Vasa Creek Channel Conditions and Slope Stability, Bellevue, Washington

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Executive Summary

This report is being prepared for the City of Bellevue (COB) and the University of Washington ESS department. Currently, Kit Paulsen and the COB are conducting a basin study of the Vasa Creek Watershed in Bellevue, Washington scheduled to be completed by the end of 2014. The goal of their study is to improve the accuracy of the current floodplain designation, evaluate Kokanee salmon habitat conditions in Vasa Creek, identify illicit discharges of pollutants through the storm drainage system, and identify areas that are feasible or infeasible for stormwater infiltration techniques. Due to concerns of local homeowners near the creek, COB is also concerned with the stability of slopes adjacent to the stream. My focus upon discussion with Ms. Paulsen is the current channel conditions with regard to kokanee habitat and slope stability. This required a geomorphic and geologic assessment of the stream and riparian corridor along Vasa Creek.

Given a short time-period, I was not able to complete an assessment throughout the entire basin. Instead, I focused my efforts in a 720m study-reach just south of I-90 in which COB had no information. My assessment is divided into 3 categories: channel morphology, geology, and landslide hazards. I described the channel morphology by determining the gradient of the channel, longitudinal and cross-channel geometries, grain size distribution, embeddedness observations, type of channel reaches present, and the locations of significant in-channel woody-debris, landslides, scarps, landslide debris, and erosional features. This was done by conducting a longitudinal survey, 7 cross-channel surveys, pebble counts, and visual observations with the aid of a GPS device for mapping.

I completed my geological assessment using both field observations and borehole data provided by GeoMapNW. Borehole data provided logs of the subsurface material at specific locations. In the field, I interpreted local geology using material in the channel as well as exposures in the adjacent slope.

I completed the landslide hazard assessment using GIS methods supplemented by field observations. GIS methods included the use of aerial LiDAR to discern slope values and locations of features. Features of interest include the locations of scarps, landslides, landslide debris, and erosional features which were observed in the field. I classified 4 slope classes using ArcMap10 along with the locations of previously mapped landslides, scarps, and landslide debris. I describe the risk of slope failure according to the Washington Administration Code's definition of critical areas (WAC 365-190-120 6a-i).

My results are presented in the form of a map suite containing a channel morphology map, geology map, and landslide hazard map. The channel is a free-formed alluvial plane-bed reach with infrequent step-pools with riffles associated with landslide debris that chokes the channel. Overall I found that there is not the potential for kokanee habitat due flashy behavior (sudden high flow events), landslide inundation, and a lack of favorable conditions within the channel. The updated geologic map displays advance outwash deposits and alluvium present within the study-reach, as opposed to exposures of the Blakeley Formation along with other corrections from borehole data interpretations. The landslide hazard map shows that there are areas at high risk for slope failure along the channel that should be looked into further. The work I have completed may serve as a template for the COB basin study.

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1.0 Introduction

Vasa Creek is one of several tributaries of Lake Sammamish in Bellevue, Washington (Figure 1). The creek flows in a northerly direction until it abruptly turns east where it flows into the lake. A buried high-flow bypass was installed at the bend, directing overflow into the lake as well. North of I-90, a majority of the land use along the creek consists of residential developments while the southern portion consists primarily of both commercial and residential use (*The Watershed Company, 2009*). The total length of open channels within Vasa Creek is 16,118ft (*City of Bellevue, 2009*). There is approximately 103,034ft of storm drainage pipes in the watershed, a large percentage of which are directed into Vasa Creek.

Lake Sammamish is one of several water bodies within the state of Washington in which kokanee salmon occur (*King County, 2008*). In Lake Sammamish, the salmon migrate upstream into several tributaries for spawning, including Vasa Creek. Moving upstream, the creek is abruptly redirected southward, extending beneath I-90. Here, a culvert was installed beneath the interstate creating an impassible fish barrier (*City of Bellevue, 2009*).

Per the request from Kit Paulsen and the City of Bellevue (COB), I worked within the Vasa Creek Watershed determining the kokanee habitat potential and slope stability. Between the dates of July 22 and September 18, 2013 I completed 14 days of field work with an assistant in Vasa Creek. I had 4 objectives for my field work: 1) determine the existing longitudinal and cross-sectional channel geometries, 2) determine the subsurface geology within the study-reach, 3) characterize the grain sizes within the channel and 4) locate significant features associated with slope failure. With this information I was then able to compile the data, conduct a GIS analysis of the information, and produce a map suite. This in turn may act as a template for the basin study that will be conducted by COB.

COB's interest in the Vasa Creek Watershed includes improving the current floodplain designation, evaluating kokanee salmon habitat conditions, and identifying illicit discharges of pollutants through the storm drainage systems as well as areas that are feasible or infeasible for stormwater infiltration techniques. Homeowner concerns also prompted COB to evaluate slope stability near the stream. My study provides detailed information regarding the channel conditions present that may concern kokanee habitat and an assessment of local landslide hazards.

The scope of work is heavily concentrated in the 720m segment of Vasa Creek just south of I-90. According to COB's map of steep slopes along Vasa Creek south of I-90 all slopes have an equal risk of failure. However, COB does not have any field data or field work completed within this particular segment. For this reason and due to relatively easy access, I chose the segment as my study-reach.

Originally I had planned to assess the entire length of Vasa Creek, but due to time constraints I decided to provide a detailed assessment of the study-reach. Though it is not accessible to fish because of the culvert, I assessed the channel with regard to conditions adequate for kokanee salmon. I also used a short field day to observe and describe the lower reach north of I-90 in order to compare with the study-reach south of the culvert.

2.0 Background

2.1 Stream Condition

Vasa Creek flows north into Lake Sammamish through southeast Bellevue and passes just outside city limits through Eastgate (*City of Bellevue, 2009*). The headwaters cascade through pools that have been carved into the bedrock. As it flows through Eastgate, the creek transitions from bedrock reaches to an ephemeral gravel channel. South of I-90 the channel runs through primarily residential neighborhoods, transitioning into both residential and commercial land use north of the interstate. Subsequently, downstream of I-90, the gradient of the creek is shallower with surface flow.

Where I-90 intersects Vasa Creek, the Washington State Department of Transportation (WSDOT) installed a culvert. It is at this point that Vasa Creek transitions rapidly from an E-W trending to a relatively N-S trending stream. The culvert has been described by COB as an impassible fish barrier with associated overflow structures and sedimentation ponds on either side of the interstate. A high flow bypass was also installed downstream of the interstate, deflecting storm flows directly into Lake Sammamish. It is unclear to COB whether the lack of higher flows in the lower reach results in embedded gravels that would therefore limit spawning habitat. COB is also concerned with slopes adjacent to Vasa Creek and their level of stability. At this time no damages have occurred to homes along the stream as a result of slope failure.

2.2 Salmon Habitat

Kokanee salmon that inhabit Lake Sammamish typically use the mouth of the Vasa Creek for spawning grounds. In Vasa Creek, Kokanee have migrated upstream in some occasions, but not as far upstream as they have migrated in other tributaries throughout the state. No fish were discovered upstream in Vasa creek during a survey conducted in 2000 by the Washington Department of Fish and Wildlife (*Downen, 2000*). A study completed in 2009 shows that there was a decline in local kokanee salmon populations (*City of Bellevue, 2009*). However, recent spawning counts have increased (*Paulsen, 2013*). Within the spawning creeks the only suitable and accessible habitat is located in short reaches near the mouth (*Cross, 2012*). Upstream in rivers there are typically barriers such as culverts, dams, and channelization that do not allow for the transport of adequate gravel for redds. These barriers also create a difficult migrating environment where the channel is choked and flows rapidly through a steeper than natural gradient. This is observed in Vasa Creek where several culverts have been installed throughout the reach.

For salmon, a higher fraction of fine sediment within the streambed can result in low embryo survival (*Phillips et al., 1995; Hausle and Coble, 1976; Tappel and Bjornn, 1983*). Spawning, which occurs from late August until late September, requires a particular ratio of coarser gravels to fine sediment. Overall, loose and relatively unconsolidated substrate of clean gravel within the channel is necessary to allow for the kokanee to create redds and spawn (*Kondolf, 2000*; *Barton and Dux, 2013*). The fine sediment present within the channel is necessary to fill void spaces between the gravel, incubating the egg while still allowing for oxygenated water to flow into the pocket (*Barton and Dux, 2013*). According to a recent study of sockeye salmon production potential in Yakima, Washington, habitats composed with less than 12% of fine sediment are classified as good (*Bureau* *of Reclamation, 2007*). Their study also determined 12-128mm to be a size range suitable for spawning, using Wolman pebble counts to assess this in the field.

The shape of the longitudinal profile controls the slope of the channel, the energy of channel flow, and the sediment transport rate (*Dade and Friend, 1998*). Creating a longitudinal profile can also help to define the channel morphology type and indicate locations of pool features. Cross-channel geometries are important too as kokanee need some type of pool or off-channel habitat with cover. Cross-channel profiles can be used to define these features.

The degree to which the channel contains embedded gravels can contribute to the percentage of fine sediment within the channel. Embedded gravel refers to the amount of fine sediment that either surrounds or covers larger particles such as gravels and cobbles. In this scenario there are high levels of fine material which, as discussed above, can reduce the permeability of the egg pocket resulting in either slow growth or suffocation. If the embedded gravels are cemented then they are difficult to lift out, preventing the salmonids from being able to build redds.

Another variable influencing the bed material is woody debris within the channel. Woody debris can store sediment (typically finer sediment) as well as organic matter (*Bisson et al. 1987; O'Connor & Harr 1994; Peterson et al. 1992*). Though a large percentage of fine sediment is not ideal for creating redds, the organic matter releases nutrients into the water by processes of decay that benefit the salmonids (*Bisson et al. 1987; O'Connor & Harr 1994; Peterson et al. 1992*). It can also provide habitats that benefit salmonids. It can also form pools that protect from salmonids from predators and high channel flow (i.e. flooding or storm events) and are used for rearing as well. When found along channel margins, woody debris can form the most productive fish habitat.

Enough water is needed from spawning in the fall to emergence and migration in the spring. Though the amount of water pertains mostly to the hydrology within the basin, it can also be influenced by the amount of sediment within the channel. In aggrading streams there is more sediment deposited on the streambed, creating a thicker bed surface that can accommodate subsurface flow. Where aggradation is not occurring, the bed surface material is thinner and water flows on the surface.

2.3 Past Impacts

Anthropogenic changes that caused adverse impacts to the local Kokanee include modification and dredging of the Sammamish River for flood control in the 1950s; Issaquah Creek carried effluent into Lake Sammamish until the late 1960s; and between 1970 and the late 1980s, upstream passage access in many Lake Sammamish tributaries (including Vasa Creek) were blocked by residential developments. This effectively hindered Kokanee migration (*Connor et al., 2000*).

There have also been recent changes by homeowners with property adjacent to Vasa Creek. Modifications I observed north of I-90 included bridges, rockeries, and other landscaping projects. Much of this is done without the proper authorization by the city who then issue fines. However, this issue continues to persist. COB requires that homeowners living next to a stream, lake, or wetland must obtain a permit before moving earth or clearing vegetation next to a stream, lake, or wetland. They also require that native vegetation be left and no “landscaping” occur next to these waterways or lawns extend up to the edge of water.

2.4 Local Geology

The Vasa Creek Watershed is located in the Puget Lowland which has been effectively shaped by glaciation and fault systems brought on by tectonic forces. A previous published geologic map was completed by Kathy Troost in April 2012, showing that a majority of the area is covered by glacial deposits (Figure 2). According to the map, Vasa Creek crosses through bedrock, glacial till (Qvt), glacial advance outwash (Qva), glacial lacustrine deposits (Qvrlb), and fan deposits (Qf) before draining into Lake Sammamish. The only bedrock in the watershed is a combination of sandstone and mudstone known as the Blakeley Formation (Tb). The uplift associated with thrust along the Seattle Fault Zone (SFZ) exposes Tb primarily in the southern extent of the watershed.

The E-W trending SFZ accommodates the N-S compression occurring in the Pacific Northwest (*Liberty and Pratt, 2008*). It is defined by basement rocks in the south thrust up over the younger sediments to the north. Though several scenarios are argued, a favored one is a thrust in which the uplift is the result of a large fault-propagation with a forelimb breakthrough at Vasa Park (*Liberty and Pratt, 2008*). It has been hypothesized that slip occurring on the fault is at a rate of .07mm/yr with a recurrence interval of 5700-28500 years. The fault slipped approximately 1,100 years ago, producing a moment magnitude 7 earthquake. This in turn produced what has been interpreted as 8m of offset.

A strand of the SFZ named the Vasa Park Fault (VPF) cuts across Vasa Creek and follows along I-90 (Figure 3). Evidence of the VPF has been exposed in a trench and was presented by the Washington Military Department Emergency Management Division in 2005. Here, the fault broke the surface and clearly displays the juxtaposition of older rock thrust up on younger sediments.

In the event of the fault slipping again, the 2005 report predicts that areas near the fault that would experience the most extreme effects of ground shaking would be alluvial soils and those consisting of disturbed soils. Using a computer loss-estimation program (HAZUS) developed by FEMA and the National Institute of Building Sciences, a likely earthquake scenario was determined. They found that the most likely scenario to occur would be that of a 6.7 moment magnitude earthquake with a rupture length of approximately 14mi and 6.5ft of surface rupture. They then created hazard maps using values based on estimates of magnitude, recurrence, and location. Along with the SFZ, there are several major fault systems present within the Puget Lowland that may pose a threat to the Vasa Creek Watershed and have also been assessed using HAZUS based maps.

