CHANNEL MIGRATION AND AVULSION POTENTIAL ANALYSES
UPPER NISQUALLY RIVER
PIERCE COUNTY, WASHINGTON

JUNE 26, 2007

FOR
PIERCE COUNTY PUBLIC WORKS AND
UTILITIES, WATER PROGRAMS DIVISION

GEOENGINEERS

Pierce County
Public Works and Utilities
Water Programs Division

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Channel Migration- and Avulsion-Potential Analyses
Upper Nisqually River
Pierce County, Washington
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EXECUTIVE SUMMARY

The upper Nisqually River, located in southeast Pierce County, is a braided river system consisting of a high flow corridor (confined by terraces) with one or more low flow channels. Both the corridor and its low flow channels are subject to unpredictable changes in geometry and channel/corridor location, typically driven by major storm/flood events. For example, aerial photos and maps dating from 1955 show that a section of the river abandoned its existing channel and establish a new channel elsewhere on the floodplain (a process known as avulsion) between 1986 and 1996, and a storm in 2006 caused significant erosion and unprecedented recession of corridor banks in a single storm event.

Pierce County Public Works and Utilities, Water Programs Division (County) contracted GeoEngineers to conduct a Channel Migration Zone (CMZ) analysis for the Upper Nisqually River. It is the fifth in a series of CMZ studies to be completed for major streams within the County. The County intends to use the CMZ map as a decision making tool regarding floodplain management, revision of critical area and floodplain ordinances, and identification of potential future levee setback projects.

The Upper Nisqually CMZ project area extends from Sunshine Point, located just east of the Mount Rainier National Park boundary, to the Alder Reservoir inlet, located near the town of Elbe, Washington.

CMZ delineation criteria and methods of measuring migration rates were developed to address the unpredictable migration character of the Upper Nisqually River. Short and long term high flow corridor changes and bank erosion were documented in a database from the photo-record. The data was used to estimate terrace erosion and episodic fluctuation of the high flow corridor width and position throughout the project area.

The principal findings of the study are shown in Plate 1, including the historic channel occupation tract (HCOT), potential avulsion routes, and severe and moderate CMZ boundaries. The severe CMZ is based on the greatest bank loss and/or channel movement documented over short periods or a single historic storm event. The severe CMZ includes a number of populated areas including: the Mount Rainier National Park entrance and associated buildings, as well as residential and vacation properties located at Nisqually Park, Kernahan Road, and multiple sites on the south side of the river (Lewis County). The moderate CMZ represents a 200% factor of safety to account for corridor movement, caused by multiple storm events, in excess of the largest documented short-term movement. A Low CMZ was not delineated for the Upper Nisqually River because it is not consistent with observed channel behavior.

CHANNEL MIGRATION ANALYSIS
UPPER NISQUALLY RIVER
PIERCE COUNTY, WASHINGTON
FOR
PIERCE COUNTY PUBLIC WORKS AND UTILITIES, WATER PROGRAMS DIVISION

INTRODUCTION

This report summarizes the results of the Channel Migration Zone (CMZ) Analysis for the Upper Nisqually River, prepared for Pierce County Public Works and Utilities, Water Programs Division. This is the fifth in a series of CMZ analyses conducted by GeoEngineers for Pierce County. The project area, shown in Figure 1, includes the main stem Nisqually River channel and floodplain extending from Sunshine Point, located just east of the Mount Rainier National Park boundary, to the Alder Reservoir inlet, located near the town of Elbe, Washington.

PROJECT UNDERSTANDING AND OBJECTIVES

The upper Nisqually River is a braided river system with a history of abrupt migration and full scale avulsion that occur over short time periods of ten years or less. For the purposes of this study, channel migration is defined as the abrupt movement of a braided river across the valley floor; avulsion is defined as the relocation of the river to a new route elsewhere on the floodplain; and the CMZ is defined as the zone within which the river can move episode`ically in short time periods.

We understand that the County intends to use the Upper Nisqually CMZ as a decision making tool in the following applications:

- Maintenance of existing infrastructure (levees, revetments, roads, bridges)
- Floodplain management
- Revision of critical area and floodplain ordinances
- Identification of potential future levee setback projects.

As stated above, the Upper Nisqually River CMZ analysis is one of several CMZ studies to be conducted by Pierce County. A principle objective of the project is to employ an approach and technology that is generally consistent with previous CMZ studies. Some new techniques and analyses were incorporated into the Upper Nisqually study: the most important of which is the use of Digital Terrain Models derived from LiDAR and orthophotography.

In order to address the migration habits of the Upper Nisqually River it was necessary to modify previously applied CMZ delineation criteria and methods of measuring migration rates. The upper Nisqually River includes a rapidly changing braided river system consisting of a high flow (alluvial) corridor with one or more low flow channels. Both the corridor and its low flow channels are subject to unpredictable changes in geometry and channel/corridor location, typically driven by major storm/flood events. The changed criteria resulted in a map (Plate 1) showing severe and moderate channel migration zones. The Severe CMZ is based on the record of short-term movement of the high flow corridor, and the Moderate CMZ reflects a factor of safety applied to the short-term movement. A Low CMZ was not delineated for the Upper Nisqually River because it is not consistent with observed channel behavior.

PROJECT APPROACH AND SCOPE

The purpose of the project is to delineate severe and moderate Channel Migration Zones for the Upper Nisqually River Valley based on observed basin and reach scale characteristics.

The approach to delineating the CMZ involved several major elements: 1) data collection, review, and aerial photo selection; 2) Geographic Information Systems (GIS) data preparation; 3) geomorphic evaluation; and 4) CMZ delineation. Aerial photo, geologic, hydrologic, gradient, and topographic analyses were conducted to support the geomorphic evaluation and the CMZ delineation. Methods and technology used in completing project goals are described in the methods and reference section (Appendix A), including the following:

- Literature Review
- Dated Photo and Map Interpretation
- GIS Data Development
  - Georectifing Historical Aerial Photos
  - Stream Centerline Stationing
  - Topographic Analysis including:
    - DEMs, Contours and hillshades of LiDAR and DEM datasets
    - Relative surface model
    - Gradient Calculations
  - Digitizing Features
  - Delineation of Boundaries
- Systematically Measuring Channel Corridor Movement
- Geomorphic Reach Characterization
- Site Verification (pre and post storm reconnaissance):
- Geologic Analysis
- Hydrologic Analysis

The study began in September 2005 and was scheduled for completion in June 2007. However, a large flood occurred in November 2006 causing significant changes in channel geometry and physical location, which in turn resulted in significant damage to property and infrastructure. The damaged infrastructure included bridges, roads, and levees; property losses were typically documented as large areas of severe bank erosion and recession. To document storm related channel changes, orthorectified aerial photos were flown in April 2007.

Deliverables for this project include (1) this report; (2) GIS layers including CMZ boundaries, dated channel locations, the Historic Channel Occupation Tract (HCOT), and (3) selected aerial photos (1955, 1966, 1981, 1986, 1994, 2001, 2005, and 2007) prepared in GIS compatible format. GIS layers and digital documentation are provided on a DVD-R, which accompanies this report.

REPORT ORGANIZATION

This report is presented in four parts: 1) Watershed Setting, 2) Geomorphic Analysis, 3) Channel Migration Zone Analysis, 4) Supporting Appendices. The Watershed Setting section provides basin scale information and conditions having an influence on channel behavior. The Geomorphic Analysis presents reach-scale channel characteristics with respect to channel migration fluctuation and avulsion. The Channel Migration Zone Analysis describes the approach, assumptions, and results of the CMZ delineation.

WATERSHED SETTING

INTRODUCTION

Basin-scale conditions and processes are those which influence the general character of a watershed. Geologic and climatic processes mold the landscape into unique forms with distinct drainage characteristics. Basin-scale conditions and processes strongly influence the internal character of watersheds including the performance and behavior of drainage channels. The location of the watershed, its topography and geologic history and dominant climate patterns combine to determine the watershed's hydrology, as well as the production and delivery of sediment. And all of these natural characteristics are influenced by human modification of the landscape. The purpose of this section is to provide a background context from which river channel behavior and migration can be understood.

LOCATION

The Nisqually River originates in the glacial terrain of Mount Rainier (14,411 feet above mean sea level (amsl) and from its source areas, flows out of the Cascades and across the eastern flank of the Puget Plateau and Lowland to the south portion of Puget Sound. The upper portion of the Nisqually River flows generally east to west from Mount Rainier to the Alder Reservoir, situated near the town of Elbe, Washington. The upper Nisqually River forms the boundary between Pierce County (north of the river) and Lewis County (south of the river).

BASIN TOPOGRAPHY

The source waters of the Nisqually River originate primarily from the South Tahoma, Kautz and Nisqually Glaciers, all located on the west flank of Mount Rainier between Elevations 5,400 and 6,000 feet amsl. Glacial melt water and sediment is conveyed to the main stem river via two major drainage channels; Tahoma and Kautz Creeks, Numerous other tributary channels also contribute surface runoff and sediment to the Upper Nisqually River from un-glaciated sub-basins situated at or lower than 6,500 feet amsl. The most important un-glaciated tributary streams include Copper, Goat and Texas Creeks (entering from the north), and Big and Mineral Creeks (entering from the south).

From the confluence with Tahoma Creek to the Alder Reservoir, the Upper Nisqually River flows in a generally broad valley. The valley bottom is occupied by terraces, glacial features such as moraines, and occasional bedrock outcrops. The gradient of the valley floor axis ranges from roughly 3 percent in the upper watershed, to 0.5 percent just upstream of the reservoir. Although the topography of the valley floor is relatively flat, the valley walls and headwater source-areas are typically steep, exceeding 50 percent in places.

GEOLOGIC HISTORY

The topography of the Upper Nisqually basin is a result of the combined effects of ongoing tectonic, volcanic, glacial and fluvial activity associated with Mt Rainier. Mount Rainier is a composite volcano less than one million years old. The volcano overlies a sequence of Tertiary-aged (65 to 1.6 million years before present (BP) sedimentary and volcanic bedrock that extends beneath most of the Cascade Mountain Range.

Throughout its development, alpine glaciers have played a significant role in shaping both the upper slopes and drainage channels of Mount Rainier, as well as the adjacent lower river valleys. At their maximum extent between approximately 50,000 to 15,000 years (BP), alpine glaciers carved out the U-shaped Nisqually River valley as far west as Alder. Throughout and following the ice age, the U-shaped valley was partially filled with glacial drift, including deposits of outwash, and till. These

relatively erosion resistant deposits were slowly incised by the river forming a set of steep-walled terraces.

Voluminous volcanic debris flows (lahars) from Mount Rainier also played a role in shaping the topography of the Upper Nisqually River valley. Lahars, typically associated with mobilized volcanic debris en mass, are capable of entraining and transporting trees and sediment up to boulder sized rocks. The most extensive and voluminous lahar deposits, the Paradise (5,600 yrs BP), the National (2,200 yrs BP), and the Tahoma (>530 years BP) each buried entire sections of the Nisqually River channel and portions of its forested floodplain (Graham, 2005). A voluminous lahar, the National, extended all the way to Puget Sound and deposited from 9 to 120 vertical feet of debris in the valley (Scott et al, 1995). With the arrival of each lahar, the river channel was inundated, forcing abandonment of the former channel the formation of a new channel else where within the valley (avulsion). Over the course of the last 2,200 years, repeated episodes of lahar burial followed by fluvial erosion formed additional terraces.

The current topography of the upper Nisqually River valley floor is a direct result of the glacial, volcanic and fluvial processes described above. The valley floor is characterized by the complex set of paired and unpaired terraces that extend towards the river from the valley walls (see Figure 2). Fluvial processes, including deposition from future floods, debris flows, and lahars, coupled with erosion of the terraces will continue to modify the valley topography.

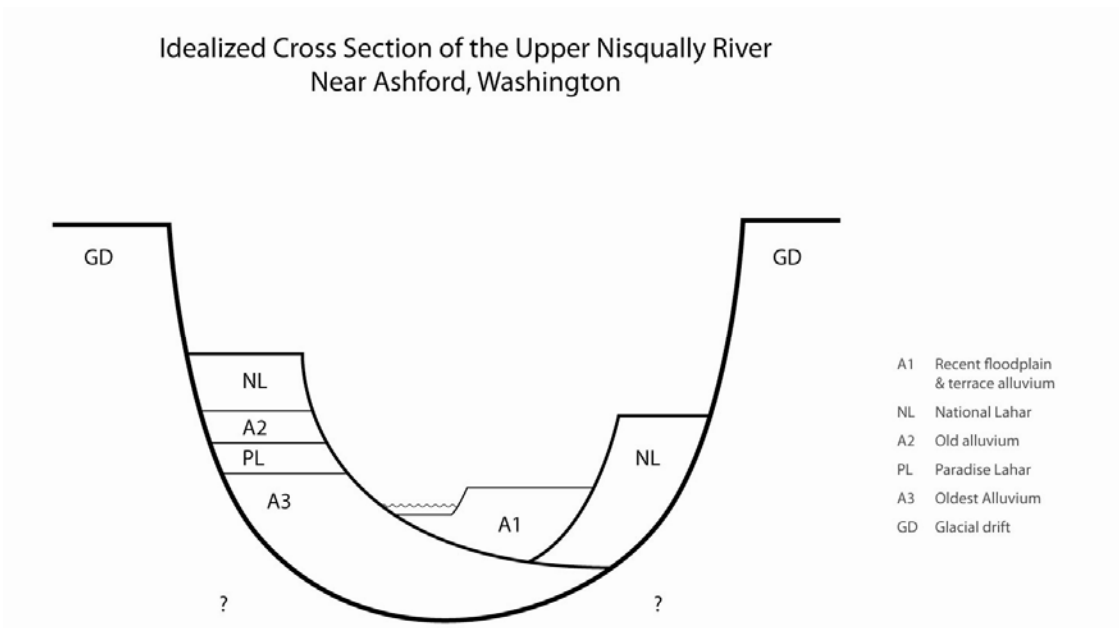

Figure 2:

CLIMATE

The Upper Nisqually River watershed is situated within the winter range of the Pacific storm tract. The basin climate is typical of the mild temperatures and wet conditions normally experienced along the west slope of the Cascade Mountains. However, the basin is also subject to the climatic effects of Mount Rainier. As a result, abundant precipitation and mild temperatures consistently occur from mid-October through April. Approximately 80% of the total annual precipitation within the basin falls during this period primarily as rain in lower elevations and as both rain and snow in higher elevations (see Table 1).

The basin terrain determines the distribution of precipitation throughout the basin. Orographic lifting of the prevailing southwesterly winds causes a dramatic increase of precipitation at high elevations. Consequently, storms that produce one inch of rain at La Grande will consistently yield 3 feet of snow,

equivalent of 4 inches of rain, at Paradise Ranger Station on Mount Rainier (see Figure 1). Precipitation may average 116 inches per annum at the Paradise Ranger Station and less than 40 inches at La Grande. Actual totals, however, vary from 70 inches to 152 inches at Paradise, and from 31 inches to 48 inches at La Grande (Western Regional Climate Center, 2006).

Departures from "normal" climate patterns are common. The typical pattern of recurrent winter storms is often interrupted by more-or-less persistent high pressure systems (dry, cold weather). Long-wave troughs can stagnate along the coast and cause prolonged periods of warm southerly winds (Pineapple Express). Pineapple Express events may follow, major arctic troughs in the Northwestern United States producing snow in the Cascades. Winter storms produced by such warm fronts often cause rapid melting of the transient snow pack producing large runoff events. These heavy rain-on-snow events are typically the cause of most of the region's floods (DOE, 1981). In the Upper Nisqually basin, rain on snow events typically occur between November and March, and account for nearly all the major runoff/flooding events (December 1964, February 1996, and November 2006).

BASIN HYDROLOGY

Introduction

The Nisqually River Basin covers approximately 720 square miles. The upper portion of the basin drained by the Upper Nisqually is situated upstream of the La Grand Dam, and includes roughly 292 square miles of the total basin. The portion of the basin up-valley from stream gage near National, WA is roughly 133 sq miles. The portions of the basin up-valley from Sunshine Point and Longmire are 65 square miles and 19.1 sq miles, respectively (Nelson, 1987). Table 2 shows the length and mean discharge of selected Nisqually River reaches and tributaries.

Runoff

The estimated average runoff from mountainous sections of the basin is 120 inches per year (10 acre-feet/acre), decreasing to about 40 inches in the lowlands (DOE, 1981). Three stream gages within the project area help characterize the hydrology – Upper Nisqually River Gage near National, Mineral Creek near Mineral, and the Nisqually River gage at La Grande (see Figure 1). Two distinct peak runoff periods normally occur at the National stream gage. The first peak is caused by increasing precipitation from autumn storms (November); the second, which typically occurs in May and June, is the result of melt water from the snow fields and glaciers of Mount Rainier (see Figure 3).

Mineral Creek and other tributaries downstream of the National stream gage, proportionally contribute more water from January through March (higher mean discharge per area), compared against that of glacial streams in the upper basin. The average flow of the tributaries typically drops off in July as precipitation wanes. As a result, the tributaries contribute less flow to the Nisqually River in May through September (see Figure 4).

The Nisqually River's low flow period usually occurs in August and September with glacial snowmelt and groundwater base flow making up the majority of the discharge. During the summer months, glacial melt water is the main source of runoff. Meltwater is distinguished by its cloudy appearance, which is derived from suspended fine-grained sediment. More melt water is generated during the day than at night, resulting in a diurnal fluctuation in stream discharge during the hot summer months.

