Channel Migration Zone Delineation
Upper White River

RM 44.5 to 51.5
Near Town of Greenwater
Pierce County, Washington

for

Pierce County Planning and Public Works
Surface Water Management

June 10. 2020

GeoEngineers
Earth Science + Technology

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File No. 0497-172-00

June 10, 2020

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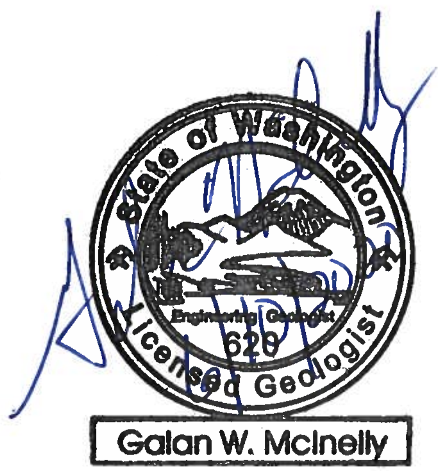

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GLOSSARY OF TERMS

Active channel	Unvegetated portion of a river, including gravel bars.
Aggradation	Accumulation of sediment in a river channel.
Alluvial fan	A fan-shaped (plan view) deposit of sediment that accumulates where a steep stream or river flows out onto a flatter valley floor.
Alluvium	Sediment deposited by a stream or river.
Andesite	A volcanic rock crystallized from molten magma that is extruded to the ground surface.
Angle of repose	The steepest angle at which a pile of loose material will stand without sliding. In this report it designates the angle at which an eroded bank will stand over the long term.
Anthropogenic	Originating from human activity.
Avulsion	Sudden relocation of a river channel to a new location, often occurring during flooding.
Avulsion hazard zone	Areas that may be subject to avulsion or sudden shifting of a river channel to a new location. These areas are added to the migration potential area for the river.
Bars	Accumulations of sediment within a river channel, usually composed of gravels, cobbles, sand and/or boulders.
Base flood elevation	The water surface elevation of a one-percent annual chance flood flow (a.k.a. 100-year flood) for a specified location on a stream or river.
Bed material	Sediment that comprises the bottom of a river channel; often consists of a combination of sand, gravel, cobbles and boulders.
Bedrock	Solid rock underlying loose deposits such as soil or alluvium.
Braided system	A braided channel is a multi-channel form in which channels are separated by bars or temporary islands called eyots. Braided channels tend to form in rivers that have an abundant bedload, variable discharge, and a steep profile with high stream power.
Channel	The pathway a river or stream follows.
Channel bank	The lateral margin of the active channel, extending from the channel elevation up to a higher elevation.

Channel centerline	The physical center of an active channel.
Channel gradient	A measure of the steepness of a river channel (amount of rise [elevation gain/loss] over the run [length]).
Channel migration	Movement of a river or stream channel over time; can be lateral and/or vertical movement.
Channel migration zone	The area that might be subject to erosion and river relocation over a given period of time if the river were to migrate in that direction.
Channel migration zone delineation	The delineation of the area in which a river or stream channel could migrate over a given time, based on historical migration rates associated with a given geologic unit or deposit.
Channel planform	The expression of the morphology of a river channel as observed in plan view.
Channel trace	The trace of the channel margins (based on aerial photographs) at a given point in time; generally includes the active channel.
Clast	A discrete constituent or fragment of rock or other geologic unit.
Cohesive	The sticking together of particles (as opposed to loose material).
Colluvium	Material that accumulates at the foot of a steep slope as a result of gravity, rain-splash or frost heave moving particles gradually downslope.
Confined	With respect to a river, this term indicates a restriction or impedance in the movement of the river channel, either laterally or vertically.
Confluence	The point at which two rivers or streams merge and flow as one water body.
Debris flow	A fluid mixture of water, rock, sand and gravel and other debris. Debris flows typically travel down established river valleys. Debris flows are generally more viscous (thicker) than water.
Disconnected migration area	A portion of the area of potential migration that is permanently separated from the river by a man-made structure.
Erosion	The process of movement of materials by wind, water or other natural agents. Rivers erode material from one source and move it downstream to another location.
Erosion hazard buffer	Migration rates multiplied by a specified number of years provide an erosion hazard buffer distance that is applied landward from the combined historical migration and avulsion hazard zones.

