GeoEngineers

Memorandum

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From:	Mary Ann Reinhart, PG GeoEngineers; Leif Embertson, PE, Natural Systems Design
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File:	0441-012-00, Farmhouse Reach Restoration
Subject:	Geomorphic Characterization and Response Assessment

GeoEngineers, Inc. and Natural Systems Design (NSD) is pleased to present this summary memorandum regarding our geomorphic characterization of a Restoration project situated within the Farmhouse Reach of the North Fork Nooksack River, located near Maple Falls, Washington. The services for this project were completed in general accordance with the scope of services described in our subconsultant agreement with Herrera dated November 8, 2010.

The purpose of the this project is to determine the location, feasibility, and design of multiple large engineered logjams (ELJs) intended to slow rates of channel migration, increase the stability of forested islands and the riparian corridor, increase pool habitat, improve connectivity between the low flow channel and side channels, and reduce redd scour to ultimately improve habitat conditions for North Fork Nooksack early Chinook salmon (*Oncorhynchus tshawytscha*).

The Farmhouse Reach is located 2 miles southwest of the Town of Maple Falls and along the North Fork Nooksack River (North Fork) in Whatcom County, Washington. The reach begins at river mile (RM) 46.8 near the Bennett Farms (Bennett Farms) Ranch and extends upstream to RM 49.4 near the outlet of a confined canyon reach. State Route 542 is located north of the channel and runs primarily in east-west direction along the project reach. Figure 1, attached to this report, is a vicinity map of the project area.

Geomorphic Characterization Approach

The goal of characterization is to identify and describe dominant channel forming processes within the North Fork Farmhouse Reach for use in the development of project alternatives. Tasks and services performed included field reconnaissance, a qualitative geomorphic assessment and characterization, review of pertinent studies and reports for the North Fork and important tributaries, review of aerial photographs, preliminary analyses using available Light Detection and Ranging (LiDAR) and hydrologic data, review of conceptual restoration plans and hydraulic model results, assessment of potential channel response to proposed restoration features, and participation in multiple meetings with Herrera and Nooksack Tribe Natural Resource staff. Specific materials used for this characterization include;

- Studies and reports listed in the references section of this memorandum
- Aerial photos, maps, and digital channel traces provided by the Nooksack Tribe for years 1891, 1938, 1955, 1967, 1976, 1986, 1994, 2008, and 2010.
- Aerial photos available from Google Earth© for years 1998, 2003, and 2005.
- LiDAR from 2005 and 2006 provided by the Nooksack Tribe.
- Photogrammetry from 1994 and 2004 provided by the Nooksack Tribe.

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- Hydrologic gage records for USGS gage 12205000
- Conceptual layouts of project alternatives provided by Herrera

BACKGROUND

The North Fork Nooksack River (North Fork) historically supported healthy populations of anadromous fish that included spring Chinook, coho, chum, pink, and sockeye salmon as well as coastal cutthroat and ESA-listed species; Chinook, steelhead and bull trout, all of which are threatened. Within the project reach, recent Chinook spawning has been limited however it was once one the more active spawning areas in the North Fork (Schuett-Hames et al. 1988c). Currently, many of these species are listed as threatened or endangered under the Endangered Species Act (ESA) within the Nooksack watershed. Human actions such as timber harvest, removal of natural logjams, clearing of floodplain forests, channel confinement, bank armoring, loss of side channel habitat, and installation of road crossing structures have led to a general simplification of habitat within the Nooksack watershed and are attributed to the recent decline in salmon abundance within WRIA1 (WRIA SRB, 2005). Within the North Fork watershed, channel instability, due in part to human actions has led to simplification and reduction of key habitat quantity and diversity in the form of a decrease in frequency and stability of channel islands and side channel habitat, lack of stable logjams and stable key pieces, and redd scour, which have been identified as the primary limiting factors for endangered spring Chinook salmon (Hyatt, 2007). The Farmhouse reach has one of the lowest concentrations of stable large wood within the North Fork (Hyatt, 2007). Restoration goals for this project include;

- Goal 1 – Improve low flow connectivity of side channels.
- Goal 2 – reduce the width of the active channel by encouraging development of a positive feedback cycle involving large wood deposition, vegetation establishment and stable bar/ island formation.
- Goal 3 – Increase key habitat quantity within mainstem and side channel areas by placing ELJs and LWD that cause local scour and complex edge habitat.
- Goal 4 – Increase the persistence of mature forested islands and riparian habitat.
- Goal 5 – Do not increase risk to private property

Based on these broad restoration goals, the specific project objectives for the Farmhouse Reach were developed through discussion with Herrera, the Nooksack Tribe and GeoEngineers and include the following;

- Create 11,000-feet of side channels that are connected with dominant channel
- Reduce the active channel area to 200-acres or to similar extents observed in early 20th century records.
- Create 30 pools within the active channel with a focus on side channels where stable spawning habitat exists.
- Encourage the development of mature conifer-dominated islands and floodplain forests.

REGIONAL SETTING

Introduction

The North Fork Basin is approximately 40-miles in length and drains a 287-square miles area composed primarily of high relief mountainous terrain along the western edge of the North Cascades Range. The North Fork originates at an alpine glacier on the east side of Mount Shuksan and flows west and south to its confluence with the Middle Fork near Deming, Washington.

Basin Topography

The terrain comprising the North Fork Basin is rugged and of very high relief. The drainage divide separating the North Fork Basin from adjacent basins is formed by three major peaks, Mt. Shuksan (elevation 9,040-feet) Mt. Baker (elevation 10,750-feet) and Sumas Mountain (elevation approximately 3,500-feet), and several lesser peaks including Goat, Church, and Slide Mountains.

The North Fork channel corridor is confined in a deeply incised valley. The geometry of the upper river valley varies from V-to U-shaped; the valley walls are generally steep. The valleys confining the middle and lower river reaches widen sufficiently in the downstream direction to form broad U-shaped valleys with alluvial floodplains and glacial outwash terraces.

The upper one-third of the drainage extends from the headwaters down to Glacier Creek. The river flows generally westward and is confined on the south by Mt. Baker, on the east by Mt. Shuksan, and on the north by Goat and Church Mountains. The vertical relief of the valley walls in this area exceeds 6,500-feet. Topography within the river corridor consists of relatively low relief flood terraces and mixed landslide and alluvial fan deposits.

The middle section of the drainage is situated in terrain similar to the upper drainage, but with a wider valley floor. This section extends from Glacier Creek to Maple Falls at Maple Creek. The river is bounded by Slide Mountain on the south and Church, Bald, Black, and Red Mountains on the north. Through this area, the river flows through a series of large radius bends forming an S-turn. Corridor topography and geometry is controlled by reach scale landslide deposits. Two major landslide features are noted here: 1) the Church Mountain Landslide (Van Siclen 1994), which originated on the north side of the river and buried the channel floor in the vicinity of Glacier, Washington, and 2) a large block-slide originating on the north side of Slide Mountain, which forces the river north and west. Channel form and behavior within this section are highly influenced by alluvial fans located at the mouths of Glacier and Canyon Creeks. The fans, which form by deposition of large volumes of sediment debouching from the tributary creeks, influence the location and stability of the river channel throughout the section.

The lower one-third of the drainage, where the Farmhouse reach is located, is wider than the middle segment. The river is bounded on the west by Sumas Mountain and on the east by Slide Mountain. The river corridor is set in an open U-shaped valley bounded on river right by the sloping flanks of Red and Sumas Mountains, and on the left by landslide debris from Slide Mountain. The valley walls are drained by numerous tributaries, including Kendall, Coal, and Racehorse Creeks. The river corridor consists of a well-developed braided channel system with broad floodplains, and low relief outwash terraces. Two alluvial fans extend into the active corridor from the mouths of Coal and Racehorse Creeks, both of which influence the dynamics of the

river. Just downstream of the confluence of Coal and Racehorse Creeks is an ancient landslide from Slide Mountain that confines the river valley on the downstream end of this section.

Geology

The North Fork Basin is composed primarily of five geologic units: bedrock, undifferentiated glacial drift, ancient landslide debris deposits, alluvial fans and alluvial sediments. Bedrock units consist of Pre-Tertiary volcanic and metamorphic rocks, and Tertiary marine and terrigenous sedimentary rocks. Typically, these rocks are resistant to stream erosion. These rocks are locally exposed on the mountain sides and valley walls throughout the upper basin.

Undifferentiated glacial drift is composed of till, and outwash not separated at the map scale. Till consists of an unsorted, unstratified, highly compacted mixture of clay, silt, sand, gravel and boulders deposited by glacial ice, Outwash consists of glaciofluvial sand and gravel, with lacustrine clay, silt and sand deposited by meltwater flowing from advancing or retreating glaciers. Till deposits are generally more resistant to erosion and less pervious than outwash soils.

Ancient landslide deposits consist of poorly sorted, massive, unconsolidated, and very angular material of the Nooksack Group with varying degrees of fine sediment matrix (Van Siclen 1994). These “mega” landslides were likely the result of large magnitude earthquakes (Van Siclen 1994) and are derived primarily from the upper portions of mountainsides and ridges. The remnants of these deposits exposed to river flow are typically composed of large angular boulders up to several tens of feet in diameter, with varying amounts of fine grained sediment. Landslide deposits are typically found at the base of valley slopes, although these deposits are also found great distances from their origin. In some cases, these landslide deposits filled the entire river valley and impounded the river 10s to over 100 feet vertically from its previous location (Van Siclen 1994). Centuries of river processing have winnowed out fine sediments as the river incises through the landslide deposits. Consequently, the riverbed and banks are armored with large angular boulders increasing the resistance of the bed and lower banks to river erosion.

Alluvial fan deposits are located at the mouths of tributaries throughout the North Fork corridor. The primary mechanism for fan development is generally the deposition of excess sediment delivered from a variety of sediment production and transport processes. Peak stream flow, mud or debris flows, log dam or landslide dam break floods, rock falls, and snow avalanches have all been associated with fan formation within the North Fork corridor (Raines et al, 1996). In addition, large magnitude landslides and mass wasting within tributary basins have resulted in massive sediment influx to the North Fork (Gowen 1989, Mt Baker Ranger, 1995, Watts 1997).

Alluvial fans in the North Fork Basin vary in age and level of activity. Some alluvial fans date back to the demise of the last glacial event, with mature trees growing over large portions of their surface area, suggesting they are relatively stable, while others consist of unsorted sediment typical of recent debris flow activity and younger forested areas. The largest and most active alluvial fans in the North Fork basin are located at Glacier, Canyon, and Racehorse Creeks. Lesser fans are located at Cornell, Gallop, Boulder, Coal, and Bell Creeks.

Alluvial deposits consist of fine to boulder-sized sediment transported and deposited relatively recently by river flow. These deposits include floodplain, riverbed and gravel bar deposits. Alluvium is relatively loose

and unconsolidated, and therefore highly susceptible to erosion. Within the North Fork, there are also large sized particles that are not regularly transported by the river and likely deposited during past glaciations and from valley wall source areas.

Sediment Sources

Sediment is supplied directly to the North Fork from tributary creeks, the main stem channel, and from erosion of local channel banks and bars. The braided nature of the main stem channel, presence of older alluvial terraces, and alluvial fan characteristics within the project area, indicate that, over the long term, the Farmhouse Reach has functioned as a zone of deposition and temporary sediment storage. Sediment is stored on the valley floor in bar deposits and alluvial terraces until migrating dominant and high flow side channels engage and erode into the storage areas, at which time the project area serves as a sediment source to downstream reaches.

Upstream gravel bars, channel banks, and other fluvial deposits are likely the dominant source of sediment to the project area. The river channel is highly dynamic and gravel deposits are being continually reworked as the dominant channel migrates across the active channel area. Furthermore, the dynamic nature of the channel generates additional sediment supply by eroding banks and bluffs composed of older alluvial and glacial material. Sediment delivery to the Farmhouse reach occurs primarily via two processes; 1) relatively consistent bedload that increases in volume with stage and discharge, and 2) large, episodic, sediment impulse events commonly derived from landslides or other significant sediment production within the watershed.

Tributaries delivering sediment to the project reach include Boulder and Maple Creeks, of which Boulder Creek is more significant due to the prevalence of landslides. The Boulder Creek watershed has had 50 landslides catalogued with 58% related to inner gorge failure (Peak Northwest, 1986). Failure rates and sediment supply from Boulder Creek have been shown to have steadily increased from 1940's to 1980's with a fourfold increase in landslide area between 1969 and 1989 that is primarily attributed to land use practices within the watershed during this period (Peak Northwest, 1986; Gowen, 1989).

Hydrology

The climate within the North Fork watershed can be characterized as mild and wet. The mean annual precipitation in the vicinity of project area is 100-inches and varies between 60-inches in the lower basin to over 130-inches in the upper basin. The elevation of the channel ranges between 400- and 500-feet within the project area with basin elevations extending up to 10,800-feet. Precipitation primarily falls as rain within the project reach and in the lower areas of the watershed, and as snow in the upper watershed. This results in a bi-modal annual hydrograph that is dominated by rainfall events from November to March, snow melt from May to July, and glacial melt from August to September. Major flood events storms are often the result of "pineapple express" warm fronts that create a rain on snow event.

The drainage basin area for the project reach is approximately 230-square miles out of a total of 287-square miles for the entire basin. Significant tributary inputs affecting the project reach include Maple, Boulder, Canyon, Glacier, and Wells Creek that contribute 2%, 5%, 15%, 20%, and 25% of the total drainage area to the North Fork watershed, respectively (GeoEngineers, 2001)

The United State Geological Survey (USGS) maintains a streamflow gage 12205000 upstream of the project reach at RM 63 below the confluence with Cascade Creek. USGS gage 12205000 has a drainage basin area of 105-square miles and a 72-year period of record that begins in 1937. The top ten peak flows from this gage are shown below in Table 1 and peak flows for the full period of record are included in Figure 1, attached. A Log Pearson Type III was performed for this project, and the results are shown below, in Table 2. Following recommendations by Knowles and Sumioka (2001) the results from the gage analysis were scaled to the project reach.

TABLE 1. USGS 12205000 TOP TEN PEAK FLOWS

Rank	Date	Flow (cfs)
1	10/16/2003	15,200
2	11/6/2006	12,600
3	11/10/1989	11,200
4	11/26/1949	10,300
5	1/4/1984	9,700
6	10/21/1963	9,680
7	10/28/1937	9,670
8	11/10/1990	9,540
9	1/7/2002	9,300
10	11/11/1999	9,220

Six of the highest discharges for the North Fork have occurred within the past 20-years and during the rainfall driven portion of the annual hydrograph (November through January). Across the watershed, changes in precipitation patterns and intensity are thought to be influencing the frequency of large magnitude flood events (Hyatt, 2007). If this hydrologic trend continues in the future, geomorphic conditions within the project area should be expected to change as the channel adjusts to greater volumes of water.

TABLE 2. NORTH FORK NOOKSACK PEAK FLOWS

Recurrence Interval	USGS 12205000	Farmhouse Reach
1	2,700	5,800
2	6,000	12,900
5	8,100	17,500
10	9,500	20,500
25	11,300	24,400
50	12,600	27,200
100	14,000	30,200

PROJECT REACH CONDITIONS

The Farmhouse project area is located in the Lower North Fork section, roughly 2.0 miles southwest of Maple Falls, and upstream from the confluence with Racehorse Creek. The project reach extends downstream from the mouth of a confined canyon reach at RM 49.4 to RM 46.8 and adjacent to Bennett Farms. Within the project reach the North Fork flows in a west direction with a braided and highly dynamic planform. The river is bound along the right and left bank by Pleistocene era glacial outwash terraces and a valley wall composed of Chuckanut formation bedrock, respectively (Dragovich, 1997). The project reach is primary composed of riffles, braids, and glides that provide little to no spawning habitat in off-channel areas. For the purposes of this assessment, the project reach was further sub-divided into the gravel bar and braided sub-reach, which are further described below. The gravel bar sub-reach is located in the upper portion of the Farmhouse reach, beginning at RM 49.4 and extending downstream to RM 48.0. The braided sub-reach is located in the lower portion of the Farmhouse reach beginning at RM 48.0 and extending downstream to RM 46.8. The inlet to Bear Slough is located within the braided sub-reach at RM 47.8 along the left bank and proceeds in along the left most margin of the active floodplain until confluencing with the dominant channel at RM 45.7.

Channel processes within the Farmhouse reach are strongly influenced by conditions immediately upstream of the reach where the North Fork flows through a narrow canyon. The canyon is formed by remnant landslide debris along the south and bedrock overlain by glacial outwash deposits along the north. The confinement caused by these features has resulted in a significantly smaller channel width which in turn, generates twice the stream power of the Farmhouse reach (GeoEngineers, 2001). Immediately downstream from the canyon, the North Fork enters the Farmhouse reach where both the valley and active channel width increases greatly. The increased width creates an unconfined condition where flows expand and spread out, generating decreased stream power and sediment transport capacity. The reduction in sediment transport capacity results in sediment deposition and long-term formation of an alluvial fan topography. Evidence of local alluvial fan characteristics in the gravel bar sub-reach are illustrated in Figure 9 with fan morphology observable within both terrace features and the current active channel area.

The channel within the gravel bar sub-reach can be considered transitional, between the characteristics of the upstream confined reach and the downstream highly dynamic braided sub-reach. As the channel exits the confined canyon reach, it is characteristic of a single thread meandering channel with gravel point bars located on the inside radius of channel bends. At RM 49.0 the channel is actively eroding into glacial outwash deposits 50- to 60-feet in height creating an erosional scarp along the right bank (Figure A7). A short distance downstream of this feature, two riprap dikes exist along the right bank from RM 48.9 to RM 48.7 (Figure A3) and was constructed by the Glenn between 1986 and 1994 following erosion along the right bank and significant expansion of the active channel northward in this area. The riprap dike is presently preventing channel migration northward and directing the dominant channel southward along the dike alignment. Downstream of the riprap dike, the dominant channel continues to have a single thread meandering character within a much larger active channel width. The dominant channel in this region, is located within the right portion of the active channel with a large, expansive and high gravel bar within the center portion of the active channel. Elevations near the center of the gravel bar are significantly higher than elevations within the dominant channel and perimeters of the active channel. Throughout most of the gravel bar sub-reach, small to moderate sized side channels extend along the entire left portion of the active channel (Figure A15 to A18) until confluencing with the dominant channel at RM 47.9.