Flooding

Historic documentation of the Nisqually River shows this river has a long history of winter flooding and glacial outburst floods. Based on the USGS gage near National no significant regional or basin-wide flooding has occurred in the summer months over the period of gage operation (from 1942 to 2004). The

highest daily peak flow recorded on the Upper Nisqually River reached 15,700 cfs on February 8th, 1996 (1996 Event) at the USGS gage near National. *Winter floods* within the watershed appear to be continuous across sub-basins (i.e. a tributary's flood flow increases in proportion to the main-stem flow). The duration of high flows appears to influence the extent of flooding and channel migration. Table 3 shows both the average peak flow over 1 and 3-days for notable storm events.

Glacial Outburst floods are local events that release high volumes of water in short time periods. First documented in 1947, glacial outburst floods occur most commonly on Tahoma Creek. The USGS states that glacial outburst floods occur during either hot, dry-weather or wet-weather in the summer or early autumn (Walder and Driedger, 1994; Vallance, et al., 2003). These floods may not be associated with *regional* flooding but do rapidly transport large quantities of sediment.

SEDIMENT AVAILABILITY

Glacial, fluvial and volcanic process described above produce large volumes sediment available for transport to the main stem river and tributary channels Of the 300,000 tons/yr of suspended sediment reaching National, 278,000 t/yr can be attributed to modern-day erosion on Mount Rainier (Mills, 1979). Of this average volume, 93 percent of the sediment in the main stem channel is derived from Tahoma, Kautz, and Nisqually headwaters. In addition to upper sediment source areas, alluvial and glacial terraces within the valley are also subject to significant erosion and add to the sediment load.

Glaciers actively produce sediment, which is stored near the terminus of the glacier until it is mobilized by stream flow. In the summer and fall, seasonal snow and ice (sediment binders) melts, making the sediment available for transport. Normal glacial meltwater can transport some sediment, but higher flows generated by intense rain storms, the release of ice-dammed water, and the rapid melting of ice from volcanic activity are necessary to entrain and transport large quantities of sediment.

Debris Flows and Lahars

The proximity of the Upper Nisqually Valley to an active volcano with glaciers, make it susceptible to sediment laden debris flows and lahars. The USGS has classified the frequency of various sized debris flows and lahars (Vallance, et al., 2003.) as follows:

- Frequent (every 1-2 yr); these comprise glacial outburst floods with associated debris flows in the upper headwaters. They are not capable of extending below Sunshine Point.
- Infrequent (every 100-500 yr); these comprise lahar or debris flow deposits (noncohesive) capable of extending downstream of Sunshine Point.
- Very infrequent (every 500-1000 yr), these events include very large lahars deposits (cohesive) extending all the way to the Puget Lowlands. Cohesive lahar deposits have been shown in flume and case-studies to travel 2-10 times further than non-cohesive deposits of a similar volume (source) and slope.

Glacial outburst floods do not generally coincide with large regional flooding events, nor do they typically maintain sufficient volume, momentum and/or duration to extend downstream of Sunshine Point. The most voluminous recorded debris flow (38 million cubic meters) at Mount Rainier occurred between October 2 and October 3, 1947, in Kautz Creek (Crandell, 1971); however, runoff from this event did not exceed the top 50 daily peak flows measured at the La Grande stream gage.

HIGH SEDIMENT-YIELD STORM EVENTS

The timing of significant storm events likely plays a significant role in the volume of sediment available for fluvial transport. Major storms in mid-winter months, such as the February 1996 event, typically occur well after the snow pack has developed and/or available sediment has frozen in place. Rain falling on a developed snow pack or frozen ground likely results in high runoff with low sediment loading. In

contrast, early-season storms occur before the snow pack has developed and/or available sediment has frozen in place. In this case, high runoff could entrain large sediments yields, as was the case of the 2006 event. The 2006 event mobilized large quantities of sediment, evident in the amount of deposition observed in the field following the storm. This is in direct contrast to the 1996 event, the flood of record, during which smaller volumes of sediment appear to have been mobilized despite having greater 1- and 3-day mean flows.

Anecdotal evidence suggests that the November 6, 2006 storm event resulted in the largest channel movement observed between two consecutive photos and it triggered numerous flows laden with debris in the valley tributaries. Yet, the 2006 event was neither a glacial outburst flood nor the flood of record. The difference in sediment yield may be a result of the timing of a *winter* flooding rather than the intensity or duration of run-off.

BASIN DEVELOPMENT AND LAND USE PRACTICES

Since development first began in the basin in the late 1800s, land use in the upper Nisqually Basin has been centered on timber extraction, hydroelectricity, rural housing, and recreation. Similar to other basins in the area, timber harvesting and its associated infrastructure shaped the direction of early development in the basin. Mount Rainier National Park, created in 1899, significantly limited development and logging in the headwaters of the Nisqually basin; these lands remain relatively undeveloped today.

Downstream of Mount Rainier National Park, Tacoma Public Utilities operates two hydroelectric dams – The La Grande dam completed in 1912 forming the La Grande reservoir, and the Alder dam completed in 1945 forming Alder Reservoir. Alder Reservoir represents the downstream end of the study area.

Infrastructure supporting the timber extraction, hydroelectric operations, rural housing, and recreation has grown in step with the respective development it supports. Numerous dirt and paved roads crisscross the drainage basin, and at least seven bridges cross the river tributary channel. Levees, revetments, and weirs have been constructed to protect private property, rail, and road bridges. Presently, only two vehicle bridges are passable, State Route 7 (station 0) and Kerahan Road (station 62). Two bridges were damaged in the 2006 storm, Tacoma Railroad Bridge (station 16) and Forest Serve Road (station 42). The date and cause of the demise the other bridges have not been determined. A timeline of the Basin History is included in Table 4.

GEOMORPHIC ANALYSIS

INTRODUCTION

The geomorphic analysis included two components; 1) evaluating the effects of basin scale controls on channel behavior, and 2) identifying and characterizing the long and short term channel behavior on a geomorphic reach scale with respect to channel performance, migration, bank and terrace erodability, and potential for avulsion. The analysis is based on review and evaluation of published professional papers and unpublished reports, historic aerial photographs, and field reconnaissance.

CHANNEL BEHAVIOR

Review of historic and very recent aerial photos reveal three important channel behavior characteristics that helped define and constrain the geomorphic analysis.

1. The river system is braided, meaning that multiple low flow channels are contained within a broad high flow corridor over most of the project area.
2. The width of the braided corridor fluctuates unpredictably from one aerial photo set to the next.
3. The location of the braided corridor moves unpredictably from one aerial photo set to the next.

4. The November 2006 storms caused corridor changes and erosion of terraces at a scale not observed in earlier aerial photos (1955 to 2005).

Over the course of the historic aerial photographic record, three principal types of migration were noted: braided channel migration, high flow corridor width fluctuation, and avulsion. A brief discussion of the migration types observed in the project area is provided below.

Braided Channel Migration

The Upper Nisqually River is a braided system consisting of many branches separated by bars within a larger channel corridor (high-flow corridor). Individual braid channels are generally shallow and migrate rapidly within the high-flow corridor as bars are eroded and re-deposited. The character of migration is typically abrupt and unpredictable, occurring most frequently during storm events. The entire high-flow corridor may also migrate and/or widen over time. Unlike migration of a braid channel bend, fluctuations of the Upper Nisqually River high-flow corridor are stochastic and occur.

High Flow Corridor Width Fluctuation

On the Upper Nisqually River, high flow corridor widening occurs due to the erosion of one or both banks without concurrent deposition along the other bank (as with meander bend migration). Bank erosion resulting in corridor widening is commonly caused by increased discharge and/or sediment loads in the high-flow corridor requiring a larger (i.e. wider) flow area, and/or by increased deposition across the entire corridor, reducing flow depth, therefore increasing flow width. Corridor widening is commonly observed in aggrading or newly formed reaches. Narrowing of the high flow corridor may also occur where erosion has been limited for a period of time and vegetation encroaches from one or both banks.

Channel Avulsion

Channel avulsion is the abrupt movement of an active channel to a new location in the river valley. This process usually occurs in response to sudden deposition and infilling of the active channel by sediment or debris, causing the stream to erode a new channel or reoccupy a formerly abandoned channel. Frequent movement of braid channels within the high-flow corridor suggest small scale avulsions occur annually within the Upper Nisqually River's braided channel sections. Braid channels may abruptly abandon their location forming new channels within the high-flow corridor during a single high flow event.

Avulsions of a larger scale occur less frequently, where the channel abandons its existing location to form a new channel within the valley, but not necessarily within the existing high-flow corridor. This type of large-scale event was observed in the historic aerial photographic review between 1986 and 1996 on the Upper Nisqually River, and conditions persist for an avulsion of this magnitude in the future. Avulsion may also occur as a meander bend cutoff, wherein a highly sinuous, looping bend is pinched off at the neck, thus abandoning the bend, and straightening the channel pattern. Avulsion by meander bend cutoffs is common in lower gradient, sinuous reaches with highly erosive bank soils.

REACH-SCALE CONTROLS IN RELATION TO CHANNEL BEHAVIOR

Introduction

The location of the Upper Nisqually valley within the drainage basin and the geologic history of the basin both significantly influence reach-scale channel behavior. Terraces, bedrock outcrops, alluvial fans, and human modifications to the landscape have affected the behavior of the braided river corridor historically. Unglaciated tributaries and vegetation appear to have negligible affects on the behavior of the Upper Nisqually River. A brief discussion of potential basin controls on channel behavior and their observed impact on historical conditions within the project area is provided below.

Terraces

A terrace is a relatively flat landform perched above the modern floodplain. Terraces are fluvial/glacial landforms created by aggradation of the valley floor followed by subsequent fluvial incision. Terraces in the Upper Nisqually Valley are discontinuous and have a heterogeneous composition. The heterogeneity is due to multiple events of localized deposition and incision. The height and composition of a terrace influences the rate of channel migration in places where the channel impinges upon the terrace. Terraces in the Upper Nisqually River valley are primarily composed of dense glacial sediment, volcanic lahar deposits, and/or unconsolidated alluvium. Dense glacial sediment and thick lahar deposits are relatively resistant to erosion, form vertical scarps, and limit high-flow corridor widening and/or migration. Terraces composed of unconsolidated alluvium on the other hand erode more easily, and contribute large volume of sediment that must be transported by the river. Terrace height and composition can change at a sub-reach scale, as is seen on the Upper Nisqually River.

Bedrock (Valley Wall and outcrops within the valley floor)

Another basin-level control on channel behavior is the location of bedrock within the valley. Erosion-resistant bedrock, such as the volcanic and sedimentary bedrock of the Upper Nisqually Valley, constrains migration and/or reduces channel incision wherever encountered. The position of a bedrock-confined high-flow corridor will remain relatively fixed over time when compared with a section of the corridor flowing through alluvium or other more easily-erodible material.

Alluvial Fans

An alluvial fan is a convex, depositional landform that often takes the shape of a fan or cone spread over a relatively flat surface. Alluvial fans are generally formed in places where flow can spread out to the point where the increasing width of the channel is no longer able to transport its sediment load resulting in deposition. Alluvial fans are generally characterized by frequent avulsions and flooding over the entire fan surface. Large alluvial fans can be found in the upstream project area where confined, sediment-laden tributaries (Tahoma and Kautz Creeks) enter the broad Nisqually River Valley. These large alluvial fans span the entire width of the valley and contribute substantially to the sediment load of the main channel.

Several small alluvial fans are located downstream of Sunshine Point, where smaller streams carrying less sediment (Texas, Goat, and Copper Creeks) enter the broad Nisqually River Valley. These small alluvial fans have minimal long-term influence on the form and function of the Nisqually River as they only deliver a small fraction of the total Nisqually sediment load. However, they can steer the channel corridor toward another portion of the valley floor.

Avulsions (Big and Texas Creeks)

As discussed above, an avulsion is the abrupt movement of the active channel to a new location in the valley. Avulsions upset the stream's dynamic equilibrium by altering channel position and gradient thereby potentially increasing the local availability of sediment. A recent major avulsion occurred on the Upper Nisqually River between Nisqually Park and the Kerahan Bridge. High flows in 1990, 1996 and 2006, first created, then widened the new channel and sent large volumes of sediment and debris downstream. These events caused unstable channel conditions downstream of the avulsion.

The delivery of large sediment volumes to the Upper Nisqually drainage basin (discussed in the sediment availability section above) substantially increases the potential for channel aggradation and adds to the overall instability of the channel. This is most true where the channel gradient decreases rapidly and valley width increases.

Large-scale volcanic lahar deposits appear to cause major avulsions. Big creek flows parallel (south of) to the Upper Nisqually River near Sunshine Point and likely occupies an abandoned ancient channel of the Nisqually. Thick deposits of Paradise lahar found in the floodway and between the two drainages suggest that the lahar caused an avulsion and forced the Nisqually to its current more northern route. Approximately 10 feet of vertical relief currently separate the two drainages.

Tributaries

Tributaries to the Upper Nisqually River can be classified in two categories – those that are fed by active glaciers and those that are not. Glaciers on Mount Rainier feed the Upper Nisqually headwaters, Kautz Creek and Tahoma Creek, and as a result, they contribute large volumes of sediment to the main-stem Nisqually River. None of the tributaries entering the main-stem below Tahoma Creek are fed by glaciers, and, while these streams contribute substantially to the mean flow of the Nisqually River, they contribute only negligible sediment loads when compared with the three glacial tributaries upstream. The geomorphic character of the braided river is controlled predominantly by the volume and availability of sediment delivered to the high-flow corridor, and therefore, channel character is little affected by tributaries entering the river within the project area.

Human Influence

A number of human activities affect the Upper Nisqually River corridor including levees, revetments, bridge crossings, dams, and timber harvesting. Levees are built to protect portions of the floodplain from flooding, while revetments are intended to harden banks in order to minimize bank erosion. Many of the levees observed along the Upper Nisqually River are armored with rock revetments and thus serve two functions – flood prevention and bank protection. When levees persist for a long period of time in a river corridor influenced by sediment deposition and aggradation, such as the Upper Nisqually River, the active river corridor may become perched above the floodplain protected behind the levee. Under this scenario, failure of the levee may also trigger an avulsion as the channel seeks out lower elevation land behind the levee. Furthermore, constricting the channel by preventing high-flows from spreading out, results in greater water depth and therefore greater velocity. This may increase potential scour adjacent to the levee/revetment and may increase bank erosion immediately downstream of the levee/revetment.

Bridge crossings can also affect the character of a river, especially if the bridge span is undersized (less than the width of the river's high-flow corridor). This appears to be the case for most bridges on the Upper Nisqually River. One result of this condition is that high-flows become constricted resulting in high-velocity flow accompanied by potential scour near the bridge and backwater conditions accompanied by deposition upstream of the bridge. A severe backwater may overtop the bridge or the bridge approach, potentially washing out the bridge and/or its approach, increasing the potential for avulsion. The Kernahan Road Bridge, Tacoma Railroad Bridge, and Forest Service Road 1 bridge near National were all damaged or washed out in the 2006 event as a result of a narrow bridge span over a transport-limited river.

Dams also impact channel character by creating a large backwater in the form of a reservoir, such as Alder Reservoir at the downstream end of the project area. A lake or reservoir is a local base level for all of the streams entering it. In other words, the elevation of the reservoir represents the level below which a stream entering the reservoir cannot erode its bed – similar to a grade control. Normally, changes in the reservoir level will influence the fluvial processes of sediment transport, deposition and scour upstream of the base level. The local base level generated by Alder Reservoir corresponds with a natural bedrock grade control beneath the Hwy 7 Bridge in Elbe, and therefore has not greatly affected the character of the Nisqually River upstream of Elbe.

Timber harvesting appears to have had little effect on sediment delivery to the Upper Nisqually River. In part this is because limited timber harvesting has occurred in the headwaters that fall within Mount Rainier National Park, and in part because the volume of sediment resulting from timber harvests is negligible compared with the volume derived from glacial activity on Mount Rainier.

FINDINGS; GEOMORPHIC REACH CHARACTERIZATION

Introduction

The project area extends from the confluence of Tahoma Creek near the western National Park boundary to the State Route 7 Bridge at Elbe, totaling approximately 15 miles (see Figure 1). Within the study area, the Nisqually River is predominantly transport limited characterized by its braided channel nature, voluminous sediment supply, and variable discharge. Much of the high-flow corridor is confined by up to three sets of terraces. Channel form and character on the Nisqually River are driven primarily by the availability of sediment, which in turn is driven primarily by the timing, duration, and intensity of storm events. As a result, the braided Upper Nisqually River does not migrate in a unidirectional, predictable fashion, as is the case with meander-bend streams. Instead, the channel high-flow corridor width fluctuates episodically, driven primarily by storm events (i.e. event driven).

For the purpose of this project, the Upper Nisqually River was divided into seven geomorphic reaches. The reaches were delineated on the basis of several factors including channel pattern, channel morphology, migration type, channel gradient, bank soil composition, and geomorphic history. The following is a summary of reach-scale geomorphic observations and conclusions based on field reconnaissance and a review of applicable literature, historical photos, and GIS data. Information discussed below is presented in Figures 5 through 11. Stream centerline stations were positioned from downstream to upstream every 1,000 feet along the 2004 high-flow corridor centerline for reference. Supporting information regarding general characteristics of each reach can be found in Appendix B General Reach Characteristics. The reach descriptions below are given from upstream to downstream within the study area.