FEMA floodway	A regulatory floodway defined by FEMA that includes the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood (100-year return interval) without cumulatively increasing the water surface elevation more than a designated height.
Floodplain	An area of low-lying ground adjacent to a river, formed mainly of river sediments and is subject to flooding.
Floodway	The channel of the river or stream and the adjacent land that must remain free from obstruction so that the 100-year flood can be conveyed downstream.
Fluvial	Having to do with, or found in, a river.
Gabion basket	A wirework container filled with rock, broken concrete, or other material, used in the construction of dams, retaining walls, etc.
Geomorphology	The study of the physical features of the surface of the earth and their relation to its geological structures.
Geotechnical setback	A buffer added to the channel migration zone to account for freshly eroded banks to adjust to the natural angle of repose for a given geologic material.
GIS	Geographic Information System—a system for storing and manipulating geographical information electronically.
Glacier/alpine glacier	A slowly moving mass or river of ice formed by the accumulation and compaction of snow near the poles or on mountains (alpine).
Glide	A deeper part of a stream or river with smooth water, commonly considered to have a plane bed morphology.
Historical migration zone	The historical migration zone is the entire area that has been occupied by the active channel within the historical photo record.
Holocene	A geologic time unit relating to or denoting the present epoch (which began about 12,000 years ago), which is the second epoch in the Quaternary period and preceded by the Pleistocene epoch.
Hummocky	An extremely irregular surface with alternating small mounds and depressions.
Hydrology	The branch of science concerned with the properties of the earth's water, and especially its movement in relation to land.
Incision	Vertical migration of a river channel as it erodes and removes the underlying geologic material.
Intrusive bedrock	Bedrock derived from magma and crystallized beneath the surface of the earth.

Inundation	Flooding, or covering an area with water.
Lahar	An often destructive mudflow with varying amounts of debris originating on the slopes of a volcano.
Levee	An embankment built to prevent the overflow of a river.
LiDAR	Light Detection and Ranging—a remote sensing system that uses light from a laser to measure relative elevations of the ground surface and other objects.
Log jam	An accumulation of logs partially or fully blocking a river.
Log skidding	The practice of dragging logs across the ground to a central location where they can be loaded onto a truck or train.
Log-Pearson Type III	A method of calculating hydrologic discharge, as a method of determining flow return intervals.
Longitudinal profile	A graphical depiction of the elevation along the centerline of a river or stream.
Low flow channel	The area that is underwater when the river is flowing at or near its lowest (annual) level.
Mainstem	The active portion of a river channel that carries the greatest quantity of water.
Matrix	Fine material used to bind together the coarser particles of a composite substance or sedimentary material.
Meander	Following a winding course. Sometimes used to denote a single curve in a river channel (i.e., a meander bend).
Megaclast	Very large clasts of rock (boulders, etc.).
Migration	Movement of a river channel across the valley floor; can be lateral and/or vertical movement.
Migration potential area	The area that could be potentially occupied by a river based on a given migration rate and time period.
Migration rate	The migration rate, as used in a historical context for this report, is the averaged rate of migration of a river within a given geologic material calculated from historical data.
Miocene	A geologic time unit that represents the fourth epoch of the Tertiary period, between the Oligocene and Pliocene epochs (approximately 23 to 5.3 million years ago).

Moraine	A mass of rocks and sediment deposited by a glacier, typically as ridges at its edges or extremity.
Mudflow	A relatively fluid stream or avalanche of mud.
Neck cut-off	An avulsion event where two ends of a full meander migrate towards each other such that the river erodes all material between them, effectively generating a new path for river channel that bypasses and abandons the meander.
Oligocene	A geologic time unit that represents, the third epoch of the Tertiary period, between the Eocene and Miocene epochs (about 34 million to 23 million years ago).
Pistol butt tree	An evergreen tree that has developed a curved trunk because of soil creep or landslide activity. Evergreens have a vertical-growth habit resulting in straight trunks unless outside forces alter the growth pattern.
Pleistocene	The first epoch of the Quaternary period, between the Pliocene and Holocene epochs, typically defined as the time period that began about 2.6 million years ago and lasted until about 11,700 years ago.
Polygon method	A method of calculating average erosion rates for a given river reach that is based on the change in area for the historic migration zone between historical aerial photos.
Potential avulsion pathway	Typically a linear feature that could capture the main flow of the channel causing an avulsion. These features generally include old, abandoned river channels or areas of low topography where erosion could create a new channel during flooding.
Quaternary	A geologic time unit that represents the most recent period in the Cenozoic era, following the Tertiary period and comprising the Pleistocene and Holocene epochs (approximately the last 2.6 million years).
Reach	A segment of river channel that has similar geomorphic expression and processes.
Recurrence interval	The statistical probability of a given flow occurring (i.e. the flow has the probability of occurring once in 100 years).
Relative water surface elevation	A GIS-derived depiction of topographic elevations relative to a water surface elevation such as the 2-year recurrence interval flow. It is commonly produced relative to the water surface elevation depicted in a LiDAR dataset.
Relict channel	An older channel path that is no longer occupied by the river or stream.