At the beginning of the braided sub-reach the and RM 47.9 the character of the channel changes from a single thread meandering channel to a severely braided condition (Figure A1, A2, and A4) with flow split between the right and left portions of the active channel. The inlet to the Bear Slough inlet is located at RM 47.8 along the left bank (Figure A19). Erosion along the left bank immediately upstream of the inlet has resulted in multiple large pieces of wood falling into the active channel and being deposited in front of the inlet. The deposited wood currently blocks the slough inlet and is causing sediment deposition to occur in that immediate area (Figure A18). Downstream from the Bear Slough inlet the channel maintains a severely braided condition to the downstream extent of the project reach, with multiple shallow channels flowing between unconsolidated gravel bars that frequently change position. Along the right bank of the active channel at RM 47.3, the Nooksack Salmon Enhancement Association (NSEA) has constructed multiple large wood structures to stabilize an eroding bank along the Bennett Farms property (Figure A23), protect the head of channel islands at RM 47.0 that have begun to be colonized by riparian vegetation, and prevent the dominant channel from capturing the Bennett side channel (Figure A24).

Channel Gradient

A plot of the channel profile and channel slope developed for this project from 2005 LiDAR is provided in Figure 13. Review of Figure 13 indicates there is no obvious slope break within the project reach. Measured channel gradients vary between 0.2- to 1.0% with an average value of approximately 0.5%. These results are slightly lower than those measured by Hyatt, 2007 of 0.67 and 0.73. The fairly consistent channel gradient and lack of defined slope breaks suggests that channel gradient does not strongly influence changes in channel processes between the gravel bar and braided sub-reaches.

Side Channels

Side channels are important to habitat quantity and quality within the North Fork Nooksack due to the reduced levels of redd scour and rearing habitat within them(Hyatt, 2007). A common mechanism for side channel development is related to sediment deposition and abandonment of a main channel location followed by riparian and forest colonization along the abandoned channel. As part of this project, GeoEngineers evaluated the connectivity of existing side channels within the project reach using a height above water surface (HAWS) model. The HAWS model was created using 2005 LiDAR data and water surface elevations of the main channel at the time the LiDAR data was collected following procedures described in Jones, 2006. It should be noted that, due to the dynamic nature of the channel within the project area and the date of the LiDAR data, differences in the HAWS model with current conditions are expected. However, the result of this analysis, shown on Figure 10, indicates that numerous side channels exist within the Farmhouse reach that offer restoration opportunities. Within the gravel bar sub-reach, there are multiple young side channels along the left (south) portion of the active channel that were actively conveying flow during the field reconnaissance,s including the Fall Creek and South Margin side channel. Results from the HAWS mapping indicate these side channels are 4- to 6-feet lower in elevation than the main channel, which suggests the main channel may re-occupy these channels sometime in the future.

Along the right (north) portion the gravel bar sub-reach, the Levitt Farm Slough is well defined but not as connected at its inlet or as deep as channels along the south portion of the active channel. Within the braided sub-reach, the Bear Slough begins along the left edge the active channel and flows along the south valley wall until confluencing with the dominant channel downstream of the project reach. Bear Slough is well developed and has a high habitat value within the North Fork watershed. Results from the HAWS mapping

indicate portions of the slough are 4- to 6-feet lower in elevation than the main channel suggesting it may be subject to a channel capture (avulsion) event. However, possible avulsion of the main channel through Bear Slouth is highly unlikely for several reasons: the location of the dominant channel in relation to the Bear Slough inlet, the presence of multiple vegetated bars protecting the inlet, and the number and size of existing logjams within the upper portion of Bear Slough, which increase roughness and reduce stream power through the slough channel..

Large Wood

Large wood and natural logjams historically influenced the channel character and habitat conditions within the North Fork Nooksack River and other Puget Sound lowland rivers. Historically, large key pieces of wood formed stable logjams that influenced the channel location, channel characteristics and the presence of stable side channels and forested islands within Puget Sound Rivers (Abbe, 2000). Within the past 100-years, timber harvest has been the dominant land use in the North Fork basin, which has led a loss of recruitable key-sized pieces of large wood in the riparian zone. While large wood is relatively common within the project reach, the majority of the wood documented is not of sufficient size to be considered stable, resulting in one of the lowest concentrations of stable large wood within the North Fork (Hyatt, 2007).

Geomorphic Site Observations

Preliminary field reconnaissance of the project area occurred on February 8th and August 17th, 2011 by GeoEngineers, Herrera, and Nooksack staff. Streamflow during both field visits was approximately 700 cfs and 950 cfs, respectively. The primary purpose of this effort was to establish a baseline channel conditions from along the left and right bank within the project reach, including current low flow channel locations, develop qualitative descriptions of sediment distributions within the channel and on the gravel bars, identify large wood and wood jam distributions, areas of bank erosion or scour, floodplain connectivity, and general channel morphology in relation to pools, riffles, and side channel habitat. Photographs from the field reconnaissance can be found in Appendix A. Observations from the field reconnaissances are as follows;

- Bars of all types and sizes are common within the project reach. Sediment sizes are generally largest at the heads of bars with fine gravel to sand near the tail end. Most of the bars appear to have accreted recently.
- Sediment size varies throughout the project reach with larger clasts (cobbles and gravel) more prevalent in the upstream portion and smaller material (sand and gravel) more prevalent in the downstream portion (Figure A5 and A6).
- Fine sediment deposition is present in some areas of the right floodplain near RM 47.6 (Figure A9). Sediment in these areas was loose and poorly consolidated indicating that it was recently deposited.
- The elevation in the middle of the active channel area is noticeably higher than the channel margins from RM 48.6 to RM 47.6 which is suggestive of sediment deposition and alluvial fan processes.
- Side channels of various lengths and widths are common within the gravel bar sub-reach. The side channels are characteristic of broad high flow corridors subject to the periodic arrival of large sediment volumes. Typically, side channels correspond to historic locations of the main channel and/or more recently developed high stage channels.

- Channel braids are common in the lower portion of the project reach creating very complex flow patterns and distribution of flow across the active channel area (Figure A1, A2, and A4). At the time of both field visits, two thirds of the flow appeared to take a right flow path and the remaining one third to take a left flow path around a forested island at RM 47.4. The left and right flow paths converged at RM 47.1 near the location of the NSEA bank protection and large wood stabilization.
- There is a low frequency of woody debris within the project reach especially for stable "key" members. What wood is present is either assembled in chaotic natural jams or on floodplain surfaces.
  - Wood located in natural jams is generally engaged at moderate to high flows. At the time of the site visits, sediment had deposited upstream of jams, with fine sediment deposited behind the jam, and with occasional scour pools at the upstream end of the jam (Figure A12).
  - Natural and placed wood in the lower portion of the reach near RM 47.3 and Bennett farms has been buried by 2 to 4-feet of sediment deposition (Figure A10). Future placed wood and engineered logjams are expected to illicit a similar channel response in the braided sub-reach.
  - The location and spacing of ELJs placed by NSEA at RM 47.3 appears to have increased the hydraulic roughness of the channel in the local area, resulting in sediment deposition in front of the structures and movement of the channel braids away from the structures. With similar spacing, future placed wood and engineered logjams are expected to illicit a similar channel response in the braided sub-reach.

Historic Channel Character and Behavior

Prior to Euro/American settlement the North Fork had an anabranching pattern with multiple stable side channels, sloughs and forested islands (Collins and Sheikh, 2004). The forest occupying the Nooksack floodplain consisted primarily of red alder and other hardwood species with western red cedar being the most common coniferous species (Collins and Sheikh, 2004). Following settlement of the region the majority of the North Fork floodplain was logged or burned and then allowed to return to a forested condition. Within the project reach, the floodplain and channel area was mapped as logged and/or burned and gravel bars in 1910 (Collins and Sheikh 2004, Figure 9-2) and as forested floodplain and gravel bars by 1933 (Collins and Sheikh 2004, Figure 9-4). This is supported with field observations of old growth stumps within the valley bottom and North Fork floodplain (Figure A13 and A14) and suggests the old growth forested floodplain was logged prior to the first aerial photograph (1933). Loss of the floodplain forest has contributed to the dynamic and braided channel consistently observed within the aerial photographic record. Due to the large increase in valley and active channel width, previously discussed, the Farmhouse reach has likely always been dynamic however, the removal of the old growth floodplain forest in the early 1900's has likely had a dominant destabilizing effect

Throughout the aerial photographic record, the Farmhouse reach has been one of the most dynamic sections of the North Fork channel. Figures 3 to 8 are digitized channel traces provided by the Nooksack Tribe for this project, supplemented with additional channel traces for the 2005 and 2010 aerial photographs. Historic maps and aerial photographs dating back to 1933 indicate the reach has consistently performed as a multi-channel braided system with periodic sections of single thread sinuous channel subject to dramatic changes in channel location. The degree of channel braiding varies between moderate and severe and is likely related to the occurrence of high sediment loads and high flow events preceding a particular aerial photograph. While

the channel within the Farmhouse reach is dynamic, results from a channel occupancy analysis performed by Collins and Shiekh (2004) show high occupancy values within the active channel region indicating the dominant channel has migrated within a consistent corridor since 1933.

The aerial photographic record can be divided into three key periods, those being pre-1933, 1933 to 1980, and 1986 to present, with distinctive channel characteristics. Government Land Office (GLO) mapping and the 1918 channel trace (provided by the Nooksack Tribe) show a meandering channel with forested islands and prominent side channels throughout the project reach and the main channel in the present location of Bear Slough prior to 1933. The 1933 aerial photograph exhibits a major change in the planform and location of the channel with a severely braided condition throughout the project reach and a major channel avulsion at RM 47.0 towards the west. The channel avulsion resulted in abandonment of the prior channel location, formation of the present Bear Slough and may have been influenced by the clearing of the forested floodplain observable within the 1933 aerial photograph. From 1933 to 1980 the active channel generally maintained a sinuous pattern with a dominant channel actively migrating within a broad expanse of gravel bars. During this period expansion of the active channel area was primarily related to the downstream translation of this sinuous active channel planform. In 1986, the active channel significantly expanded northward through channel bends at RM 48.3 and 47.4 resulting in a straightened alignment of the active channel. This period of active channel expansion corresponds to a period of high landslide activity within the North Fork watershed (Gowen, 1989, Mt Baker, 1995, Watts, 1997). Following large northward expansions of the active channel in 1980 and 1986, a riprap dike was constructed along the right bank at RM 48.9 to 48.7 to protect the Glenn subdivision from further erosion. Since the construction of the riprap dike, the dominant channel and has been in relatively close connection with this feature. The construction of the riprap dike appears to have constricted the channel and directed the dominant channel further south downstream of the structure, allowing riparian vegetation to re-establish and side channel network to develop in the area behind the dike (Figure A-8 and A-9).

Review of all available traces and aerial photographs indicates that there have been very few stable channels and bars within the project area in recent history (Figure 12). Areas of stability that are observed within the aerial photographic record are related to the colonization of gravel bar expanses by riparian vegetation along the perimeter of the active channel area, periodic incision of the dominant channel, or are associated with the riprap dike at RM 48.9 to 48.7. Very few forested islands are observed within the aerial record throughout the project reach. Islands observed within the aerial photographic record tend to be a result of dominant channel migration into forested area which in turn isolates a portion of that area and creates a forested island that persists for a short period of time. Migration of the dominant channel and expansion of the active channel area similar to this is often the related to sediment deposition across the active channel area causing flow deflection.

Bed Elevation Trends

The vertical trend (aggradation, downcutting, equilibrium) of the North Fork is an important consideration to achieving restoration objectives, as well as the planning and function of proposed ELJ structures. In lieu of historic elevation data set or measurements, the contraction or expansion of the active channel width is often used as a surrogate to elevate vertical trends within the river environment. As part of this project, GeoEngineers evaluated the active channel width through the aerial photo record within the project area. Active channel widths were determined at 10 cross sections equally spaced within the study reach. For the

purposes of this project the active channel width is defined as the exposed bar and low flow area excluding vegetated surfaces or forested islands. The results of this analysis are shown below, in Table 3, and indicate the Farmhouse reach has experienced periods of significant channel widening in the past 100-years followed by periods of channel narrowing with a long-term trend of active channel expansion. Periodic channel narrowing has occurred through riparian vegetation establishing along the active channel perimeter. Prior to riprap dike construction the location of maximum channel width generally occurs between RM 48.6 and 48.3. Following the construction of the riprap dike the channel width is generally located further downstream between RM 47.6 and 47.3. Large changes in planform and channel widening between the 1976 and 1986 photographic years is likely related to a high flow event on the North Fork in 1984 and sediment/flood events the North Fork watershed document by Gowen (1989) and Peak Northwest (1986).

Periodic and long-term channel widening could have been caused by a number of scenarios. One scenario is the influx and deposition of significant sediment volumes during very high flow events coupled with aggradation of the high flow corridor. In this scenario, gravel is deposited over much of the active high flow corridor, raising the average elevation of the active channel area. A second possible scenario that could cause corridor widening, is erosion due to extreme high flows where less sediment is being transported than the flow has capacity to move. In this scenario, erosion is a response to high discharge, stream power and shear stress applied over the wetted perimeter of the corridor, in which case bank erosion would be accompanied by scour and downcutting of the corridor floor. The corridor widening observed in the aerial photographic record is more consistent with sediment influx and aggradation, based on changes in channel planform, number and alignment of high flow channels, and the location and dimensions of the dominant channel.

TABLE 3. CHANNEL WIDTH COMPARISONS

	High Flow Channel Width (ft)			Percent Change From Previous Record (%)		
Year	**Minimum**	**Average ()***	**Maximum**	**Minimum**	**Average**	**Maximum**
1938	210	720 (-120)	1170	--	--	--
1955	420	760 (-80)	1430	100%	6%	22%
1976	470	740 (-100)	980	12%	-3%	-31%
1986	370	1010 (170)	1580	-21%	36%	61%
1994	370	1060 (220)	1880	0%	5%	19%
1998	220	780 (-60)	1370	-41%	-26%	-27%
2005	150	770 (-70)	1150	-32%	-1%	-16%
2010	170	850 (10)	1300	13%	10%	13%

*Values in () represent difference with historic average width of 840-feet. Positive values are greater than the historic average. Negative values are less than the historic average.

As part of this project GeoEngineers evaluated elevation changes between the 1994 and 2005 photogrammetry digital elevation model (DEM) data, provided by the Nooksack Tribe. By subtracting the two data sets and classifying the results, a visual representation of erosion, deposition, and changes in the dominant channel was created and is shown in Figure 11. The results indicate the majority of the active channel area was slightly lower in elevation in 2004 with some areas of incision as much as 6- to 9-feet lower, and some areas of sediment deposition as much as 3- to 5-feet higher. Results on a volumetric basis

are, as shown Table 4, indicate that within the project reach the active channel area incised between 1994 and 2004.

TABLE 4. PHOTOGRAMMETRY VOLUMETRIC COMPARIONS

Description	Result
Volumetric difference (yd^3)*	- 260,000
Average difference (yd^3/year)*	- 26,000
Volumetric difference over active channel area (ft)*	- 0.5

*Positive values represent aggradation or sediment deposition. Negative values represent incision or sediment loss.

Results from the channel width evaluation, aerial photograph review, comparison of photogrammetry data sets, LiDAR and field observations suggest that the Farmhouse reach is subject to both sediment deposition and incision. Historical aggradation can be correlated to fan topography observable on channel and terrace features beginning at the downstream end of the confined canyon reach and extending through the project reach. Short term aggradation can be correlated to the periodic expansion of the active channel, elevations along the perimeter of the active channel relative to the center, and braided nature of the channel. Presently, the active channel area within project reach appears to be incising within sediments deposited between 1976 to 1994, as suggested by results from a comparison between photogrammetry data sets, narrowing of the active channel from historical maximums, and entrenchment of the dominant channel within the gravel bar sub-reach.

Geomorphic Assessment Summary

Based on the information provided in the preceding sections of this report, a qualitative geomorphic assessment was conducted for the Farmhouse project reach. The intent of the assessment is to identify dominant channel forming processes having the greatest influence on local reach scale conditions, and the cause/effect relationships between those processes and the physical features defining the reach. The preliminary results of the assessment are provided below. Key points from the geomorphic assessment are as follows;

- The primary influence to channel response within the project reach is deposition of a portion of the incoming sediment load. Deposition is controlled, at least in part, by 1) the volume of incoming sediment, 2) the rapid expansion of the active channel area immediately downstream of the canyon reach, and 3) a rapid drop in stream power and shear stress (due to high flow corridor expansion).
    - Sediment deposition within the project reach is likely influenced by landslide activity within the greater North Fork watershed. High sediment load and sediment deposition is likely a contributing factor to a straightening of the active channel observed within the aerial photographic record between 1976 and 1986.
    - Given current hydrologic and sediment production processes within the North Fork and its tributaries, the influx of sediment to the project area is not likely to decrease in the near future. Total sediment discharge entering the main stem river and tributaries may decrease somewhat resulting from a general decrease in logging and improved land management practices within the basin. The amount or longevity of any such decrease will likely be overprinted by current trends in precipitation and regional climate change influencing mass wasting, and loss of local glacial

mass, all of which have potential to increase sediment delivery to the river. In addition, changes in local storm behavior, which will affect main stem discharge and transport capacity is uncertain. Given the variability of local climate patterns and long term trends of sediment delivery from mass wasting events, we recommend a high sediment load be considered in the planning and design of proposed ELJ structures within the Farmhouse reach.

- Field observations, fan morphology, and the braided character of the channel indicate the project reach is prone to excess sediment load and deposition which results in significant changes in channel location, configuration, and rates channel migration. However, comparison of photogrammetry data sets and recent contraction of the active channel area suggests the project reach has slightly incised during the 1994 to 2004 time period.
- The harvest of mature floodplain forest, removal of natural logjams, and depletion of recruitable key sized pieces within the North Fork has contributed to the highly dynamic braided planform of the channel, largely in response to the loss of stable hard points from the channel and decreasing bank resistance to erosion. However, due to the large increase in valley and active channel width, previously discussed, the Farmhouse reach has likely always been a dynamic reach within the North Fork watershed.
- The downstream fining of sediment sizes within project reach is likely related to the dramatic loss of stream power as the North Fork exits the canyon reach, influencing differences in channel characteristics between the gravel bar and braided sub-reaches. As the North Fork exits the confined canyon reach large sized sediments are deposited first within the gravel bar sub-reach. The larger, imbricated nature of the sediments is harder for the dominant channel to mobilize resulting in a more stable channel that is slightly entrenched within sediment deposits. The smaller and unconsolidated nature of material in the braided sub-reach can be mobilized by in-channel more frequently, during low stage flows, resulting in a wider, shallower channel prone to frequent shifts in position.