Upper Nisqually

Reach 1:
Reach 1 is located on a broad alluvial fan formed by sediment shed from Mount Rainier since the last glaciation. Reach 1 is a depositional reach with large volumes of sediment episodically entering the reach from upstream. Downstream of Tacoma Creek the Nisqually River's gradient rapidly decreases as the valley width increases.

The high-flow corridor in Reach 1 is characterized as highly braided and, for at least the last 100 years, has been positioned in the middle of the valley floor. The right bank is protected by an armored levee (see Figure 5) that was originally constructed in the 1950's to prevent flooding and a possible washout of the National Park Entrance (Kennard, personal communication 2006). Historical accounts and field visits indicate that large volumes of sediment supplied by upstream tributaries are deposited within Reach 1 (see High Sediment-Yield Storm Events Section of this report). This local aggradation has caused episodic corridor widening, and frequent damage to the levee, including the loss of Sunshine Point Campground in November of 2006.

On the landward side of the right bank levee, recent alluvium and abandoned channels suggest that, historically, the river has occupied all portions of the valley floor. These old channels are lower than the existing channel and pose an avulsion risk if the levees were breached. The risk of avulsion here is particularly high, as the levee/revetment has cut off an active portion of an alluvial fan. Furthermore, the episodic release of extremely large volumes of sediment from Mount Rainier in the form of debris flows

and/or lahars increases the potential for large-scale, short-term channel aggradation. An infrequent lahar of the scale described by the USGS (Sediment Availability Section) would likely overtop the existing levee spreading sediment and debris over the entire valley floor.

On the left bank channel corridor, deposits of the Paradise Lahar and islands of outcropping bedrock form at least an 8-foot high terrace separating the Nisqually and Big Creek drainages. The terrace width was receded in the 1996 and 2006 storms and additional sections of the left bank likely will continue to erode.

Reach 2:

Reach 2 is a transitional reach that is currently incising in the upper sections of the reach, aggrading in the lower reach, and widening throughout as the channel continues to adjust to a recent (1986-96) avulsion (see Figure 6). Photo review and observed stratigraphy indicate that the 1996 avulsion was the cumulative result of channel aggradation and flooding. In 1981, the Upper Nisqually (at station 76), experienced extensive channel widening. In 1986 a small channel was visible capturing flow from the main-stem. Flooding in 1990 scoured out the 1986 channel. This new channel presented a more direct path through the valley along a steeper gradient. As a result, the pre-1986 channel was abandoned and the new streambed became deeply incised. A flooding event in 1996 forced a second avulsion downstream of the first (at station 70) and further widened the new channel.

The new (avulsion) channel is characterized as braided and is confined by bedrock and terraces on the left bank and an erodible terrace on the right bank composed of alluvium and Paradise Lahar sediment. In response to the November 2006 storm, the corridor widened considerably and had one of the highest measured width increases of all the reaches (643 feet of the right bank was lost between 2005 and 2007). A large amount of this floodplain sediment was transported downstream to Reach 3.

Many floodwater channels and abandoned channels are present in the right floodplain, including the pre-1986 main-stem channel. The pre-1986 corridor is now occupied by the combined flow from Texas, Goat, and Copper Creeks, and does not appear to significantly migrate.

Reach 3:

Reach 3 is a braided, depositional reach (transport limited) located immediately downstream of a recent, major avulsion (Reach 2). Corridor widening and local incision associated with the avulsion upstream are contributing large volumes of sediment to Reach 3. Up to 4-feet of deposition was measured beneath the Kernahan Bridge in late November, 2006 (station 62, see Figure 7), indicating potential aggradation. If aggradation is sustained, corridor widening and possible changes in channel pattern could occur.

Deposition and potential corridor aggradation are expected to continue in Reach 3. Further bank erosion and widening are also expected but will be limited by bedrock outcrops and terraces generally composed of older alluvium, lahar deposits, and glacial till from low (2-4 feet) to high (30+ feet on the right bank) respectively. A prominent bedrock outcrop is present on the right side of the valley floor to the east of Kernahan Road. .

The November 2006 storm nearly washed out the Kernahan Bridge and eroded up to 375 feet of the right bank upstream of the bridge. Debris collecting on or upstream of the bridge may force flood flows across the low terrace to the north of the bridge. With sufficient aggradation, a channel avulsion around the Kernahan Bridge constriction (leavening the channel at station 64 and reentering at station 57) is also possible.

A major tributary, Texas Creek, enters the Nisqually River near station 65 with no visible impact to the main-stem other than increasing the mean flow volume.

Reach 4:
Reach 4 is a transitional reach – broad, braided, and predominantly transport limited upstream, becoming relatively narrow, single-threaded, and supply limited downstream (see Figure 8). Reach 4 is confined by increasingly higher erosion-resistant terraces that confine the high-flow corridor to the southern portion of the valley. The terraces are primarily composed of National lahar deposits and glacial till in this reach (see Figure 2). Despite this fact, significant erosion (450 feet) into the high terrace (composed of glacial till) was recorded on the right bank near Station 50 between 1955 and 1966 illustrating the event-driven potential for bank erosion on Upper Nisqually River. The high-flow corridor width will likely continue to fluctuate and individual braid channels will continue to avulse within the high-flow corridor, episodically impinging upon and eroding the terrace walls. However, due to the height and composition of the terraces, there is little potential for avulsion outside of the existing terrace boundaries.

Other observations include the following: Several highly erodible low-height terraces in Reach 4 are composed of Paradise lahar and pre-1966 alluvium. The north approach of the Forest Service Bridge, which was composed of a low-height, alluvial terrace (at Station 42), was washed away in the November, 2006 flood. A major tributary, Big Creek, enters the Nisqually River near station 45 with no visible affect to the main-stem other than increasing the mean flow volume.

Reach 5:
Reach 5 is unique in the study area in that it is single-threaded and bedrock confined. Confining bedrock in most areas and high glacial terraces in others inhibit migration and avulsion. Confined flow through Reach 5 represents a channel constriction and serves to create a back-water effect influencing flow velocity and therefore rates of deposition upstream (in Reach 4). Narrowing of the channel also increases flow velocity through the reach creating conditions favorable for sediment transport. Channel aggradation and associated instability are not likely to occur under existing conditions, inhibiting channel migration and avulsion potential. Effectively all the sediment and debris entering Reach 5 is transported through the reach. Little or no fluctuation in channel width was measured in this reach through the photo record (see Figure 9).

Reach 6:
As the channel emerges from the bedrock-confined, transport reach upstream (Reach 5), it broadens out and transitions to a primarily depositional reach with a braided channel pattern (see Figure 10). Like Reach 4, Reach 6 is also confined by multiple terraces. The low terraces are composed of erodible alluvium, the moderate height terraces are composed of erosion resistant glacial and lahar deposits, and the high terraces and composed of erosion resistant glacial till. Basalt bedrock is exposed in the left bank near the middle of the reach (Station 23-20). The braid channels will likely continue to migrate and avulse within the high-flow corridor, episodically impinging upon and eroding the terrace walls.

In the lower reach, the channel is constricted by a two-span railroad bridge (station 16) with one opening along the right bank of the high-flow corridor and a second opening along the left bank with an island between the two spans. The island between the two spans has been armored with large, angular, boulders. The railroad bridge is a constriction point in the high-flow corridor that has caused a channel avulsion and has been washed out twice, including during the high discharge events in February of 1996 and in November of 2006.

Reach 7:
Reach 7 is a low-gradient, primarily transport-limited, reach with a braided channel pattern. Terraces are present throughout the reach, but the distance between the terraces is much larger than upstream reaches suggesting the Nisqually has occupied a large portion of the valley in Reach 7 (see Figure 11). In the upper reach (station 14-7) the high-flow corridor is contained between a roughly 10-foot-high terrace composed of lahar deposits on the right bank, and bedrock on the left bank. In the lower reach, the high-

flow corridor and valley width broaden significantly. The terrace of lahar deposits define the right side of the high-flow corridor but the left side is defined by a small section of lahar terrace and a low (6 to 8 feet high) terrace composed of alluvium younger than the lahar. The downstream most 2,500 feet of the left bank are protected by a rock-armored levee. Behind the levee is a low-lying abandoned floodplain with many visible abandoned channels.

Significant widening of the high-flow corridor was observed in the photo record, particularly on the right side of the downstream portion of Reach 7. This is likely due to the backwater affect of a channel constricting bridge (Hwy 7) and a levee located along the left bank at the downstream end of the reach. The constriction promotes backwater conditions and deposition upstream, which in turn, increases the potential for channel widening. The presence of a bedrock grade control near the bridge maintains the local base level for this reach.

It is clear from the presence of low lying channels landward of the left bank levee that the Nisqually River once occupied a much broader area of the valley at the downstream end of Reach 7 than at present. As the high-flow corridor continues to widen, the potential for avulsion behind the levee increases, particularly if the levee is out-flanked upstream. Considerable left bank erosion (119 feet) of the lahar terrace in 2006 (near station 5) upstream from the levee, suggests this is a plausible threat.

CHANNEL MIGRATION ZONE ANALYSIS

The approach to delineating the probable extent of channel migration assumes that, in the absence of channel constraints, the future character of migration will be similar to that of the past, given similar water and sediment discharge conditions. The results of our geomorphic analyses include the following key characteristics:

1. Main stem channel behavior is a stochastic, event driven, response to major flooding and/or sediment transport events. Typically, both the width and position of the high flow corridor is subject to unpredictable change during these events.
2. Depositional reaches (1, 3, and 7) are susceptible to localized sediment aggradation. Historically, aggradation has led to corridor widening and at least on significant avulsion event.
3. Existing river terraces varied in both composition and height, either of which can affect their susceptibility to erosion.
4. Bedrock outcrops, massive glacial deposits, and debris flow fans constrain the river's movement over large portions of the valley.

CMZ DELINEATION

The Channel Migration Zone (CMZ) delineation approach was developed to address key factors listed above. In particular the CMZ delineation approach needs to account for potential corridor flux due to episodic channel behavior and sediment yields documented in our geomorphic analysis. The CMZ was delineated based on several factors including the following:

1. The location of historical channel occupation track over the observable period of record,
2. The greatest bank loss or channel movement observed between two consecutive photo years (often the bank loss as a result of a single major storm),
3. An avulsion risk due to potential localized sediment aggradation, and
4. The resistance of glacial and lahar terraces to erosion.

The delineation criteria also included development of two migration hazard zones; Severe and Moderate. The **Severe CMZ** delineation is meant to represent the boundary equal to the greatest bank loss or channel movement associated with a single historic storm event. The **Moderate CMZ** Boundary represents a 200% factor of safety to account for possible corridor movement that could exceed documented short-term changes experienced in the 2006 Event.

Severe CMZ Delineation Methodology

As described above, **the Severe CMZ** delineation represents the greatest bank loss or corridor movement associated with a single storm event over the period of the photo record. Complicating the CMZ delineation is the heterogeneous topography and composition of the terraces, and valley floor and walls. To account for the heterogeneity, delineation began by creating a *severe CMZ base width* representing the greatest bank loss and channel change in the most erodible material. The severe CMZ base width was then modified to account for more erosion-resistant surfaces and/or fixed boundaries such as bedrock. Delineating the severe CMZ required five analyses (or steps), listed below, the combined results of which were synthesized to construct the **Severe CMZ** boundaries:

1. Identify the historical channel occupation track (HCOT),
2. Determine 'severe CMZ base width' (i.e. the boundary representing the greatest bank loss in the most erodible material within a geomorphic reach that we observed over a short period of time),
3. Identify depositional reaches for potential avulsion sites and routes,
4. Locate, describe and measure the recession of terraces (less erodible valley topography) to characterize their potential to recede in storm events, and
5. Map fixed boundaries that do not appear to have eroded over the course of the photo record, and will not likely erode in the future.

The results of these five steps where then translated into GIS boundaries with buffers for each reach to create a Severe CMZ boundary, as shown in Plate 1. Please refer to Appendix C and Plate 2: Prescription for Delineation the CMZ Boundaries, for a detailed discussion of the values used in creating the boundaries. In locations where two methods of delineation converged common professional geomorphic/cartographic judgment was used to create the boundary. The rational for those decisions were recorded as attributes in the GIS Layer.

HCOT Identification

The Historical Channel Occupation Tract (HCOT) identifies the documented zone that the stream has occupied over the 62 year (1955-2007) period of record. The HCOT is relevant to the CMZ analysis because it is composed of alluvial sediment that is generally susceptible to erosion, depending on the extent of vegetation. For this study it is assumed that the channel corridor can reside anywhere within the HCOT in the period of a single storm event. The outside boundary of the HCOT is used in this project as the line of origin from which the Severe CMZ base width is measured.

CMZ Base Width

The severe CMZ base width was delineated to identify the greatest short-term distance the channel corridor could shift within a given reach. We make the assumption that given similar geomorphic conditions, the magnitude of bank loss that occurred in the past could occur again. Since channel behavior is stochastic, it is appropriate to apply the maximum observed short-term change is the channel corridor that we observed to the entire reach.

Data compiled from systematically measuring channel corridor movement throughout the photo record (Appendix A) were further evaluated, within each reach and on each side of the channel, for the greatest channel change between two consecutive photo year sets. The greatest or maximum channel change per reach was then added as a buffer from the HCOT to create the CMZ Base width.

Evaluating Potential Avulsion Sites and Estimating Their Route

An avulsion analysis was conducted to identify avulsion routes within the project area. The approach involves identifying likely sites for a channel avulsion and then determining the flow paths across the floodplain and back to the main stem.

The potential for avulsion is great when there is a combination of a loss of channel stream power and a large potential decrease in head between the channel and the adjoining floodplain. By reviewing the downstream increases in the corridor width (from 2007 photos) and the downstream decreases in gradient sections of the river with a perceived loss of channel stream power (labeled as potential avulsion sites, Figures 5, 6, 7, and 11 and summarized below) were identified. Light Detection and Ranging (LiDAR) image-based relative surface models helped to determine that two of the five sites, are currently subject to conditions that can cause water to flow away from the existing channel, Nisqually Park and along the SR 7 levee. Along portions of the Nisqually Park and SR 7 levees, both a potential head and a perceived loss of stream power is present and is considered a severe risk. Hence these sites have been included in the severe CMZ. At the other sites, localized sediment or debris aggradation would need to occur in order to create the head necessary for avulsion to take place. Such conditions may occur in the future and therefore three sites were added to the moderate CMZ delineation.

Once a potential avulsion site is determined, LiDAR-based relative surface models (Appendix A) and data collected from the field were utilized to determine a likely avulsion flow path. (i.e. the most like route across the valley including reconnection to the main stem). Where LiDAR was not available, e-SADI (Scale Accurate Digital Imagery) stereographic photos with contours were used to identify potential avulsion routes. The widths of the avulsion routes were determined based on the dimensions and representative channel characteristics of existing main stem river reaches, and weather or not the route follows an existing tributary channel. It is important to note, that the actual route utilization will depend on a combination of factors and circumstances including the volume of sediment and large woody debris carried into the avulsion channel, deposition and possible flow obstructions occurring within a newly formed channel, and existing floodplain surface conditions.

LOCATING, DESCRIBING, AND MEASURING RECESSION OF TERRACES

Many resources were utilized to locate, describe, and measure erosion over approximately 20 linear miles terraces. The location and height of terraces was determined in the office using GIS layers. We utilized LiDAR-Base Relative Surface models (Appendix A) to create a GIS database of existing terraces (2004), and to determine their approximate heights. Where LiDAR was not available, USGS topographic maps and stereographic photos were used locate and estimate the terrace height. Geologic reports, surfical geology and soils maps were consulted to determine the composition of the terraces. Field verification in August 2006 was used to spot check the results. However, not all terraces could be field checked. Subsequently, GIS terrace layers were checked against historical air photos to identify and measure the greatest short-term terrace recession. Measurements of the maximum amount of terrace recession between any two consecutive photo-year sets were cataloged and sorted by reach, river bank right or left), bluff composition and height.

The resulting terrace recession catalog was used to modify the CMZ base width. The maximum measurement of erosion per reach and terrace type was used to create a buffer on the landward side all

classified terraces. The severe CMZ boundary was located on that buffer when the CMZ base width intersected the classified terrace.

MAPPING BEDROCK OUTCROPS, MASSIVE GLACIAL DEPOSITS, AND ALLUVIAL CONES

The results of the above analysis indicated that the highest and most competent glacial terraces did not erode appreciably over the period of record. As a result, the width of the severe CMZ was modified to account for terraces and other surfical units that appear resistant to erosion. These glacial terraces, bedrock outcrops and thick colluvial (rock debris accumulated through the action of gravity) slopes were mapped as *fixed boundaries*, and a 50-foot buffer was applied; fifty feet accounts for potential errors in mapping at the scale used. Therefore anything landward of the buffer should be on bedrock, a colluvial slope, or massive compact glacial terrace. The severe CMZ base width or the adjusted terrace buffer was modified wherever the two intersected the *fixed boundary*, and the CMZ boundary was located on the *fixed boundary* buffer.