2.5 Slope Stability

The current hazard areas in the Vasa Creek Watershed have been defined by COB as slopes >40%. A majority of these areas are located in river valleys and at the base of large hills. Known landslide deposits were also mapped by Kathy Troost in 2012, of which there is only one location within the basin (Figure 4). Though slope grade does significantly affect slope stability, the proximity of the VPF is also of concern. Since the entire basin lies within the SFZ, earthquake induced landsliding is a possibility.

3.0 Purpose

There were three main purposes to my summer study. The first was to aid Kit Paulsen and COB in evaluating the Kokanee salmon habitat conditions that exist in Vasa Creek. My work will provide them with a template for their basin study as well as relevant field data from the study-reach. The second purpose was to gain independent experience working in the field while performing a dynamic geologic analysis. Finally, this study completes one of the final requirements for my Masters of Earth and Space Sciences in Applied Geosciences from the University of Washington.

4.0 Methods

During three phases I compiled background information and current data both in the office and in the field. Phase 1 was completed in the office, compiling relevant background information and current available data. Phase 2 consisted of field visits and techniques used to obtain live information about the channel's geomorphology, geology, habitat conditions, and slope stability. Phase 3 consisted primarily of compiling and organizing all my data and then using the information to produce a map suite. The map suite consists of a basemap, an updated geologic map, landslide hazard map, and a stream channel map.

4.1 Geology

I used the most recently updated, published geologic map completed by Kathy Troost as a basis for my interpretations. I determined the map's accuracy with field observations and borehole interpretations. In the field I observed exposures at the base of the adjacent slopes that are composed of both Qvt and Qva. The Qvt is gray-tan and contains poorly sorted gravel and cobbles within a fine-grained sand and silt matrix. The Qva has a similar appearance to the Qvt; however, it exhibits greater sorting, bedding, and is less dense than the glacial till.

Map accuracy was also determined by analyzing borehole data. Borehole data is provided by GeoMapNW's online database and is in the form of point shapefiles. I reviewed the subsurface information and used it to interpret the geologic unit present at each location. I then used the field and borehole information to update the map to fit my interpretations. ArcMap10 was used to adjust the locations of geologic contact lines and create an updated geologic map. Some contacts were left unchanged because either borehole data confirmed their locations or I did not have enough data to make accurate interpretations.

4.2 Channel Morphology

An assessment of the channel morphology was completed to characterize the existing channel conditions. Parameters of channel morphology to focus on when describing kokanee habitat include channel gradient, channel width, grain size of the streambed material, water depth, temperature, turbidity, embeddedness, and pools or other off-channel habitat (*Young, 2005*).

To complete the assessment I conducted both a longitudinal and multiple cross-sectional surveys, pebble counts, and made visual observations of reach-type and presence of woody debris. Also included in the assessment are the visual observations used for the slope stability analysis i.e. erosional features, scarps, landslides, and landslide debris.

I began by surveying the channel's longitudinal profile. This was done using standard surveying practices with an auto level, stadia rod, and measuring tape. I worked my way upstream, following what I interpreted to be the main channel. As survey data was collected, several waypoints were recorded using the GPS system, identifying survey locations as well as the locations of the features that can influence the channel morphology (i.e. woody debris and visual observations for slope stability analysis).

Survey data recorded in the field was then used to plot the stream profile and calculate the average slope of the channel (Figure 5). Slope breaks were determined using the longitudinal profile and are associated with changing channel conditions. The same survey techniques were used to create cross-sectional profiles. Seven cross-sections were surveyed along the study-reach (Figure 6). I chose locations that would best represent the variation in channel geometries throughout the study-reach. The profiles were conducted between the bases of the adjacent slopes and represent the valley-width.

I characterized the gravel within the streambed by conducting pebble counts at each cross-channel transect. At these locations I chose at least 100 particles at random within a $1m^2$ area in what is interpreted as the main channel. This is a surface sampling technique referred to as a grid count as described by Abt and Bunte (*2001*). The particles were categorized based on grain size and used to create distribution curves with which I determined the D50 and D84 values as well as the percentage of fine sediment (particles <4mm)(Figure 7).

I then classified the stream by reach-type according to Montgomery and Buffington (*1998*). Being that salmon place their eggs in riffle, I will pay close attention to moderate gradient pool-riffle features. Streams can be described on a spatial scale of 10^1-10^3m. There are colluvial reaches, free-formed alluvial reaches (FFA), forced-alluvial reaches (FA), and bedrock reaches (*Montgomery and Buffington, 1998*). In the case of an FFA or FA, the channel can be further classified according to the existing bedforms. FFA reaches are further classified into cascade, step-pool (SP), plane-bed (PB), pool-riffle, and dune-ripple. FA reaches are further classified as either a forced SP or forced pool-riffle. FFA features are those that are created by a means of strictly fluvial processes while FA features can be created as products of landslide debris such as boulders to logs.

600m of the 720m study-reach had only subsurface flow occurring. Because of this, I was unable to determine water depth, temperature, or turbidity. Also, neither the USGS nor the City of Bellevue has installed any gages in the basin to monitor the channel flow. I was, however, able to estimate the high flow water level by measuring the height at which moss and mud marks were on trees near the sedimentation pond. A lack of water also made interpretations of channel features in some cases speculative.

4.3 Slope Stability

I used GIS methods supplemented by field observations to complete a landslide hazard assessment of my study-reach. While in the field, I used a Garmin GPSmap 76CSx to determine the locations of scarps, landslides, landslide deposits, and erosional features (i.e. outcrops and undercuts). These locations were then projected in ArcMap10 in conjunction with the locations of landslides, scarps, and landslide deposits previously mapped by Kathy Troost (*2012*). Because I was unable to determine slope in the field, I used LiDAR with GIS to determine the slope grade of the valley walls. The slope values were categorized 4 classes: 1) slopes ≥80°, 2) slopes 40-79°, 3) slopes >15°, and 4) slopes <15°. The slope class was then mapped along with the projected data to create a landslide hazard assessment map. The classification of slope failure is based off of the Mercer Landslide Hazard map completed by Kathy Troost and Aaron Wisher in 2009 according to WAC 365-190-120 6a-i.

5.0 Assumptions

I conducted this study under the following assumptions:

- That the borehole data provided is representative of the subsurface units.
- That channel reach classifications can be made without the presence of flowing water.
- That pebble counts of the bed surface material is representative of the channel bed.

6.0 Findings

6.1 Geology

In the field I established that there is no exposure of the Blakely Formation bedrock within the study-reach. Though rip-up clasts of the bedrock were observed, there were no exposures within the bed. Throughout a majority of the study-reach, I observed loose, Quaternary age alluvium (Qal) within the streambed. Further upstream the bed is primarily made up of Qva with little to no alluvial deposits in the streambed.

On the slopes I observed that there is a weathered cap of Qvt with Qva exposed below (Figure 8). The Qva is capped by Qvt which is very thin and weathered downstream, gradually becoming more consolidated upstream, reaching a thickness of approximately 3.5m.

Borehole data provides, in most cases, detailed descriptions of the subsurface material. Though there were several inconsistencies between what was mapped and what borehole data said, most of these were minor changes in geologic contact locations (Figure 9). The geologic units that make up both the channel bed and slopes directly impact stream conditions. Since much of the area is defined as either Qvt or Qva, there is a significant input of gravel into the channel bed. According to my updated map Vasa Creek now flows through Tb, Qvt, Qva, Qal, briefly through Qvrlb, and finally through Qf before draining into Lake Sammamish.

According to the maps based off of probabilistic seismic hazard analysis by the US Geological Society, in the event of an earthquake triggered by the SFZ, my project area would incur violent shaking (Figure 10). However, there are several other major fault systems that may also induce earthquakes affecting the site. These include the Whidbey Island Fault (WIF), Tacoma Fault (TF), and the Cascadia Fault (CF). An earthquake induced by WIF would produce very strong shaking and TF and CF would produce strong shaking. As a result, certain areas may be susceptible to liquefaction. These areas have been mapped by King County (Figure 11).

In a recent study completed by Sue Bednarz and Jacobs Associates in early August 2013, evidence of faulting near Vasa Creek was presented. Boreholes were drilled and sampled along a proposed wastewater tunnel location in Bellevue (Figure 12). The borehole labeled BH-2 is located within Vasa Park. At approximately 44ft below the ground surface, they discovered a completely weathered shear zone (Figure 13). The location of BH-2 is along the projected location of the VPF within the SFZ. According to Brian Sherrod (2002), the most recent earthquake event (16,000-4,500ya) created vertical offsets of approximately 6.5ft and horizontal offsets of 12ft along the VPF.

6.2 Channel Geomorphology

From the longitudinal profile I identified 4 major slope breaks, breaking the study-reach into 5 segments with an overall average gradient of .032. The breaks occur at 175m, 320m, 570m, and 705m (Table 1). The first two segments both are associated with a wide valley bottom in which there appears to be cross-channel migration across floodplains between the main and side channel. Few pool features are observed and are present where there is a log (Figure 14) however there are only two locations of a significant amount of woody debris (Figure 15). There is a transition between the first and second segment from dense vegetation (cottonwood) on the floodplain to only blackberry bushes. No water is present. Very localized areas of armoring in the channel and some embedded gravels.

Moving upstream into the third segment is a greater break in slope. This segment is largely characterized by two large scarps and associated landslide debris. The debris includes a lot of woody material, choking the channel and forcing small riffle and step-pool features. Also within this segment, both the valley and channel width are smaller than what is observed downstream and no apparent side channels are present. No water is present. Not a lot of armoring and a majority of gravels near the scarps are covered in sediment from landslides.

Within the next segment the channel and the valley have become much narrower with little to no floodplain. Water is first observed within this segment at 600m, trickling over a plane-bed streambed with few locations of significant woody debris. Just beyond where I observed the surface flow there is gabion wall (Figure 16). It is located on the east side of the channel, locally armoring the bed. Moving upstream, defined walls of Qvt and Qva confine the channel. At the base of these walls there has been slight undercutting and erosion occurring (Figure 17).

The final segment has a gradient of .154 and is what I would describe as a small slot-canyon (Figure 18). The upstream culvert drain is located just beyond the segment. Water flowing from the drain has created a knickpoint that is moving upstream and has created a step-pool.

There was also a significant variation in cross-channel profiles. The valley width decreases in the upstream direction and the topography is irregular (Figures 19-21). Transects 1, 2, and 3 have defined floodplains with little to no scouring of the streambed. Transect 4 has a similar pattern but shows scouring occurring at the base of the west side of the channel. In Transects 5 and 6 it is apparent that the channel is being choked on the west side and has a more defined channel. Transect 7 shows both a narrower valley and channel. Though water is present where transects 6 and 7 are located, it was too shallow to show up in the profile.

I determined the D50 and D84 values from distribution curves as well as the percentage of both fine sediments and those suitable for habitat (Table 2). Fine sediments make up less than 12% of the material at each transect and a majority of the locations have >50% of grain sizes suitable for habitat. Transect 5 had the largest D50 and D84 values of 8mm and 11mm. Transect 2 had the smallest D50 and D84 values of 5.4mm and 7.8mm. Transect 5 is located further upstream near one of the landslide scarps while transect 2 is located downstream with no adjacent slope failure. I plotted these values on a graph, showing an overall trend of fining downstream (Figure 22). However, it also appears that the percentage of fine to coarse grains stays relatively constant (Figure 23).

As noted, during dry seasons the first water observed occurred 600m upstream in the study-reach while downstream water flow occurred in the groundwater. Within the study-reach, I observed an expression of the water level downstream in an existing overflow structure in the sedimentation pond. The groundwater level was at an elevation of 295.22m, approximately 1.95m below the ground surface (Appendix 1). Estimated high flow height was at an elevation of 298.76m, creating a water depth of approximately 1.44m in the downstream segment.

After heavy rains I returned to the study-reach and observed water 300m upstream instead. There was also evidence within the channel that water had been flowing throughout the entire channel. The evidence included fresh scouring, the deposition of the sand bars, and vegetation blown in the direction of flow (Figure 24).

Taking into consideration these variables and visual observations I identified the alluvial channel as a plane-bed reach with infrequent pools and riffles. However, I divided the channel into 4 sub-reaches: two plane-bed reaches, a forced step-pool reach, and a free-formed step-pool reach (Table 3). One large plane-bed reach defines the first two slope break segments with infrequent pools and riffles. Where the landslide debris occurs I identified the channel as a forced step-pool reach with riffles. The channel then continues as a plane-bed reach again until it reaches the slot-canyon upstream in which the stream had incised into the Qvt, creating large steps. I defined this as a free-formed step-pool.

Within the free-formed step-pool reach, the walls expose glacial till. Qvt is also exposed near the top above Qva where the landslide scarps are located. Qva is also exposed in erosional features along the base of the slope. All exposures occur along the west side of the stream and are indicated on the resulting channel morphology map (Figure 25).

6.3 Slope Assessment

The only landslides, scarps, and outcrops observed occur on the west side of the channel. The west slopes are at risk of failure due to recent landsliding events, stream erosion, and having a grade

≥40%. According to the map, however, the steepest slopes primarily occur on the east slope with grades 80% and greater which causes them to be at risk as well (Figure 26).

Risk of landsliding can also be attributed to earthquake events. According to ground shaking maps developed by the Washington Military Department Emergency Management Division, slopes ≥80% are extremely susceptible to failure during seismic shaking. Valley walls with this slope grade occur within Vasa Creek which is in the direct vicinity of the VPF.

6.4 Vasa Creek North of I-90

The channel in the lower reach just north of I-90 appears narrower than the southern segment; however there is surficial flow throughout its entire length. There has been a significant amount of disturbance from homeowners landscaping their property along the stream. Locals have reported that they haven't seen fish much farther than Lake Sammamish Parkway (Figure 27). The creek flows through backyards and into Lake Sammamish alongside the high-flow bypass. According to a survey by the City of Bellevue in 2012 the average width of the creek is 1.43m with an average depth of .061m. The channel has a low-gradient riffle, plane-bed reach-type. Gravel is the dominant substrate with subdominant sand and cobbles.