Revetment	A barricade of earth, rock or other material to provide erosion protection to a segment of riverbank.
Riffle	A rocky or shallow part of a stream or river with rough water, visible as a patch of waves or ripples.
Riparian	Relating to or situated on the banks of a river.
Riparian buffer	A riparian buffer is a vegetated area (a “buffer strip”) near a stream, usually forested, which helps shade and partially protect the stream from the impact of adjacent land uses.
River corridor	The area that the stream or river needs to maintain physical / geomorphic equilibrium.
River mile	The calculated mile markers along a river channel, starting at the mouth of the river.
Rock vane	Vanes are discontinuous, transverse rock structures angled into the river flow in an effort to reduce local bank erosion by redirecting flow from the near bank to the center of the channel.
Sediment transport	Movement of sediment by a river in the downstream direction.
Side channel	Small secondary channels on the floodplain that are generally connected to the main channel at both up and downstream ends.
Single-thread	A channel form that is composed of a single channel, without side channels or significant gravel bars.
Sinuosity	The degree to which a river meanders back and forth across its floodplain, in an S-shaped pattern, over time. As the stream moves across the landscape, it may leave behind evidence of where the river channel once was (these can take the form of meander scars or oxbow lakes).
Slope ratio	The ratio of vertical change divided by horizontal change for a given length of slope.
Stream profile	Graphical depiction of the elevation change along a river or stream.
Sugar dike	A dike (levee) made by pushing floodplain sediment into a long mound in an attempt to keep floodwater within a channel.
Terrace	An elevated surface once occupied by a river and its floodplain or created by other processes such as mudflows or lahars. Terraces are located at elevations above the 100-year floodplain elevation.
Thalweg	A line connecting the deepest points in a river or stream.

Topography	A detailed description or representation on a map of the natural and artificial features of an area.
Transect	A line representing the elevation changes along the ground surface, usually drawn perpendicular to the thalweg.
Transect method	A method of calculating migration rates derived from changes in the river centerline location.
Transport reach	A reach of a river or stream that displays no net change in sediment storage (i.e. all sediment that enters the reach is transport through that reach).
Tributary	A river or stream flowing into a larger river or lake.
Tuff/tuff breccia	A light, porous rock formed by consolidation of volcanic ash and/or clasts of ash and rock.
Unconsolidated	A descriptive term for a geologic formation that is generally loose (i.e. not cohesive or rock-like).
Valley width	The width of a valley between the toes of slopes on either side.
Volcanic rocks	Rocks formed from cooling lava at or on the surface of the earth.
Watershed	The area drained by a given stream or river.

EXECUTIVE SUMMARY

Pierce County Planning and Public Works, Surface Water Management Division (County) contracted GeoEngineers to conduct a Channel Migration Zone (CMZ) analysis for the Upper White River located in southeast Pierce County. It is the last in a series of CMZ studies to be completed for major streams within the county. The County intends to use the CMZ study as a decision-making tool for floodplain regulation under Pierce County Code (PCC) 18E.70.020. The study will aid in future potential revision of critical area and floodplain ordinances to help guide development out of high-risk areas, enhance fish habitat and ecological function by precluding development of the floodplain adjacent to the channel, and help minimize net loss of ecological functions pursuant to PCC 18E.70.010(F).

The Upper White River CMZ study area extends from just downstream of the confluence with the Greenwater River (river mile 44.5) upstream to near the Mount Baker Snoqualmie National Forest (river mile 51.5). The study reach contains three residential areas including the Crystal River Ranch and Crystal Village communities and areas within the town of Greenwater.

The Upper White River is a gently sloping, braided river system, with the exception of the lower reaches (approximate river miles 44.5 to 48.9), where the channel is somewhat straight and more closely resembles a single-thread channel with mid-channel and lateral gravel bars. The braided portion of the system is characterized by one or more low-flow channels separated by prominent gravel bars.

Within the historical photo record (1944 to 2017), the river has migrated back and forth across the valley floor. The total extent of this observed meandering is defined as the historical migration zone. The channel is bordered by river terraces and lahar (mudflow) deposits from Mount Rainier. The most recent lahar occurred about 5,000 years ago; the river has since cut into the lahar and subsequently widened its channel. Both the historical migration zone corridor and the low-flow channels are subject to unpredictable changes in geometry and channel location, typically driven by major storm/flood events with high volumes of sediment input from Mount Rainier. The process of avulsion (rapid change in channel location) usually occurs within the active channel, along back bar channels after relatively recent channel migration and near bar building. Because of the dynamic nature of the river, it is assumed that during any given flood event, the necessary circumstances exist such that an avulsion outside of the historical migration zone could occur in certain locations.