Moderate CMZ Delineation Methodology

The *Moderate* CMZ boundary represents a 200% factor of safety applied to the severe CMZ boundary (i.e. bank loss possible from multiple storm events or a cascade of bank erosion). Pierce County and GeoEngineers mutually agreed on the 200% factor a safety. To delineate the moderate CMZ boundary, buffers equal to the severe CMZ boundaries were used to create a moderate CMZ base width (i.e. twice the buffer of a severe CMZ boundary). The same methodology of modifying the severe CMZ boundary to account for more erosion-resistant surfaces and fixed boundaries was applied to the moderate CMZ base width. However, if the severe CMZ boundary was defined by a fixed boundary a factor of safety was not added to the moderate CMZ, based on the criteria that the fixed unit is erosion resistant and a factor of safety is, therefore, unnecessary.

CMZ DELINEATION RESULTS

The results of the severe and moderate CMZ delineation for the Upper Nisqually River are shown on Plate 1 and the GIS DVD package (Appendix D). The results show the broad variation of potential for corridor movement throughout the project area. Variations in the CMZ are a result of the local maximum corridor movement for each reach over a short period of time and the influences on corridor movement and bluff recession caused by terraces, bedrock outcrops, and debris flow fans. Table 5, summarizes by reach the greatest measurements of corridor movement and terrace recession. In addition, there is a (severe or moderate) potential of avulsion at the following locations.

Potential Avulsion Site (upstream)		Likely Reconnection	Relative Potential	Rational
Stationing	Bank	(Stationing)		
81 to 76	Right	65 to 57	Severe	A, B,C, D
71 to 69	Right	65 to 57	Moderate	A, B, D
64 to 62	Right	58	Moderate	A, B, D
8 to 6	Left	Alder Reservoir	Moderate	A, B
4 to 2	Left	Alder Reservoir	Severe	A, B, C

Notes:
A = Decrease in gradient
B = increase in corridor width
C = existing potential head
D = potential for localized aggradation

The severe CMZ includes the National Park entrance and associated buildings, as well as residential and vacation properties at Nisqually Park, Kernahan Road, and multiple sites in Lewis County. The November 2006 storm events provided many reminders of the upper Nisqually River channel migration potential. Three of the four bridge approaches were damage or washed away and 1000's of feet of levee were washed away. Moreover, as much as 350 feet of 30 foot glacial terrace collapsed and washed into the river.

This study show the bank and terrace recession is stochostic and driven by storm events. The timing of a Storm/Flooding event appears to be important in how debris laden the event will be. No one can predict the timing of or intensity of the next event to impact the Upper Nisqually, but one can learn from what was observed from its past.

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TABLE 1
MONTHLY PRECIPITATION TOTALS FROM BASIN WEATHER STATIONS
UPPER NISQUALLY RIVER
PIERCE COUNTY PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES
WATER PROGRAMS DIVISION

Station			Period of Record		Precipitation						Total Snowfall		Number of Months when the average tempurature is below freezing
Name	ID	Elevation	Start	End	Mean	High	Low	1 Day Max.	>= 0.50 in.	>= 1.00 in.	Mean	High	
Paradise Ranger Station	456898	5,500	1948	2006	116.6	151.9	70.5	7.8	80	38	676.2	1,106.5	7
Longmire Ranger Station	454764	2,600	1978	2006	79.3	114.7	54.8	6.0	55	20	135.5	269	5
Mineral (1 SW)	455425	1,520	1948	1979	85.4	118.1	34.8	10.2	54	26	55.8	120.5	1
La Grande	454360	930	1954	1983	38.5	48.3	31.7	2.5	21	3	4.2	14	0

TABLE 2
MEAN DISCHARGE FOR SELECT REACHES AND TRIBUTARIES
UPPER NISQUALLY RIVER
PIERCE COUNTY PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES
WATER PROGRAMS DIVISION

Name of Sub Basin	Approximate River Mile[1]	Mean flow of the basin	Percent of mean flow within the project basin	Mean flow of the Basin at seven/ten low flow) SVTNFLOW[2]	Percent of SEVENFOLD within the project basin	Mileage of stream within basin	Percent of stream miles within the project basin
Tahoma Creek	64.3	91	7%	22	9%	8.7	9%
Goat Creek*	61.8	50	4%	12	5%	4.0	4%
Big Creek	56.6	230	19%	55	24%	18.5	18%
Mineral Creek	50.1	387	32%	25	11%	24.3	24%
Nisqually above Tahoma Creek	64.3	287	24%	68	30%	27.4	27%
Nisqually at start of Project Area	64.3	378	31%	--	39%	36.1	36%
Nisqually above Texas Creek*	61.8	406	33%	97	42%	38.6	38%
Nisqually above Big Creek	56.6	520	43%	124	54%	47.8	48%
	57.1	102	8%	24	11%	8.2	8%
	57.1	122	10%	29	13%	9.8	10%
Nisqually above Mineral Creek	50.1	810	67%	198	85%	72.8	73%
	53.9	152	12%	9	4%	9.2	9%
	53.9	186	15%	11	5%	11.3	11%
Nisqually at Elbe (Alder Res)	46.8	1218	100%	231	100%	100.4	100%
Nisqually (upstream of diversions)	28.0	1830	--	268	--	192.9	--
Nisqually at the Puget Sound	0.0	1473	--	37	--	224.5	--

Notes:

This is calculated before the Reach 2 avulsion: Goat Creek trib is larger (includes Texas creek and former channel of Nisqually, Nisqually river is shorter.

[1] Estimated from EPA database

[2] Seven ten low flow

TABLE 3
AVERAGE PEAK FLOWS FROM NATIONAL STREAM GAGE
MAJOR FLOOD EVENTS
UPPER NISQUALLY RIVER
PIERCE COUNTY PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES
WATER PROGRAMS DIVISION

Year of Event	1-day Averaged Flow		3-day Averaged Flow		Date of Peak Flow
	CFS[1]	Rank*	CFS	Rank*	
2006[2]	10,977	4	8,741	3	11/7/2006
2003	8,620	9	5,117	12	1/31/2003
1997	8,000	10	5,280	11	3/20/1997
1996	**15,700**	1	10,200	2	2/8/1996
1995	12,500	3	**11,070**	1	11/30/1995
1990	9,860	5	6,073	8	1/9/1990
1980	7,770	11	5,947	9	12/26/1980
1977	12,500	2	6,817	6	12/2/1977
1975	8,720	8	8,133	4	12/4/1975
1974	9,540	6	7,813	5	1/15/1974
1965	9,200	7	6,777	7	1/29/1965
1959	7,220	12	5,900	10	11/23/1959

Notes:

* Rank in order of greatest flow

[1] cubic feet per second

[2] Preliminary Data from USGS gage, Highest instantaneous flow = 21,000 cfs

TABLE 4
BASIN HISTORY TIMELINE
UPPER NISQUALLY RIVER
PIERCE COUNTY PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES
WATER PROGRAMS DIVISION

Dates	Finding
Pre 1896	First Development (Logging, Farming)
Pre 1904	First Railroad in the Valley
1899	Mt. Rainier National Park created
1906-1931	La Grande Gage operation
1912	Completion of LaGrande Dam and hydroelectric facility
1926, October	Glacial outburst flood from Nisqually Glacier estimated at 7,000cfs at the hwy 706 crossing immediately below the glacier (Nelson, 1987)
1945	Completion of Alder Dam (created Alder Reservoir)
1947, October	Kautz Creek outburst flood estimated at 20,000 cfs at the confluence with the Nisqually River (Nelson, 1987)
1955	Glacial outburst flood from Nisqually Glacier estimated at 70,000 cfs at the hwy 706 crossing immediately below the glacier (Nelson, 1987)
1960s	Sunshine point levee constructed to contain 25-40 yr event (Randy Brake, presonal communication)
1967, August	Tahoma Creek outburst flood estimated at 24,000 cfs in the upper Tahoma basin (Nelson, 1987)
1966	Osborn Rd bridge is out (observed in photo record)
1968, June	Glacial outburst flood from Nisqually Glacier estimated at 5,000cfs at the hwy 706 crossing immediately below the glacier (Nelson, 1987)
1970, July	Glacial outburst flood from Nisqually Glacier estimated at 3,000cfs at the hwy 706 crossing immediately below the glacier (Nelson, 1987)
1977	Highest recorded daily mean discharge = 17,100 cfs (11.5 miles downstream of Sunshine point)
1981	2 revetments along 706 installed (source?) New FS-1 Bridge built (observed in photo record) Old Bridge removed/Distroyed
1975-1998	Progressive channel avulsion from north to south in reach N2 (Observed in photo record)
1990	Channel avulsion near Sunshine Point Campground (Reach N-2)
1996	Channel avulsion destroyed Hideen Valley Subdivision (Reach N-2)
1996	Channel avulsion took out south RR bridge approach, it was fixed. (source?)
1981	Installation of FS1 Bridge Across the River (observed in photo record)
NA	Installation of FS85 Bridge Across the River (Kernahan Rd)

TABLE 5

MAXIMUM MEASURED DISTANCE OF EROSION[1] PER REACH

UPPER NISQUALLY RIVER

PIERCE COUNTY PUBLIC WORKS AND UTILITIES, ENVIRONMENTAL SERVICES

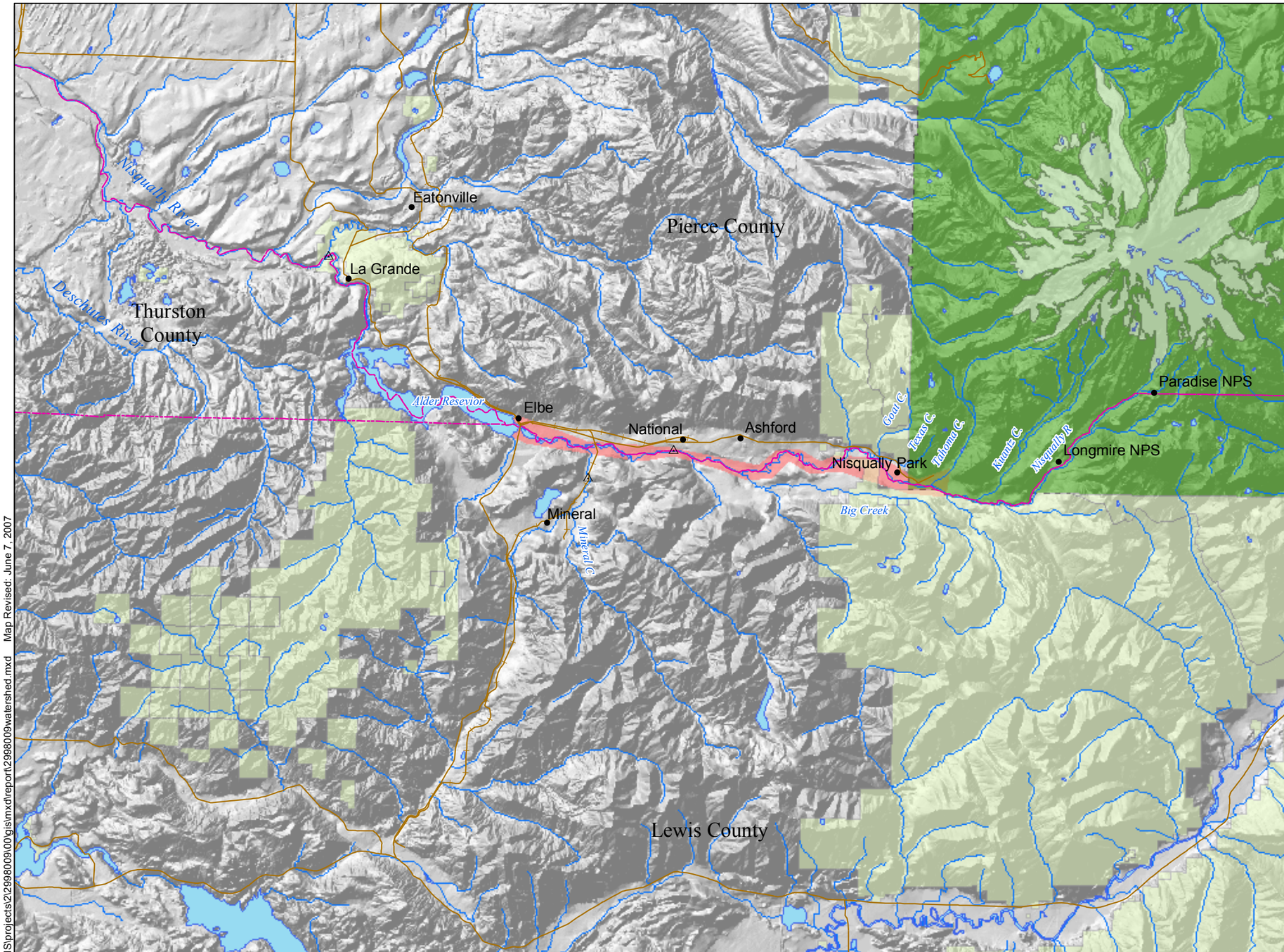
WATER PROGRAMS DIVISION

Reach	Alluvial (greatest amount)		Glacial Terraces		Lahar Terraces	
	Right bank	Left bank	Right bank	Left bank	Right bank	Left bank
7	132.0	53.0	NA	NA	359	119
6	944.0	729.0	164	NA	100	350
5	411.0	382.0	NA	NA	NA	NA
4	643.0	710.0	450	343	NA	NA
3	920.0	463.0	NA	NA	99	362
2	704.0	926.0	NA	NA	358	NA
1	340.0	392.0	NA	NA	NA	NA

Notes:

All distances are in feet.

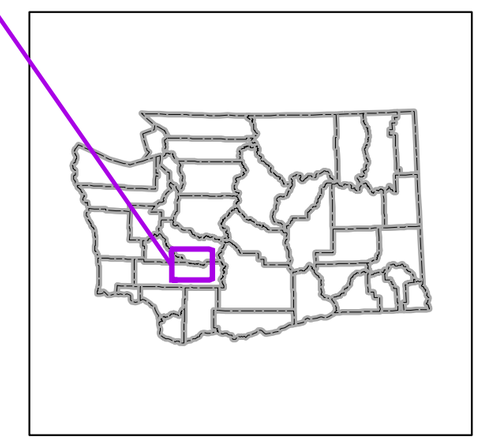
[1] Short Term Erosion (i.e. between two consecutive photo sets)



Study Area
Towns
State Highways
Railroad Lines
Waterbodies
Glaciers (Mount Rainer)
Rainier National Park
Major Public Lands
County Boundaries

0 1 2 4 6 Miles

N W E S



Pierce County Public Works and Utilities Water Programs Division

GeoEngineers

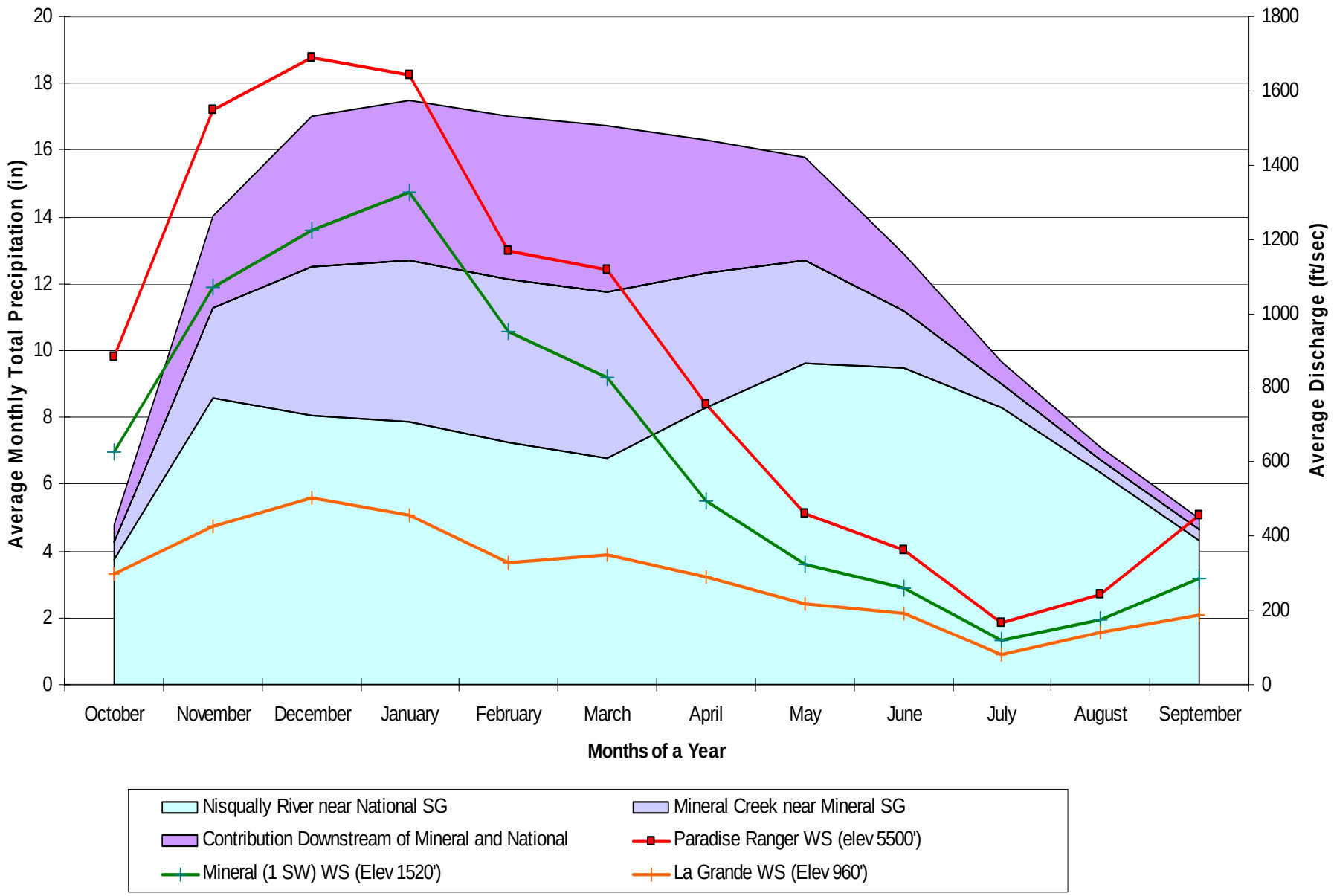
CHANNEL MIGRATION ZONE STUDY
UPPER NISQUALLY RIVER
PIERCE COUNTY

FIGURE 1

Data Sources: Rivers, waterbodies, state highways, railways, and political boundaries are provided by the Washington Department of Transportation. Watersheds, glaciers, and major public lands are from the Washington Department of Natural Resources. Study area, gage stations, and towns locations were created by GeoEngineers.