7.0 Discussion

7.1 Geology

It is likely that there will continue to be updates to this map as the Qvt is quite extensive and likely contains more variation. This variation is due to the irregular deposition of material associated with glacial events and disruption by the SFZ. Within the study-reach I expected to observe Qvt on the slopes and Tb within the channel bed. Though rip-up clasts of Tb were observed, no exposures within the bed were present. This may however be an issue of resources, had I been able to explore the subsurface further I would have been able to make more certain interpretations.

Without many exposures of subsurface material, I was unable to observe features associated with local fault movement. However, with evidence of past surface rupture in Vasa Park, there is potential for future surface rupture. Implications associated with an event such as this include violent shaking exhibited in Figure 10, liquefaction, and slope failure. Liquefaction has a moderate-high hazard rating within Qf, including the lower-reach of Vasa Creek. In the event of liquefaction occurring within the stream, the structural integrity of the material in the slope could be affected and lead to landsliding. In the event of landslides being triggered, the creek may experience several threatening scenarios. This includes but is not limited to the channel being inundated with sediment and debris, the formation of dams upstream, the integrity of the rocks forming the slopes decreases, and an extreme change in the channel gradient.

7.2 Slope Stability

According to my results, there are four categories of landslide risk within the study-reach: 1) areas that have shown recent movement, 2) areas where stream incision is occurring, undercutting the slope, 3) areas with a slope >40% with a vertical relief of 10ft or more, and 4) areas with a slope >80%. However, in the study-reach the landslide events that have occurred have not been dramatic enough to severely alter the existing channel. Landslide debris does choke the channel and create hummocky terrain, but it does not appear to be impassible. In the landslide assessment map, though the only observed landslides occur on the west side of the channel, the east side has a steeper slope. I did not observe many signs of slope instability in the field, however, dense vegetation on the slope may have obscured what are clear indications of movement. What I did observe included few pistol-butt trees, few areas of jack-straw trees, and hummocky terrain. It could also be attributed to a lack of landslides; the west side may have in effect stabilized itself for the time being and so overall has a lower gradient while the east side remains unstable and steep.

Though not observed within the study-reach, there is the potential for landslide risk associated with slopes that are parallel or sub-parallel to planes of weakness such as bedding planes, joint systems, and fault planes in subsurface materials. The SFZ is projected cross Vasa Creek downstream near Vasa Park.

The landslide hazard map provides valuable information but may not be entirely representative of the channel. In the summer months when it is dry and hardly any surficial flow is occurring, I did not observe springs or other expressions of groundwater flow. However, in the wet winter months these features may be present and would factor into the slope stability assessment.

I also observed within the upstream slot-canyon the potential for slope failure. The channel has created a knickpoint that is continuing to erode upstream. As this occurs, it will cause the adjacent slopes to fail. This is located within a dense residential neighborhood and would affect local homes, roads, and other infrastructure. This type of failure may also occur in the event of the drain rupturing and discharging a greater amount of water, i.e. a blowout, in which there would also be a high influx of sediment into the channel.

7.3 Channel morphology

The longitudinal profile and associated slope breaks within the study-reach shows that the channel is steeper upstream than it is downstream. Upstream is where the slot-canyon and other exposures within the slopes are observed. I believe this can be attributed to channel incision whereas the shallower downstream segments display the opposite process occurring. Where the landslide debris occurs fine sediment was deposited into the channel, increasing sediment supply at a shallower slope and causing channel aggradation. However, the channel only appears to be aggrading locally and not throughout the entire downstream segment. It also is aggrading further downstream as the channel flows into the sedimentation pond.

I believe this transition from an incising to an aggrading channel is directly related to the geologic units present. As discussed, Qvt was observed to be thickening in the upstream direction above the thinning Qva. Qva, though dense, is more erodible than Qvt and allows for the stream to erode the material at a more uniform rate, therefore forming a shallower slope. Following this trend is also a change in width. The valley and channel width both become narrower in the upstream direction for the same reasons as the change in slope.

According to my grain size analysis, the material is suitable for kokanee habitat. However, the substrate composition also factors into the habitat potential which I did not complete. Where I observed landslide debris, woody debris in the channel, areas of high embeddedness, and sand bars habitat may locally be inadequate for the salmonids. Because of the low frequency of these areas of embedded gravels, I do not believe that it is a dominant feature. Overall, the gravels are small enough for the kokanee to create redds but are not so small that they will suffocate the eggs.

Besides in the slot-canyon pools only occur where landslide debris has force step-pool features and where woody debris occurs in the channel. These pools are infrequent and many may only be temporary as the stream may quickly and easily redistribute the sediment from landslides. As discussed the channel appears to be aggrading and has the potential to be inundated by landslide debris. With the potential of redds being destroyed by these processes I do not believe that the study-reach provides an adequate habitat for kokanee.

8.0 Recommendations

Without flowing water throughout the entire reach, several measurements and observations were difficult to assess. I had to infer the location of the main channel as well as features such as pools and was unable to measure water temperature, water depth, and turbidity. I recommend that a survey of the stream and landslide hazard be conducted during the wet season as well as continued monitoring within the channel with flow gages.

The water that was present near the upstream drain was orange with a viscous outer film. It is mostly likely an oxidation reaction occurring but there should be an evaluation of water quality.

Included in the survey should be an evaluation of the current conditions of the culvert, drains, and overflow structure. In the field I observed that the drain from the east tributary of Vasa Creek appears to have been damaged by failure of fill material from above.

With the upstream erosion occurring in the slot-canyon, there should be an assessment/monitoring of that slope and the flow from the drain in order to hopefully prevent damage to local property.

9.0 Limitations

This report has been prepared for use by the City of Bellevue as a template for a basin study of the Vasa Creek Watershed. It provides the geologic and geomorphic conditions that are present within my study-reach of Vasa Creek. This is based on personal field work and data analysis and should not be used as a guarantee of slope stability, channel conditions, or subsurface information. Other factors including hydrology, water quality, and a complete survey of kokanee salmon habitat and channel morphology are excluded from my work.

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Figures

Figure 1. Geographic location of Vasa Creek and my study-reach. Image from Google Earth.

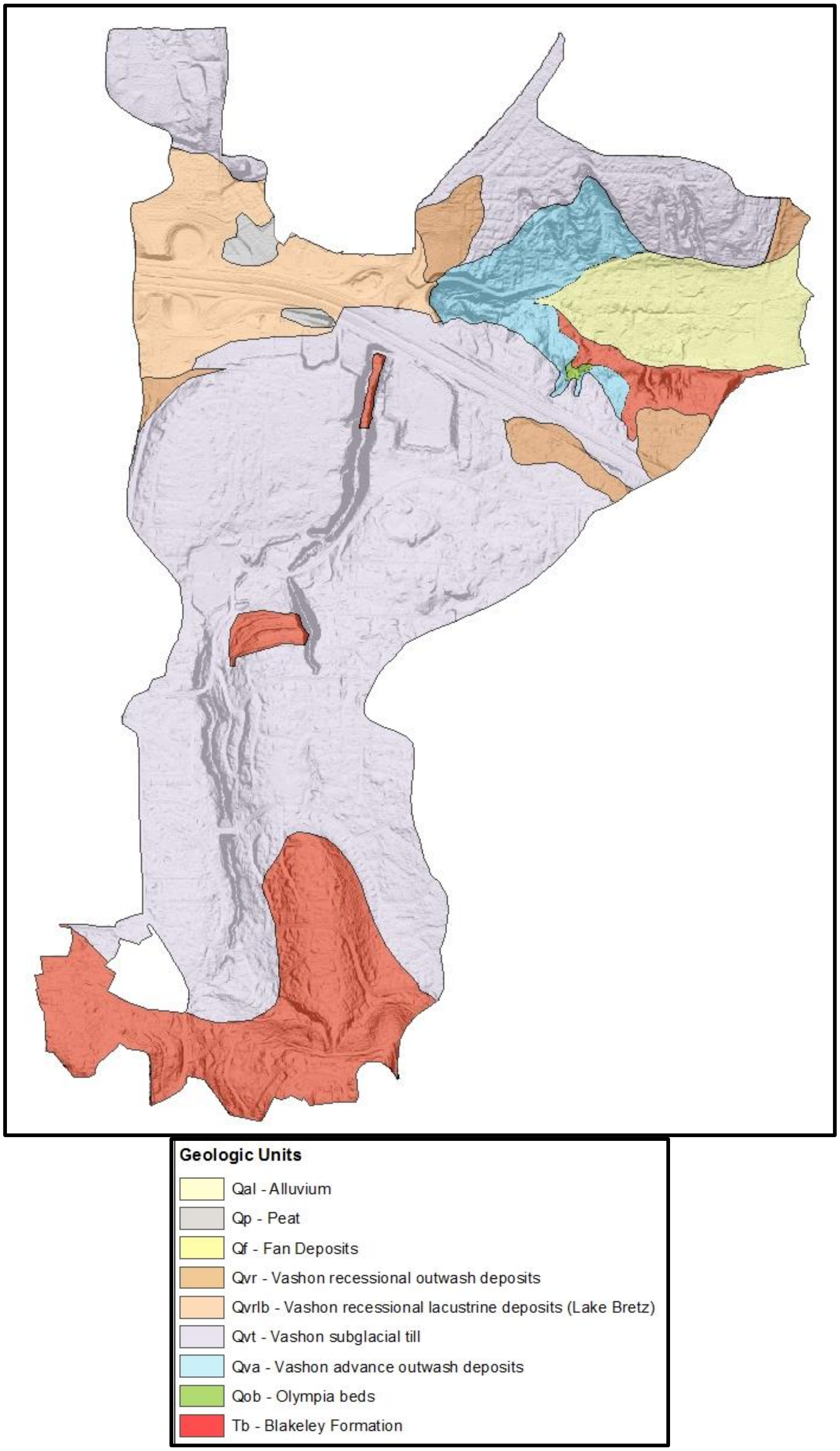


Figure 2. Geologic map by Kathy Troost, 2012. This map was used as a basis for interpretations made in the field to produce an updated geologic map.

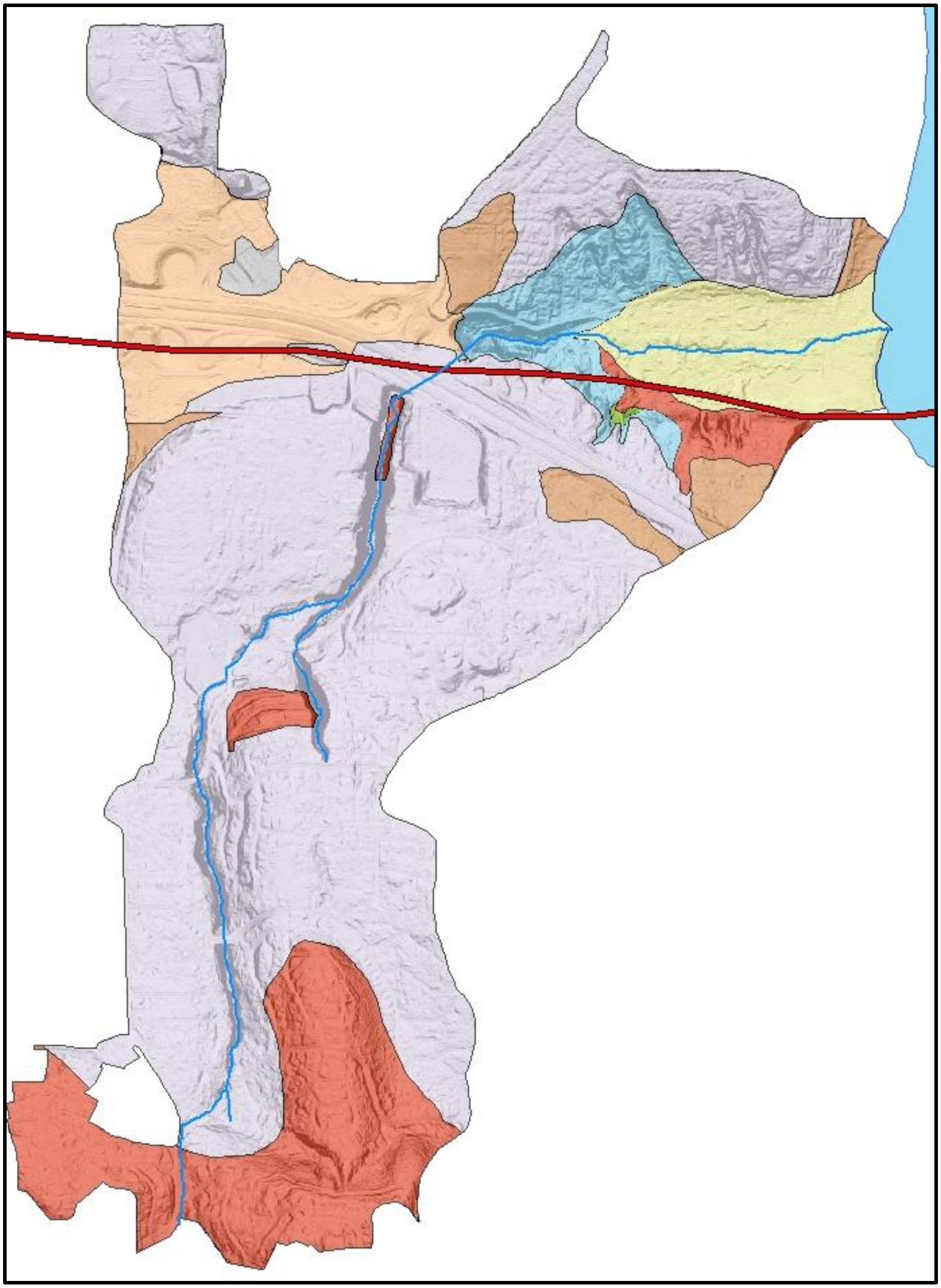


Figure 3. Location of the Vasa Park Fault, a strand of the Seattle Fault. The entire basin lies within the boundaries of the Seattle Fault Zone.