The methods used to delineate the upper White River CMZ are a combination of Washington State Department of Ecology methodology, based on Rapp and Abbe (2003), and professional judgment. Reach-scale CMZ delineation requires division of the river into reaches (segments), based on similar geomorphic characteristics and processes. Past erosion extents were measured based on the available 73-year period of aerial photos and reach-averaged rates of migration were calculated. The annualized average migration rates for each reach, multiplied by a specified risk period, provide an erosion hazard buffer distance that is applied landward from the historical migration zone plus any potential avulsion hazards. The migration or erosion risk is shown in three migration potential areas: severe (10-year period), moderate (20-year period), and low (50-year period). The migration potential area also includes a geotechnical setback to account for a freshly eroded bank's adjustment to the bank material's natural angle of repose.

The principal findings of the study are shown in Plates 1, 2 and 3, including the historical migration zone; potential avulsion routes; and severe, moderate and low migration potential areas. The severe migration

potential area extends into residential and vacation properties located along the riverbanks. Many more private properties fall in the moderate and low migration potential areas. The County regulates the severe migration zone areas as a floodway, in order to protect public safety and limit the potential for future property damage. Areas within the moderate and low migration potential areas are not regulated.

This Executive Summary should be used only in the context of the full report for which it is intended.

1.0 INTRODUCTION

The purpose of this report is to provide a channel migration zone (CMZ) delineation of approximately 7 miles of the upper White River (Figure 1) for adoption into the Pierce County Code (PCC) and regulation as a floodway under PCC 18E.70.020. This report summarizes the methods, data, analysis and limitations used to delineate the CMZ on the upper White River. The White River originates from the slopes of Mt. Rainier in the southeast corner of Pierce County (county), as shown on Figure 2.

1.1. Project Goals and Objectives

The project goal is to complete a reach-scale CMZ delineation and identify severe, moderate and low migration potential areas along the upper White River to provide Pierce County with technical information to regulate zoning and development.

The project evaluated the upper White River from river mile (RM) 44.5 to 51.5 (Figure 2). Residential areas within the project include the Crystal River Ranch and Crystal Village communities and areas within the town of Greenwater (Figure 1). Specific objectives are to:

1. Estimate migration rates
2. Identify potential avulsion pathways
3. Estimate the extent of severe, moderate and low channel migration potential
4. Identify geotechnical setbacks

The main purpose of this study is to delineate the migration zone and migration potential areas for regulation of development of the floodplain. In addition, the CMZ will enhance fish habitat and ecological function simply by precluding development of the floodplain adjacent to the channel, consistent with the purpose of floodplain and floodway analysis, pursuant to: PCC 18E.70.010(F) Minimize damage to critical fish and wildlife habitat areas; and (G) Minimize net loss of ecological functions of floodplains. The study could potentially be used in planning by others for river and floodplain restoration.

1.2. Regulatory Framework

Development near shorelines of the state are governed by the Washington Administrative Code (WAC). Specifically, Flood Hazard Reduction and the Shoreline Master Program pertain to development in or around waterbodies. WAC 173-26-241(3)(j)(iii) states: Residential development, including appurtenant structures and uses, should be sufficiently set back from steep slopes and shorelines vulnerable to erosion so that structural improvements, including bluff walls and other stabilization structures, are not required to protect such structures and uses (see Revised Code of Washington [RCW] 90.58.100(6)).

Under PCC 18E.70.020.A.1.f. and 18E.70.020.B.4, adopted CMZs identified at severe risk of migration are regulated as floodways. The White River is identified in section 18E.70.020.B.4.a.(4) as one of the regulated water courses in the county that requires a geomorphic and CMZ study to be completed for regulation. CMZs are also defined as riverine erosion hazard areas, as stated in PCC 18E.110.020.B.1.b. and B.4.

1.3. Project Scope

The following scope of services was completed to meet the project goals and objectives:

Desktop Study. The desktop study included review of available information about the physical attributes of the project area. Available digital data from the county and other sources was compiled into a geographic information system (GIS) database and reviewed for a preliminary geomorphic reach characterization that was used as a guide in the field investigation.

Fieldwork. GeoEngineers, Inc. (GeoEngineers) conducted a field reconnaissance covering the study reach over the course of three days in July 2019. Selected areas upstream were also viewed to assess the stream variability and contributing factors to the reach processes that may affect the understanding of channel migration in the study area. Geomorphic data and photographs were recorded on GIS-enabled hardware and notebooks.

Data Analysis and Delineation. Data collected from the desktop study and fieldwork were used to complete the CMZ delineation, erosion hazard analysis, and migration potential areas identification. Methods used to complete these analyses are described in detail below in the Section 3.0.

Deliverables. This report is the primary deliverable for this project, along with electronic geodatabase files of the CMZ and related elements. GIS data files will be transmitted to the county for incorporation into their database after the project is final.