This map is for information purposes. Data were compiled from multiple sources as listed on this map. The data sources do not guarantee these data are accurate or complete. There may have been updates to the data since the publication of this map. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication. The locations of all features shown are approximate.

Office: BAM DJS S:\GIS\projects\2\2998009\00\gis\mxd\report\2998009watershed.mxd Map Revised: June 7, 2007



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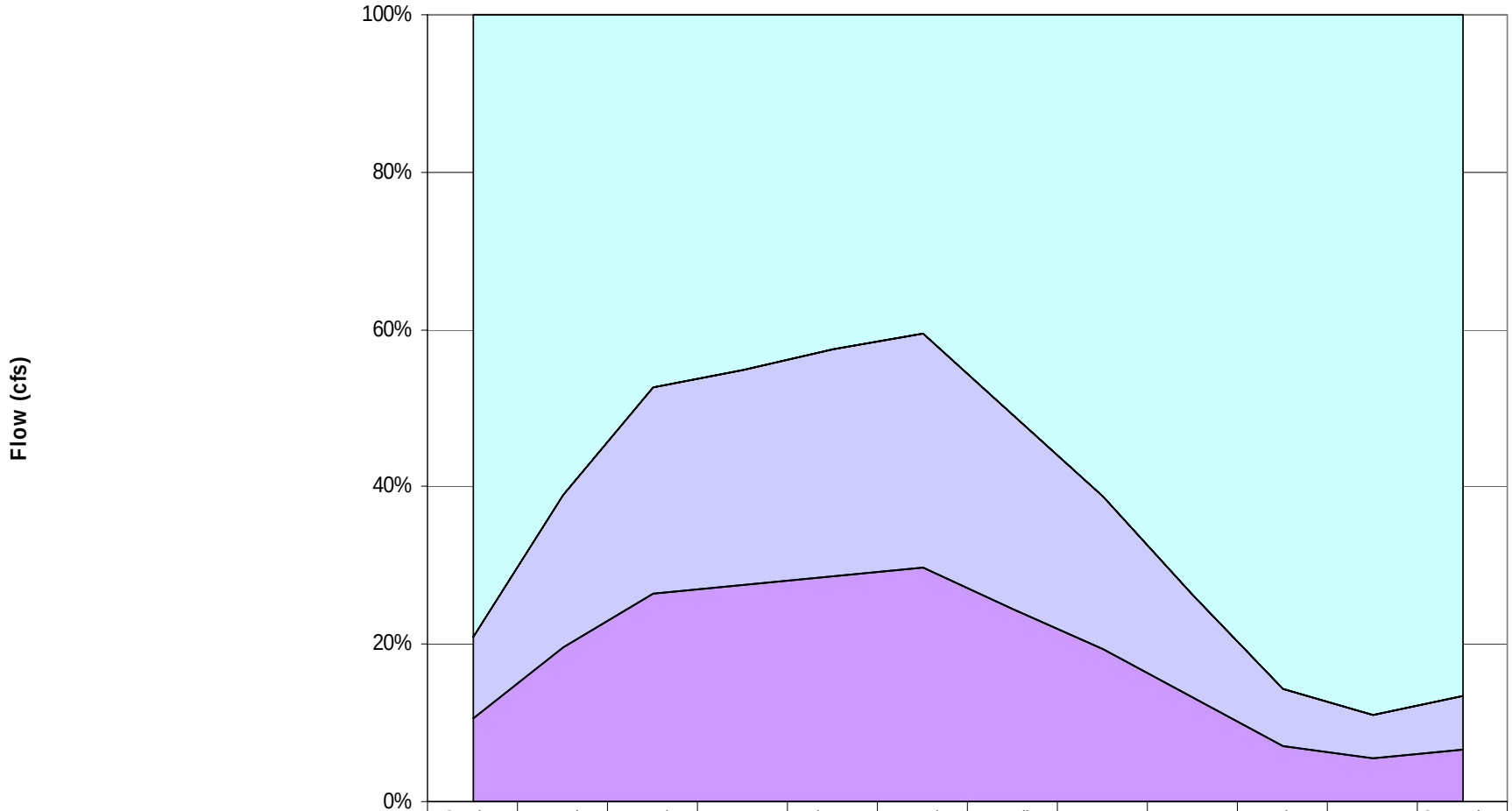
Pierce County
Public Works and Utilities
Water Programs Division

Monthly Precipitation and Discharge

FIGURE 3

Office: REDM DJJP:/2/2998009/00/Report/2998009figure4.ppt Revised: June 3, 2007



	October	November	December	January	February	March	April	May	June	July	August	September
Nisqually River near National SG	339	770	723	710	651	609	747	868	855	747	571	387
Contribution Downstream of Mineral and National*	45	247	404	433	441	449	361	276	152	62	35	30
Mineral Creek near Mineral SG	45	247	403	432	440	448	360	275	152	62	35	30

Period of the Year

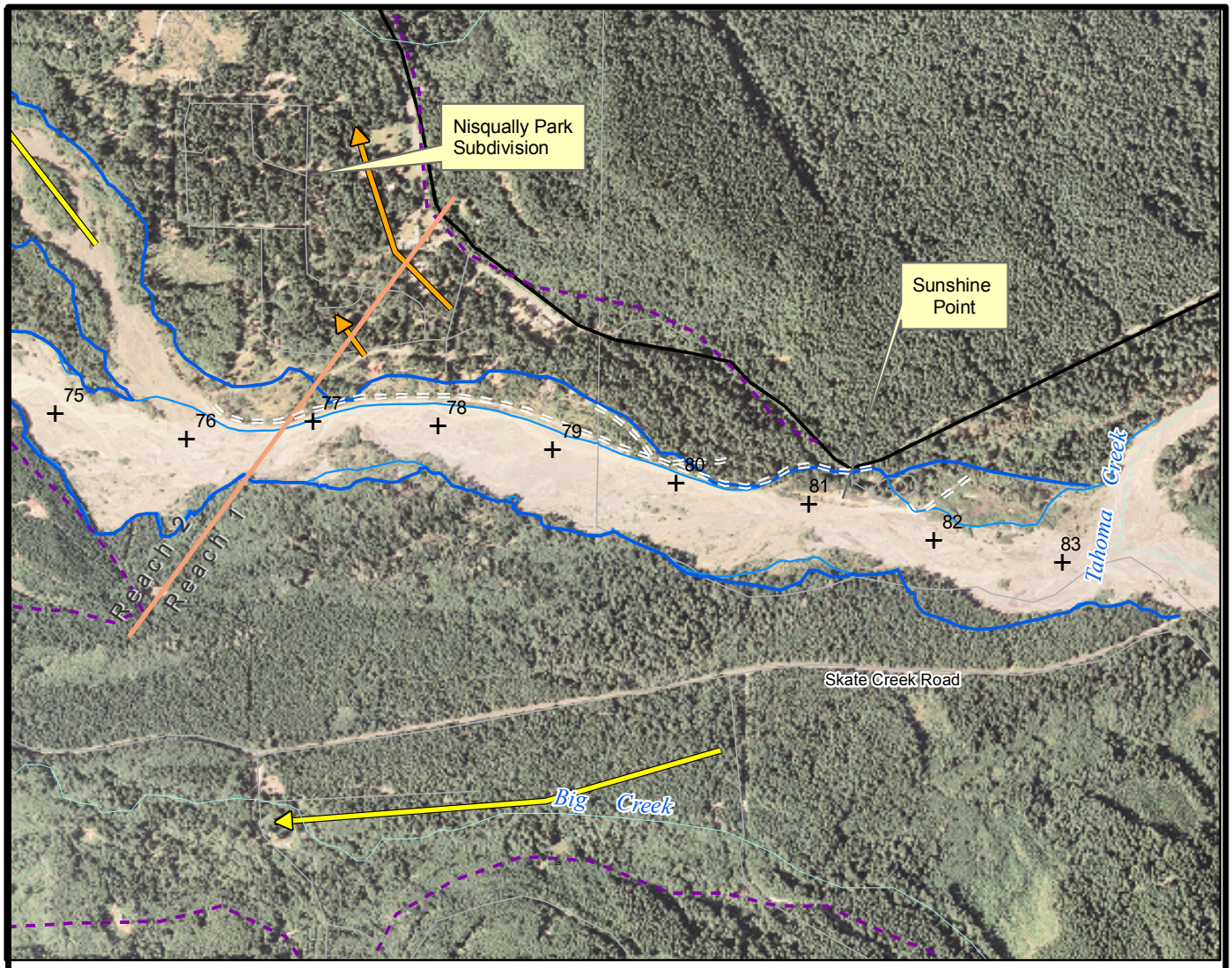
GeoEngineers

Pierce County
Public Works and Utilities
Water Programs Division

Monthly Sub-basin Contribution to the Mainstem Flow

FIGURE 4

Office: REDM DJJP:/2/2998009/00/Report/2998009figure4.ppt Revised: June 3, 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

Notes: 1) The locations of all features shown are approximate.
2) All data is produced at a scale of 1:12K unless otherwise noted.
3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet

4,000

1 inch equals 1,250 feet

N

Note: This drawing is for informational purposes. It is intended to assist in showing features discussed in an attached document.

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Explanation

Terrace and Bedrock Boundaries

- **Low (5-20 ft)**
- **Moderate (15-45 ft)**
- **High (>35 ft)**
- **Stationing (1000 ft)**
- **Reach Boundary**
- **Armored Levees and Revetments (2006)**
- **Potential Avulsion Route**
- **HistoricNisqually River Channel**
- **Historical Channel Occupation Tract (1955-2007)**
- **Abandon Channel Tracks**
- **2007 High Flow Corridor (Bars and Channels)**
- Highway
- Major Road
- Local Road
- Minor Road

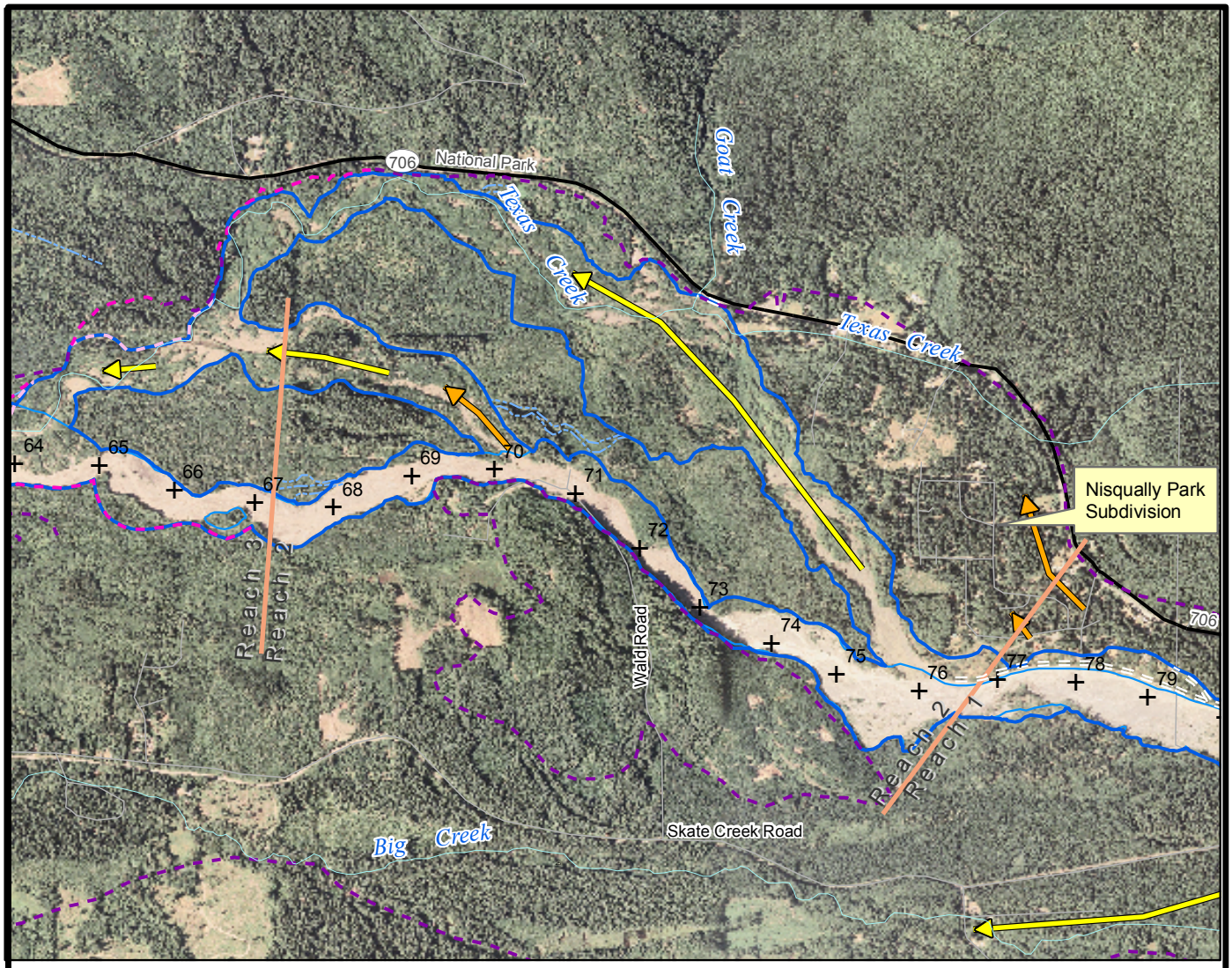
Pierce County
Public Works and Utilities
Water Programs Division

GeoEngineers

REACH 1
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 5

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

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Feet

9,000

1 inch equals 2,000 feet

N

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Explanation

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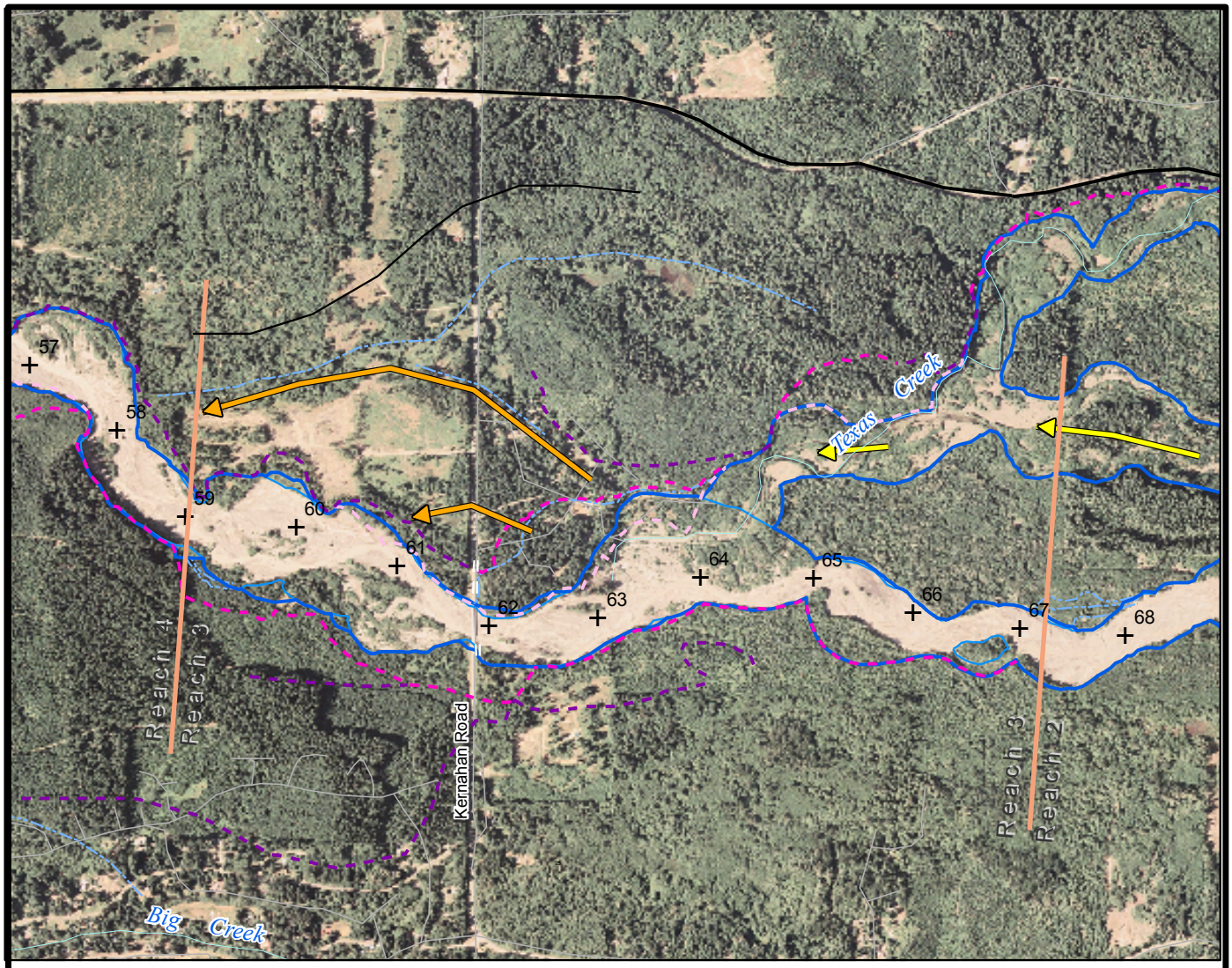
REACH 2
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 6