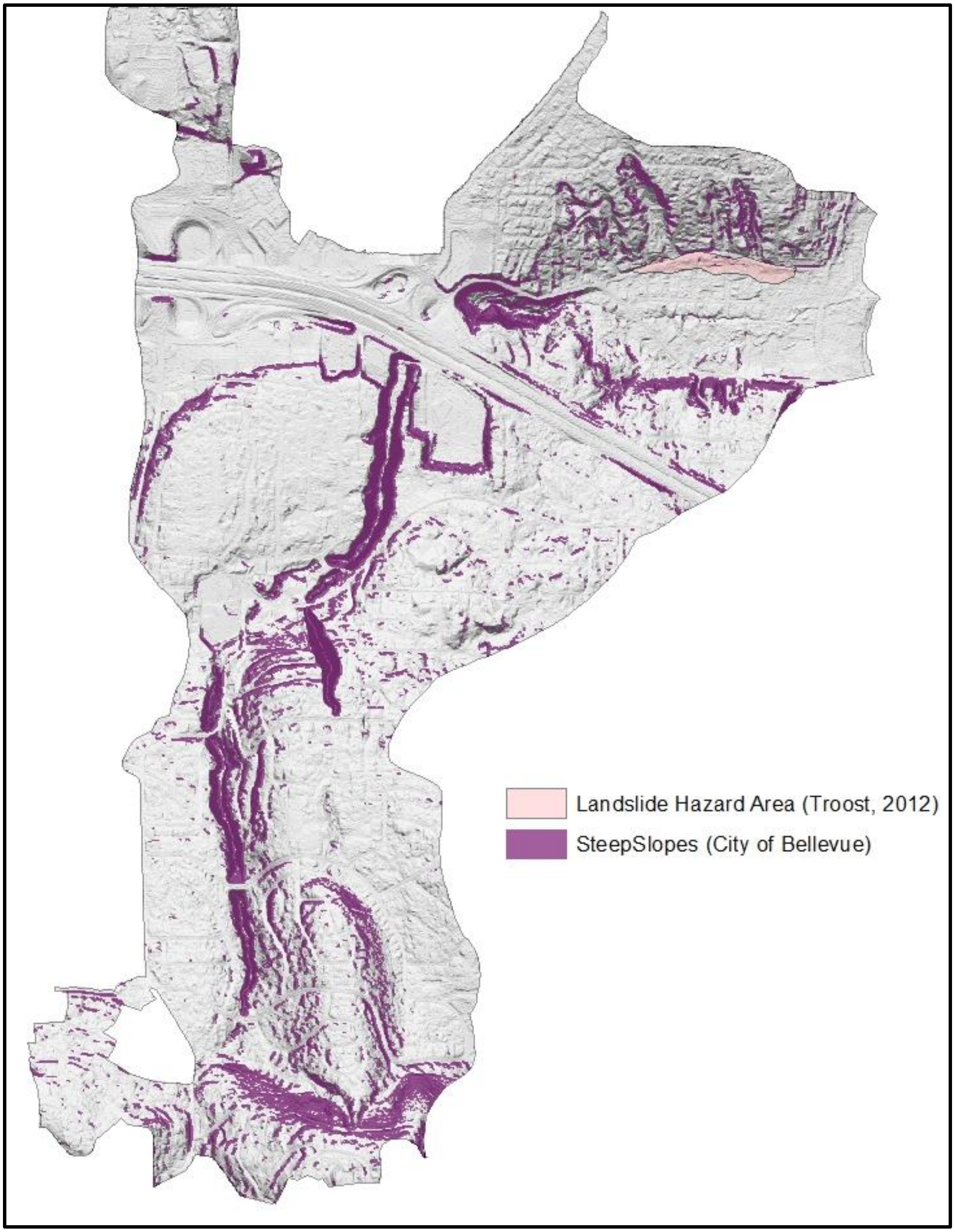


Figure 4. Previously mapped areas susceptible to landsliding. The City of Bellevue defines steep slopes at those >40%. Though steep slopes are mapped within Vasa Creek, no locations of landslides occur here. This is not a complete landslide hazard assessment.

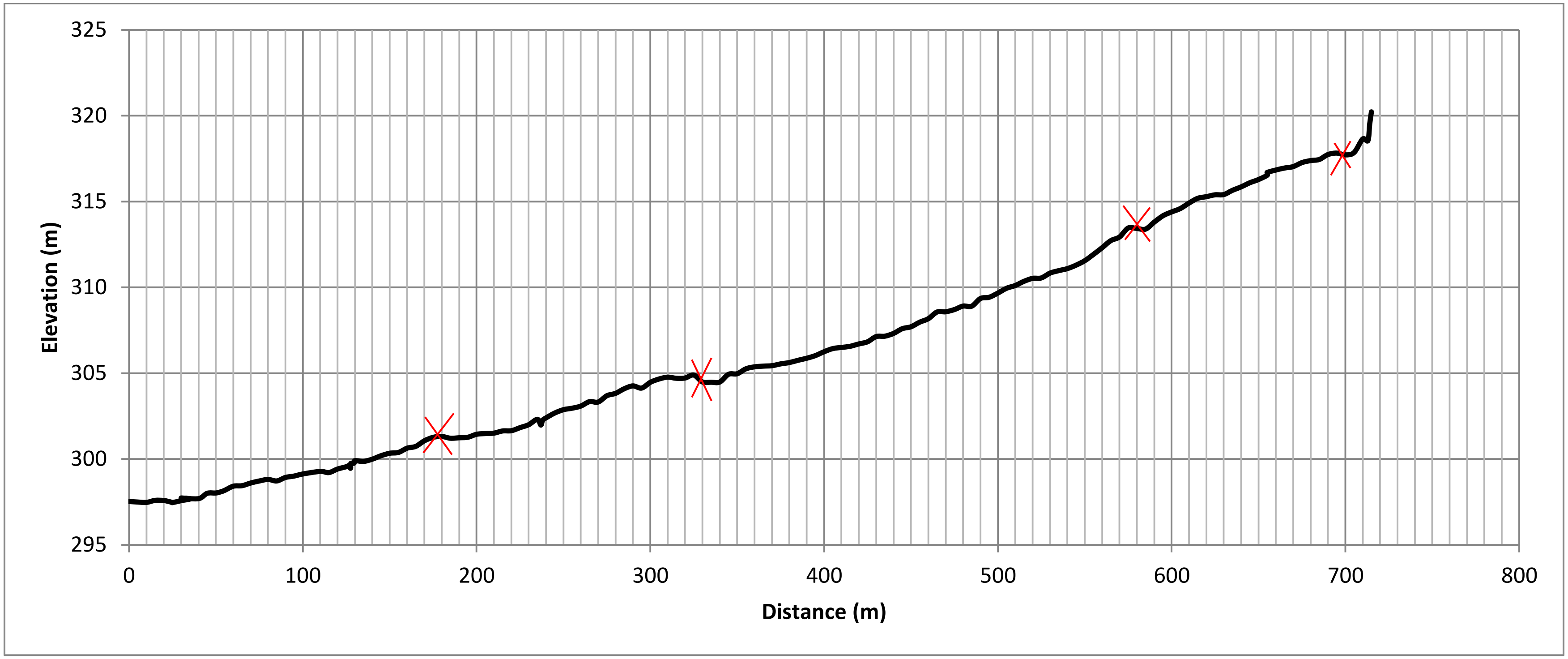


Figure 5. Longitudinal profile of the study-reach. The survey followed what was interpreted to be the main channel. A break in slope is indicated by a red 'x'. X10 vertical exaggeration.

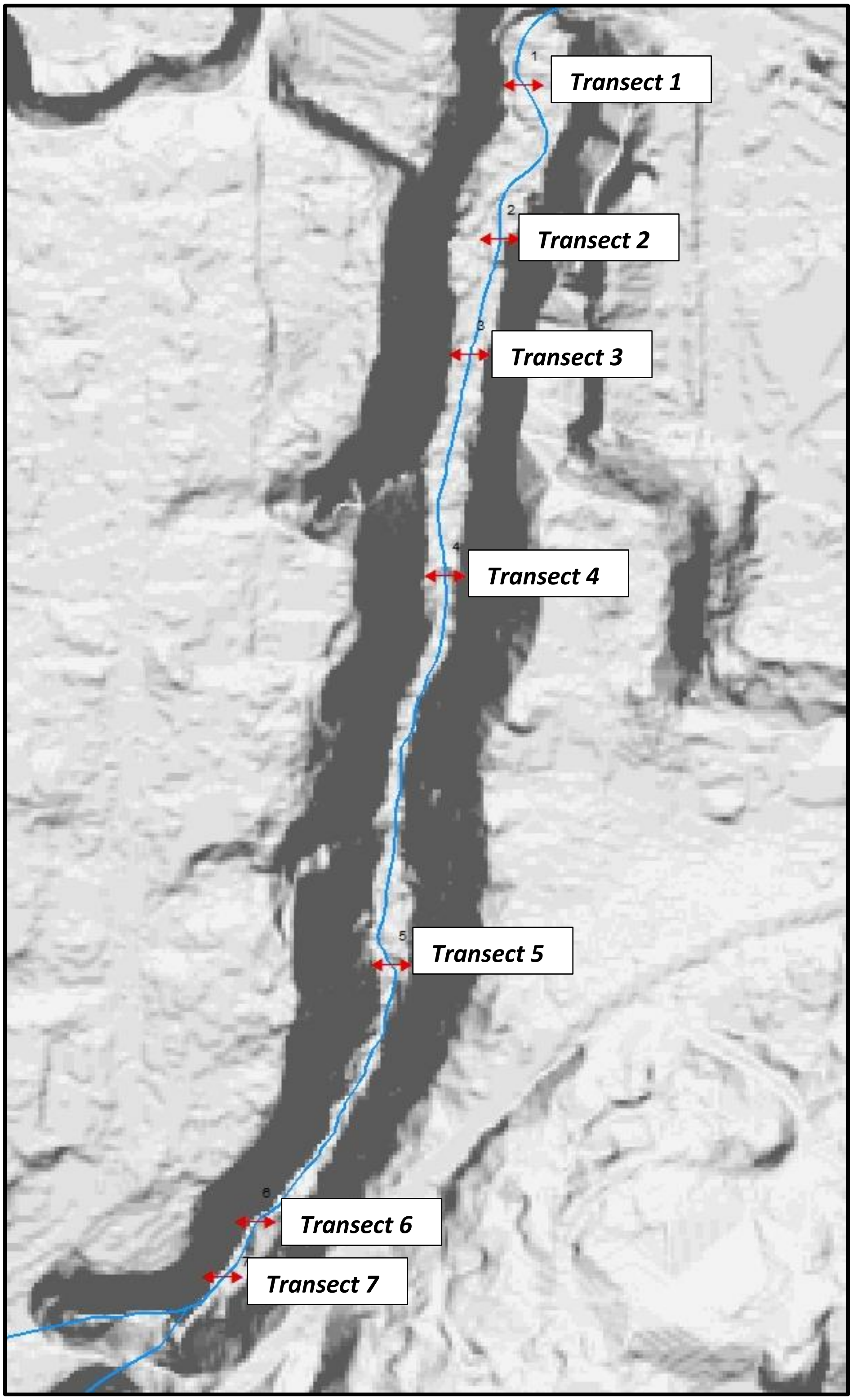
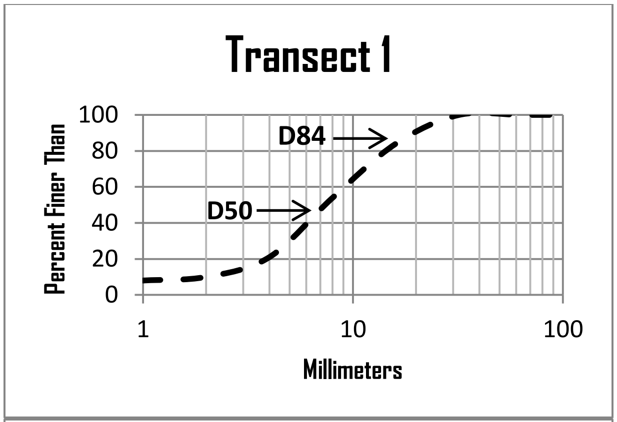
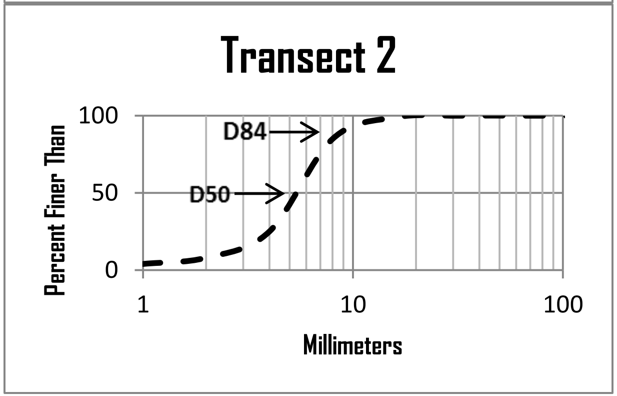
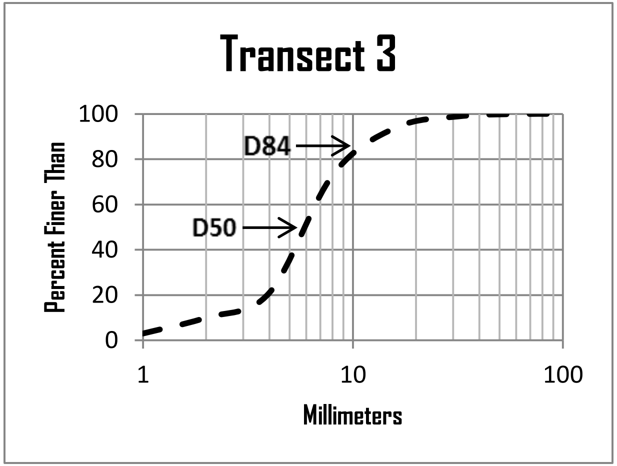
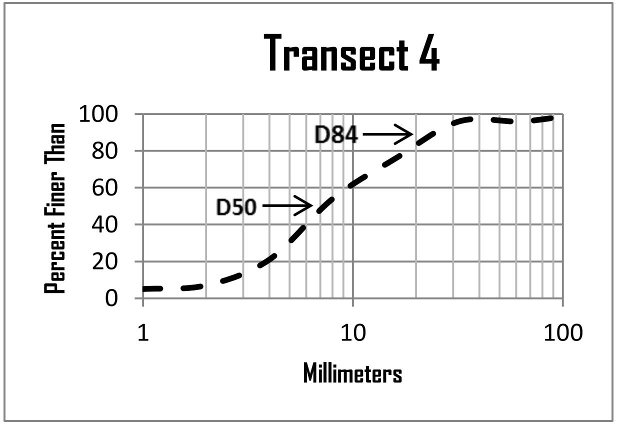