2.0 PHYSICAL SETTING

2.1. Topography, Geology and Geomorphic Setting

The White River is approximately 76 miles long, stretching from the slopes of Mt. Rainier down to the confluence with the Puyallup River near Puget Sound. The White River is fed by the Emmons and Inter glaciers on the northeast side of Mt. Rainier (up to approximately 14,400 feet elevation). From these glaciers, the river generally flows east-northeast off the steep mountain front, before turning north and then back to the west toward Puget Sound. The river discharges into the Puyallup River in the town of Sumner at an elevation of approximately 50 feet.

Several larger tributaries upstream of the project boundary include Silver, Goat and Huckleberry creeks (Figure 2). The West Fork White River joins the White River near RM 48 within the project area. Downstream of the confluence of the West Fork White River, the valley widens where the Greenwater River valley merges with the White River valley. The downstream project boundary is marked by the confluence of the Greenwater River where it joins the White River near RM 44.5 (Figure 2).

Prior to human development, the upper White River in the study area appeared to be a combination of single-thread meandering and a braided planform along the 7-mile stretch of the study area. Large timber lined the river corridor. The lower reaches of the study area were logged extensively by the 1960s. Currently, the planform pattern in the upper project area is mainly braided, while the lower project area is more similar to a single-thread channel with several mid-channel and lateral bars.

Geology plays a major role in shaping any river system. The underlying geology in the White River watershed is a mix of volcanic and intrusive bedrock overlain by Holocene-age (0 to 12,000 years before present [BP]) volcanic tephras and lahar deposits associated with periods of volcanism that alternatively built and obliterated portions of Mt. Rainier. Regional geology mapped by Washington State Department of Natural Resources (DNR) was accessed via the Washington Geologic Web Portal in September 2019 (Figure 3).

The 1:100,000 scale at which the DNR geologic boundaries were generated is not appropriate for use in the CMZ delineation, but this mapping provides the context for the underlying geology and geomorphic history.

The White River within the project area lies in a wide bedrock valley that was influenced by Pleistocene-age (12,000 years BP to 1.8 million years ago [Ma]) alpine glaciation and glacial meltwater processes. The latest advance of alpine glaciers of Evans Creek age (15 to 25 years BP) flowed down the sides of Mt. Rainier to within several kilometers of the West Fork White and White River confluence (Crandell and Miller 1974, cited in Vallance and Scott 1997). Bedrock that forms the ridges and valley walls along the upper White River consists of Miocene-age (5.33 Ma to 23.03 Ma tuffs and tuff breccias of the Fifes Peak Formation (Mvt_{fps}), Oligocene-age (23.03 Ma to 33.9 Ma) volcanic rocks of the Ohanapecosh Formation (Ovc_{oh}), and Miocene- and Oligocene-age intrusive andesite (MO_{ian}). Ohanapecosh and Fifes Peak formations are exposed along both east and west valley walls. Andesite is mapped mainly as intruding the Ohanapecosh in various locations. Bedrock is highly resistant to erosion.

The valley was inundated during the Holocene by the Osceola Mudflow, a massive lahar that originated on the northeast flank of Mt. Rainier about 5,600 years ago. The lahar filled the West Fork White River and the White River valleys to as much as 330 feet thick in places along the White River valley before eventually reaching Puget Sound. Cohesive Osceola Mudflow deposits consist of an unsorted mixture of sub-angular to sub-rounded volcanic rock fragments in a consolidated matrix of sand, silt, and clay. In the vicinity of the Greenwater River–White River confluence, the mudflow has a hummocky facies (a distinct unit of the lahar) characterized by megaclasts (house-sized blocks) of andesite up to 65 feet high by 200 feet wide protruding from a cohesive, unsorted matrix (Vallance and Scott 1997). In the study reach there are exposures of lahar up to 40 feet above the current riverbed. The lahar left behind deposits up to approximately 80 feet thick in other places (Vallance and Scott 1997). The cohesion and clay content of the Osceola Mudflow provide considerable resistance to erosion for this unit.

The White River has since incised into the Osceola Mudflow and widened to form floodplains at the current bed elevation and previous bed elevations observed as terraces. The post-Osceola floodplains are defined by the extent of mapped alluvium (Q_{al}). Alluvium consists of sand- to boulder-sized sediment transported and deposited relatively recently by stream flow. These deposits include both active and former riverbeds and gravel bar deposits. Alluvium is relatively loose and unconsolidated and, therefore, highly susceptible to erosion.

Colluvium is locally mapped along the valley margins (material deposited at the bottoms of slopes, generally through sheetwash, rainwash and/or soil creep from upgradient slopes). Colluvium is also relatively loose and unconsolidated and, therefore, considered highly susceptible to erosion.