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

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3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet

8,000

1 inch equals 1,500 feet

N

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Explanation

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- Highway
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- Minor Road

Pierce County
Public Works and Utilities
Water Programs Division

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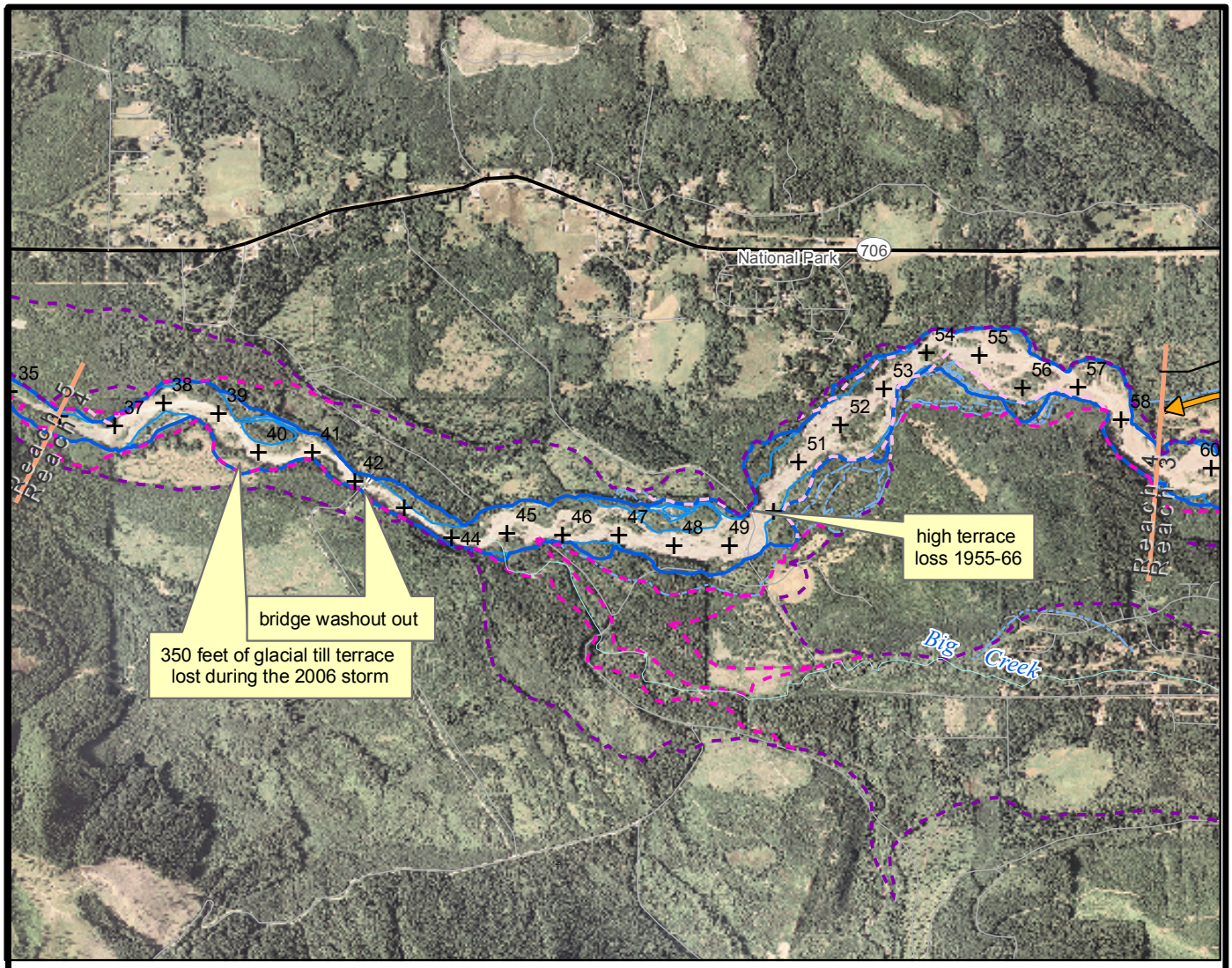
REACH 3
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 7

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

Notes: 1) The locations of all features shown are approximate.
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3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet

7,000

1 inch equals 3,000 feet

N

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Explanation

Terrace and Bedrock Boundaries

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- Highway
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- Minor Road

Pierce County
Public Works and Utilities
Water Programs Division

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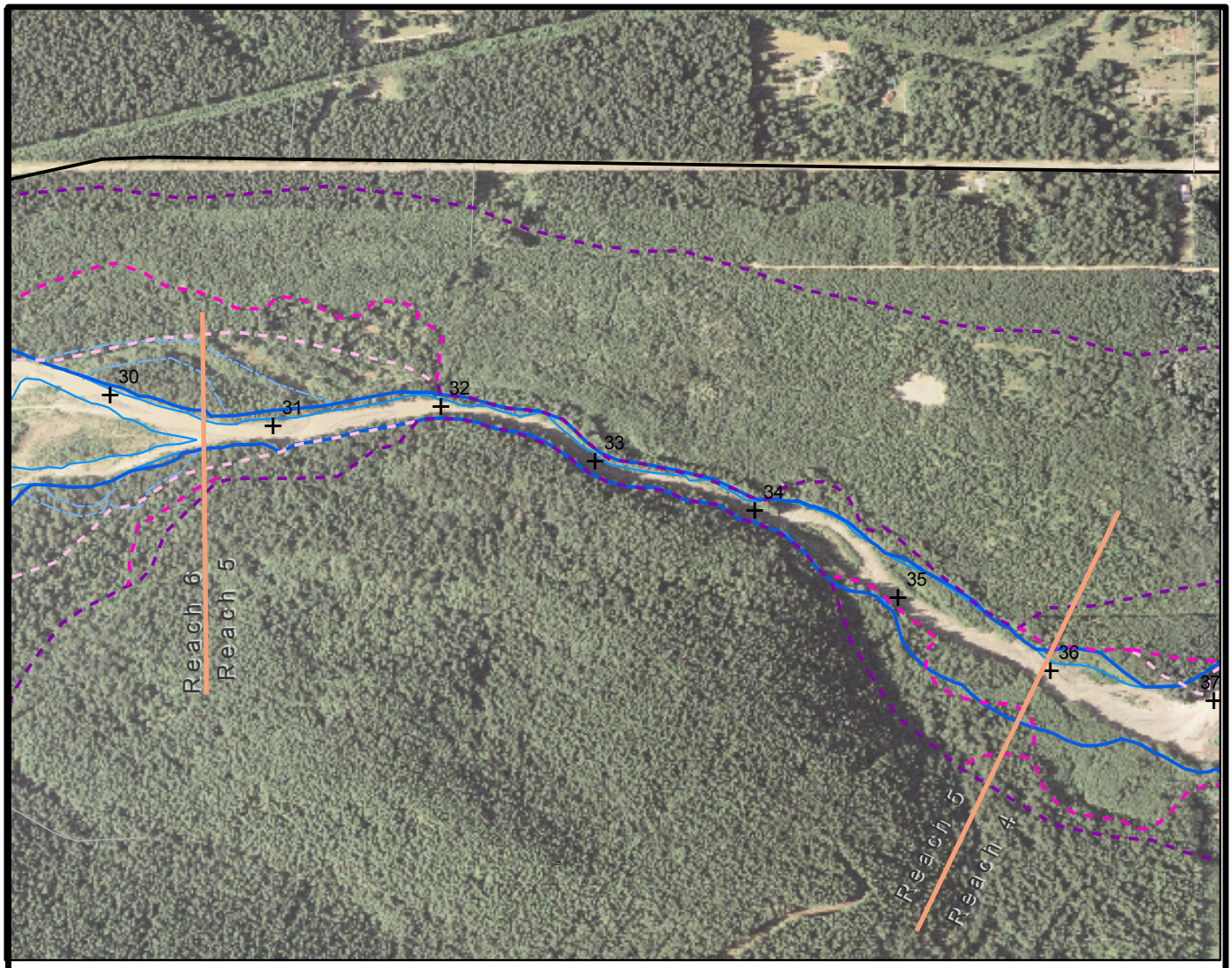
REACH 4
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 8

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

Notes: 1) The locations of all features shown are approximate.
2) All data is produced at a scale of 1:12K unless otherwise noted.
3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet
2,000

1 inch equals 1,000 feet

N

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Explanation

Terrace and Bedrock Boundaries

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- **Moderate (15-45 ft)**
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- Highway
- Major Road
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Water Programs Division

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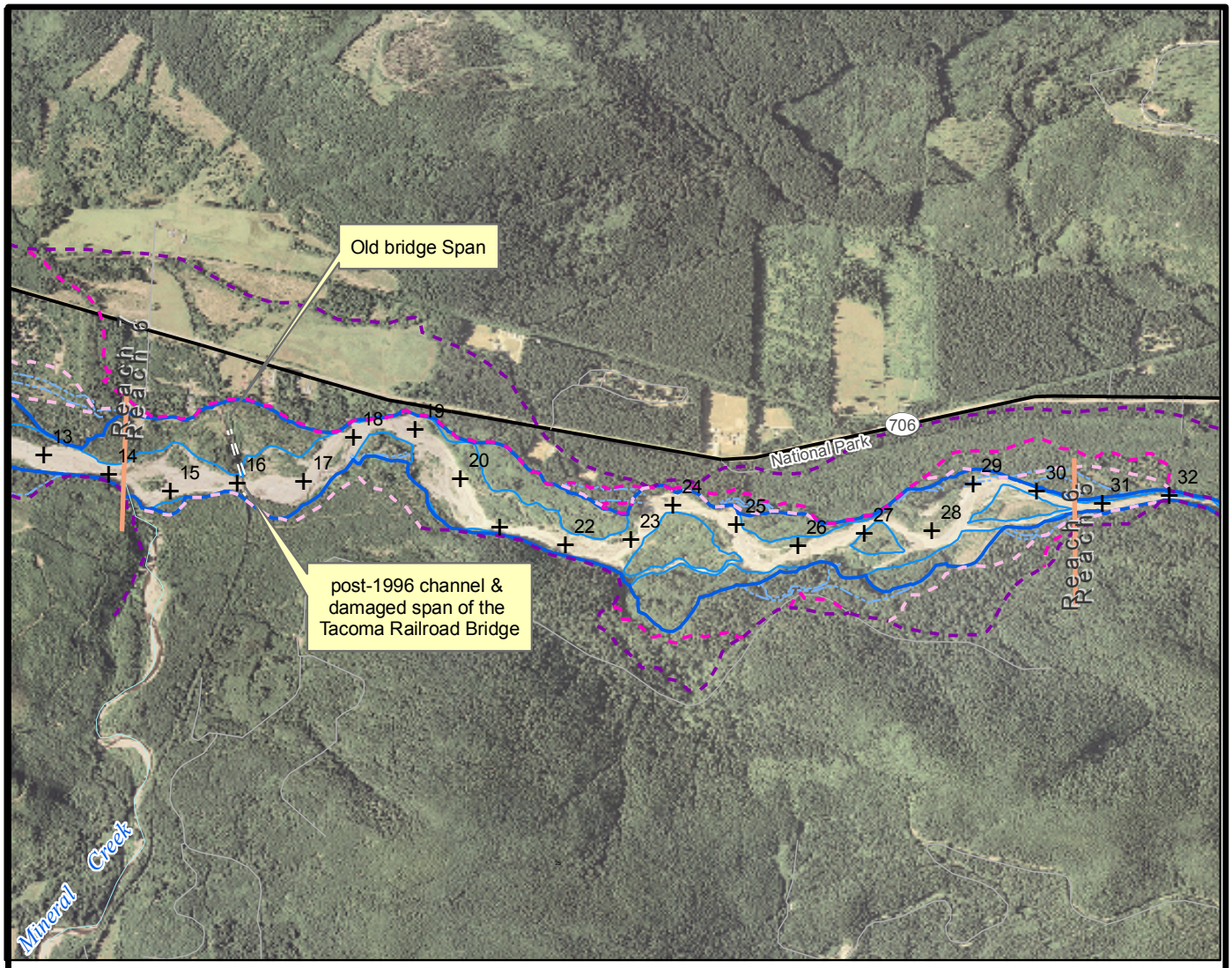
REACH 5
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 9

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

Notes: 1) The locations of all features shown are approximate.
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3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet

7,000

1 inch equals 2,500 feet

N

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Explanation

Terrace and Bedrock Boundaries

- **Low (5-20 ft)**
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- Highway
- Major Road
- Local Road
- Minor Road

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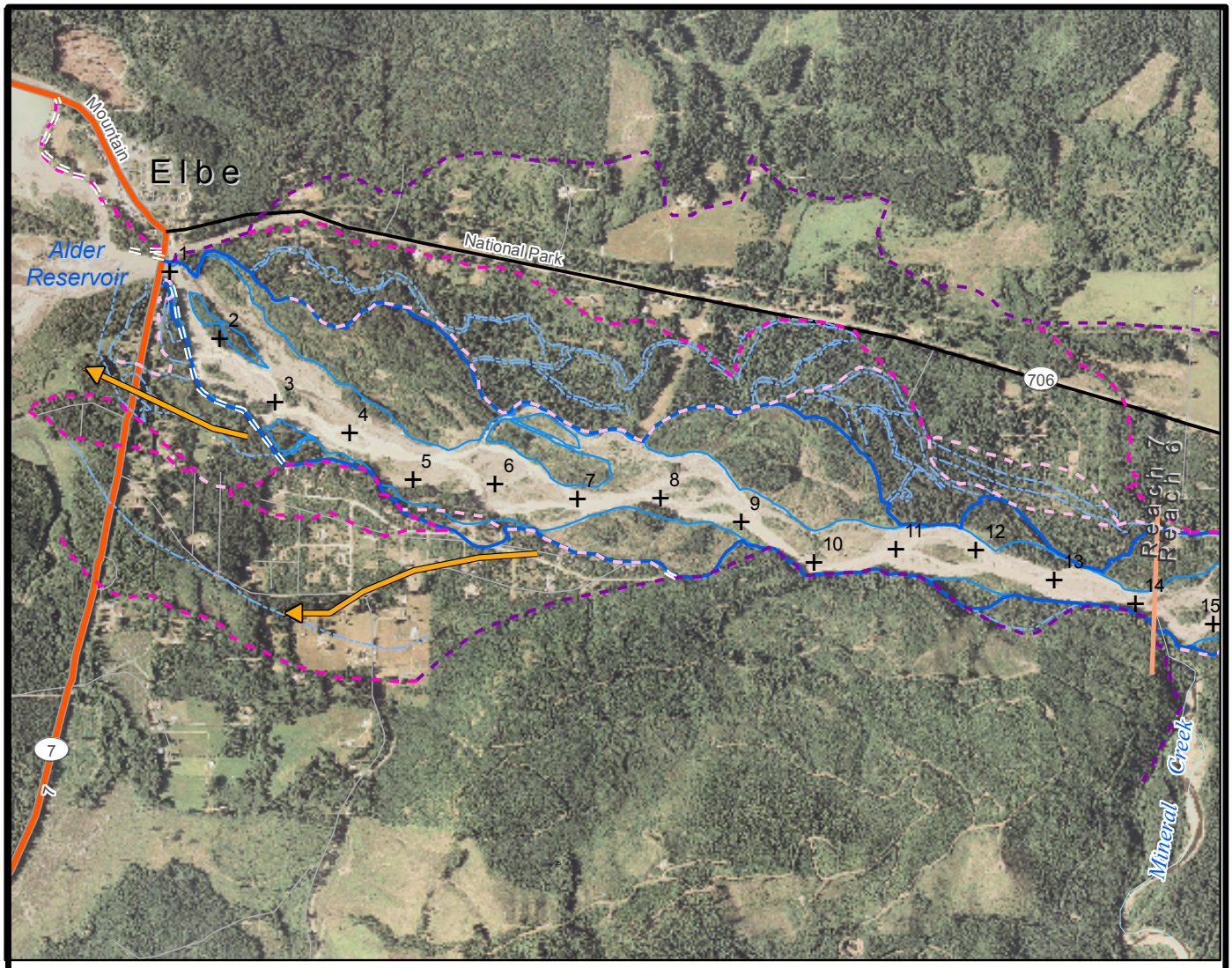
REACH 6
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 10

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007



Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. 2007 channel features digitized by GeoEngineers from 2007 infrared orthophotographs collected by ETG, inc. for Pierce County Water Programs. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, LiDAR and ortho-base relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound LiDAR Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph.