CHANNEL RESPONSE

The placement of engineered log jams (ELJs) and other wood structures within the river environment will alter the physical condition of the reach, and ultimately, deflect flow sufficiently to cause changes in local and reach scale flow patterns and sediment conveyance. These changes almost always invoke channel responses in terms of erosion, deposition and flow direction, which can alter the form and character of the river channel over time.

The 4 alternatives described below were each assessed qualitatively for channel responses most likely to result from installation of ELJs and other structures. The configuration of Alternative 1, 2, and 3 are similar with the main difference being the scale of proposed restoration treatments. Thus, the relative scale of the channel response is expected to vary similarly with a few notable exceptions. The assessment was based on historic and recent geomorphic characteristics and our understanding of the proposed alternatives. Historic and recent channel patterns and behavior were considered in terms of channel location and orientation over time, and major changes following known large sediment influx events. In the section below, proposed alternatives were also evaluated with respect to the goals and objectives described at the beginning of this document and according to the ranking explanation shown below in Table 5. Due to funding and construction constraints this project will have multiple phases this however, assessment did not consider the incremental

effects of each phase. This assessment also only considered the effects of established forested islands and side channels as shown on the concept plans. Mature forested islands will take many years to decades to develop and ELJ spacing along the perimeter of islands may allow for additional side channels to develop that were not explicitly evaluated, as part of this project.

ALTERNATIVES

3 project scale concept alternatives were assessed and compared for the project with a 4th alternative (the first phase of the selected alternative) being assessed using hydraulic modeling. The project scale alternatives were developed to provide a sliding scale of log jam quantities and densities to evaluate project temporal effectiveness and the probability of realizing goals.

1. The Alternative 1 concept was developed to illustrate the minimal level of log jam construction that would provide a reasonable assurance of project goals being achieved. Of the three reach scale alternatives, Alternative 1 is expected to require the longest temporal length to achieve goals and has the highest level of uncertainty.
2. The Alternative 2 concept was developed be a middle ground between the minimum and the maximum number of log jams constructed. As such the level of certainty that goals will be achieved by this alternative are higher than Alternative 1 and lower than Alternative 3
3. The Alternative 3 concept was developed to reasonably illustrate the highest level of log jam construction. This alternative has the associated highest level of certainty of project goals being achieved in the shortest time frame..

TABLE 5. ALTERNATIVE SCORING GUIDELINES

Scoring	Explanation
++	Large benefit to reaching habitat targets
+	Small to medium benefit to reaching habitat targets
0	Neutral, neither a benefit or detriment
-	Detriment to reaching habitat targets
N/A	Not applicable

Alternative 1 - Minimum Scenario

This alternative would include the placement of island type ELJ structures within the active channel area of the North Fork in four separate phases (see attached layout). Island type ELJs would be grouped to initially encourage the development of 11 relatively small channel islands, which could then merge to form larger islands as clusters of ELJs rack additional material and affect the channel form. Existing structures constructed by NSEW would remain near the inlet of the Bennett's Farm Slough (RM 47.0) with additional structures constructed downstream to encourage and maintain forested islands in the area. ELJ's would be constructed upstream of the inlet to Bear Slough (RM 47.5) to reinforce and create new channel islands, and along the Fall Creek and South Margin side channels (RM 48.0 – 49.0) to reinforce channel islands and encourage perennial flow into the side channels. ELJs would be relatively evenly spaced within their

respective grouping and composed of Type 1 (large) and Type II (medium) ELJs. A summary of our assessment is provided in Table 6 and below;

- This alternative will be effective at developing smaller scale forested islands within the project area while allowing the dominant channel the most space (as compared) to the other alternatives and to adjust its form and location in response to future flood and sediment events.
  - The width of the structures and island groups relative to the active channel may result in little or no engagement of structures during low flow periods due migration of the dominant channel.
  - The low density of constructed ELJ's may allow a channel to continue to be highly mobile within a larger than historic active channel.
  - Large scale forested islands will require time to develop as their formation is dependent on delivery and collection of suitable large woody debris on constructed ELJ's and the uncertain nature of how that process would develop.
- ELJs placed within the braided sub-reach (cluster 1 and 3) will function as a locus for sediment deposition behind and adjacent to the ELJs due to increases in roughness and hydraulic shadowing. This deposition in turn, may deflect the dominant channel away from the ELJs and cause migration of the dominant channel.
  - Channel migration caused by cluster 3 may result in erosion along the north margin of the active channel area and private property. Evaluation of this potential is critical to further development of designs associated with this project and may require modifications of cluster 3, or the inclusion of "margin structures" as illustrated in Alternatives 2 and 3.
- ELJs placed within the gravel bar sub-reach (cluster 2 and 4) will be effective in reinforcing small channel islands and encouraging flow into their respective side channels. Due to the river training effects of the riprap dikes and the large mid channel bar, structures have a higher likelihood of engagement with either the dominant channel or prominent side channel.

TABLE 6. ALTERNATIVE 1 MINIMUM SUMMARY TABLE

	Benefit				Risk
Description	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**
Overall	+	+	+	+	-
Cluster 1	+	0	+	+	0
Cluster 2	+	+	+	+	0
Cluster 3	+	+	+	+	-
Cluster 4	+	+	+	+	0
Side Channel Habitat Structures	NA	NA	0	NA	0
Channel Margin Structures	0	0	0	0	0

Goal 1 – Improve side channel connectivity, Goal 2 - narrow active channel, Goal 3 – increase key habitat quantity, Goal 4 – increase mature forested islands, Goal 5 – do not increase risk to private property.

Alternative 2 – Medium Scenario

This alternative would include the placement of island type ELJ structures within the active channel area in four separate phases, in addition to margin roughening ELJ structures and side channel ELJ structures (see attached layout). Island type ELJs would be grouped to encourage the development of 17 moderate sized channel islands. Structures would also be placed near the inlet of the Bennett's Farm Slough (RM 47.0) to reinforce the channel island and encourage perennial flow into the slough, upstream of the inlet to Bear Slough (RM 47.5) to reinforce and create new channel islands, downstream of the existing riprap dikes (RM 48.0) to reinforce and create new channel islands, and along the Fall Creek and South Margin side channels (RM 48.0 – 49.0) to reinforce channel islands and encourage perennial flow into the side channels. ELJ structures would be relatively evenly spaced along the perimeter of their respective grouping and composed of Type 1 (large) and Type II (medium) engineered logjams (ELJs). Groupings of structures within this alternative are larger in size than Alternative 1 but smaller than Alternative 3. A summary of our assessment is provided in Table 6 and below;

- This alternative is likely to encourage a transition of the dominant channel to an anabranching or multi-thread planform, while providing the active channel an adequate amount of area to adjust its form and location to future flood and sediment events. Spacing between clusters 2, 3, and 4 is wide enough (100-150 feet) to allow either the main channel or prominent split channels to occupying, consistent with anabranching channel behavior.
  - This will result in a dramatic reduction in average hydraulic pressures and reverse the 130-year trend of active channel expansion within the project area. Reduction in hydraulic pressures will also slow recent trend of channel incision improving floodplain and side channel connectivity.
  - An anabranching planform will also maximize the available side channel and edge habitat within the project area. Future development of the alternatives should include hydraulic analysis of the existing side channels to ensure that their function is either enhanced or maintained.
- This alternative will increase the sinuosity of the active (unvegetated) channel as ELJ clusters begin to narrow the active channel. The alternative was modified to increase the width of the active channel and reduce the potential for a single thread channel to develop. This is likely to result in the following;
  - A lengthening of the active channel, thus reducing the channel slope. The decrease in slope will be most pronounced between RM 47.4 – 48.4, which will reduce sediment transport capacity and induce sediment deposition. The reduction in stream energy will encourage the development of forested islands and will reduce average hydraulic pressures within the project area. However, in certain cases sediment deposition may act to deflect flow towards the channel margins, increasing local hydraulic pressures acting along the channel banks and causing erosion. Future development of designs in this reach should consider hydraulic modeling and placement of channel margin structures where erosion may not be consistent with the project objectives.
  - A decrease in the radius of curvature of the active (unvegetated) channel at RM 47.5 and RM 48.3. The decrease in the radius of curvature in these areas will increase the hydraulic pressure acting along the outside of the channel bend and increase the likelihood that channel margin structures engage with the dominant channel. The decrease in radius of curvature may also result in minor erosion and local expansion of the active channel area. Future development of

designs in this reach should consider hydraulic modeling and placement of channel margin structures where erosion may not be consistent with the project objectives.

- Channel margin ELJs placed in these areas will create complex edge habitat and reduce the hydraulic pressure acting along the active channel margins reducing the likelihood of significant active channel expansion. Channel margin ELJs may also provide a source for recruitable key sized pieces in the future as mature forested patches develop in the lee of the structures.

- Side channel and channel margin structures will be effective at increasing local complex edge habitat and locally reducing hydraulic energies within the Bennett's Farm Slough, the upper Bear Slough, the South Margin side channel, and the Fall Creek side channel. Future development of these designs should include assessment of side channel structure size and placement to avoid over roughening of the side channels which may lead to sedimentation or abandonment by the mainstem.
- ELJs placed within the braided sub-reach (cluster 3 and to a lesser extent cluster 1) will function as a locus for sediment deposition behind and/or adjacent to the ELJs, due to increases in roughness and hydraulic shadowing. If the deposition continues, bars could form and possibly cause local aggradation of the active channel floor. Under these conditions, developing bars could deflect flow away from the ELJs. and initiate migration of the dominant channel within the active channel. In this event the following could occur:
- Dominant channel migration caused by cluster 3 may result in erosion along the north margin of the active channel area in the vicinity of private property. Channel margin ELJs placed north of cluster 3 (RM 47.5) will reduce the risk of erosion along the north margin of the active channel and private property. Cluster 1 is unlikely to cause bar development or dominant channel migration due to the location and aspect of the structures. ELJs placed within the gravel bar sub-reach (cluster 2 and 4) will be effective in reinforcing channel islands and encouraging flow into their respective side channels. Due to the river-training effects of the riprap dikes and the large mid-channel bar, structures have a higher likelihood of engagement with either the dominant or prominent side channel. Future development of the designs should include assessments of structure sizes and placements so that further constriction of the channel, along the riprap revetments, in a way that reduces side channel splitting and flow..

TABLE 7. ALTERNATIVE 2 MEDIUM SUMMARY TABLE

	Benefit				Risk
Description	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**
Overall	+	++	++	+	0
Cluster 1	+	0	+	+	0
Cluster 2	+	+	+	+	0
Cluster 3	+	++	++	++	-
Cluster 4	+	++	++	++	0
Side Channel Habitat Structures	NA	NA	+	NA	+
Channel Margin Structures	NA	+	+	NA	+

Goal 1 – Improve side channel connectivity, Goal 2 - narrow active channel, Goal 3 – increase key habitat quantity, Goal 4 – increase mature forested islands, Goal 5 – do not increase risk to private property.

Alternative 3 – Maximum Scenario

This alternative would include the placement of island ELJ structures within the active channel area, along with margin roughening ELJ structures, and side channel ELJ structures (see attached layout). Due to the large number of anticipated ELJ's this alternative is anticipated to include 6 different phases of construction. Island type ELJs would be grouped to encourage the development of 7 large channel islands. Structures would also be placed near the inlet of the Bennett's Farm Slough (RM 47.0) to reinforce the channel island and encourage perennial flow into the slough, upstream of the inlet to Bear Slough (RM 47.5) to reinforce and create new channel islands, downstream of the existing riprap dikes (RM 48.0) to reinforce and create new channel islands, and along the Fall Creek and South Margin side channels (RM 48.0 – 49.0) to reinforce channel islands and encourage perennial flow into the side channels. ELJ structures would be relatively evenly spaced along the perimeter of their respective grouping and composed of Type 1 (large) and Type II (medium) ELJs. Groupings of structures and the total number of structures within this alternative are larger than both Alternative 1 and 2. A summary of our assessment is provided in Table 6 and below;

- This alternative is most effective, in relation to other alternatives evaluated, in reducing the width of the active channel within the project area. While ELJs will have immediate effects, development of channel islands, as shown on the concept plan will occur slowly as the current active channel transitions to forested islands and/or riparian area.
- Similar to Alternative 2, this alternative will increase the sinuosity of the active channel as ELJ clusters begin to narrow local sections of the active channel. This is likely to result in the following;
  - A lengthening of the active channel, thus reducing the channel slope. The decrease in slope will be most pronounced between RM 47.4 – 48.4 and will reduce sediment transport capacity, which in turn will induce sediment deposition and possible fining of the channel material. The reduction in stream energy will encourage the development of forested islands and will, in general, reduce average hydraulic pressures within the project area. However, in certain cases sediment deposition may act to deflect flow towards the channel margins, increasing local hydraulic pressures acting along the channel banks and causing minor erosion.

  A decrease in the radius of curvature of the active (unvegetated) channel at RM 47.5 and RM 48.3. The decrease in the radius of curvature in these areas will increase the hydraulic pressure acting along the outside of the channel bend and increase the likelihood that channel margin structures engage with the dominant channel. The decrease in the radius of curvature may also result in minor erosion and local expansion of the active channel area. Future development of designs in this reach should consider hydraulic modeling and placement of channel margin structures where erosion may not be consistent with the project objectives.

  - Channel margin ELJs placed in these areas will create complex edge habitat and reduce the hydraulic pressure acting along the channel margins reducing the likelihood of significant active channel expansion. Channel margin ELJs and may also provide a source for recruitable key sized pieces in the future.

- Side channel and channel margin structures will be effective at increasing complex edge habitat and reducing hydraulic energies within the Bennett's Farm Slough, upper Bear Slough, South Margin side channel, and Fall Creek side channel.
- ELJs placed within braided sub-reach (cluster 1 and 3) will function as a locus of sediment deposition behind and adjacent to the ELJs due to an increase in roughness and hydraulic shadowing. This deposition in turn, may deflect the dominant channel away from the ELJs and cause migration of the dominant channel.
  - Channel migration caused by cluster 3 may result in erosion along the north margin of the active channel area and private property. Channel margin ELJs placed north of cluster 3 (RM 47.5) will reduce the risk of erosion along the north margin of the active channel and private property.
- ELJs placed within the gravel bar sub-reach (cluster 2 and 4) will be effective in reinforcing channel islands and encouraging flow into their respective side channels. Due to the river training effects of the riprap dikes and the large mid channel bar, structures have a higher likelihood of engagement with either the dominant channel or prominent side channel. These end results and benefits are quite similar to those provided by the Medium Alternative but will be achieved in a much shorter period of time.

TABLE 8. ALTERNATIVE 3 MAXIMUM SUMMARY TABLE

	Benefit				Risk
Description	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**
Overall	+	++	++	++	0
Cluster 1	+	0	+	++	0
Cluster 2	+	+	+	++	0
Cluster 3	+	++	++	++	-
Cluster 4	+	++	++	++	0
Side Channel Habitat Structures	NA	NA	++	NA	+
Channel Margin Structures	NA	+	+	NA	+

Goal 1 – Improve side channel connectivity, Goal 2 - narrow active channel, Goal 3 – increase key habitat quantity, Goal 4 – increase mature forested islands, Goal 5 – do not increase risk to private property.

Alternative 5 – Phase 1 of the Maximum Scenario (Preferred alternative)

This alternative would include the placement of island ELJ structures within the gravel bar sub-reach along with margin roughening ELJ structures and side channel ELJ structures (see attached layout). Island type ELJs would be grouped to encourage the development of a large channel island, which in turn would encourage stability of the existing southern margin side channel on the left bank. Channel Margin ELJ's would be constructed downstream of the left bank island ELJ's to help prevent channel migration into the left bank, further expansion of the active channel, and reduction of vegetated buffers. Structures would also be placed

at the upstream end of the existing riprap revetment on the right bank to provide cover habitat and attraction to the existing "chum channel" while reducing the risks associated with existing erosion that is threatening to undermine the revetment. ELJ structures will also be constructed along the right bank vegetated edge downstream of the revetment to help prevent channel migration into 1960' era abandoned channels, which are currently vegetated. Channel migration into this area would not be consistent with the goal of reducing the current width of the active channel, and associated habitat objectives. Smaller side channel structures will be constructed in the existing south side channel to improve local habitat and channel complexity. ELJ structures would be relatively evenly spaced along the perimeter of their respective groupings and composed of Type 1 (large) and Type II (medium) ELJ structures. Structure spacing is intended to promote the dissection of the large island by side channels, while discouraging mainstem occupation.. A summary of our assessment is provided in Table 6 and below;

- Hydraulic modeling iterations were performed to evaluate side channel function associated with the Phase 1 left bank Island size and location. The model results show localized increases in velocity in the left bank channel margin side channel, indicating the occurrence of flow velocities at both maintenance and higher stage flow events, which in turn would encourage a higher probability of side channel function.
- The extent and spacing of the ELJ's downstream of the Glen revetment were iterated in the hydraulic model to determine an optimum design that would meet the project habitat objectives. As can be seen in the velocity difference figures in the appendix there is an overall reduction in velocities within the right bank vegetated buffer (near the 1960's era channel scar) which indicates that channel migration through this vegetated buffer is less likely than the "no action" alternative.
- Model iterations were performed to ensure that increased velocities are not projected onto the existing "Glen" revetment; as can be seen in the attached figures this criteria was met.
- Phase 1 model results also show reduced velocities along the left bank of the forested island. The velocity reduction is associated with the ELJ's constructed around the perimeter of the island, and indicates strong encouragement of forested island formation and localized deposition (which improves forested island formation). Flows will not be precluded from moving over and through the left bank forested island and the potential will exist for multiple side channels to form and dissect the island.
    - Lengthening the active channel will reduce the channel slope. The decrease in slope will be most pronounced between RM 47.4 – 48.4 and will reduce sediment transport capacity and induce sediment deposition and fining of the channel material. The reduction in stream energy will encourage the development of forested islands and will, in general, reduce average hydraulic pressures within the project area. However, in certain cases sediment deposition may act to deflect flow towards the channel margins, increasing local hydraulic pressures acting along the channel banks and causing minor erosion.
    - Decreasing the radius of curvature of the active channel at RM 47.5 and RM 48.3 will increase the hydraulic pressure acting along the outside of the channel bend and increase the likelihood of channel margin structures engaging with the dominant channel. The decrease in the radius of curvature may also result in minor erosion and local expansion of the active channel area.

  - Channel margin ELJs placed in these areas will create complex edge habitat. These structures will also reduce hydraulic pressures acting along the channel margins and reduce the likelihood of significant active channel expansion. Channel margin ELJs may also provide a future source for recruitable key sized wood.