Several massive landslides are mapped within or near the project area (Q_{ls}). In addition, several alluvial fans are present within the project bounds. Because both landslide material and alluvial fan material typically are unconsolidated, they are considered susceptible to erosion.

An additional geologic unit was identified in the field along the right bank near RM 50. This unit consists of large, clast-supported, sub-angular to sub-rounded boulders, approximately 1 to 4 feet in diameter, and fewer cobbles within a matrix of sand and gravel (Photos 17 and 18, Appendix A). This unit is interpreted to be a separate debris flow or lahar of unknown origin. Zehfuss, et al. (2003) describe post Osceola lahars upstream of Enumclaw as being deposited in the debris flow phase and those found at river level as being “clast-supported, extremely poorly sorted, consisting of boulders (up to 2 meters [m] in diameter) and cobbles in a matrix of pebbles and sand.” Because of the size of the material in this unit, it is highly resistant to erosion.

2.2. Historical Development

Current land use in the watershed includes forest management and recreational use of the dominantly forested terrain with minor rural residential development in the middle and lower portions of the project area. Residential development includes the Crystal River Ranch and Crystal Village communities near RM 49.5 and the town of Greenwater near RM 44.8. The only major road near the project area is State Route (SR) 410, but private roads and logging roads (working or abandoned) are present throughout the area.

The upper watershed (upstream of the project) is protected by the National Park Service (NPS) (Figure 2), although minor commercial logging occurred in the early part of the century prior to regulations restricting the practice within the Mt. Rainier National Park (NPS webpage accessed September 2019). Currently the park is used mainly for recreation.

Downstream of the park boundary, forest practices associated with commercial timber harvest began in the 1940s and became significant in the 1960s (Puyallup River Watershed Council 2014). These practices included road building, clear cut logging and log skidding. Historical aerial photos show most of the project area had been clear cut by the 1960s, commonly up to the edge of the river channel. Root reinforcement from vegetation is a primary stabilizing mechanism along riverbanks (Abernathy and Rutherford 2001 and Simon and Collison 2002, as referenced in Washington State Department of Transportation [WSDOT] 2007). Large swaths of land that were once protected by forest were exposed and more vulnerable to the river’s erosive action.

As logging practices evolve, including improvements to road building, maintenance and retaining riparian buffers, watershed impacts from logging are expected to decrease. Commercial timberland near the study area, currently owned by the Muckleshoot Indian Tribe, was previously owned by Hancock Timber. Hancock continues to manage the timberlands on behalf of the Muckleshoot Indian Tribe.

Channel and floodplain modifications to the upper White River associated with development have been relatively minor. Modifications include construction of several levees, bridges, gabion baskets and rock vanes.

2.3. Hydrology and Climate

The climate in the upper White River basin is characterized by cool, wet winters with heavy snowfall and short, mild summers. Annual precipitation varies from approximately 130 inches near Mt. Rainier to approximately 60 inches near the town of Greenwater, the majority of which falls as snow (Ketcheson, et al. 2003). Precipitation is heaviest from November through February and snow accumulations in the winter months can be significant at higher elevations.

The upper White and the West Fork White rivers flow year-round and are glacier-fed, resulting in sustained summer flows. Silver, Goat and Huckleberry creeks are fed by groundwater and snow melt, and so contribute little summer flow. However, the tributary creeks are subject to rain-on-snow events that can produce heavy runoff and flooding during winter months.

The U.S. Geological Survey (USGS) maintained a stream gauge on the upper Whiter River at Greenwater River (No. 12097000) between 1929 and 1977, for a total of 48 years of record. Currently, the USGS maintains a gauge on the White River near Buckley (1974 to present, No. 12097850). Scaling the flows recorded at Buckley to the upper White River basin by square mile produced flows that were on average 12 percent larger for peak discharge return intervals (RIs) of 2 years or greater than those recorded by the gauge at Greenwater. Therefore, only the flows from the gauge at Greenwater were used in our peak flow analysis. Peak flow data from the stream gauge were evaluated using a Log-Pearson Type III regression curve to estimate the discharge of the 1-year, 2-year, 10-year, 25-year, 50-year, 100-year and 500-year return intervals. The estimated flows are presented in Table 1. Average monthly flows are highest from May to July, but the highest flows typically are November through January (Ketcheson et al. 2003).

TABLE 1. DISCHARGE FOR RETURN INTERVALS, BASED ON USGS GAUGE NO. 12097000 ON THE WHITE RIVER AT GREENWATER

Recurrence Interval (years)	Mean Discharge (cubic feet per second)
1	1,555
2	4,736
10	10,267
25	14,047
50	17,354
100	21,116
500	31,972

The flood of record occurred in December 1933 and reached 18,100 cubic feet per second (cfs). The second highest flood of record was in December 1977 at 17,800 cfs. The 1978 aerial photograph shows a wide swath of channel that was activated during the 1977 flows. A large portion of the river corridor had been clear cut by 1962, leaving little vegetation for bank stabilization along the corridor. Other significant flooding events recorded at the gauge at Greenwater were in 1959, 1965 and 1975; large flows at the Buckley gauge that may suggest higher flows in the upper White River occurred in 1975, 1990, 1995, 2008, 2011, 2012 and 2015 (USGS gauge data).