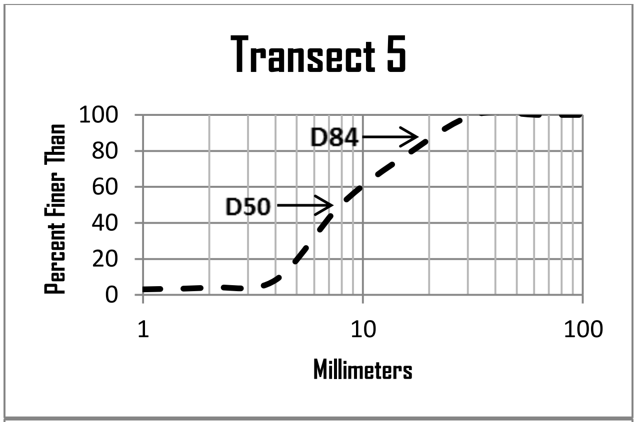
Figure 6. Locations of surveyed cross-channel transects.

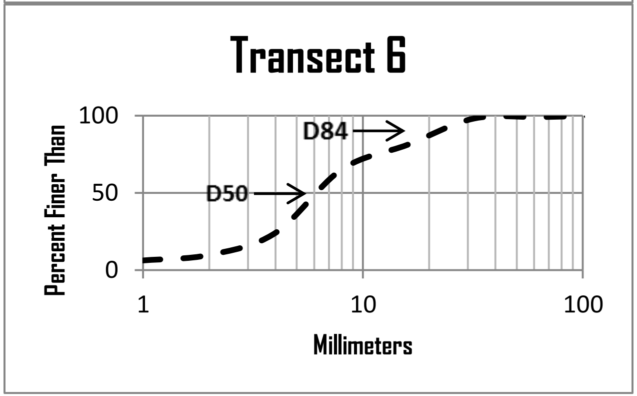












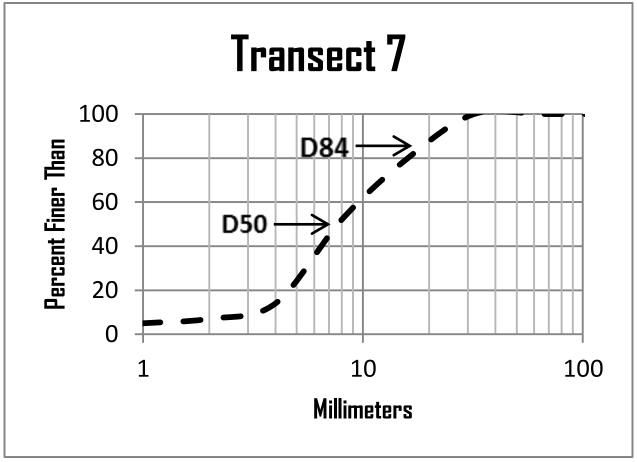
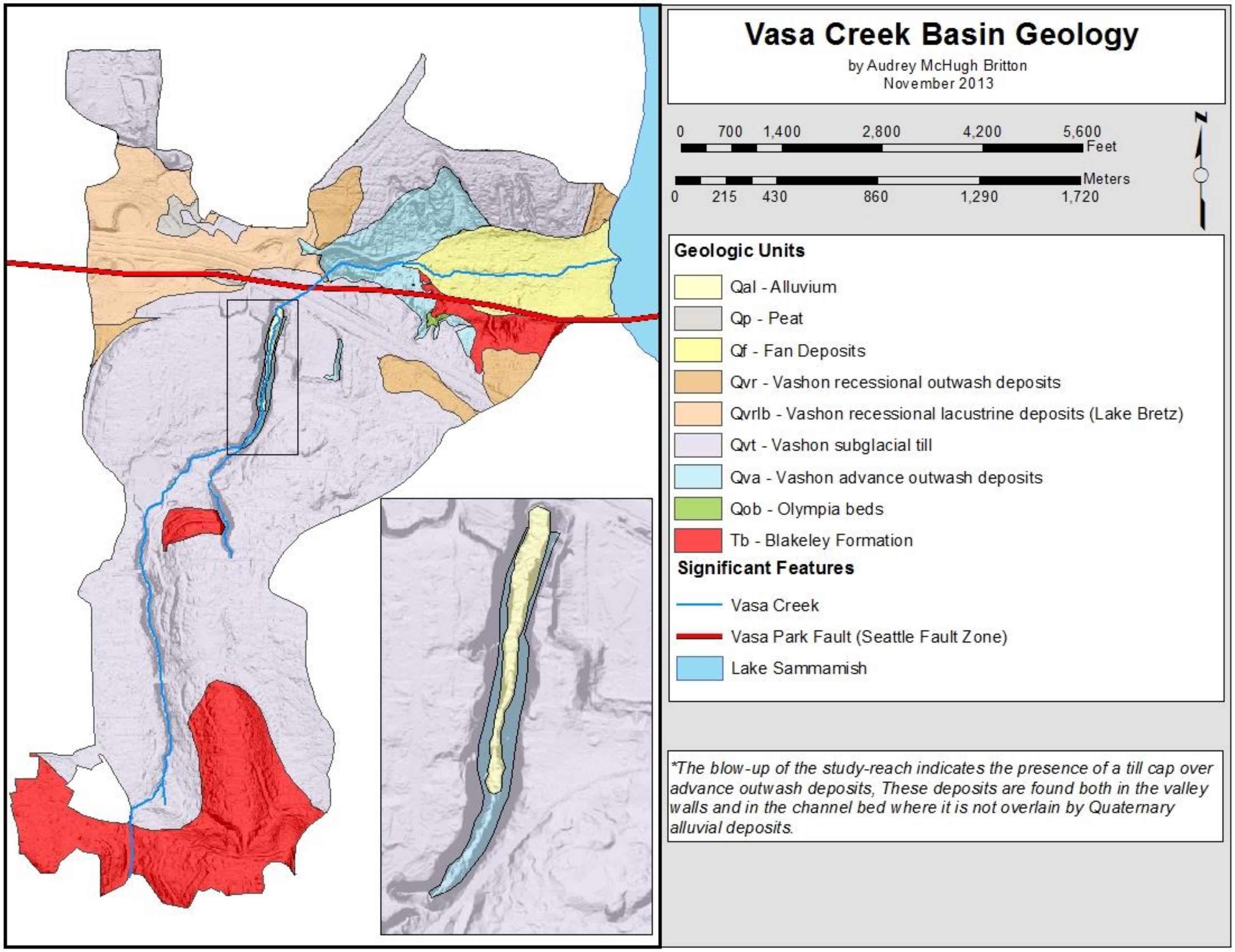


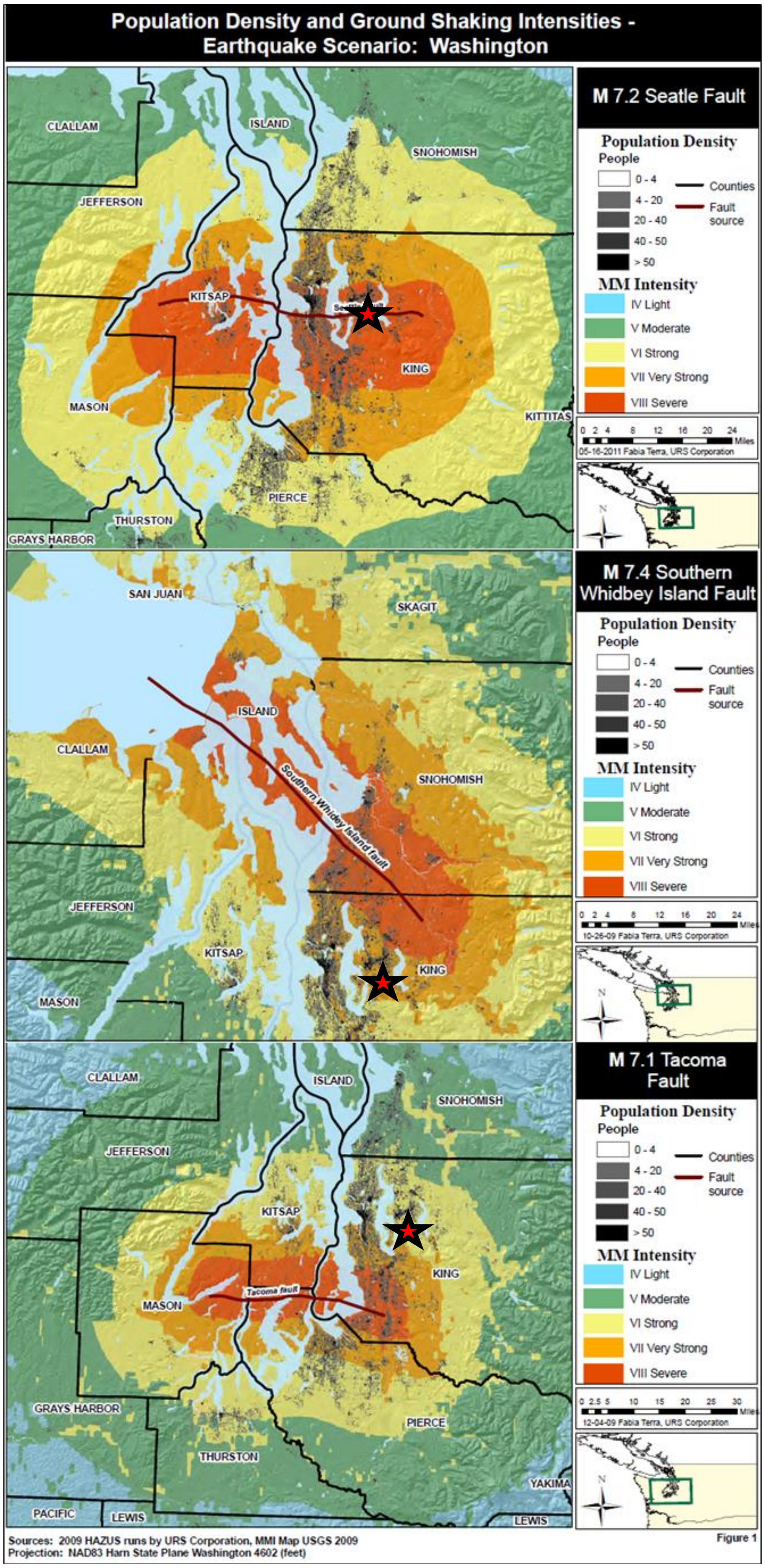
Figure 7. Particle distribution curves constructed from pebble counts at each cross-sectional transect. D84 and D50 values are indicated on the curve.

Figure 8. Landslide scarp and exposure of Qvt over Qva. The contact was interpreted where bedding associated with Qva was no longer observed.



**The blow-up of the study-reach indicates the presence of a till cap over advance outwash deposits, These deposits are found both in the valley walls and in the channel bed where it is not overlain by Quaternary alluvial deposits.*

Figure 9. Updated geologic map of the Vasa Creek Watershed. Field observations and borehole data provided the information necessary to alter the previous map.



Sources: 2009 HAZUS runs by URS Corporation, MMI Map USGS 2009
Projection: NAD83 Harn State Plane Washington 4602 (feet)

Figure 10. HAZUS maps created by FEMA to display ground shaking intensities. Location of the Vasa Creek Watershed is indicated with a star.This information can be found in the Washington State Seismic Hazards Catalog.