- Side channel and channel margin structures will be effective at increasing complex edge habitat and reducing hydraulic energies within the Bennett's Farm Slough, upper Bear Slough, South Margin side channel, and Fall Creek side channel.
- ELJs placed within braided sub-reach (clusters 1 and 3) will function as a locus of sediment deposition behind and adjacent to the ELJs due to an increase in roughness and hydraulic shadowing. This deposition may, in turn, deflect the dominant channel away from the ELJs and cause migration of the dominant channel.
  - Channel migration caused by cluster 3 may result in erosion along the north margin of the active channel area and private property. Channel margin ELJs placed north of cluster 3 (RM 47.5) will help prevent erosion along the north margin of the active channel and private property.
- ELJs placed within the gravel bar sub-reach (cluster 2 and 4) will be effective in reinforcing channel islands and encouraging flow into their respective side channels. Due to the river training effects of the riprap dikes and the large mid channel bar, these structures have a higher likelihood of engagement with either the dominant channel or prominent side channel.

TABLE 8. ALTERNATIVE 4 MAXIMUM PHASE 1 SUMMARY TABLE

	Benefit				Risk
Description	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**
Overall	+	++	++	++	0
Left bank Island ELJS	+	++	+	++	0
Right Bank Margin ELJ	+	0	+	+	+
Left Bank Margin ELJs	+	++	++	+	+
Side Channel Habitat Structures	NA	NA	++	NA	NA

Goal 1 – Improve side channel connectivity, Goal 2 - narrow active channel, Goal 3 – increase key habitat quantity, Goal 4 – increase mature forested islands, Goal 5 – do not increase risk to private property.

Alternative 5 – Do Nothing Scenario

This alternative represents the "do nothing" alternative. The underlying processes causing of the active channel expansion and migration of the dominant channel, are expected to continue within the project area as the channel and high flow corridor adjusts to incoming water and sediment loads. This will likely result in a continuation of unstable channel islands, low channel complexity, and low frequency of stable LWD within the project reach. Continuation of unstable channel conditions may also result in a channel position that

increases erosion along the margins of the active channel increasing the risk to private property. A summary of our assessment is provided in Table 10 and below.

TABLE 10. ALTERNATIVE 5 SUMMARY TABLE

	Benefit				Risk
Description	**Goal 1**	**Goal 2**	**Goal 3**	**Goal 4**	**Goal 5**
Overall	0	-	0	-	-

Goal 1 – Improve side channel connectivity, Goal 2 - narrow active channel, Goal 3 – increase key habitat quantity, Goal 4 – increase mature forested islands, Goal 5 – do not increase risk to private property.

LIMITATIONS

We have prepared this letter report for the exclusive use of Herrera and their authorized agents for geomorphic reach analyses for the Farmhouse Reach of the North Fork of the Nooksack River in Whatcom County, Washington. Within the limitations of scope, schedule and budget, our services have been executed in accordance with the generally accepted geologic and geomorphic science practices in this area at the time this report was prepared. The conclusions and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, express or implied, should be understood.

Any electronic form, facsimile or hard copy of the original document (email, text, table and/or figure), if provided, and any attachments should be considered a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.

We appreciate this opportunity to be of service to Herrera and we look forward to continuing to work with you. Please call if you have any questions regarding this memorandum, or if you need additional information.

REFERENCES

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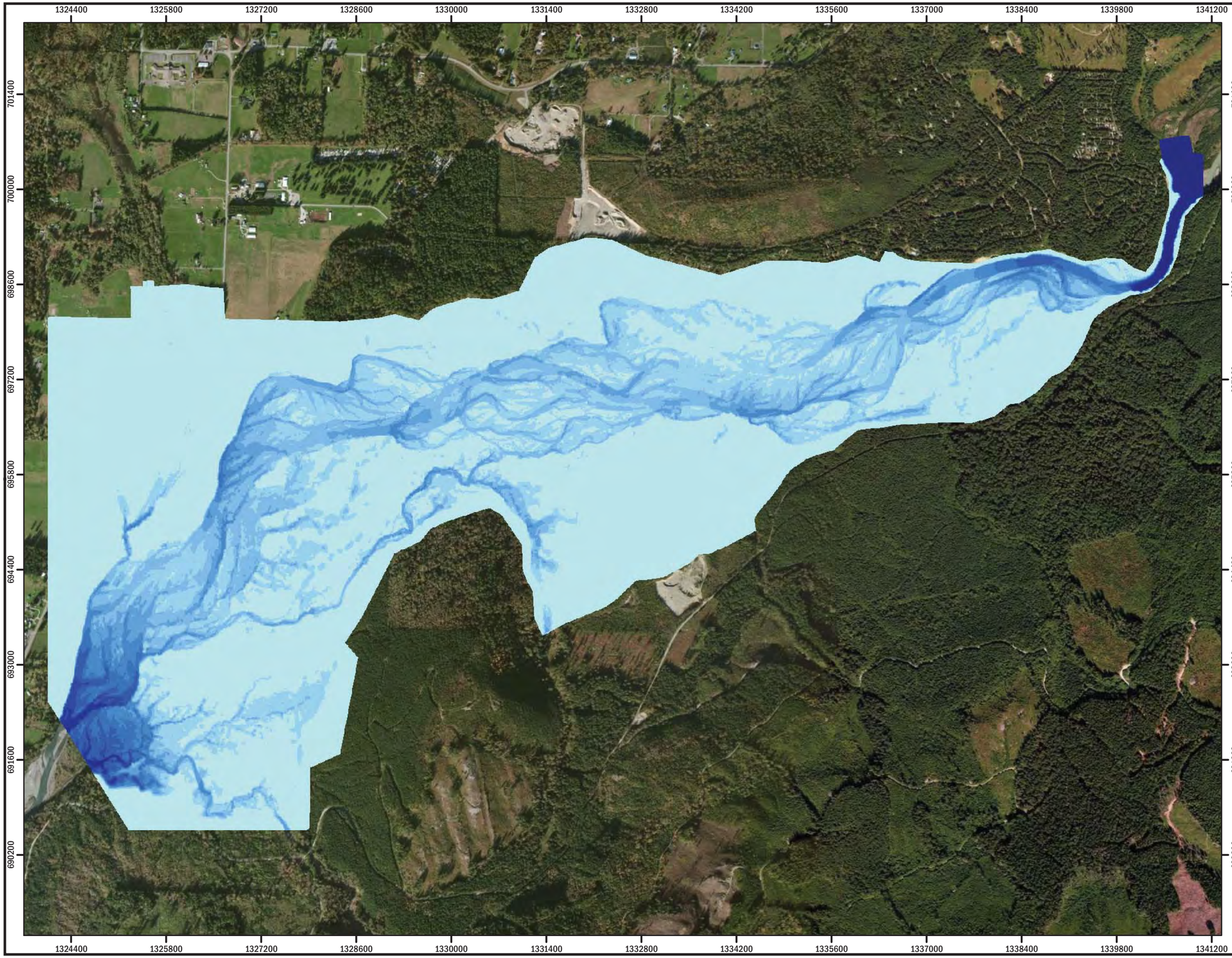
Attachments;

Figure 1 – Vicinity Map
Figure 2 – Geomorphic Features
Figure 3 – 1938 Channel
Figure 4 – 1955 Channel
Figure 5 – 1976 Channel
Figure 6 – 1986 Channel
Figure 7 – 1994 Channel
Figure 8 – 2005 Channel
Figure 9 – 2005 LiDAR Elevations
Figure 10 – Relative Elevations above 2005 LiDAR
Figure 11 – Elevation Difference 1994 to 2004
Figure 12 – Stable Features
Figure 13 – Channel Profile

Conceptual layouts for proposed alternatives (provided by Herrera)
Hydraulic model results (provided by Herrera)



Draft results. 100-year.

Legend

Depth (feet)

- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- > 18

N

0 700 1,400 2,800

Feet

HERRERA

Aerial: © 2012 NAVTEQ © 2012 Microsoft Corporation

Coordinates: NAD83 StatePlane Washington North (feet)

Produced By: GIS

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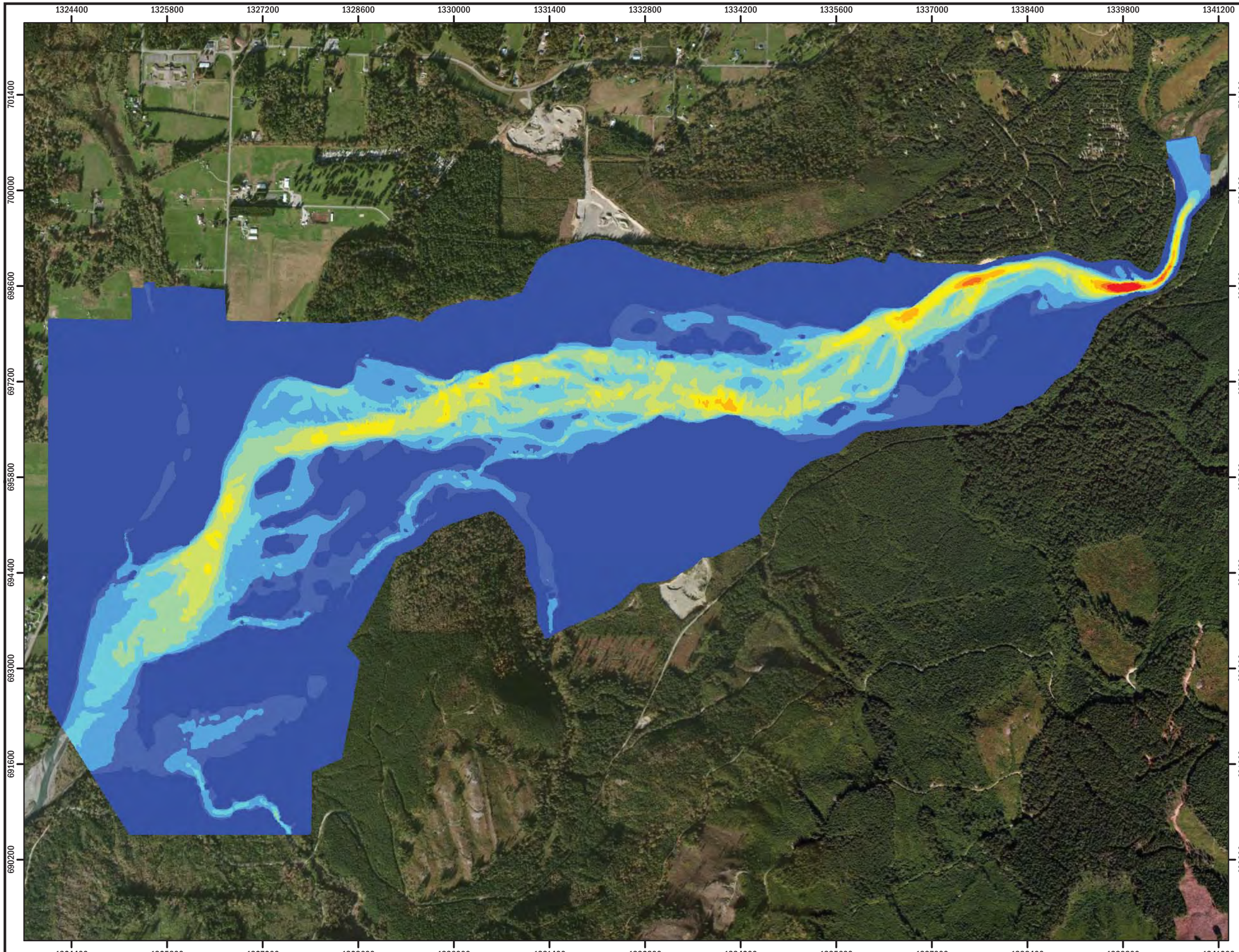


Draft results. 100-year.

Legend

Velocity (feet/second)

- 0 to 1
- 1 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- > 16

N

0 700 1,400 2,800

Feet

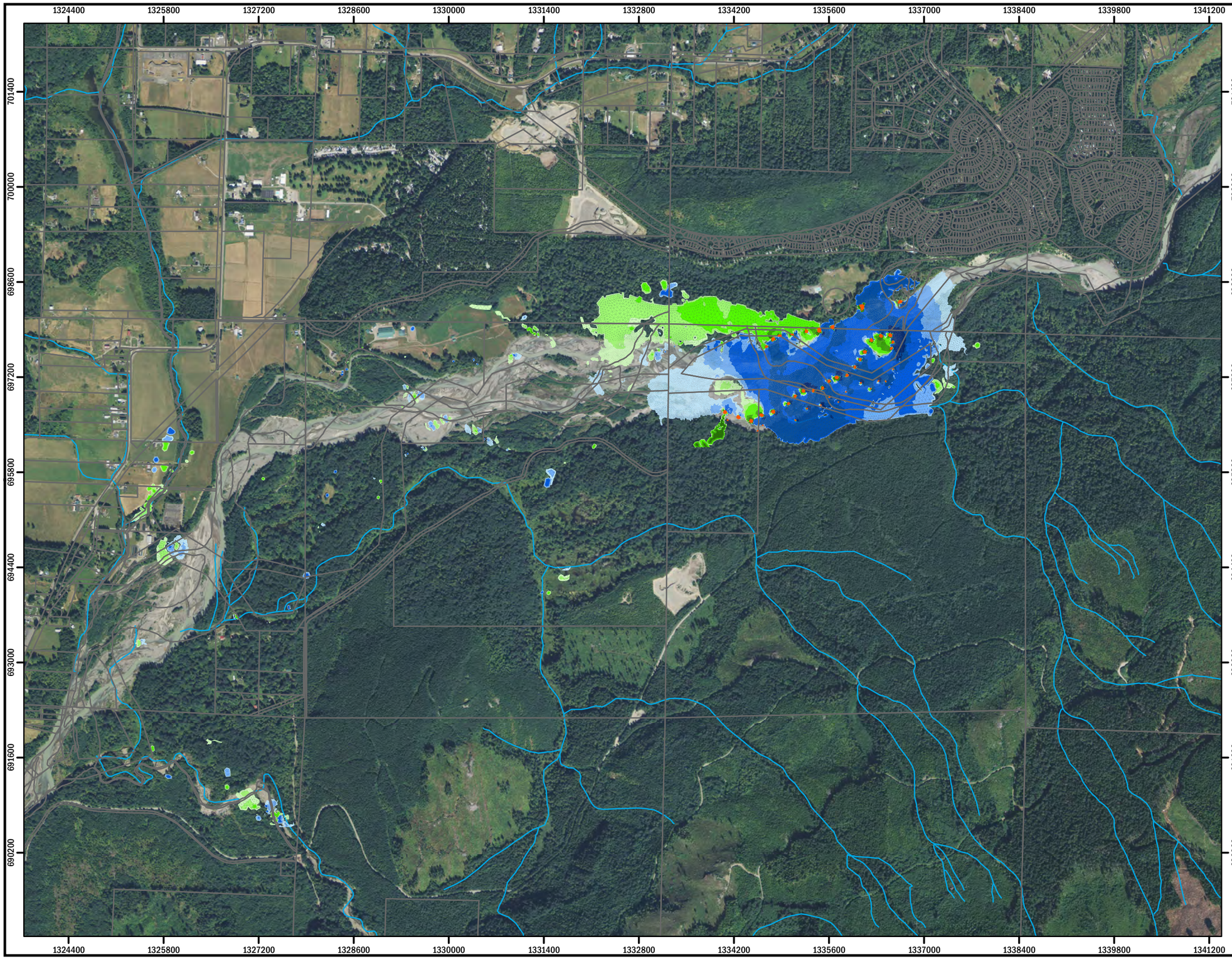
HERRERA

Aerial: © 2012 NAVTEQ © 2012 Microsoft Corporation

Coordinates: NAD83 StatePlane Washington North (feet)

Produced By: GIS

Project: K:\Projects\09-04592-001\Project\model_output\draft_results.mxd (8/21/2012)



Farmhouse - Run 17 - Phase 1 Results
100-year depth difference - DRAFT
(proposed minus existing).
05/13/2013

Legend

- ELJ
- Stream
- Parcel

Depth difference (ft)

- < -1
- -1 to -0.5
- -0.5 to -0.14
- -0.14 to -0.05
- -0.05 to -0.02
- -0.02 to 0.02 (no color)
- 0.02 to 0.05
- 0.05 to 0.14
- 0.14 to 0.5
- 0.5 to 1
- > 1

N

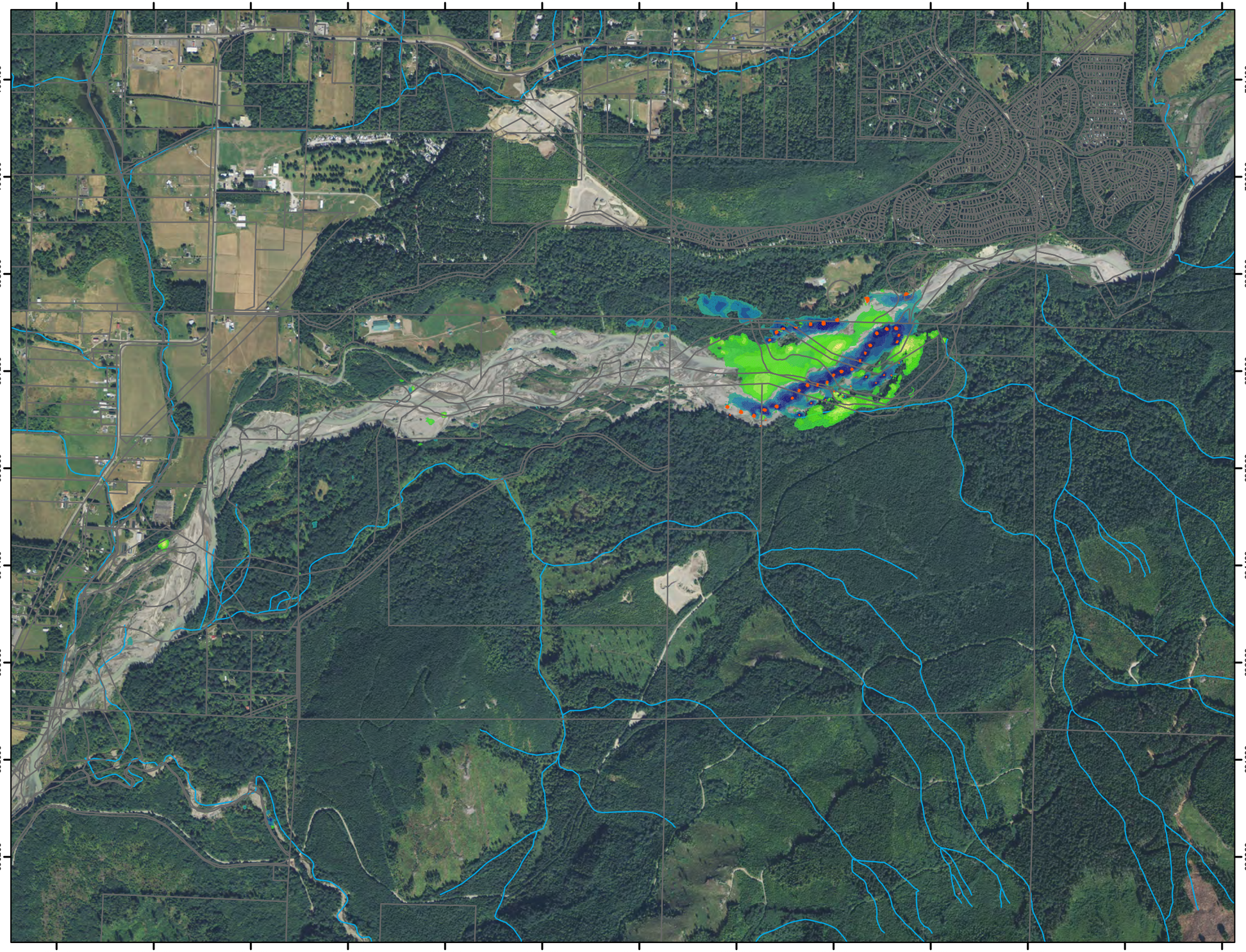
0 700 1,400 2,800

Feet

HERRERA

Aerial: Whatcom County (2011)
Coordinates: NAD 1983 WA State Plane North (ft)