3.0 METHODS

The methods used to delineate the upper White River CMZ are a combination of Ecology methodology based on Rapp and Abbe (2003) and professional judgment followed by quality assurance review by senior and principal scientists. Migration potential areas were calculated based on the channel migration analysis results and county requirements. A detailed description of the methods used is presented below.

3.1. Data Sources and Derivative Analysis Tools

Data sources obtained for the CMZ delineation are listed in Table 2. Historical aerial photographs were used to identify channel extents of various years from 1944 to 2017. Historical USGS topographic maps were used to corroborate mapping of past river locations interpreted from aerial photographs and Light

Detection and Ranging (LiDAR) imagery (refer to Table 2). The LiDAR elevation data were used to develop a stream profile of 7 miles of river to identify channel gradient, changes in the longitudinal profile, and depositional areas. A relative water surface elevation map was developed from the LiDAR elevation data to identify important features in the channel, banks and floodplain, including avulsion hazard areas, topographic low areas, alluvial fans and relict channel traces.

TABLE 2. DATA SOURCES USED IN CMZ ANALYSIS

Data Type	Source	Date
Historical and Recent Topographic Maps	USGS	1913, 1956, USGS Topo Maps (map service through ESRI)
Geologic maps	DNR and USGS publications	Website accessed June 2019; published maps and articles 2000
LiDAR elevation data	Pierce County	2010
Aerial Photographs	Pierce County	2002, 2011, 2017
Aerial Photographs	Washington State Department of Natural Resources, 1970 photos courtesy of the Muckleshoot Indian Tribe	1970, 1978, 1985
Aerial Photographs	USFS via University of Washington Library	1962
Aerial Photographs	USACE	1944
Aerial Photographs	USGS	1954, 1993
Stream gauge records, No. 12097000	USGS	1929 through 1977
Flood Insurance Rate Maps (FIRMs)	Federal Emergency Management Agency	Maps published March 7, 2017 are based on the Flood Insurance Study adopted in 1987

3.2. CMZ Delineation

A reach-scale CMZ delineation requires division of the river into reaches (segments), based on similar geomorphic characteristics and processes. Migration rates are generated separately for each reach. Delineation of the historical migration zone (Rapp and Abbe 2003) is the first step in the methodology for delineating a CMZ within each reach. Avulsion hazard zones are then identified and combined with the historical migration zone to define an area that comprises the base onto which additional erosion hazards are added. Past erosion extents are measured and reach averaged rates of migration are calculated based on the historical aerial photo record. Migration rates multiplied by a specified number of years provide an erosion hazard buffer distance that is applied landward from the combined historical migration and avulsion hazard zones. The erosional hazard buffers are defined as severe, moderate and low migration potential areas. Topographic low areas with potential for significant inundation are identified and reviewed for potential inclusion into the migration potential area. Finally, a geotechnical setback is calculated and added to all migration potential areas where applicable. All components together represent the final CMZ boundary. Descriptions of the CMZ components are described below and depicted in Illustrations 1 and 2.

3.2.1. Historical Migration Zone

The historical migration zone is the area that has been occupied by the active channel at any time within the historical photo record (1944 to 2017). The active channel is defined by the low-flow channel and any unvegetated bars (O'Conner, et al. 2003). Active channel traces for each photo year were developed in the desktop study. The combination of all active channel traces forms an outline that constitutes the historical migration zone.

3.2.2. Avulsion Hazards and Topographic Low Areas

An avulsion hazard is an easy pathway for water to travel, which could capture the majority of the flow and eventually create a new channel at a specific location. These areas are identified based on review of topography in conjunction with Federal Emergency Management Agency (FEMA) base-flood — 100-year recurrence interval (RI) flow — elevations where available. A Relative Water Surface Elevation map was generated by calculating the difference between the 100-year RI flood elevations and LiDAR elevation data. From this, historical channels representing avulsion pathways that were inundated during the 100-year RI flood were identified. Base flood elevations only were available up to RM 48.5. Elevations for the 100-year flood upstream of this location were estimated based on the base flood water surface elevation slope and average differences between the water surface and LiDAR topography.

Avulsion pathways were characterized as avulsion hazard zones if they were (1) inundated during the 100-year RI, and (2) if they had an identifiable channel that leads back to the mainstem river. The area from the historical migration zone to the outside edge of the potential avulsion pathway represents avulsion hazard zones which, when combined with the historical migration zone, form the base from which migration potential area buffers are applied.

