CY	$12		$3,600	Assumes excavation to low-water line. Structure dimensions assumed to 300'x3'x9'. Excavation cost is estimated at $12/CY. Rock to be wasted on site as part of wood crib wall.
4	ENGINEERED LOG STRUCTURES	2	LS			$26,298	
	Excavate footprint	*27*	*CY*	*$25*	*$675*		Excavation cost is estimated at $12/CY. Haul distance is assumed to be ~5mi, at $2/CY/mi, and disposal is ~$3/CY.
	Logs	*6*	*EA*	*$1,000*	*$6,000*		Engineers estimate. Assumes placement, haul, with rootwad.
	Place reused rock	*27*	*CY*	*$12*	*$324*		Size of structure is 3x3x3 yards
	Place structure	*1*	*LS*	*$1,500*	*$1,500*		1 day exacavator at $1200 + 8 hour laborer at $35/hr
	Piles	*45*	*LF*	*$70*	*$3,150*		Costs from SR 530 project.
	Drive piles	*3*	*EA*	*$500*	*$1,500*		Costs from SR 530 project.
5	WOOD CRIB WALL	1	LS			$182,800	
	Excavate footprint	*900*	*CY*	*$25*	*$22,500*		
	Logs	*70*	*EA*	*$1,000*	*$70,000*		Geometry same as SR 530. 10 logs per 40 foot section, 7 sections total. Cost from SR 530.
	Slash	*600*	*CY*	*$20*	*$12,000*		
	Place wood and rock	*900*	*CY*	*$12*	*$10,800*		
	Piles	*750*	*LF*	*$70*	*$52,500*		Steel piles every 10 feet on center, driven to 25 feet below grade. Costs from SR 530 project.
	Drive piles	*30*	*EA*	*$500*	*$15,000*		Costs from SR 530 project.
6	EROSION/WATER POLLUTION CONTROL	1	LS	$12,000		$12,000	Sum of all TESC and WM items, including 400 feet of silt curtain.
7	MINOR CHANGE	1	CALC	$5,000		$5,000	Force account that may be utilized for unknown water quality mitigation measures
DESIGN TOTAL						**$253,218**	
TAX		8.6%				**$21,780**	
CONTINGENCY		30%				**$75,965**	
TOTAL W/O CONTINGENCY						**$274,998**	
TOTAL W/ CONTINGENCY						**$350,963**	

Assumptions
Piles will be necessary to secure structures because crib will require anchoring
Reuse rock for ballast
No import of rock will be necessary
Downstream structure will require piling to ensure stability
Voids in wall around piles to be filled with reused rock, on-site fill and slash
Assumes planting will be done separately by County
Budget for grant planning only.

King County
South Fork Revetment at RM 18.5
Alternative #2 Revetment Removal
Conceptual Design Cost Estimate 2/7/14

Alternative #2 - Revetment Removal				**Task 1**		**Task 2**		**Task 3**		**Task 4**		**Task 5**		**TOTAL**	
Number of Tasks : 5				*PM*		*Permit Design*		*Hydraulic Modeling / No*		*Water Quality Variance*		*Final Design*			
COST SUMMARY															
Labor					$4,005		$16,609		$7,410		$4,436		$16,609		$49,069
Travel and per diem					$0		$84		$0		$84		$0		$168
Other direct costs (ODCs)					$0		$0		$0		$0		$0		$0
Subconsultants					$0		$4,000		$0		$0		$0		$4,000
Analytical laboratory					$0		$0		$0		$0		$0		$0
GRAND TOTAL					**$4,005**		**$20,693**		**$7,410**		**$4,520**		**$16,609**		**$53,237**
COST ITEMIZATION															
Labor			(2013 rates)												
Personnel			Rate/Hour	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost
P6	Ewbank, Mark	Practice Director	$204.39	2	$409	4	$818	4	$818	4	$818	4	$818	18	$3,679
P5	Parsons, Jeff	Associate Engineer	$164.80	12	$1,978	8	$1,318	40	$6,592	12	$1,978	8	$1,318	80	$13,184
P4	Kays, Gus	Senior Engineer	$148.88	2	$298	24	$3,573	0	$0	4	$596	24	$3,573	54	$8,039
P1	Beggs, Mark	Engineer	$87.13	0	$0	24	$2,091	0	$0	12	$1,046	24	$2,091	60	$5,228
P3	Turnidge, Laura	Project CAD/GIS	$110.11	12	$1,321	80	$8,809	0	$0	0	$0	80	$8,809	172	$18,939
SUBTOTAL LABOR (Burdened Labor)				**28**	**$4,005**	**140**	**$16,609**	**44**	**$7,410**	**32**	**$4,436**	**140**	**$16,609**	**384**	**$49,069**
TRAVEL AND PER DIE		Unit	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Auto Use		Mile	$0.56	0	$0	150	$84	0	$0	150	$84	0	$0	300	$168
SUBTOTAL TRAVEL AND PER DIEM					**$0**		**$84**		**$0**		**$84**		**$0**		**$168**
SUBCONSULTANT CO		Unit	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Survey		1.00	$4,000	0	$0	1	$4,000	0	$0	0	$0	0	$0	1	$4,000
SUBTOTAL SUBCONSULTANT					**$0**		**$4,000**		**$0**		**$0**		**$0**		**$4,000**