Produced By: GIS
Project: K:\Projects\09-04592-001\Project\Difference_plots_20130513.mxd (5/31/2013)



Farmhouse - Run 17 - Phase 1 Results
100-year velocity difference - DRAFT
(proposed minus existing).
05/13/2013

Legend

- ELJ
- Stream
- Parcel

Velocity magnitude difference (fps)

- < -3
- -3 to -2
- -2 to -1
- -1 to -0.5
- -0.5 to -0.25
- -0.25 to 0.25 (no color)
- 0.25 to 0.5
- 0.5 to 1
- 1 to 2
- 2 to 3
- > 3

N

0 700 1,400 2,800

Feet

HERRERA

Aerial: Whatcom County (2011)
Coordinates: NAD 1983 WA State Plane North (ft)

Produced By: GIS
Project: K:\Projects\09-04592-001\Project\Difference_plots_20130513.mxd (5/31/2013)

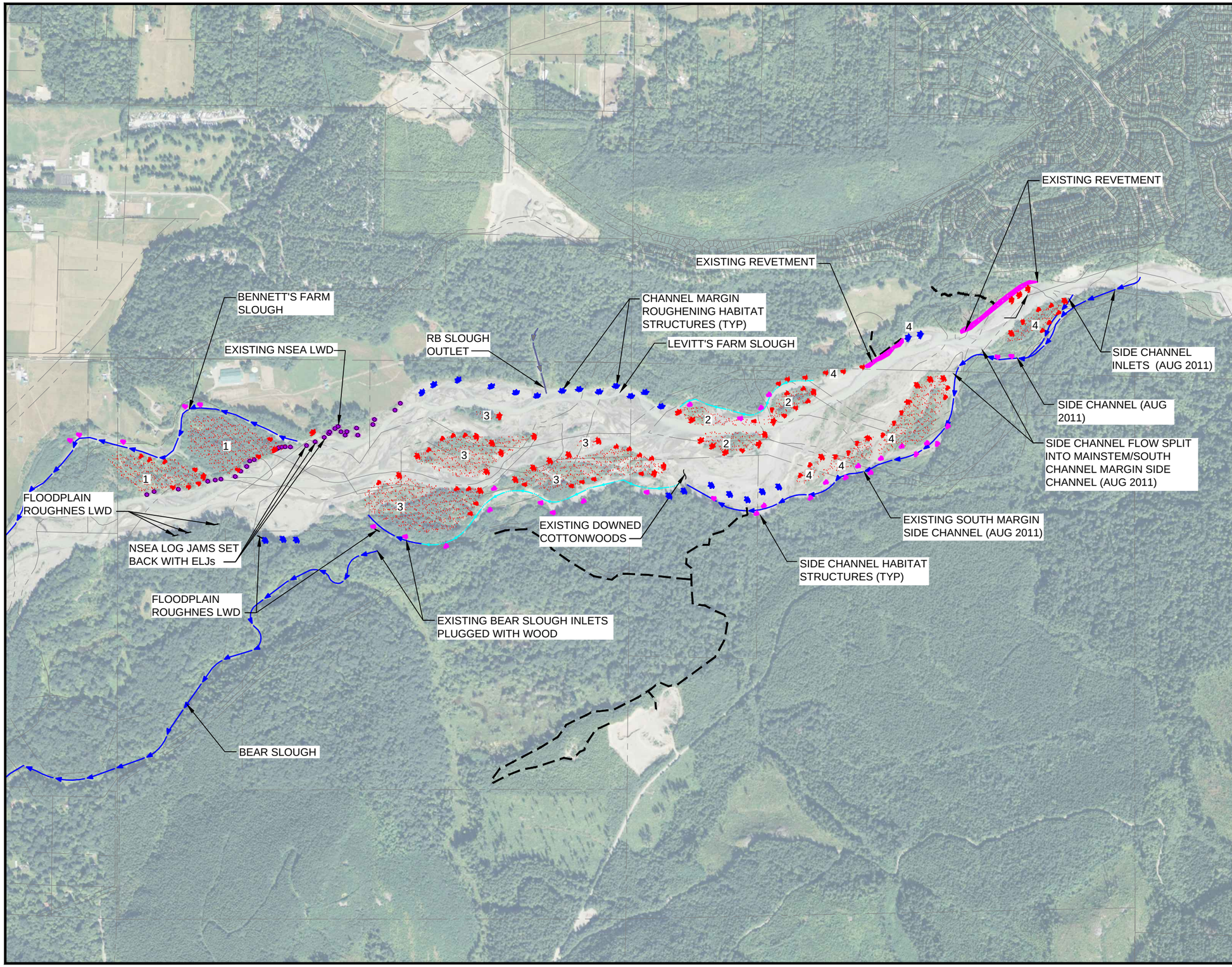


FIGURE 1. ALTERNATIVE MAX ISLAND (157 ELJs) DRAFT FARMHOUSE REACH RESTORATION 06-28-13

Legend

- ELJ TYPE 1 (ISLAND STR)
- ELJ TYPE 2 (ISLAND STR)
- ELJ TYPE 1 (CHANNEL MARGIN ROUGH STR)
- ELJ TYPE 2 (CHANNEL MARGIN ROUGH STR)
- ELJ TYPE 2 (SIDE CHANNEL HABITAT STR)
- # CLUSTER ID
- NSEA LWD
- EXISTING SIDE CHANNEL
- POTENTIAL SIDE CHANNEL
- PARCEL
- EXISTING ROAD ACCESS
- POTENTIAL FORESTED ISLAND

NOTES:

1. AERIAL PHOTO 2011.
2. STRUCTURES SHOWN ARE FOR ILLUSTRATION ONLY. FINAL DESIGN WILL REQUIRE PERMITTING, LAND OWNER AGREEMENTS, AND COORDINATION WITH STAKEHOLDERS PRIOR TO FINAL DESIGN AND CONSTRUCTION.

N

0 250 500 1000

scale in feet

HERRERA ENVIRONMENTAL CONSULTANTS

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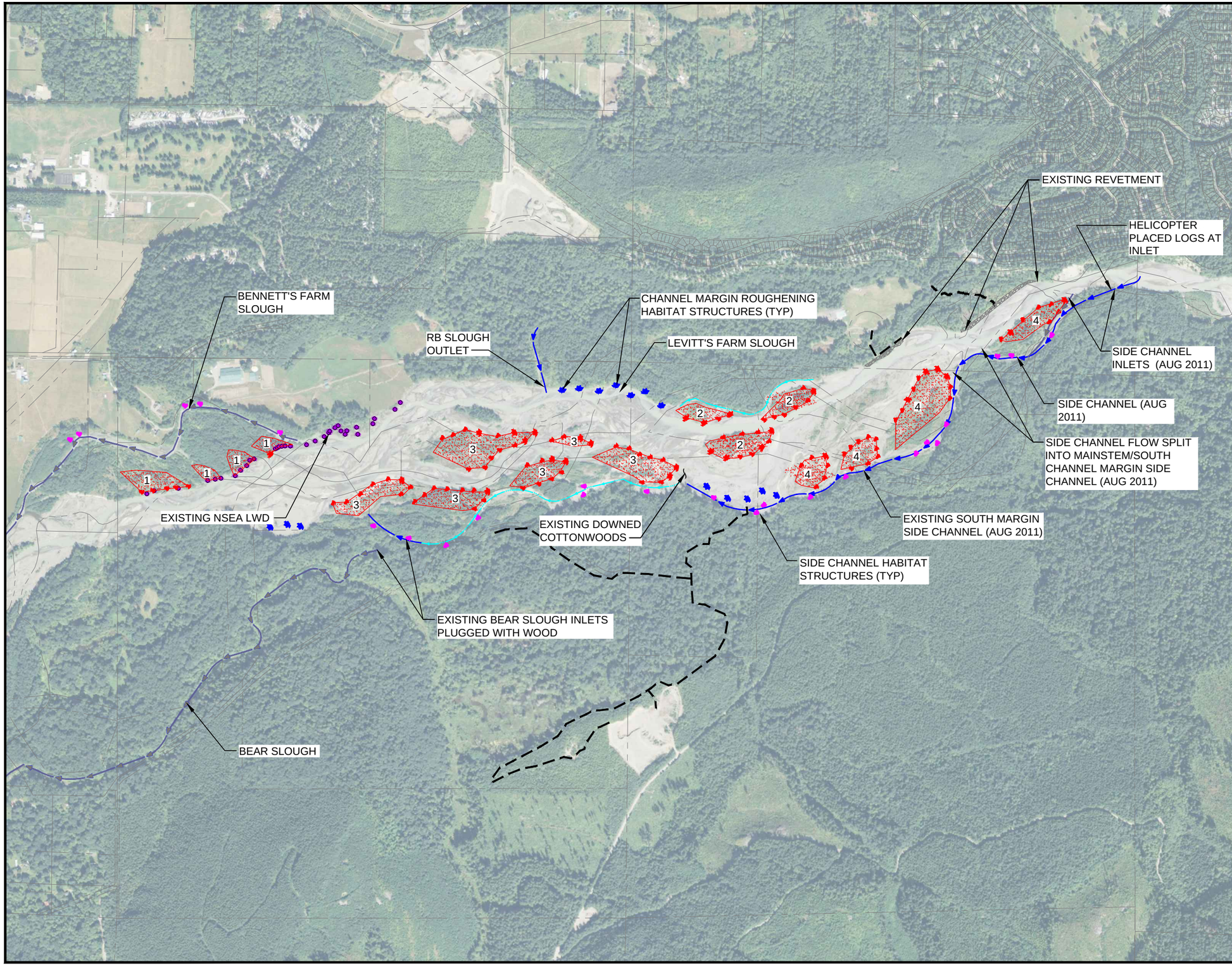

FIGURE 1. ALTERNATIVE MEDIUM ISLAND (149 ELJs) DRAFT FARMHOUSE REACH RESTORATION 06-28-13

Legend

- ELJ TYPE 1 (ISLAND STR)
- ELJ TYPE 2 (ISLAND STR)
- ELJ TYPE 1 (CHANNEL MARGIN ROUGH STR)
- ELJ TYPE 2 (CHANNEL MARGIN ROUGH STR)
- ELJ TYPE 2 (SIDE CHANNEL HABITAT STR)
- NSEA LWD
- EXISTING SIDE CHANNEL
- POTENTIAL SIDE CHANNEL
- PARCEL
- EXISTING ROAD ACCESS
- POTENTIAL FORESTED ISLAND

NOTES:

1. AERIAL PHOTO 2011.
2. STRUCTURES SHOWN ARE FOR ILLUSTRATION ONLY. FINAL DESIGN WILL REQUIRE PERMITTING, LAND OWNER AGREEMENTS, AND COORDINATION WITH STAKEHOLDERS PRIOR TO FINAL DESIGN AND CONSTRUCTION.

N

0 250 500 1000

scale in feet

HERRERA ENVIRONMENTAL CONSULTANTS

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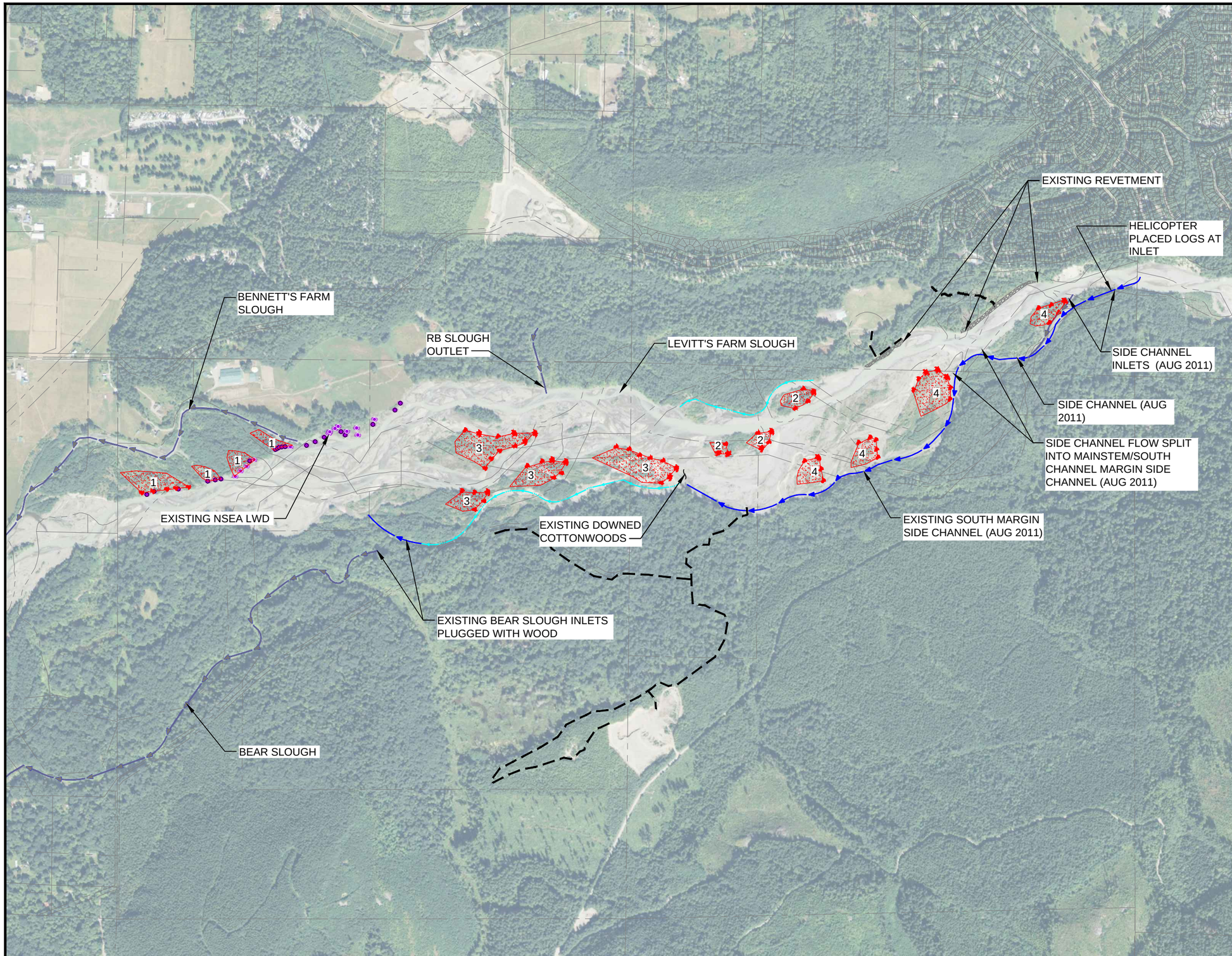


FIGURE 1. ALTERNATIVE MINI ISLAND (66 ELJs) DRAFT FARMHOUSE REACH RESTORATION 06-28-13

Legend

- ELJ TYPE 1 (ISLAND STR)
- ELJ TYPE 2 (ISLAND STR)
- NSEA LWD
- EXISTING SIDE CHANNEL
- POTENTIAL SIDE CHANNEL
- PARCEL
- EXISTING ROAD ACCESS
- POTENTIAL FORESTED ISLAND

NOTES:

1. AERIAL PHOTO 2011.
2. STRUCTURES SHOWN ARE FOR ILLUSTRATION ONLY. FINAL DESIGN WILL REQUIRE PERMITTING, LAND OWNER AGREEMENTS, AND COORDINATION WITH STAKEHOLDERS PRIOR TO FINAL DESIGN AND CONSTRUCTION.