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3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

Feet

6,000

1 inch equals 2,000 feet

N

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Explanation

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Pierce County
Public Works and Utilities
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REACH 7
CHANNEL AND VALLEY FEATURES
UPPER NISQUALLY RIVER CMZ ANALYSIS

FIGURE 11

Office: RED Path: S:GIS/project/2/2998009/00/gis/mxd/report/2998009fig3.mxd Map Revised : June 6 , 2007

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Pierce County
Public Works and Utilities
Water Programs Division

Appendix A
Method and References

APPENDIX A
METHODS

LITERATURE REVIEW

Following is a list of references for the literature reviewed for this project. The purpose of the review was to acquire basin scale information including geology, flooding, topography, soils, sediment supply and delivery, land use, roads and planning, and gain a historical perspective of the basin regarding historic channel changes, land use history, and the construction of channel confining infrastructure

AERIAL PHOTOGRAPHIC AND MAP ANALYSIS

Aerial photographic and map analysis was used to identify the locations of channels, terraces, and structural features over the period of record. The period of record extends from 1896 through 2007, as represented by dated maps and aerial photographs. During the coarse the data review, we developed a preliminary understanding of progressive channel conditions.

To manage the volume of available data for the analysis, we selected aerial photographs and maps suitable to project goals for conversion to our GIS database via electronic rectification. The criteria for selection and inclusion of aerial photographs and maps in the GIS data base included 1) obtaining the earliest and most recent flight year coverage, 2) the extent of coverage, 3) changes in channel position or other significant features, and 4) condition and visual quality of the photographs and maps. Based on these criteria, photographs from flight years 1955, 1966, 1981, 1986, 1994, 1996, 2001, 2002, 2005, 2006, and April 2007 were selected. Orthorectified aerial photos used for this project include the years 1996, 2002, 2005, 2006, and 2007. The photo period from 1955 to 2007 encompasses major floods in 1955, 1977, 1995, 1996 and 2006 as well as significant glacial outburst floods in 1955, 1967, 1968, and 1970 (see table 5). Government Land Office (GLO) maps from 1896 were compared with modern photos for differences in channel pattern, but the GLO maps were not used in any channel movement calculations due to scaling and accuracy considerations.

GIS DATA DEVELOPMENT

Five major types of GIS data were developed for this project; 1) digital rectified aerial photographs, 2) stream centerline stationing, 3) topographic models, 4) digitized features from historical data sets, and 5) delineated HCOT, terrace, and CMZ boundaries. All GIS data development and analysis were completed using ESRI's ArcGIS version 9.1 and 9.2 software.

Historical Aerial Photo Georectification

Aerial photographs derived from contact prints or digital scans of prints were georeferenced to a known coordinate system. Georeferencing is the GIS process by which a digital image is matched to a digital orthophotograph in some projected coordinate system, in this case, Washington State Plane, South NAD 1983 (feet). Orthorectified aerial photos from 1996 were used as a reference for georeferencing digitally scanned aerial photos from 1955, 1966, 1981, 1986, 1994, and 2001.

Paper prints of aerial photos were scanned at 300 dots per inch and compressed using MrSid compression software. The Mr. Sid photos were then georeferenced to the 1996 orthorectified photos for the Upper Nisqually River area in a GIS using a series of four or more control points with an average Route Mean Square (RMS) error of less than 14 feet. Control points were strategically located at highly visible, immobile objects such as road intersections and the corners of buildings. Control points were focused in areas of similar elevation on the valley floor; control points were not placed directly on the edge of an aerial photo to minimize distortion. Additional information regarding specific RMS errors and data processing is available in the associated metadata included with the georeferenced photos.

Stream Centerline Stationing

A stationing system was created to assist in locating specific features on the river. The stationing (STA 0 to STA 81) was created along a 2002 stream centerline beginning at the eastern end of Alder Reservoir and continuing upstream to Sunshine Point. GeoEngineers digitized the centerline from 2002 infrared (IR) orthophotographs, which was the most recent orthophotographs available at the time of the stationing task. Each station point is set at increments of 1,000 feet; for example, STA 81 is located 81,000 feet upstream of STA 0.

The centerlines of major tributaries were digitized and stationed using the same methods.

Topographic Modeling

DEMs, Contouring and Hillshading of LiDAR and DTM Datasets

Contouring and hillshading are common tools used to view elevation data. The following processes were used in producing these tools:

- A Digital Elevation Model (DEM) and Hillshade model of the LiDAR were generated from 2004 Puget Sound LiDAR Consortium bare surface point return data. The data was simplified and merged into a 2-foot grid format.
- The hillshade model was generated from USGS derived DEMs merged into a single 10 -meter grid format.
- 10-foot contours were generated from a 2007 Orthographic Digital Terrain Model (DTM) provided by ETG.

Available LiDAR covered only two-thirds of the project (Station 0-72). The 2007 Orthographic DTM data covers a portion of the valley floor over the length of the project area.

LiDAR –based Relative Surface Model: Valley Wide Method

In order to identify relative changes in topography for geomorphic applications, GeoEngineers developed a Relative Surface Model (RSM). There are at least three methods by which RSMs can be created. All methods require the post processing of LiDAR DEMs.

For the purposes of this project, the 'valley wide method' was used. For this method, a planar surface approximating the valley's gradient (gradient normal to the axis of the valley is created). This surface, referred to as the 'modeled surface', is then subtracted from the topography represented by the DEM. The resulting 'subtracted' surface, RSM, shows topographic features lying perpendicular to the axis of the valley as positive and negative features relative to the 'modeled surface'. Thus, the RSM depicts the topographic relief of physical features across the valley floor (side channels, wetlands, levees, roads) and the relative change in elevation between the features. It is important to note that the relative change in elevation is to the modeled surface, i.e. one can determine the relative elevation of terraces that are more or less in line with each other (normal to the valley axis). Also the modeled surface is not correlative with a water surface, such as the water surface documented in the LiDAR, or the gradient of the channel alone.

The relative surface model is provided on Plate 2. Positive and negative topography is depicted by gradational ranges of blue and orange colors. For this project, the color white represents the elevation of the 'modeled surface' (set at zero), progressively deeper shades of blue represent increasing elevations above the modeled surface (deepest blue = 60-feet above the modeled surface), and progressively deeper shades of orange represent decreasing elevations below the modeled surface (deepest orange = 60-feet below the modeled surface). For example, blue areas reside at higher elevations than white or orange areas, and features with same color reside similar elevations. Also shown on Plate 2 are black lines that have been set perpendicular to the valley axis. These lines are provided as an aid to interpreting the topographic results of the relative surface model.

Channel Gradients

Channel gradients were calculated at 1,000 foot increments along the main stem river and major tributary. All necessary data, including horizontal distance and elevation, were acquired from LiDAR at each centerline station. Where LiDAR was not available, the 10-meter USGS DEM was used.

Digitizing Features

The development of GIS data included digitizing and attributing points, lines and polygons with critical information derived from scanned aerial photographs. Digitizing was completed at a scale of approximately 1:12,000 (or 1 inch = 1000 feet). Critical information was digitized into two GIS shape files, also referred to as GIS layers: channel lines and terrace lines.

Channel lines are defined as the wetted channels and associated bars observed on the aerial photographs. The outer boundaries of morphologic features are generally correlative with the high flow corridor. Attributes were added to the GIS channel layer to distinguish aerial photograph dates.

Terraces were identified using a LiDAR-based relative surface model. The terraces were broken into three categories (low, moderate, and high) based on elevations derived from the LiDAR relative surface model. Attributes were added to the GIS terrace layer to indicate the approximate height and composition of the terrace.

Delineation of Boundaries

The ***HCOT*** is defined as the zone within which the active channel has been located between 1955 and April, 2007. Typically, the width of the HCOT is equal to or greater than the width of any single high-flow corridor. The HCOT also includes areas occupied by the channel during historic peak flows. Reaches displaying overlapping channel lines and HCOT lines typically identify reaches where the channel position has not moved appreciably over the period of record.

DOCUMENTING CHANNEL CORRIDOR MOVEMENT

Measurements were made directly from channel positions of dated georeferenced or orthographic aerial photographs. Cross channel measurements of the right and left bank and the width of any vegetated islands were taken from fixed locations. The fixed locations represent stationing every 2,000 feet along the 2002 stream centerline; for example, 42 right and left bank locations were measured from the fixed 2002 Center line per aerial photo-year set). Cross channel measurements were made for all aerial photo-year sets in the GIS data base and tabulated in a spreadsheet for analysis.

Changes in width or the location of the right and left banks between aerial photo dates were calculated from the dataset. Short-term channel changes were tracked between two sequential aerial photographs. The short-term bank fluctuation accounts for abrupt changes observed in sequential photographs. Long-term bank fluctuations were calculated for each reach based on the total distance migrated over the photo record. Both short-term and long-term fluctuations were used in characterizing the channel behavior. The maximum short-term fluctuation in channel width within a reach was used in delineating the CMZ.

GEOMORPHIC REACH CHARACTERIZATION

A key element of the CMZ analysis included identifying the geomorphic processes operating throughout the project area, and evaluating the affects of those processes on migration. Channel migration is a dynamic process driven by the interaction of physical characteristics and geomorphic processes operating at both local and watershed scales. Physical characteristics include topography, geology, regional and local channel gradients, corridor dimensions, and the composition of riverbank, terrace, and stream bed

materials. Principle geomorphic processes include local and reach-scale flow dynamics, sediment supply and delivery, sediment transport capacity, and erosion and deposition within the channel.

For the purpose of this project, the Upper Nisqually River was divided into geomorphic reaches based on channel pattern, channel morphology, migration type, channel gradient, bank soil composition, terraces, and geomorphic history. These characteristics were first identified in the GIS, and then used to delineate preliminary reach boundaries and describe reach characteristics. Site reconnaissance (discussed below) was conducted to fine-tune reach boundaries and characterizations.

SITE RECONNAISSANCE (VERIFICATION)

The GIS analysis and literature review provided a background for the project, which was built upon and verified during field reconnaissance. The reconnaissance was conducted on September 1 and 2 2006, and again on November 14, 2006. During the September field reconnaissance, the field team visited selected sites in each reach to observe and/or verify geomorphic features include channel characteristics and geometry, soil compositions and stiffness, grain sizes, geology, erosional and depositional features, large woody debris (LWD), levees and revetments, and vegetation. The team also floated the length of the Upper Nisqually River from the confluence with Tahoma Creek near Sunshine Point Campground, to the railroad bridge at the downstream end of Reach 6. Floating the river provided unrestricted access to river banks and floodplain, as well as unabridged observations regarding spatial changes in channel forming processes.

The field reconnaissance, on November 14th focused on discrete sites that had been damaged or otherwise affected by the storm events of November 6, 2006. We observed notable channel changes as a result of the storm and collecting time-sensitive data that might not persist through the season. Observing the river before and after a severe storm event provided valuable insight on the event-driven character of the Upper Nisqually. Bank recession and high-flow corridor fluctuations directly attributed to a single storm event were measured. Site reconnaissance included the Sunshine Point area, located inside Mt. Rainier National Park. Paul Kennard, the Park Geomorphologist, who provided a first-hand account of the flood and its affects in the Sunshine Point area, accompanied the team.

GEOLOGIC ANALYSIS

General stratigraphic sections, grain-sizes and degree of sediment packing were recorded in the field. Field observations were compared with digital georeferenced surfical maps of the geology and soils to determine terrace and surfical bedrock types. In order to address the sensitivity of terraces to erosion, the terraces were cataloged based on the composition of basal soil deposits,

HYDROLOGIC ANALYSIS

Historic Daily Peak Gage Data and Simultaneous Peak flow data from November 2 through November 10, 2006 were collect and analyzed from three long-term operating stream gage stations: the Nisqually River gage, located near National, the Mineral Creek gage, located near Mineral, and the Nisqually River gage, located at La Grande (see Figure 1). Software provided by Indicators of Hydrologic Alteration (IHA) was used to compile and sort the data by peak 1- and 3-day mean flows as well as by Monthly Mean flows. Because the USGS had not released the provisional data, the preliminary, Simultaneous Peak flow data from November 2 through 10 2006 from the 3 gages was compiled to calculate the 1 and 3 day mean flows of the 2006 Event.

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Appendix B
General Reach Characteristics

APPENDIX B
REACH DESCRIPTION TABLES

Reach 1

Characteristic	Description
Valley	4225ft wide; valley bottom is generally flat and consists of an alluvial fan; valley wall composed of bedrock
Terraces	None
Channel	550ft wide high-flow corridor; straight; braided pattern; scattered LWD; ~2% gradient
Bed	Cobble to boulder grain size; dominated by bars; no defined single thalweg
Banks	Alluvial cobbles/boulders/sand; up to ~6ft ft vertical face; active bank erosion (widening) in several locations; armored levee on right bank with some damage.
Floodplain	Fine to medium sand over gravel and cobbles; abandoned channels behind right bank levee; ancient abandoned channel on left floodplain now occupied by Big Creek.
Human Modifications	Armored levee on right bank; roads and buildings on right floodplain
Assessment	Transport limited; alluvial fan; potential avulsion behind levee on right bank and less likely avulsion potential on left bank into Big Creek drainage.
Other	Potential for large slug of sediment from glacial outburst or lahar; valley floor composed of aggraded lahars and alluvium (National and Paradise Lahars, Round Pass Mudflow).

Reach 2

Characteristic	Description
Valley	8600ft wide; valley bottom is generally flat and consists of alluvium overlying lahars; scattered bedrock islands in the valley bottom; valley wall composed of bedrock.
Terraces	Low alluvial terrace primarily on the right bank (up to 10ft high); low terrace on left bank composed of alluvium over lahar deposits (~8ft high).
Channel	425ft wide high-flow corridor; generally straight; braided pattern
Bed	Cobble to boulder grain size; dominated by bars; no defined single thalweg
Banks	Alluvial cobbles/boulders/sand; up to ~10ft ft vertical face; active bank erosion (widening) throughout reach.
Floodplain	Fine to medium sand over gravel and cobbles; many abandoned channels; documented avulsion (1996); primarily young riparian vegetation.
Human Modifications	Possible levee (composed of alluvium) at 1996 avulsion site; road and abandoned subdivision on left bank (subdivision destroyed by 1996 avulsion).
Assessment	Channel is adjusting to 1996 avulsion by widening; up to 10ft of incision in the upper reach; deposition in the lower reach upstream of the Kernahan bridge (constriction).
Other	Penetrometer in lahar = 2.2 tons/sq ft.; Penetrometer in weathered (orange) lahar > 4.0 tons/sq ft.; Penetrometer in overbank alluvial silt/sand = 0.75 tons/sq ft.

Reach 3

Characteristic	Description
Valley	1400ft wide (confined by terraces); valley bottom is generally flat and consists of alluvium overlying lahars
Terraces	Low terraces composed of alluvium (2-6ft high); middle terrace composed of llahar deposits over glacial till (~20ft high); high terraces composed of glacial till (~50ft high).
Channel	550ft wide high-flow corridor; constricted to 250ft wide at Kernahan bridge; generally straight; braided pattern; scattered but abundant LWD
Bed	Gravel to cobble grain size; dominated by bars; no defined single thalweg
Banks	Composed of alluvial cobbles/gravel/sand, otherwise banks defined by terraces; active and rapid bank erosion into alluvium; bank erosion concentrated on right bank in upper reach and on left bank at Kernahan bridge.
Floodplain	Fine to medium sand over gravel and cobbles; narrow floodplain due to terraces
Human Modifications	Kernahan bridge (constriction).
Assessment	Transport limited; aggradation upstream of bridge due to channel constriction and large sediment supply; high rates of bank erosion and channel widening
Other	

Reach 4

Characteristic	Description
Valley	1000ft wide (confined by terraces); valley bottom is generally flat and consists of alluvium overlying lahars
Terraces	Low terraces composed of alluvium (5-10ft high); middle terrace composed of lahar deposits over glacial till (20-30ft high); high terraces composed of glacial till (~70ft high).
Channel	100-500ft wide high-flow corridor; generally straight with two large-diameter bends; braided pattern becoming single thread downstream; scattered LWD
Bed	Gravel to cobble grain size; dominated by bars; no defined single thalweg except in lower reach
Banks	Composed of alluvial cobbles/gravel/sand, otherwise banks defined by terraces; active and rapid bank erosion into alluvium; little or no bank erosion into terraces
Floodplain	Fine to medium sand over gravel and cobbles; narrow floodplain due to terraces
Human Modifications	Forest Service bridge constriction near National.
Assessment	Transitional reach; transport limed upstream becoming predominantly graded or supply limited downstream
Other	

Reach 5

Characteristic	Description
Valley	75ft wide (confined by bedrock)
Terraces	No terraces
Channel	50ft wide; straight; littler or no LWD; channel flows through a gorge
Bed	Composed primarily of boulders and cobbles
Banks	Composed of alluvial cobbles/boulders or bedrock
Floodplain	None
Human Modifications	Gaging station near downstream end of reach
Assessment	Bedrock confined transport reach; supply limited
Other	

Reach 6

Characteristic	Description
Valley	1700ft wide (confined by terraces); valley bottom is generally flat and consists of alluvium
Terraces	Low terraces composed of lahar deposits (5-15ft high); middle terrace composed of glacial till (30-40ft high); high terraces composed of glacial till and/or bedrock (+70ft high).
Channel	500ft wide high-flow corridor; generally straight with occasional bends that change location and orientation through the photo record; braided pattern; scattered LWD
Bed	Gravel to cobble grain size; dominated by bars ~2-3ft above low water level; no defined single thalweg
Banks	Composed of alluvial cobbles/gravel/sand, otherwise banks defined by terraces; active and rapid bank erosion into alluvium; little or no bank erosion into terraces
Floodplain	Fine to medium sand over gravel and cobbles; narrow floodplain due to terraces; many abandoned channels.
Human Modifications	Railroad bridge constriction in lower reach
Assessment	Primarily transport limited; channel widens and gradient reduces from Reach 5; rapid migration/avulsion within high-flow corridor
Other	Right bank terrace lahar penetrometer >4.0 tons/sq ft.