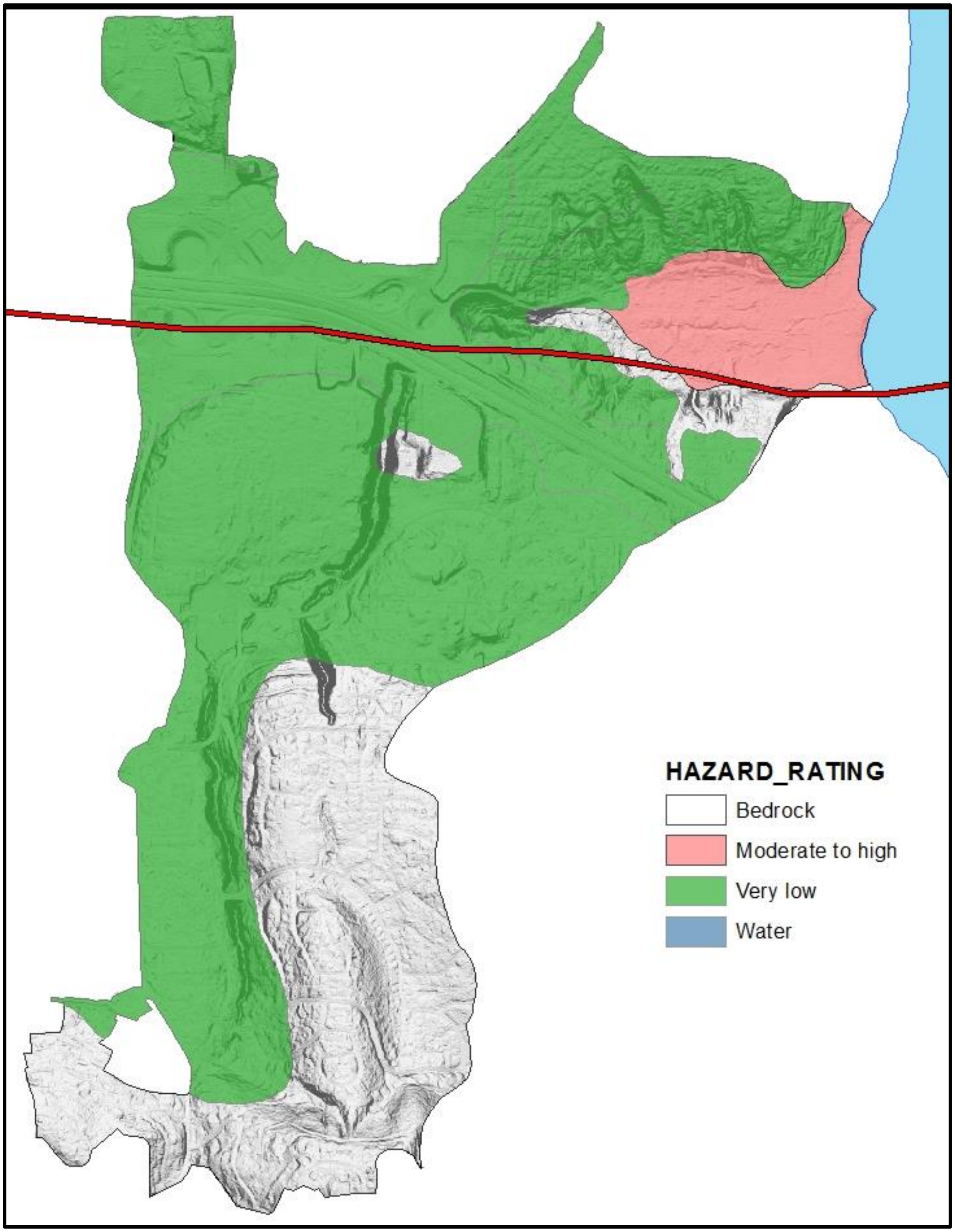


Figure 11. Liquefaction hazard map. The lower reach of Vasa Creek is most susceptible to liquefaction as it is within an alluvial fan deposit. Data provided by King County.

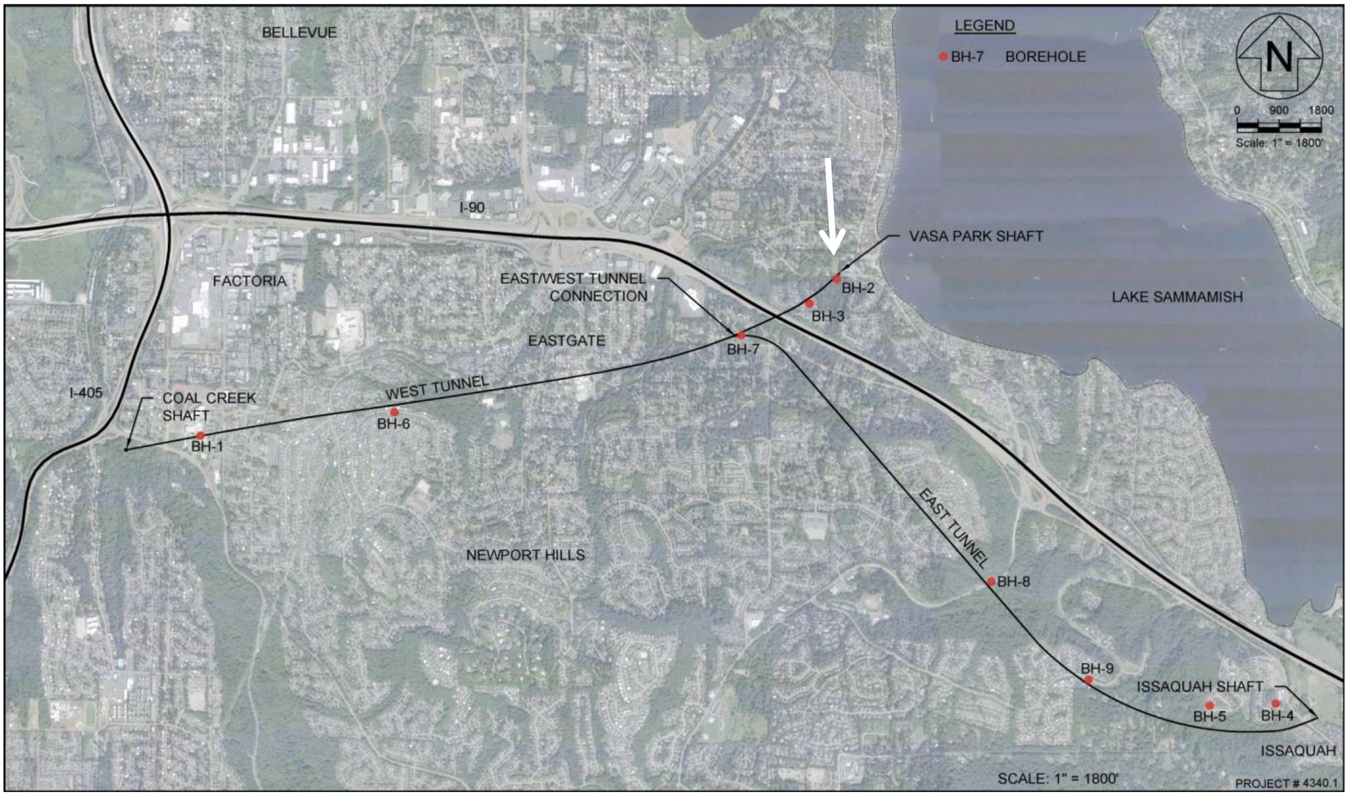


Figure 12. Borehole locations of Sue Bednarz's west tunnel study. Borehole 2 (BH-2) is located in Vasa Park and its sample provided evidence of the Vasa Park Fault.

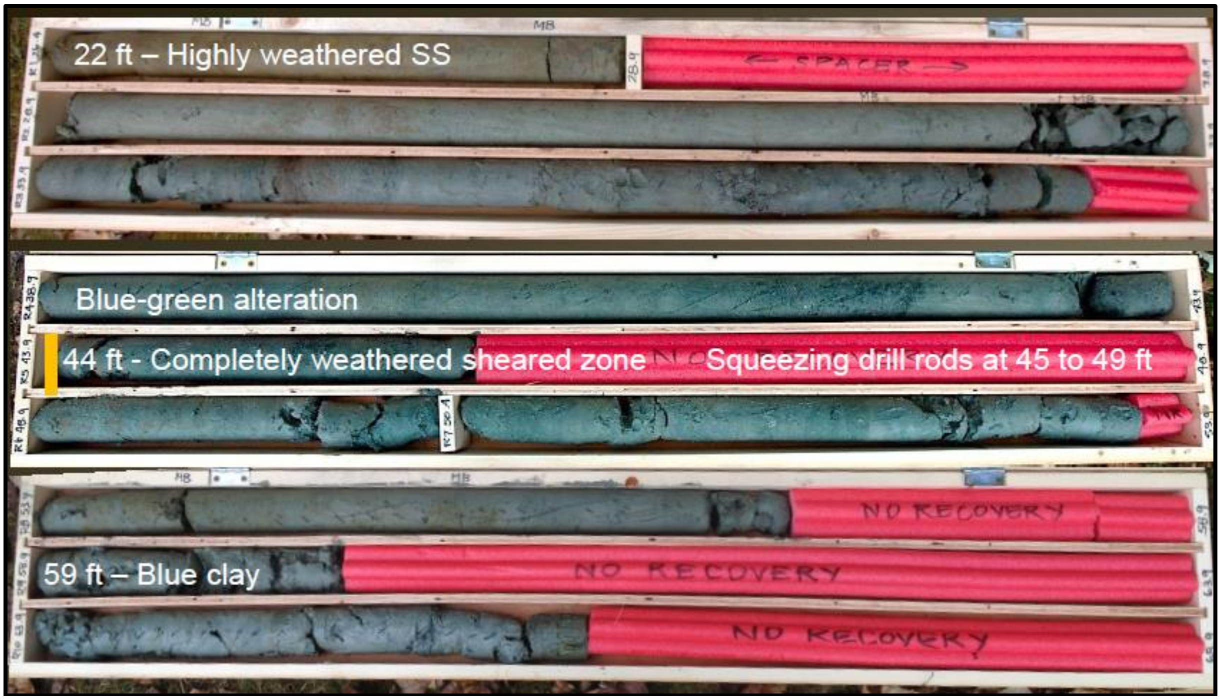


Figure 13. Photograph of the borehole sample collected at BH-2. Image from Sue Bednarz.

Figure 14. Photo of an embedded log within the channel creating a pool by scour.

Figure 15. Example of what is considered significant woody debris. The debris is assumed to influence flow and sediment accumulation within the channel.

Figure 16. Photo of a gabion wall that was installed to stabilize the west slope. Undercutting by the stream has led to angular blocks falling out from under the wire.

Figure 17. Photo of erosional feature within the channel. A slight exposure of Qva being undercut by the stream. Photo was taken after heavy rains so water is present.

Figure 18. Photo of the upstream drain (left) and the slot-canyon.

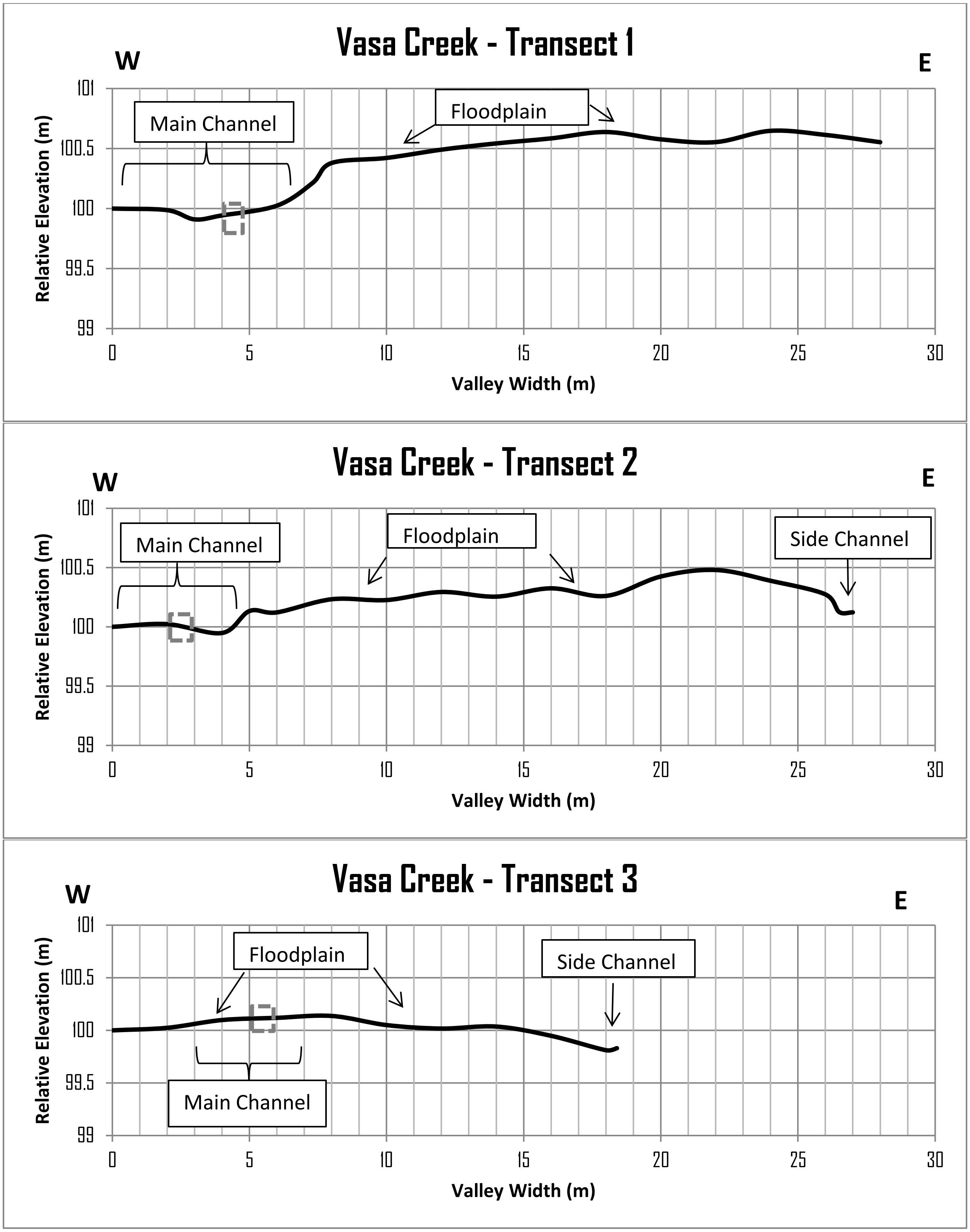


Figure 19. Cross-sectional profiles along Transects 1-3. X5 vertical exaggeration. Locations of pebble counts are outlined in gray and other observed features are labeled.