N

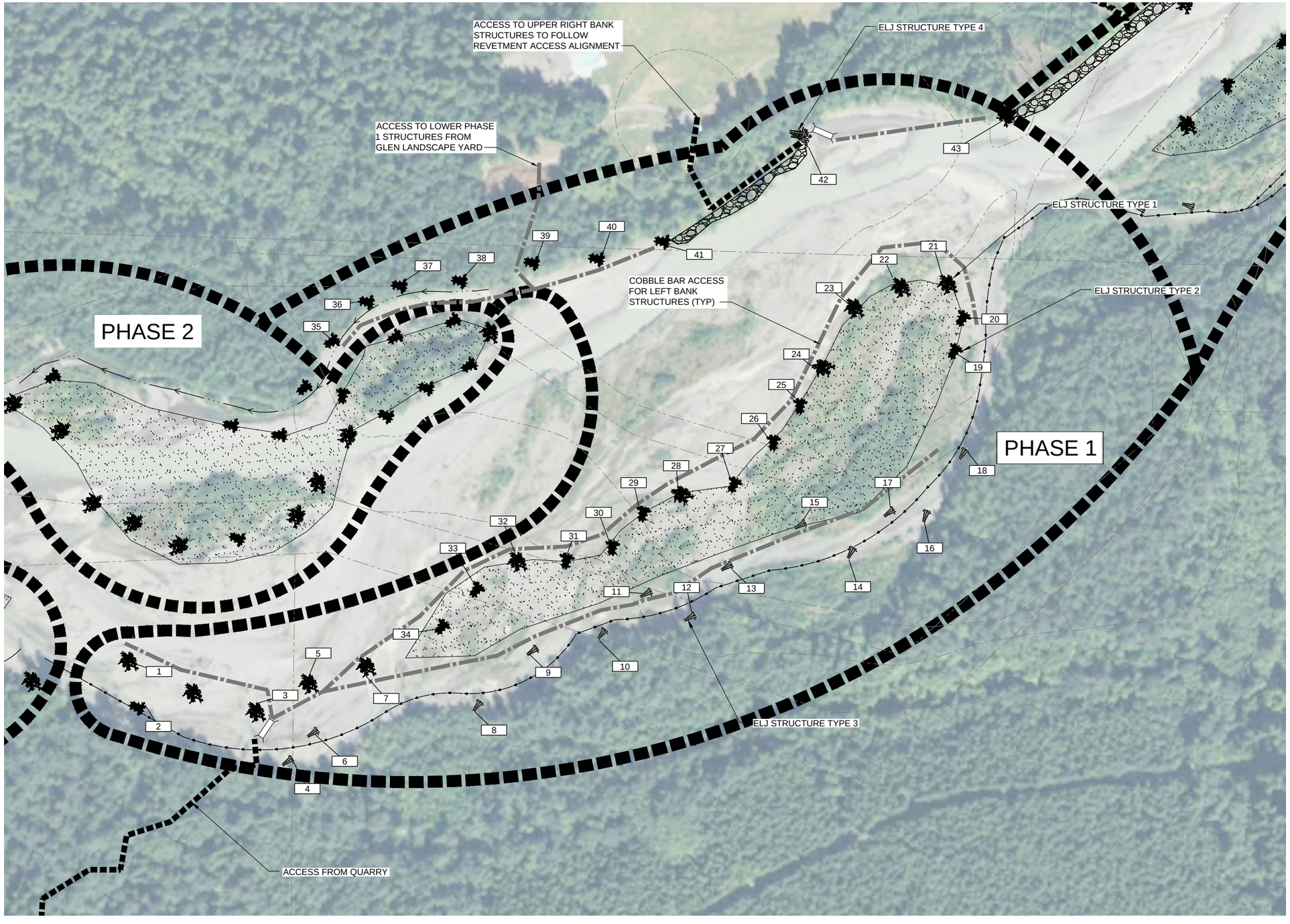
0 250 500 1000

scale in feet

HERRERA ENVIRONMENTAL CONSULTANTS

O:\proj\Y2009\09-04592-001\Draft Cad\GK\Figure MINI 060512.dwg

FIGURE 4. ALTERNATIVE MAX
PHASE 1 DRAFT
FARMHOUSE REACH RESTORATION
06-28-13



Legend

- PARCEL
- EXISTING SIDE CHANNEL
- PROPOSED SIDE CHANNEL
- POTENTIAL FORESTED ISLAND
- APPROX. EXISTING REVETMENT EXTENTS
- STRUCTURE TYPE 1 #
- STRUCTURE TYPE 2 #
- STRUCTURE TYPE 3 #
- STRUCTURE TYPE 4 #

NOTES:

1. AERIAL PHOTO 2011.
2. STRUCTURES SHOWN ARE FOR ILLUSTRATION ONLY. FINAL DESIGN WILL REQUIRE PERMITTING, LAND OWNER AGREEMENTS, AND COORDINATION WITH STAKEHOLDERS PRIOR TO FINAL DESIGN AND CONSTRUCTION.

N

150 0 150 300

SCALE IN FEET

HERRERA ENVIRONMENTAL CONSULTANTS

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Figure A1 – Aerial oblique photo of the braided sub-reach taken June, 2010

Figure A2 – Aerial oblique photo of the braided reach taken June, 2010

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GEOENGINEERS	Appendix A

Figure A3 – Right bank riprap dike RM 48.8 looking upstream

Figure A4 – Braided sub-reach channel character RM 47.8

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A5 – Bar sediments right active channel RM 48.7

Figure A6 – Bar sediments and particle imbrication center active channel RM 48.2

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GEOENGINEERS	Appendix A

Figure A7 – Right bank erosion scarp into glacial outwash terrace RM 49.0

Figure A8 – Right bank stratigraphy RM 47.6 and fine sediment deposition

Figure A9 – Right bank fine sediment deposition RM 47.6

Figure A10 – Buried large wood right bank RM 47.2

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A11 – Natural logjam center active channel RM 48.4

Figure A12– Natural large wood accumulation and scour pool RM 48.1

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A13 – Large stump center channel RM 47.2

Figure A14– Large stump left floodplain RM 46.3

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A15 – Side channel A inlet

Figure A16– Side channel A looking upstream

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A17 – Side channel B looking downstream

Figure A18– Side channel B and left bank erosion RM48.1

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A19 – Overflow pathway inlet to Bear Slough

Figure A20– Secondary overflow pathway inlet to Bear Slough

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

Figure A21 – Side channel C inlet

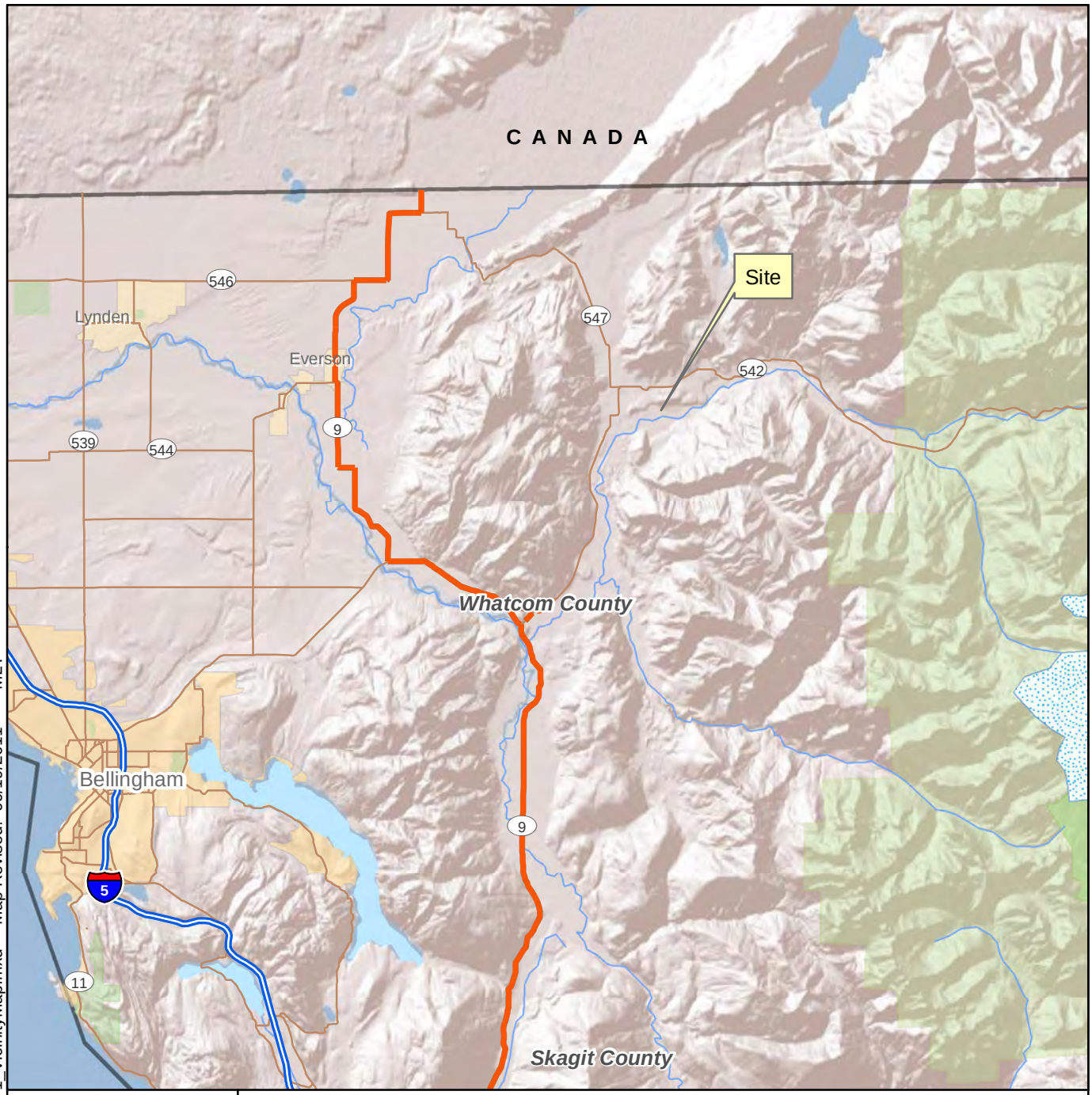
Figure A22– Side channel D inlet

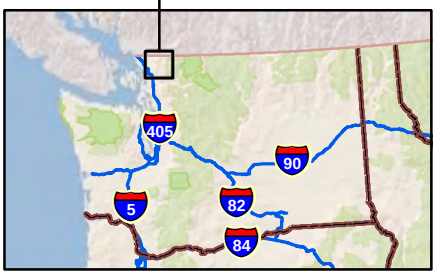
Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A

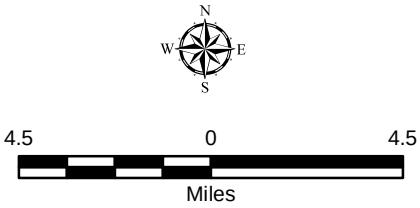
Figure A23 – NSEA right bank large wood and bank protection

Figure A24 – NSEA right bank large wood stabilization

Field Reconnaissance Photos	
Farmhouse Reach Restoration Geomorphic Assessment	
GeoEngineers	Appendix A







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Data Sources: ESRI Data & Maps, Street Maps 2008.
Transverse Mercator, Zone 10 N North, North American Datum 1983
North arrow oriented to grid north

Vicinity Map

Farmhouse Reach Restoration
Nooksack Indian Tribe
Kendall, Washington

GEOENGINEERS

Figure 1

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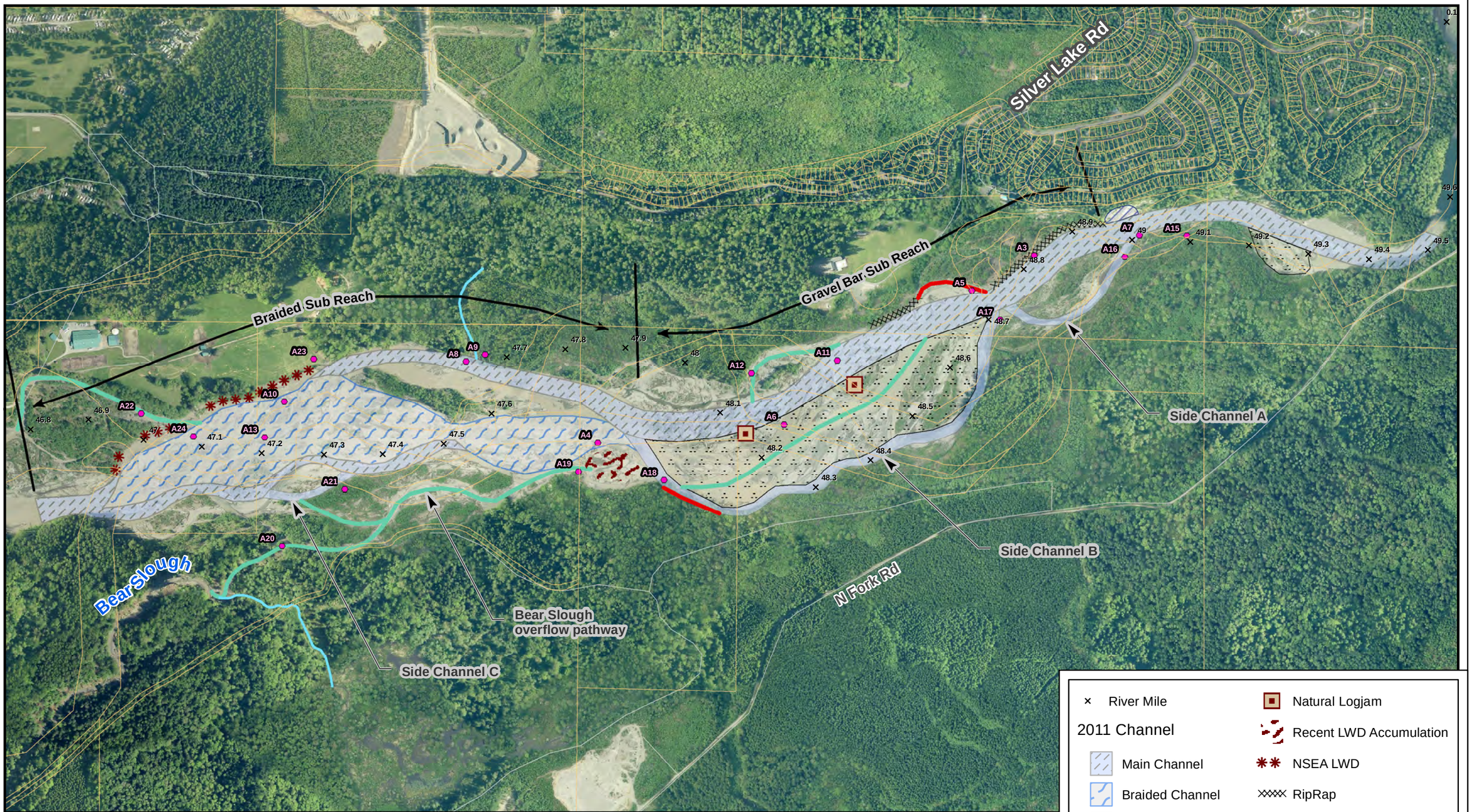

Figure 2 Geomorphic Features North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

Notes:
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Data Sources: LiDAR - Nooksack Tribe, 2005. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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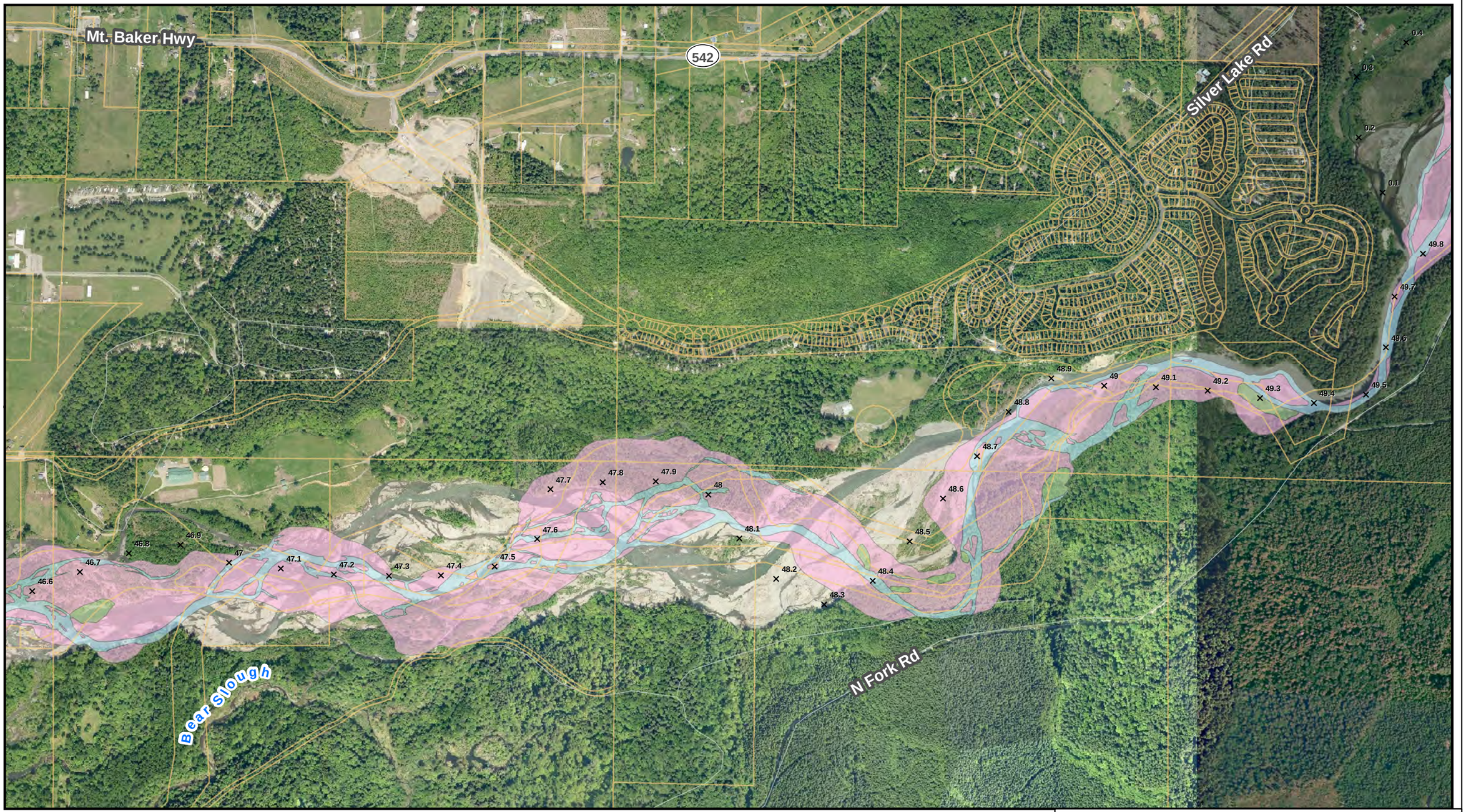