Reach 7

Characteristic	Description
Valley	1500ft wide in upper reach to 5000ft wide in lower reach (confined by terraces); valley bottom is generally flat and consists of alluvium; occasional lahar deposits in valley bottom
Terraces	Low terraces composed of lahar deposits (~10ft high); middle terrace composed of glacial outwash (~20ft high); high terraces composed of glacial till and/or bedrock (+40ft high).
Channel	550ft wide high-flow corridor; generally straight with occasional bends that change location and orientation through the photo record; braided pattern; scattered LWD
Bed	Gravel to cobble grain size; dominated by bars; no defined single thalweg
Banks	Composed of alluvial cobbles/gravel/sand; basalt bedrock exposed in right and left banks in lower reach near Elbe; Left bank in lower reach is composed of an armored levee; otherwise banks defined by terraces; active and rapid bank erosion into alluvium; little or no bank erosion into terraces
Floodplain	Fine to medium sand over gravel and few cobbles; floodplain broadens downstream as terrace width increases; many abandoned channels; many floodwater channels behind the left bank levee in the lower reach
Human Modifications	Left bank levee in lower reach; Hwy 7 bridge constriction defining the lowest extent of the reach.
Assessment	Primarily transport limited; high-flow corridor and valley widen from upstream to downstream; rapid migration/avulsion within high-flow corridor; potential for avulsion behind left bank levee in lower reach.
Other	

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Appendix C
Prescription for Delineation of CMZ Boundaries

APPENDIX C
PRESCRIPTION FOR DELINEATION OF CMZ BOUNDARIES

This appendix provides the prescription for delineating the CMZ boundaries.

STEP 1: Create a severe CMZ Base Width

The CMZ Base Width was created using variable-width buffers drawn from the HCOT. Buffer widths were generated independently on the right and left side of the HCOT based on the Maximum Measured Distance of Short-Term (between two consecutive photo sets) Erosion. The width of the buffer was based on the following observations:

Reach	Maximum Measured Distance of Short-Term[1] Erosion	
	Right bank	Left bank
7	944.0	729.0
6	643.0	428.0
5	NA[2]	NA[2]
4	920.0	926.0
3	663.0	360.0
2	358.0	547.0
1	340[3]	453.0

Notes:
All distances are in feet.
[1] Between two consecutive photo sets
[2] Banks did not erode appreciably over the period of record
[3] Maximum bank loss at Sunshine Point in 2007.

STEP 2: Buffers for relatively resistant glacial and lahar terraces.

Based on observations and documented soils/geology of terraces along the Nisqually River, a buffer was placed on the landward side that represented the maximum measured distance of Short-Term (between two consecutive photo sets) terrace recession observed within the photo record. The observations were grouped by reach and divided by the composition of the terrace. The widths of the buffers were based on the following observations:

Reach	Maximum Measured Distance of Short-Term[1] Erosion	
	Glacial Terraces	Lahar Terraces
7	NA[2]	359
6	164	350
5	NA[3]	NA[2]
4	450	NA[2]
3	NA[2]	362
2	NA[2]	358
1	NA[2]	NA[2]

Notes:
All distances are in feet.
[1] Between two consecutive photo sets
[2] No measurement of terrace recession observed, 50 feet was applied to the buffer
[3] Terrace did not erode appreciably over the period of record

STEP 3: Interim Severe and moderate CMZ base width;

The two buffers generated in Steps 1 and 2 were compared, and where the buffers overlapped, the landward of the two was omitted. The remaining buffer was used to create an interim severe CMZ boundary (i.e.: if the short-term CMZ base width buffer was wider than the lahar terrace buffer in one area, the lahar terrace buffer was used to delineate the Interim CMZ base width for that area). A buffer equal to 2-times the buffer applied to the interim severe CMZ boundary was created to make a moderate CMZ Base Width

STEP 4: Buffers for resistant bedrock, glacial terraces and colluvial slopes.

Given a catalog of resistant features along the Nisqually River, a 50-foot buffer was placed on the landward side of a given erosion-resistant feature.

STEP 5: Interim Severe and moderate CMZ boundary;

The buffer from Step 4 was then compared with the Interim CMZ base width from Step 3. Where the Interim CMZ base width fell on the landward side of the Step 4 buffer, the Interim CMZ base width was amended to the location of the Step 4 buffer (i.e. if the Step 4 buffer was narrower than the Interim CMZ base width in a given area, then the Interim CMZ base with was replaced by the Step 4 buffer in that area). This process was repeated for both the Severe and Moderate base widths. Note: the moderate and serve boundaries may be represented by the same line when resistant bedrock, glacial terraces or colluvial slopes are near the HCOT.

STEP 6: Accounting for potential avulsion routes.

Buffers for resistant bedrock, glacial terraces, and colluvial slopes were used in conjunction with the HCOT and hillshade models to determine topographic boundaries downstream of potential avulsion sites. Topographic boundaries could possibly confine over-bank sheet flow during a flood causing scour resulting in an avulsion. The area between the topographic boundary and the HCOT was added to the CMZ delineation (See the report section: Evaluating Potential Avulsion sites and estimating their route, to determine weather the potential avulsion routes were categorized as serve or moderate).

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Appendix D
GIS and Photo DVD Package

APPENDIX D
CD-ROM PACKAGE

GIS layers and documentation are provided on a CD-ROM package, which accompanies this report. The GIS layers include CMZ boundaries, migration potential areas, dated channel locations, historical channel occupation tracts (HCOT), and selected aerial photos for 1955, 1961, 1980, 1988, 1994, 2001, in GIS compatible format. The CD-ROM package was delivered to Pierce County Department of Public Works and Utilities, Water program Division.

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Appendix E
Report Limitations and Guidelines for Use

APPENDIX E
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

GEOTECHNICAL SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES, PERSONS AND PROJECTS

This report has been prepared for the exclusive use by Pierce County Public Works Department, and their authorized agents. This report may be made available to other members of the design team. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Because each geotechnical or geologic study is unique, each geotechnical engineering or geologic report is unique, prepared solely for the specific client and project site. Our report is prepared for the exclusive use of our Client. No other party may rely on the product of our services unless we agree in advance to such reliance in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. This report should not be applied for any purpose or project except the one originally contemplated.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT IS BASED ON A UNIQUE SET OF PROJECT-SPECIFIC FACTORS

This Channel Migration Zone (CMZ) Analysis for the Upper Nisqually River, Washington, has been prepared for the Pierce County Public Works Department. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structure;
- elevation, configuration, location, orientation or weight of the proposed structure;
- composition of the design team; or
- project ownership.

If important changes are made after the date of this report, GeoEngineers should be given the opportunity to review our interpretations and recommendations and provide written modifications or confirmation, as appropriate.

[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org .

SUBSURFACE CONDITIONS CAN CHANGE

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

MOST GEOTECHNICAL AND GEOLOGIC FINDINGS ARE PROFESSIONAL OPINIONS

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

GEOTECHNICAL ENGINEERING REPORT RECOMMENDATIONS ARE NOT FINAL

Do not over-rely on the preliminary construction recommendations included in this report. These recommendations are not final, because they were developed principally from GeoEngineers' professional judgment and opinion. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers cannot assume responsibility or liability for this report's recommendations if we do not perform construction observation.

Sufficient monitoring, testing and consultation by GeoEngineers should be provided during construction to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes should the conditions revealed during the work differ from those anticipated, and to evaluate whether or not earthwork activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT COULD BE SUBJECT TO MISINTERPRETATION

Misinterpretation of this report by other design team members can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also retain GeoEngineers to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

DO NOT REDRAW THE EXPLORATION LOGS

Geotechnical engineers and geologists prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering or geologic report should never be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, but recognize that separating logs from the report can elevate risk.

GIVE CONTRACTORS A COMPLETE REPORT AND GUIDANCE

Some owners and design professionals believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer. A pre-bid conference can also be valuable. Be sure contractors have sufficient time to perform additional study. Only then might an owner be in a position to give contractors the best information available, while requiring them to at least share the financial responsibilities stemming from unanticipated conditions. Further, a contingency for unanticipated conditions should be included in your project budget and schedule.

CONTRACTORS ARE RESPONSIBLE FOR SITE SAFETY ON THEIR OWN CONSTRUCTION PROJECTS

Our geotechnical recommendations are not intended to direct the contractor's procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and to adjacent properties.

READ THESE PROVISIONS CLOSELY

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these "Report Limitations and Guidelines for Use" apply to your project or site.

GEOTECHNICAL, GEOLOGIC AND ENVIRONMENTAL REPORTS SHOULD NOT BE INTERCHANGED

The equipment, techniques and personnel used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.

BIOLOGICAL POLLUTANTS

GeoEngineers' Scope of Work specifically excludes the investigation, detection, prevention or assessment of the presence of Biological Pollutants. Accordingly, this report does not include any interpretations, recommendations, findings, or conclusions regarding the detecting, assessing, preventing or abating of Biological Pollutants and no conclusions or inferences should be drawn regarding Biological Pollutants, as they may relate to this project. The term "Biological Pollutants" includes, but is not limited to, molds, fungi, spores, bacteria, and viruses, and/or any of their byproducts.

If Client desires these specialized services, they should be obtained from a consultant who offers services in this specialized field.

CHANNEL MIGRATION ZONE BOUNDARIES
UPPER NISQUALLY RIVER,
PIERCE COUNTY, WASHINGTON
PLATE 1

UPPER NISQUALLY RIVER
CHANNEL MIGRATION ZONE STUDY

Pierce County
Public Works and Utilities
Water Programs Division

COMPILED BY

GeoEngineers

Map Revised: June 8, 2007

Data Sources: Reach boundaries, channel and valley features created by GeoEngineers. Historical channel occupation tract (HCOT), approximate terrace locations, ancient abandoned channel tracts were digitized by GeoEngineers from rectified aerial photographs, maps, Lidar and ortho-based relative surface models. River stationing (every 1000 feet) was created by GeoEngineers from 2004 Puget Sound Lidar Consortium data and the channel position in 2002 orthophotographs. The background image is a 2006 USDA NIOP Orthophotograph and 10-meter hillshade from the USGS.

Notes: 1) The locations of all features shown are approximate.
2) All data is produced at a scale of 1:12K unless otherwise noted.
3) Map Projection: Lambert Conformal Conic, Washington State Plane South (feet), North American Datum 1983

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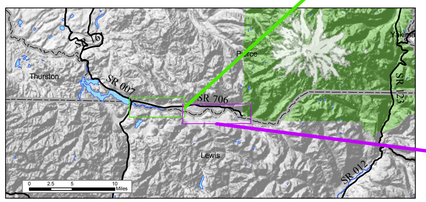
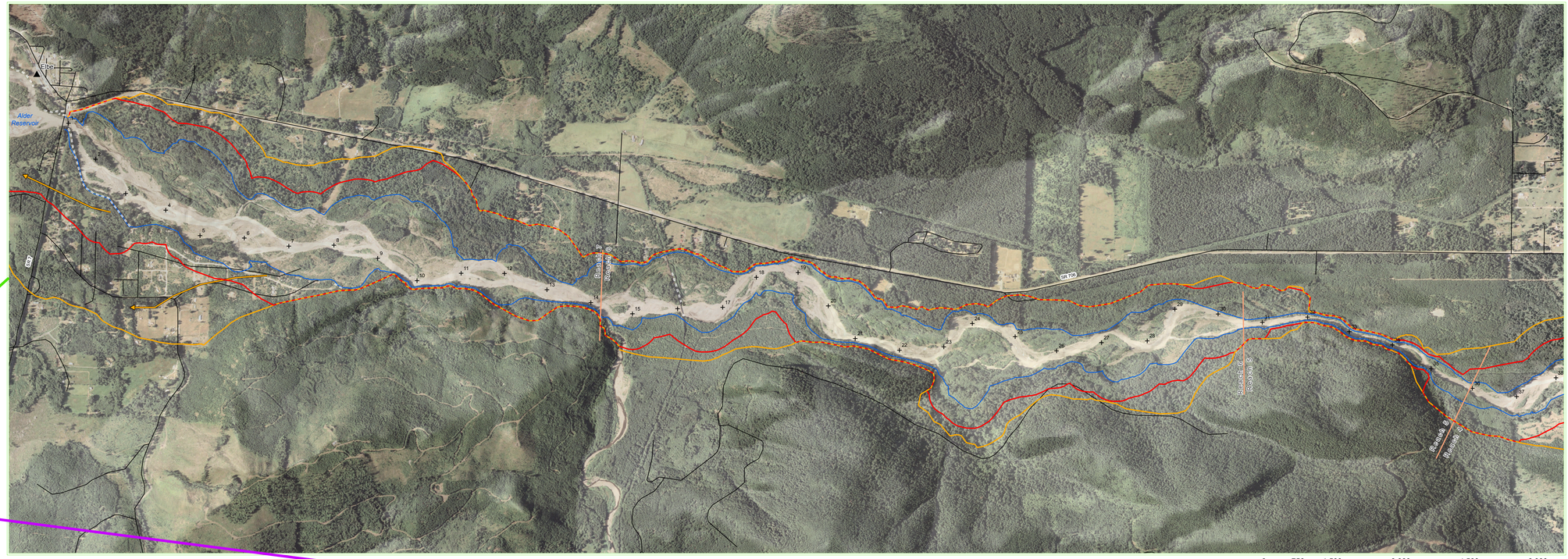
Note: This drawing is for informational purposes. It is intended to assist in showing features discussed in an attached document.

N

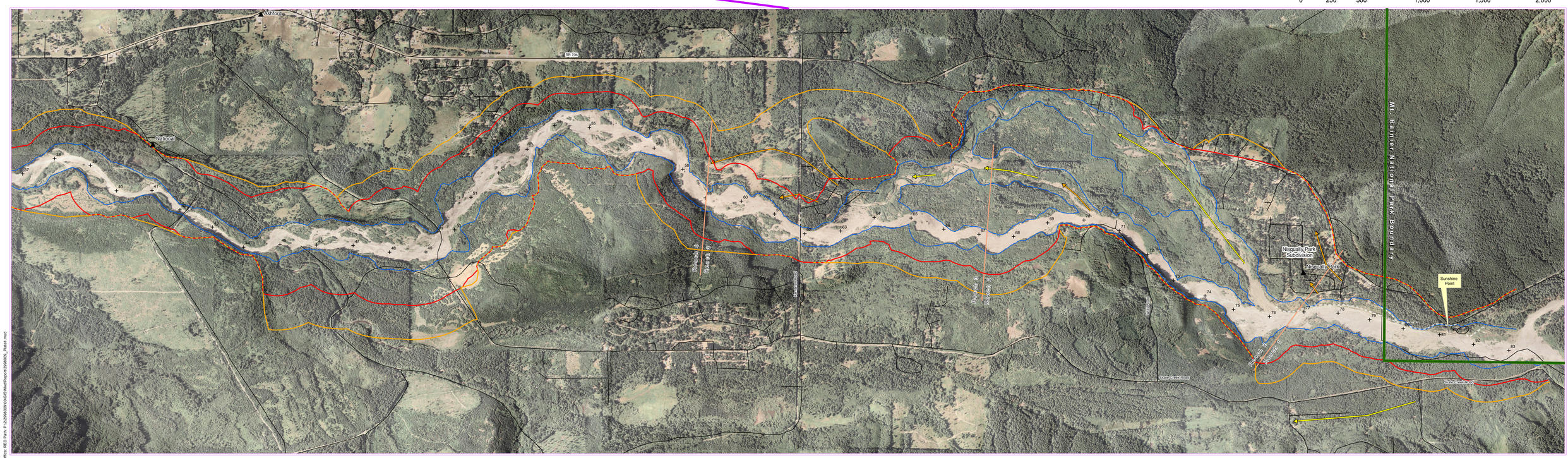
Explanation

- City
- Severe CMZ Boundary
- Moderate CMZ Boundary
- Joint CMZ Boundary
- Armored Levees and Revetments (2006)
- Reach Boundary
- Stationing (1000 ft)
- Potential Avulsion Route
- Historic Nisqually River Channel
- Historic Channel Occupation Tract (1955-2007)
- Roads
- Lakes
- County
- Mt. Rainier Glaciers
- Mt. Rainier NP





0 750 1,500 3,000 4,500 6,000 Feet
0 250 500 1,000 1,500 2,000 Meters



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