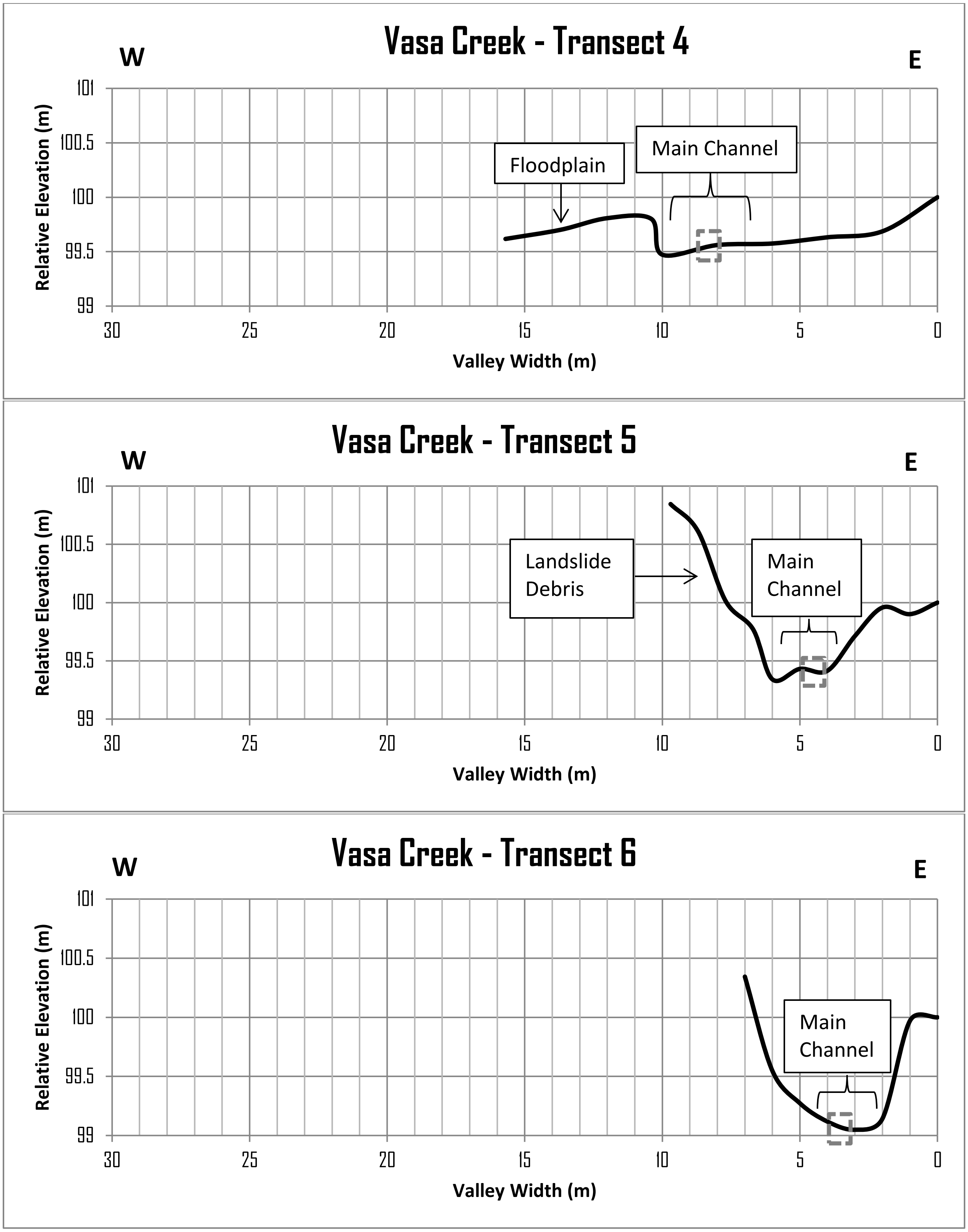


Figure 20. Cross-sectional profiles along Transects 4-6. X5 vertical exaggeration. Locations of pebble counts are outlined in gray and other observed features are labeled.

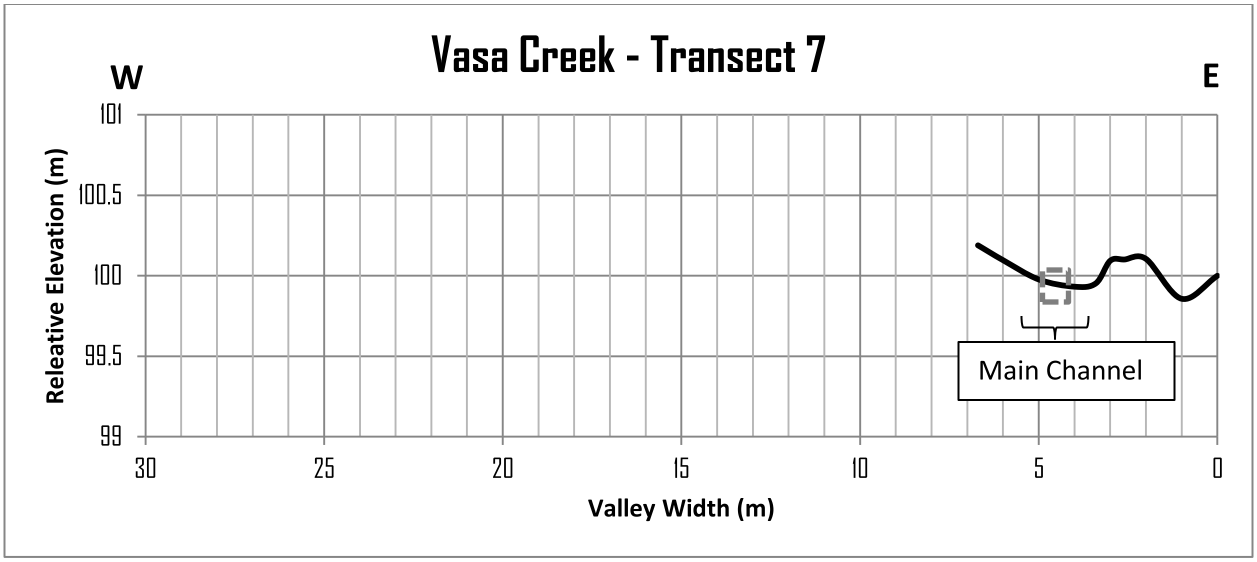


Figure 21. Cross-sectional profile along Transect 7. X5 vertical exaggeration. Locations of pebble counts are outlined in gray and other observed features are labeled.

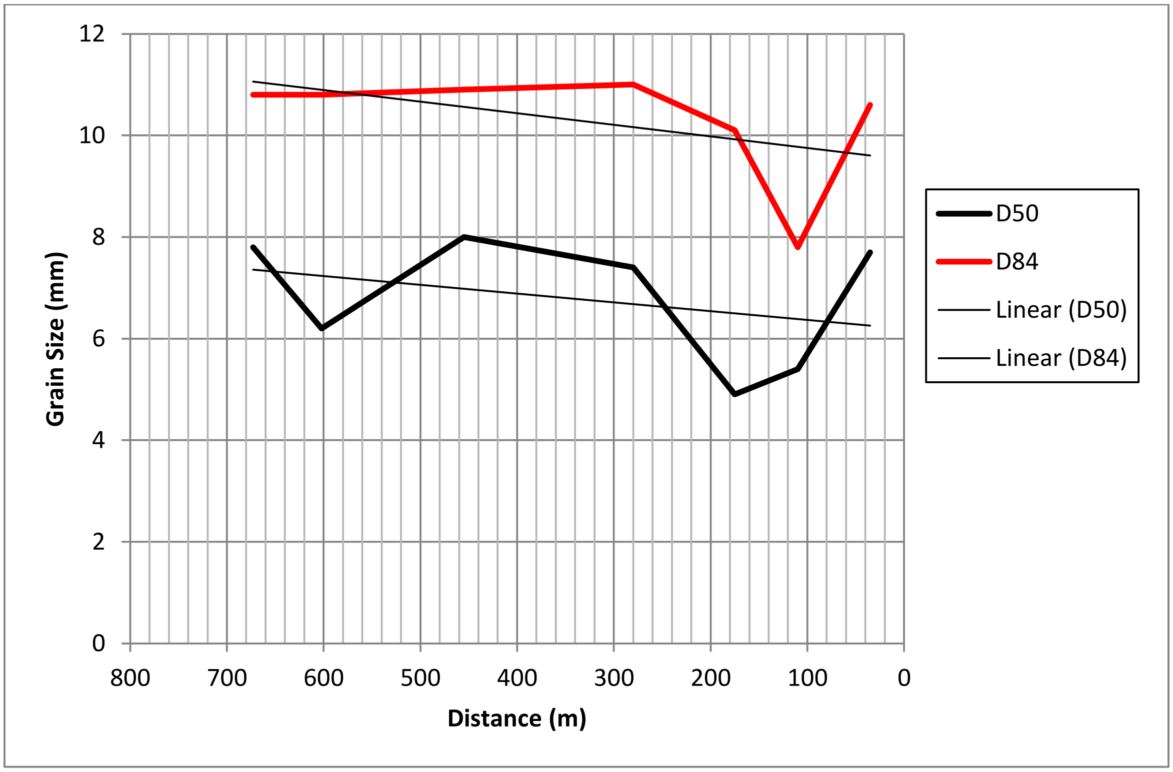


Figure 22. Downstream trend in grain size within the study-reach. Counts were conducted at each cross-channel profile indicated by the data points shown.

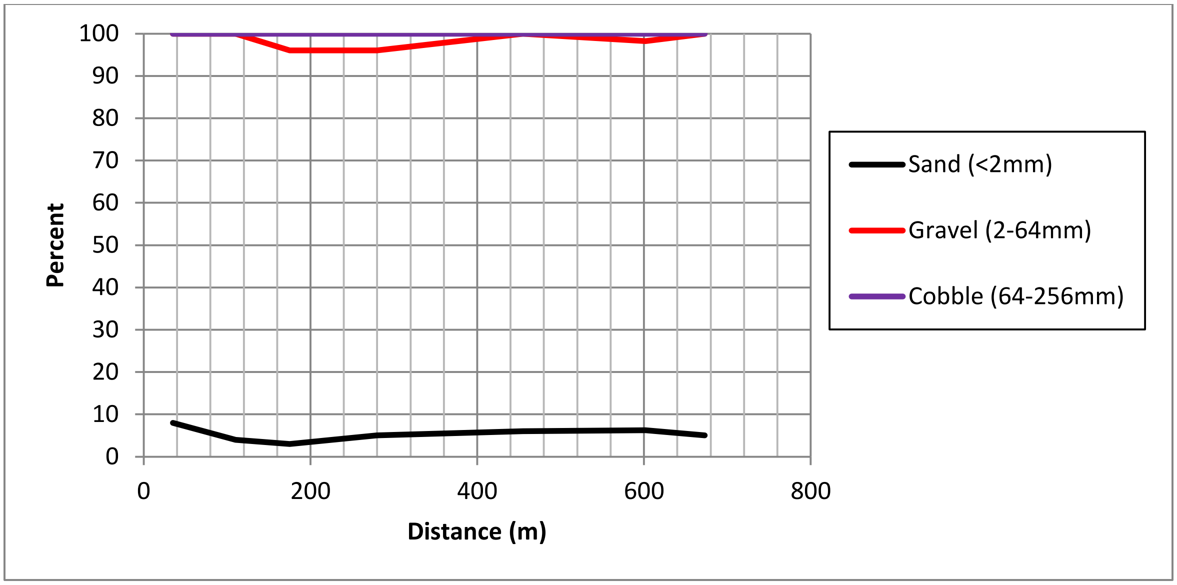


Figure 23. Upstream trends in the cumulative percentages of sand, gravel, and cobble. The percentage of each grain size class is cumulative and is represented by the space between the lines.

Figure 24. Photograph of a fresh deposit of fine sediment after heavy rains (left) and blown vegetation in the direction of flow (right) within the study-reach.