Figure 3 1938 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

900 0 900
Feet

N W E S

1938 Channel
- FI
- HF
- LF

× River Mile

Whatcom County Parcels

Notes:
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Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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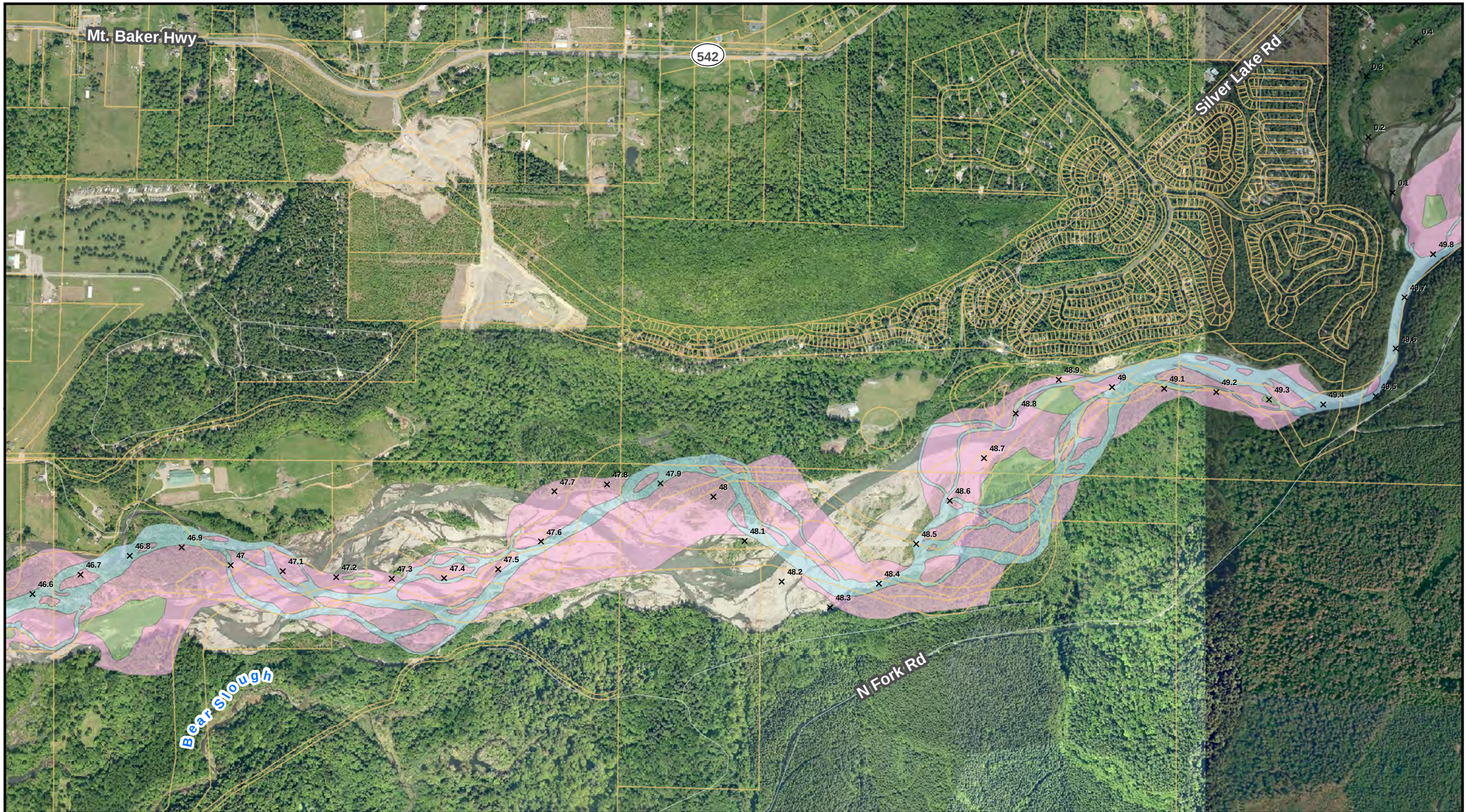

Figure 4 1955 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

900 0 900
Feet

N W E S

1955 Channel
- FI
- HF
- LF

× River Mile

Whatcom County Parcels

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Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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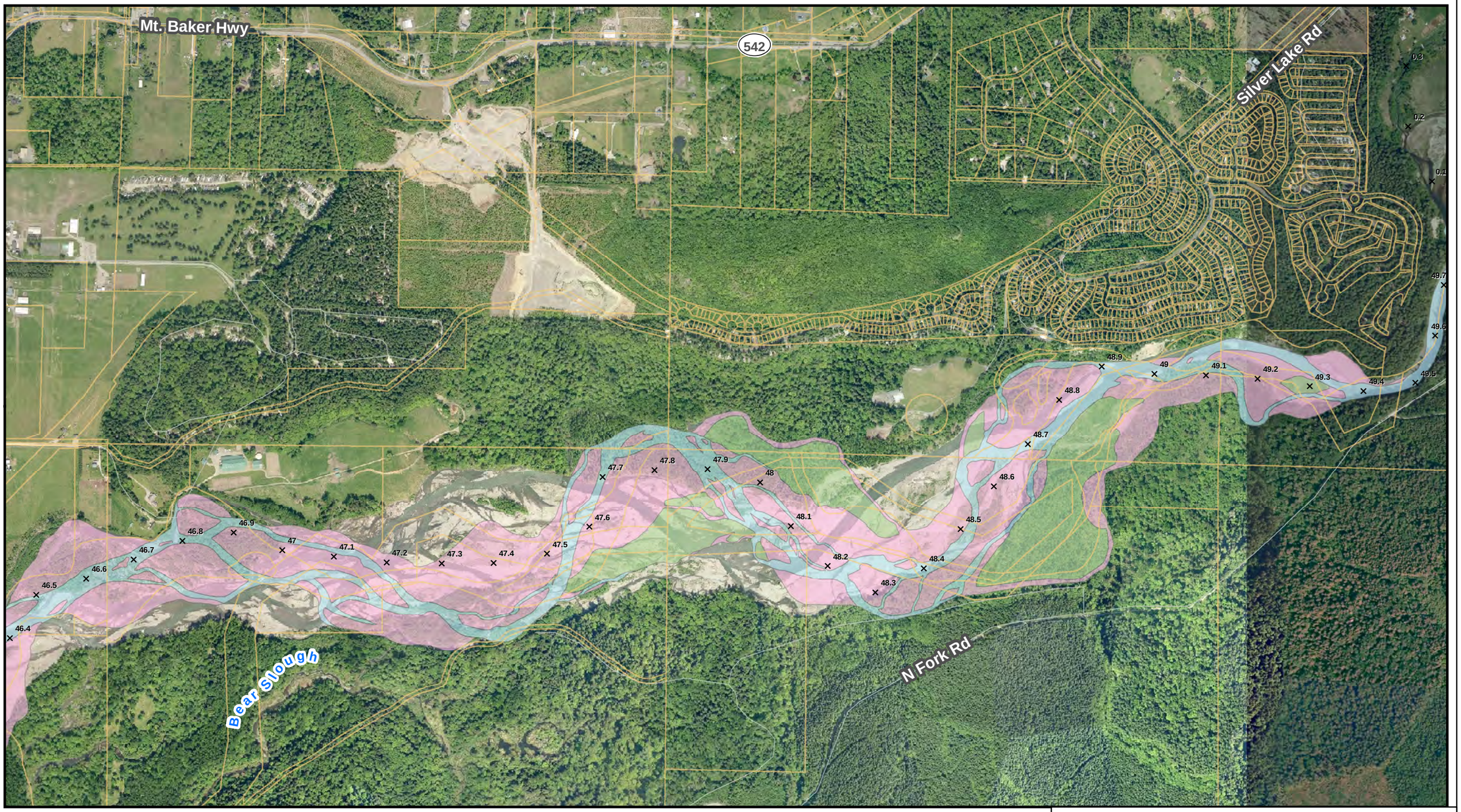

Figure 5 1976 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

900 0 900
Feet

N W E S

1976 Channel

- FI
- HF
- LF

× River Mile

Whatcom County Parcels

Notes:
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Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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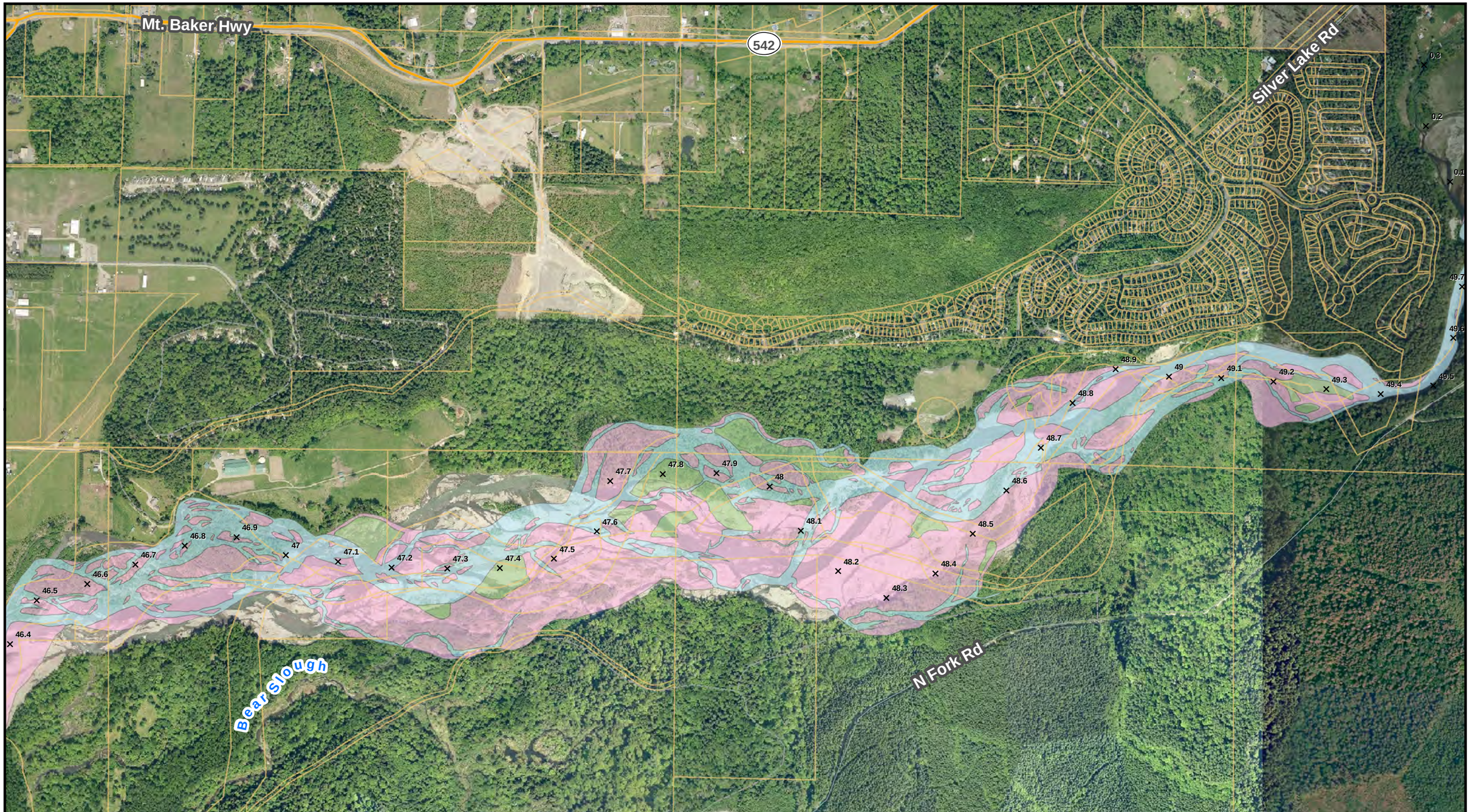

Figure 6 1986 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GEOENGINEERS

900 0 900
Feet

N W E S

1986 Channel

- FI
- HF
- LF

× River Mile

Whatcom County Parcels

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Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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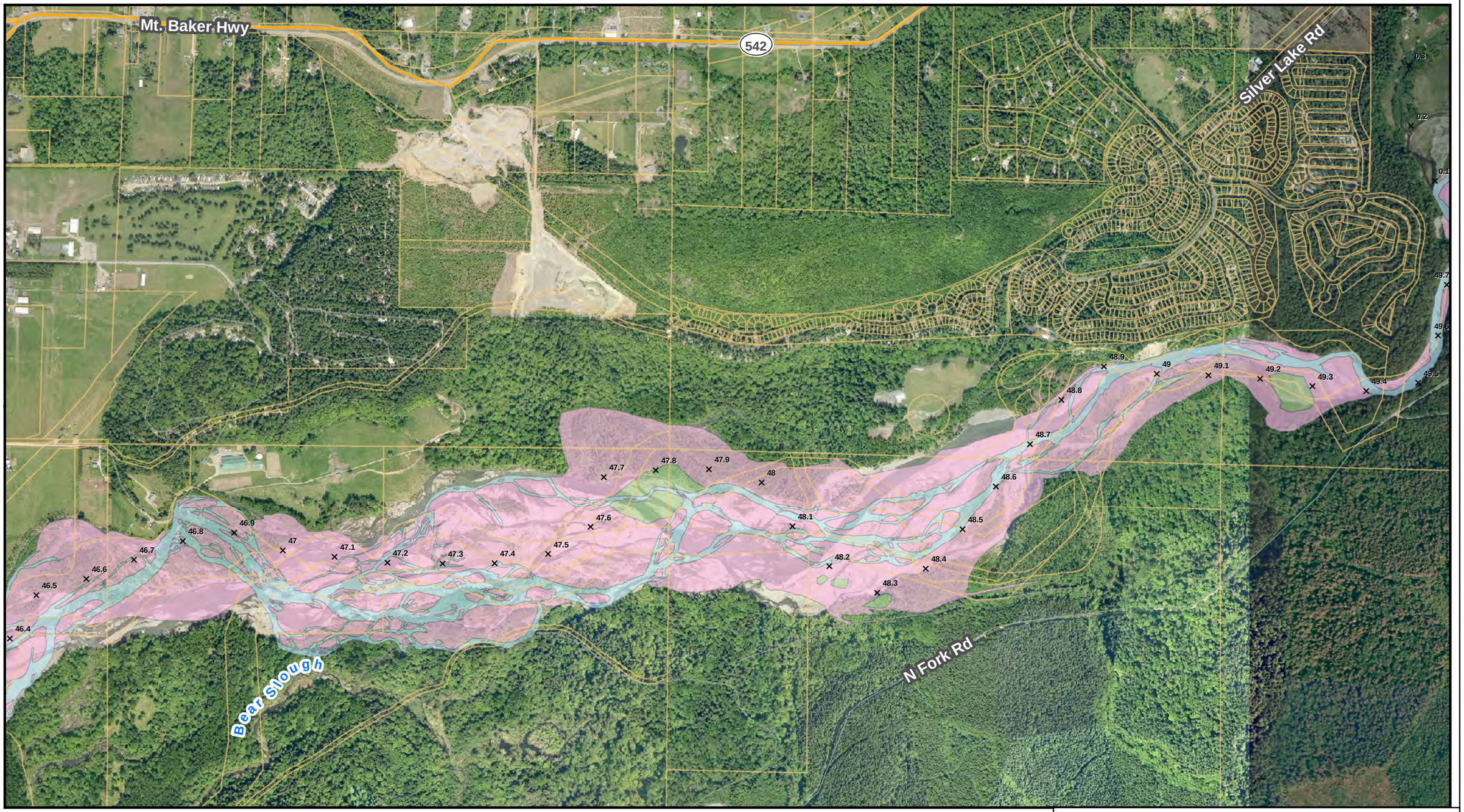

Figure 7 1994 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

900 0 900
Feet

N W E S

1994 Channel

- FI
- HF
- LF

× River Mile

Whatcom County Parcels

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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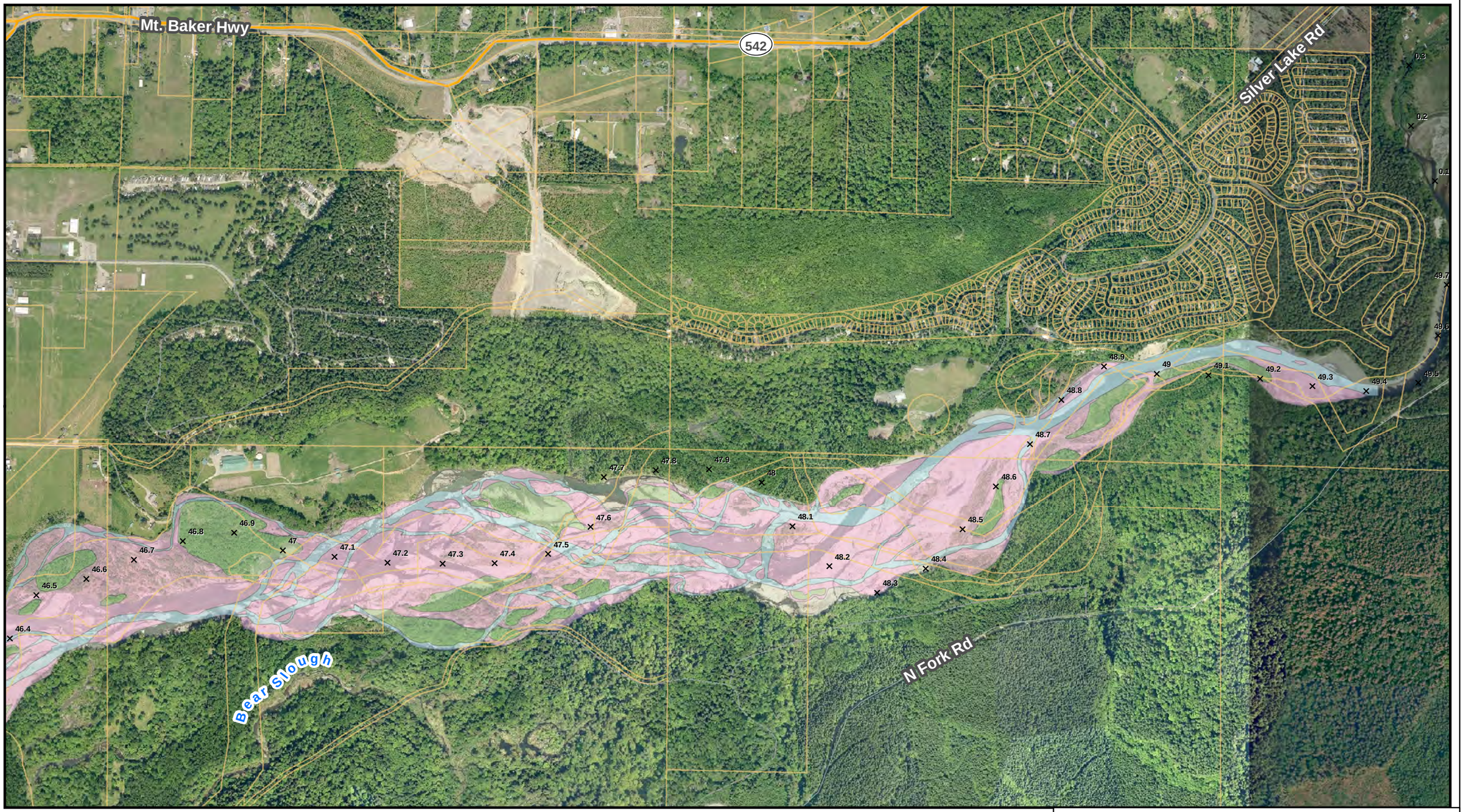