Assumptions
Removal of revetment to low-water line only
Survey to low-water only (no bathy needed)
No net rise from HEC-RAS only because removal of fill to achieve no net rise.
Assumes added cross sections at key locations to improve model near known risk areas.
Water quality variance will be required to implement project. Variance support will be provided via e-mail correspondence only.
Only one structure need to protect landowner to the east.
Budget for grant planning purposes only.

King County
South Fork Revetment at RM 18.5
Alternative #3 Revetment Removal
Conceptual Design Cost Estimate 2/7/14

Alternative #3 - Revetment Replacement				**Task 1**		**Task 2**		**Task 3**		**Task 4**		**Task 5**		**Task 6**		**TOTAL**	
Number of Tasks : 6				*PM*		*Geotechnical Engineering*		*Permit Design*		*Hydraulic Modeling*		*Final Design*		*BOD*			
COST SUMMARY																	
Labor					$6,855		$627		$26,437		$18,066		$25,040		$12,585		$89,610
Travel and per diem					$0		$0		$84		$0		$0		$84		$168
Other direct costs (ODCs)					$0		$0		$0		$0		$0		$0		$0
Subconsultants					$0		$10,000		$4,000		$8,000		$0		$0		$22,000
Analytical laboratory					$0		$0		$0		$0		$0		$0		$0
GRAND TOTAL					**$6,855**		**$10,627**		**$30,521**		**$26,066**		**$25,040**		**$12,669**		**$111,778**
COST ITEMIZATION																	
Labor			(2013 rates)														
Personnel			Rate/Hour	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost
P6	Ewbank, Mark	Practice Director	$204.39	4	$818	0	$0	4	$818	0	$0	2	$409	8	$1,635	18	$3,679
P5	Parsons, Jeff	Associate Engineer	$164.80	24	$3,955	2	$330	18	$2,966	24	$3,955	12	$1,978	40	$6,592	120	$19,777
P4	Kays, Gus	Senior Engineer	$148.88	0	$0	2	$298	40	$5,955	0	$0	40	$5,955	8	$1,191	90	$13,399
P1	Beggs, Mark	Engineer	$87.13	0	$0	0	$0	40	$3,485	120	$10,456	40	$3,485	24	$2,091	224	$19,518
P3	Turnidge, Laura	Project CAD/GIS	$110.11	0	$0	0	$0	120	$13,213	0	$0	120	$13,213	0	$0	240	$26,426
P2	Lau, Olivia	Staff CAD/GIS	$91.35	0	$0	0	$0	0	$0	40	$3,654	0	$0	8	$731	48	$4,385
F3	Sparano, Regina	Accounting Administrator	$86.76	24	$2,082	0	$0	0	$0	0	$0	0	$0	0	$0	24	$2,082
A3	Robertson, Jeanne	Administrative Coordinator	$86.21	0	$0	0	$0	0	$0	0	$0	0	$0	4	$345	4	$345
SUBTOTAL LABOR (Burdened Labor)				**52**	**$6,855**	**4**	**$627**	**222**	**$26,437**	**184**	**$18,066**	**214**	**$25,040**	**92**	**$12,585**	**768**	**$89,610**
TRAVEL AND PER DIEM		Unit	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Auto Use		Mile	$0.56	0	$0	0	$0	150	$84	0	$0	0	$0	150	$84	300	$168
SUBTOTAL TRAVEL AND PER DIEM					**$0**		**$0**		**$84**		**$0**		**$0**		**$84**		**$168**
SUBCONSULTANT COST		Unit	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Geotechnical support		1.00	$10,000	0	$0	1	$10,000	0	$0	0	$0	0	$0	0	$0	1	$10,000
Survey		1.00	$4,000	0	$0	0	$0	1	$4,000	2	$8,000	0	$0	0	$0	3	$12,000
SUBTOTAL SUBCONSULTANT					**$0**		**$10,000**		**$4,000**		**$8,000**		**$0**		**$0**		**$22,000**

Assumptions
Removal of revetment to low-water line only
Survey will include both upland project site and bathymetry in the vicinity of the project to support hydraulic modeling.
No net rise will be from 2D modeling because of the placement of additional wood and piles.
Water quality variance will be required to implement project. Variance support will be provided as part BOD task.
Structures needed at both ends of the revetment in order to prevent erosion occurrring from behind the revetment.
Budget for grant planning purposes only.