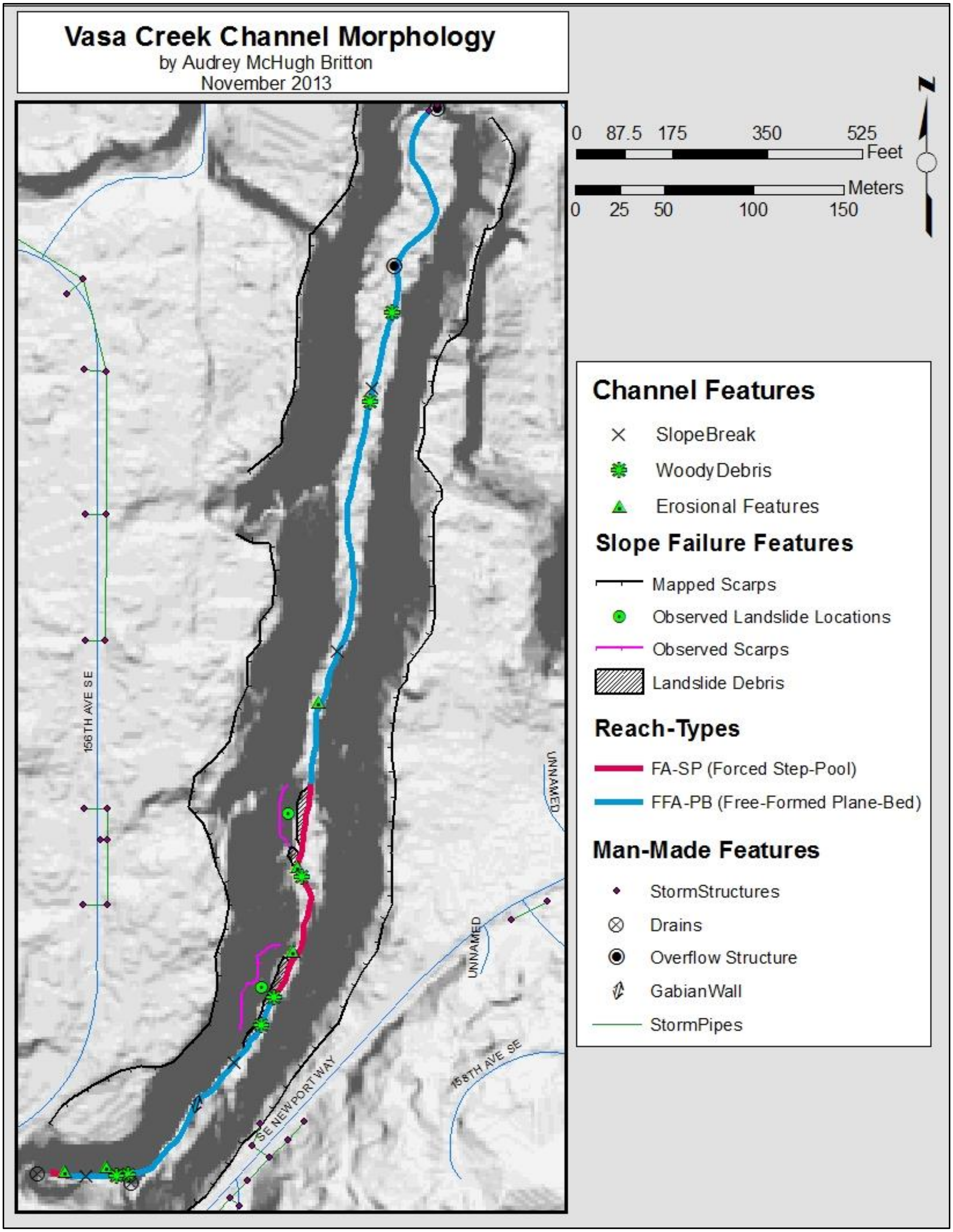
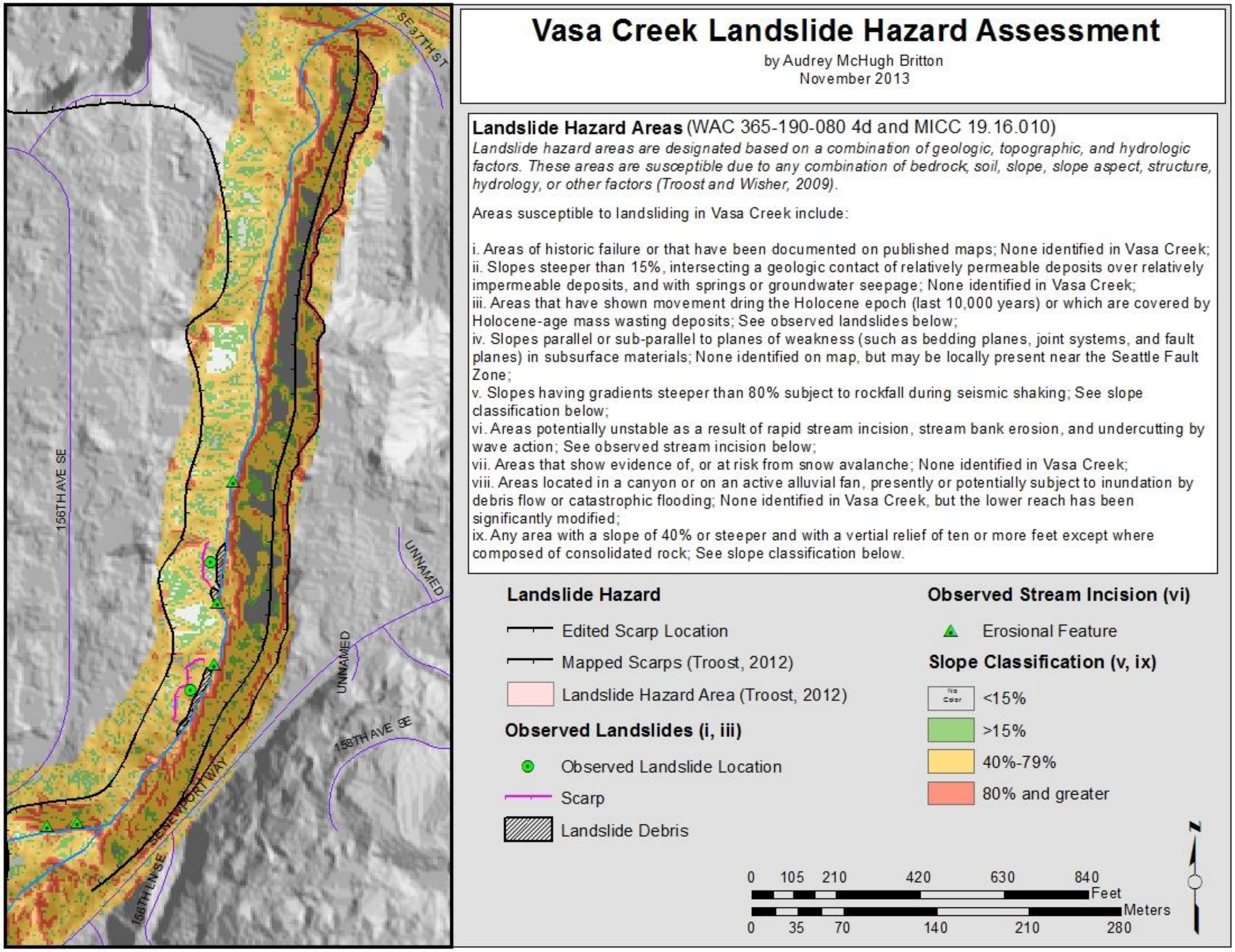


Figure 25. Channel morphology map of the Vasa Creek study-reach. Unoriginal data provided by the City of Bellevue and Kathy Troost.



Vasa Creek Landslide Hazard Assessment

by Audrey McHugh Britton
November 2013

Landslide Hazard Areas (WAC 365-190-080 4d and MICC 19.16.010)

Landslide hazard areas are designated based on a combination of geologic, topographic, and hydrologic factors. These areas are susceptible due to any combination of bedrock, soil, slope, slope aspect, structure, hydrology, or other factors (Troost and Wisher, 2009).

Areas susceptible to landsliding in Vasa Creek include:

i. Areas of historic failure or that have been documented on published maps; None identified in Vasa Creek;
ii. Slopes steeper than 15%, intersecting a geologic contact of relatively permeable deposits over relatively impermeable deposits, and with springs or groundwater seepage; None identified in Vasa Creek;
iii. Areas that have shown movement dring the Holocene epoch (last 10,000 years) or which are covered by Holocene-age mass wasting deposits; See observed landslides below;
iv. Slopes parallel or sub-parallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials; None identified on map, but may be locally present near the Seattle Fault Zone;
v. Slopes having gradients steeper than 80% subject to rockfall during seismic shaking; See slope classification below;
vi. Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action; See observed stream incision below;
vii. Areas that show evidence of, or at risk from snow avalanche; None identified in Vasa Creek;
viii. Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flow or catastrophic flooding; None identified in Vasa Creek, but the lower reach has been significantly modified;
ix. Any area with a slope of 40% or steeper and with a vertical relief of ten or more feet except where composed of consolidated rock; See slope classification below.

Figure 26. Completed slope stability assessment map of the 720m study-reach.

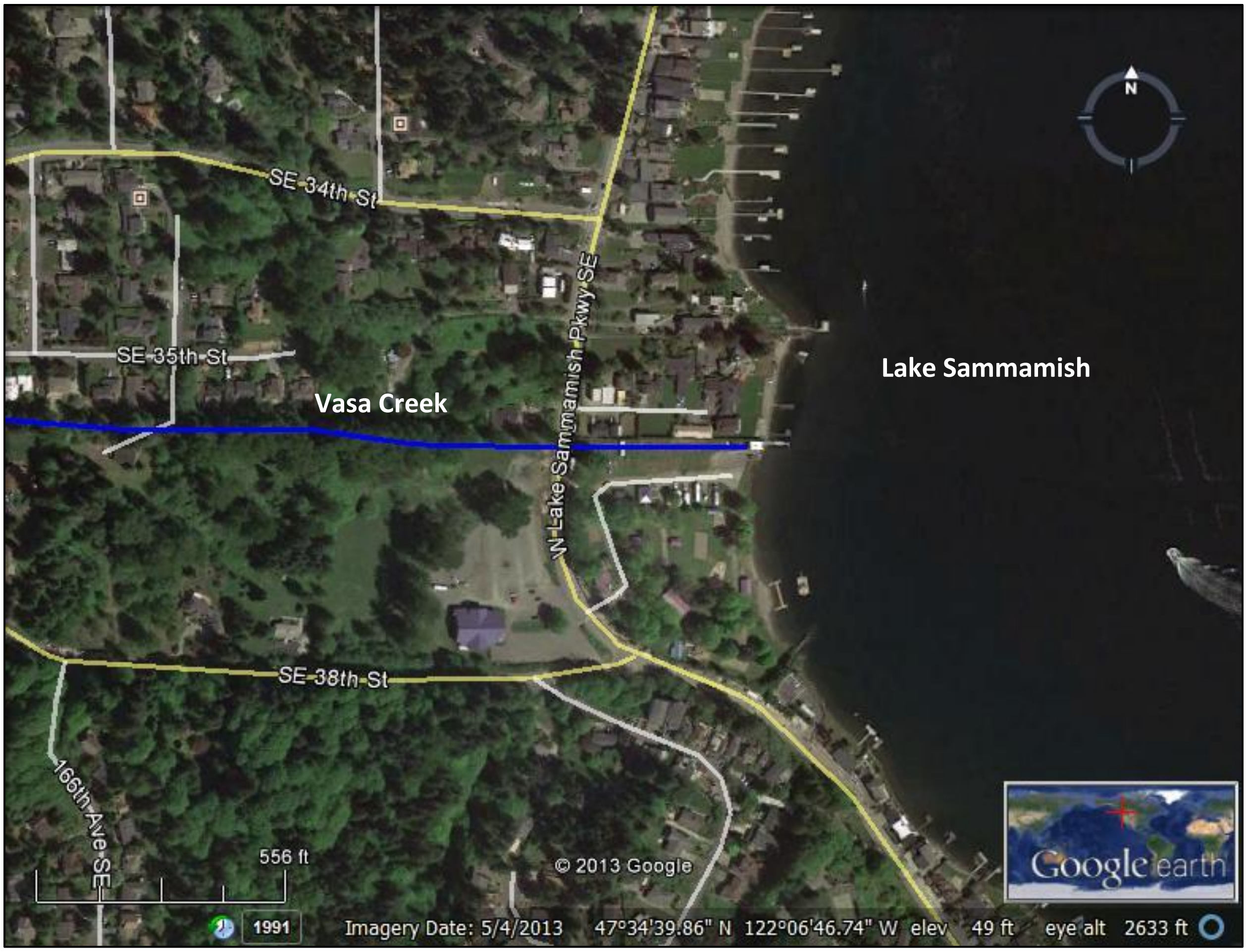


Figure 27. Location of Lake Sammamish Parkway. According to locals, kokanee salmon have not been observed migrating much further upstream than Lake Sammamish Parkway.

Tables

Table 1. Slope breaks segments along the longitudinal profile of Vasa Creek and their associated gradient. Distance within the study-reach is measured in the upstream direction (i.e. 0m is downstream and 720m is upstream)

Slope Breaks					
Channel Segment (m)	0-170	170-320	320-570	570-705	705-720
Gradient (%)	2.08	2.44	3.26	3.66	15.37

Table 2. Results from the grain size analysis at each transect location. I identified the 50th and 84th percentile grain sizes as well the percentage of fines observed and the percentage of suitable gravels as defined by the Bureau of Reclamation (*2007*).

Transect #	D50 (mm)	D84 (mm)	% Fines (<4mm)	% Suitable Gravels (12-128mm)
1	7.7	10.6	8	59
2	5.4	7.8	4	41
3	4.9	10.1	3	48
4	7.4	11	5	47
5	8	10.9	6	72
6	6.2	10.8	6.25	60
7	7.8	10.8	5	67

Table 3. Tabular representation of identified channel reach-types within the study-reach. The forced step-pool/riffle represents smaller features than are typically used to classify streams, however, material deposited within the channel creates infrequent steps and irregular terrain.

Reach Type	Segment	Length (m)	Units
Plane-Bed	0-395m	395	Infrequent small pools (<channel width)
Step-Pool/Riffle	395-485m	90	Forced by landslide debris; characterized by hummocky terrain
Plane-Bed	485-710m	225	Infrequent riffle potential, no small pools observed
Step-Pool	710-720m	10	Incision forms a small slot-canyon

Appendix

Appendix-1: Elevation is based off of data provided by the City of Bellevue.

-Overflow structure rim elevation: 298.52m
-Field measured occurrence of water below the rim: 2.75m
-Height of rim above ground surface: .8m
-Ground elevation at the structure: 297.72m