Figure 8 2005 Channel North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

900 0 900
Feet

N W E S

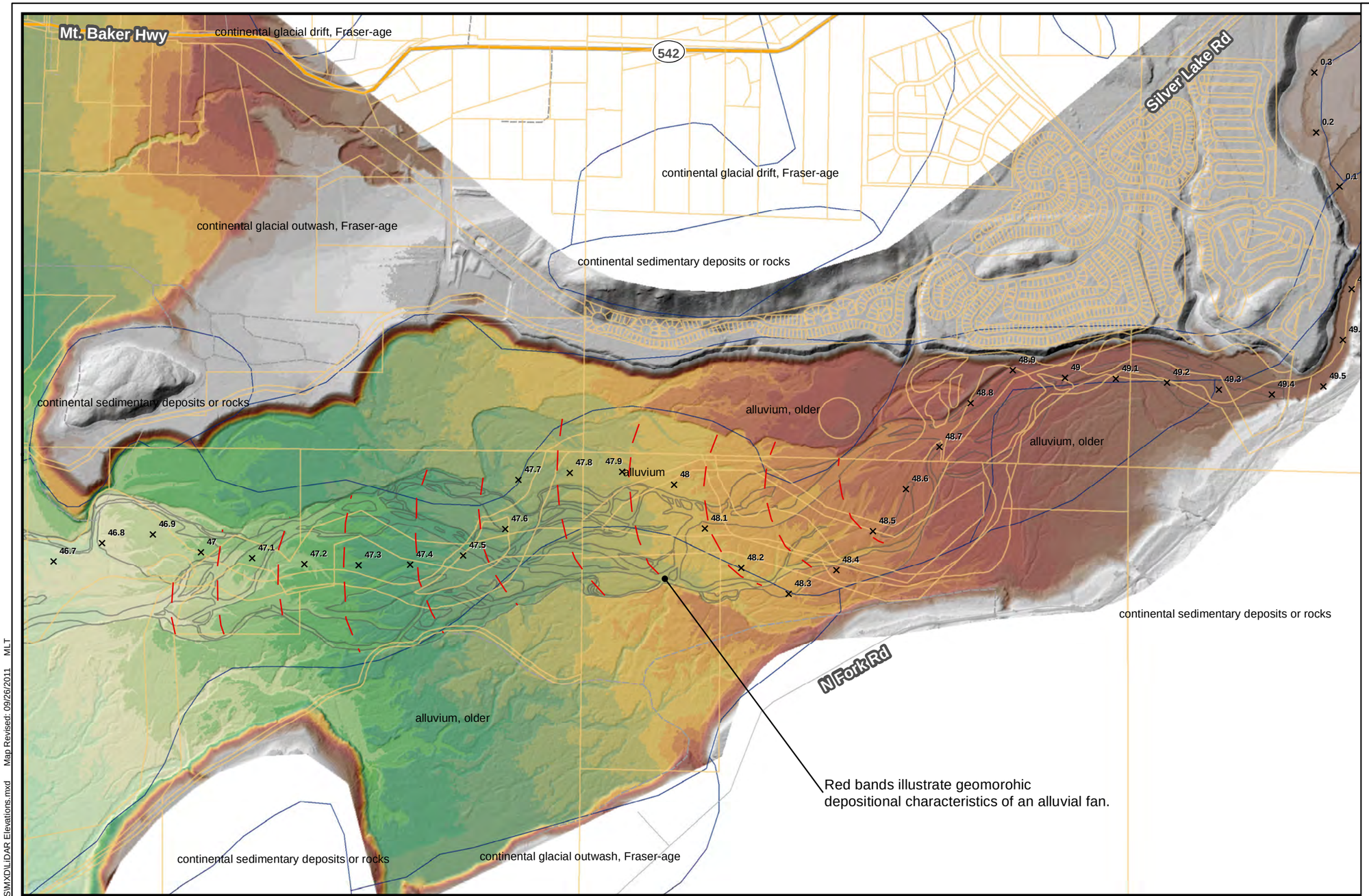
2005 Channel
- FI
- HF
- LF

× River Mile

Whatcom County Parcels

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

Office: BAM Path: P:\0441012\GIS\MXD\2005_Channel.mxd Map Revised: 09/23/2011 MLT



River Mile
Parcels
2005 Channel
Geology

Elevation (ft)

546 - 550
541 - 545
536 - 540
531 - 535
526 - 530
521 - 525
516 - 520
511 - 515
506 - 510
501 - 505
496 - 500
491 - 495
486 - 490
481 - 485
476 - 480
471 - 475
466 - 470
461 - 465
456 - 460
451 - 455
446 - 450
441 - 445
436 - 440
431 - 435
426 - 430
421 - 425
416 - 420
411 - 415
406 - 410
401 - 405

Figure 9 LiDAR Elevation North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

1,000 0 1,000
Feet

N W E S

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: LiDAR - Nooksack Tribe, 2005. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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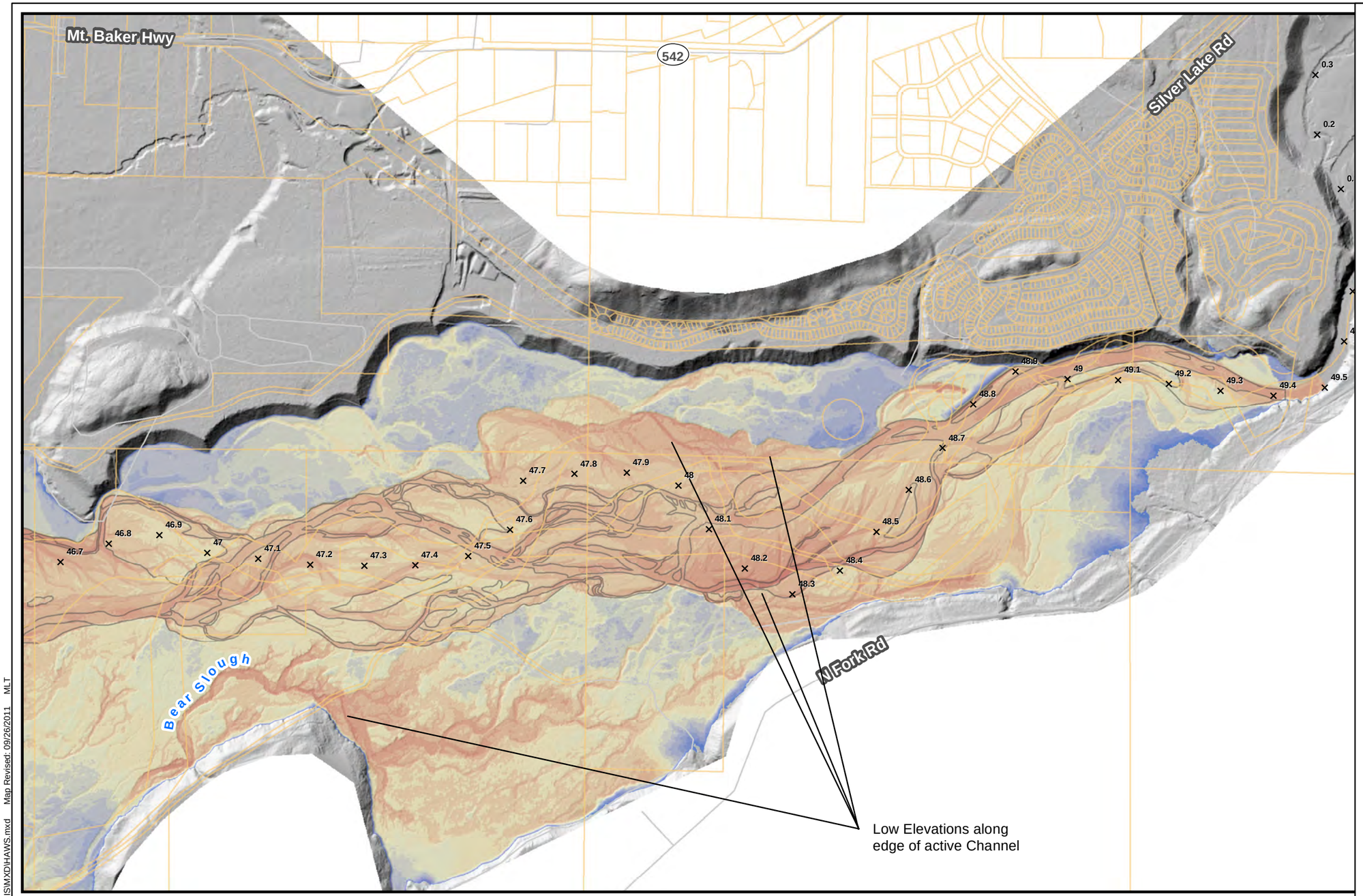

Figure 10
Relative Water Surface Elevations
North Fork Nooksack

Nooksack Indian Tribe
Kendall, Washington

GeoEngineers

1,000 0 1,000
Feet

N W E S

× River Mile

Parcels

2005 Channel

Relative Elevation (ft)

- -7 - -6
- -5 - -4
- -3 - -2
- -1 - 0
- 0 - 2
- 3 - 4
- 5 - 6
- 7 - 8
- 9 - 10
- 11 - 12
- 13 - 14
- 15 - 16
- 17 - 18
- 19 - 20

Elevation Relative to
2005 LiDAR Water Surface

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: LiDAR - Nooksack Tribe, 2005. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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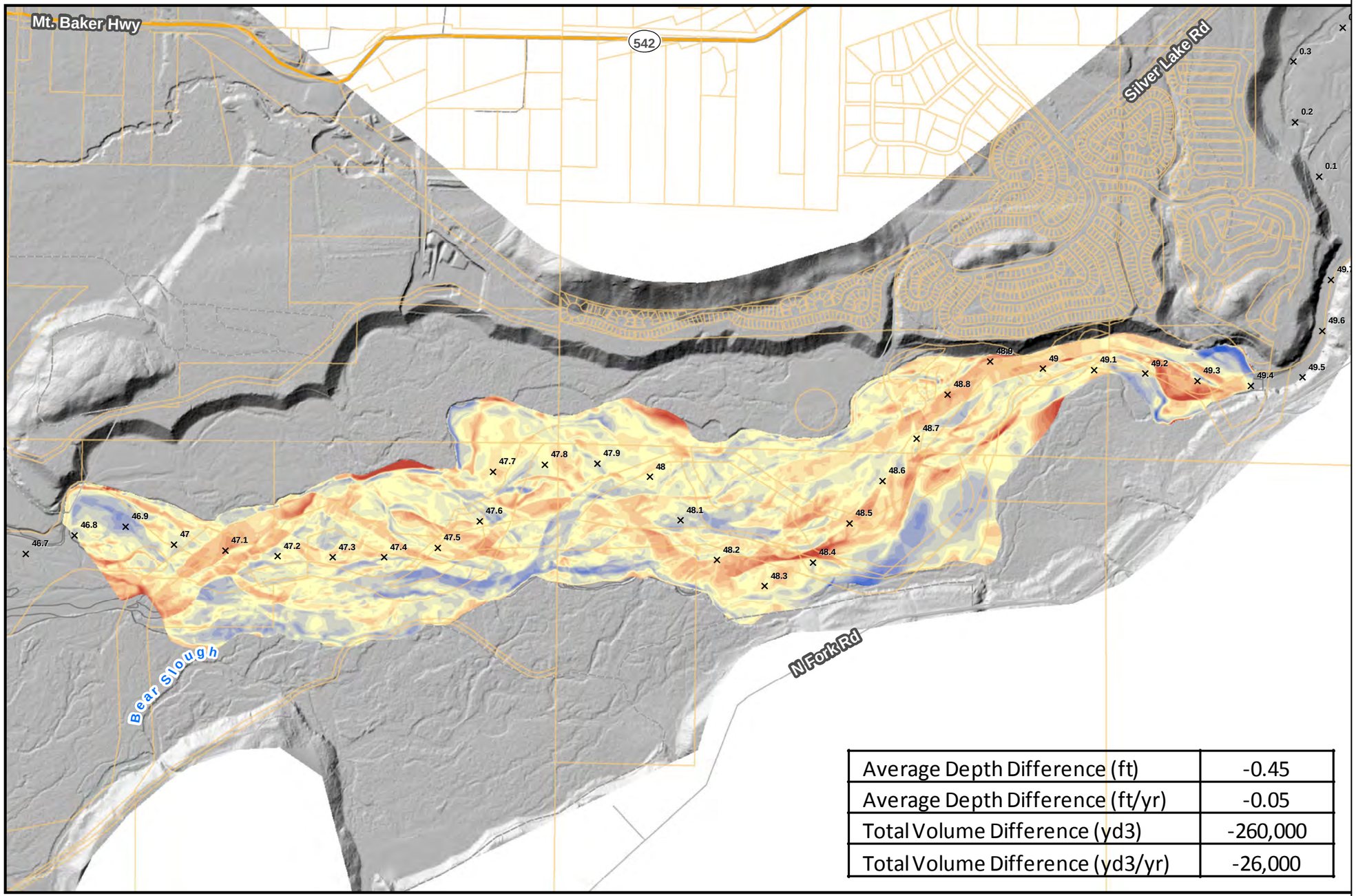

Average Depth Difference (ft)	-0.45
Average Depth Difference (ft/yr)	-0.05
Total Volume Difference (yd3)	-260,000
Total Volume Difference (yd3/yr)	-26,000

River Mile

2005 Channel

Parcels

Elevation Difference (ft)

- -14.3 - -8
- -7.9 - -7
- -6.9 - -6
- -5.9 - -5
- -4.9 - -4
- -3.9 - -3
- -2.9 - -2
- -1.9 - -1
- -0.9 - 0
- 0.1 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 7
- 7.1 - 8.2

Figure 11
1994 to 2004 Elevation Difference
North Fork Nooksack

Nooksack Indian Tribe
Kendall, Washington

GeoEngineers

1,000 0 1,000
Feet

N W E S

Notes:
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Data Sources: LiDAR - Nooksack Tribe, 2005. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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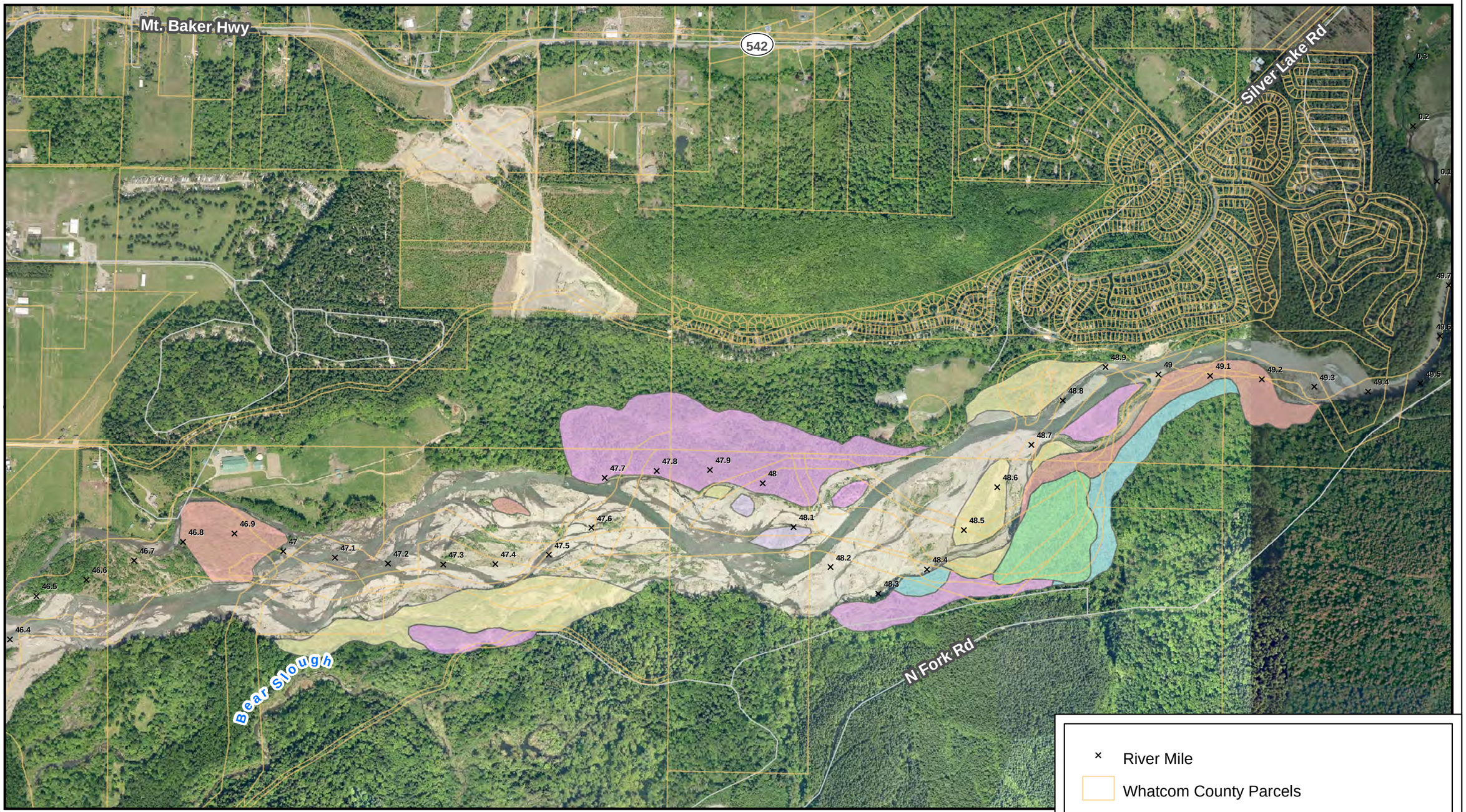

Figure 12 Stable Areas North Fork Nooksack	Nooksack Indian Tribe Kendall, Washington	GeoEngineers

Notes:
1. The locations of all features shown are approximate. 2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. 3. It is unlawful to copy or reproduce all or any part thereof, whether for personal use or resale, without permission.
Data Sources: Aerial; Nooksack Tribe, 2010; ESRI World Imagery, 2009. State Plane HARN Washington North FIPS 4601 (Feet), North American Datum 1983. North arrow oriented to grid north.

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