Topographic low areas identified in the Relative Water Surface Elevation map include areas that may be inundated on the floodplain when banks are overtopped. These areas can precipitate channel migration by avulsion if water is channelized at the downstream end where it returns to the channel. Alternatively, these locations represent areas that may be capable of capturing stream flow as a result of low topography and are considered at risk of experiencing channel migration within the timeframe of the CMZ delineation; even if not originally within the CMZ boundary. These locations were reviewed for potential inclusion in the migration potential areas.

3.2.3. Migration Rates

Migration rates were determined generally following the transect method of Rapp and Abbe (2003). This method was used versus the polygon method (Rapp and Abbe 2003) in order to differentiate rates of erosion between the different geologic units (i.e., alluvium and Osceola Mudflow). The polygon method generates rates over the reach without regard for erosion rates of different geologic units. Transects were generated at one approximately every 250 feet along the project length. The moderately frequent spacing is intended to capture a greater sample of, and therefore a better representation of, erosion rates than a lesser spacing would provide.

Different approaches were used to measure migration in the different geologic units for reasons discussed in Section 4.2.3. Migration rates in alluvium were measured at each transect based on the distance between active channel centerlines in successive order of periods of record, regardless of direction. Erosion rates into the Osceola Mudflow were measured based on the distance between the positions of the base of the slope of the Osceola Mudflow in successive order of periods of record in a single direction. Rates were measured at transects where the active channel was in contact with the Osceola Mudflow within the aerial photographic record, and where bank retreat is observable.

Channel centerlines were generated from the active channel margins, excluding side channels where vegetation between the side channel and mainstem had grown significantly. Base of slope for the Osceola was generated for each photo record based on aerial photo interpretation.

Ecology (Legg et al. 2014) developed a GIS tool for measuring channel migration rates based on the transect method. This tool was utilized to generate transects and measure migration rates in alluvium. Channel migration rates within the Osceola Mudflow were measured along transects manually using GIS and the line snapping tools as it was more precise than using the centerline tool for the fewer transects where the Osceola Mudflow is eroding.

The regional geologic mapping completed by the DNR was too coarse to use for the purpose of measuring migration rates. In order to determine and apply rates for different units, the geology had to be interpreted at the boundary of the 1944 active channel, as well as at the boundary of the current historical migration zone for the purpose of applying migration rates. Geology was interpreted to represent the geologic unit at the current channel elevation. Field observations were the primary source that guided interpretation of geologic units. Where field conditions made it difficult to evaluate geologic units, analysis of DNR geology, LiDAR imagery, and aerial photographs were used as guides. Continuity of terraces within, and geomorphic interpretation of, LiDAR were examined relative to DNR geology in order to estimate geologic unit boundaries. Osceola Mudflow, alluvium, alluvial fans and colluvium were inferred and estimated out to approximately 500 feet away from the historical migration zone.

3.2.4. Migration Potential Areas

Migration potential areas are the individual zones that together comprise the full CMZ. The migration potential areas are comprised of buffer widths that are applied laterally to the combined historical migration and avulsion hazard zones (Illustration 1) and are designated as severe, moderate and low.

The historical migration zone comprises easily erodible Quaternary-age alluvial materials, and therefore, the river could reoccupy any given area within the historical migration zone at any given time. Similarly, the avulsion hazard zone is considered to be easily accessed by the river during flood events. Therefore, these areas are included in the severe migration potential area (Illustration 1). The area beyond this boundary is added as a buffer representing the migration potential areas based on past erosion rates (see the Severe Migration Potential Area Buffer based on Erosion Rates in Illustration 1). Migration potential area buffers begin at the outside of the combined historical migration and avulsion hazard zones boundary and represent the area where future erosion could take place into previously unoccupied areas based on the available historical record and calculated erosion rates. The width of the severe migration potential area was delineated based on the distance the channel edge could travel in 10 years of steady lateral migration applied to the historical migration and avulsion hazard zones boundary. The width of the moderate migration potential area was delineated based on the distance the channel could travel in 20 years of steady lateral migration from the combined historical migration and avulsion hazard zones boundary. The width of the low migration potential area was determined based on the distance the channel could travel in 50 years of steady lateral migration from the combined historical migration and avulsion hazard zones boundary. Migration potential areas were modified and widened where topographically low areas were identified or where a geotechnical setback is required (Illustration 1).

To generate the migration potential area where erosion would potentially cross a geologic unit boundary, the width and rate of erosion for the first unit was used to back-calculate the number of years over which that erosion would occur in the first unit. The remaining number of years multiplied by the rate of erosion in the second unit determined the remaining width to apply the migration potential area landward from the unit boundary.

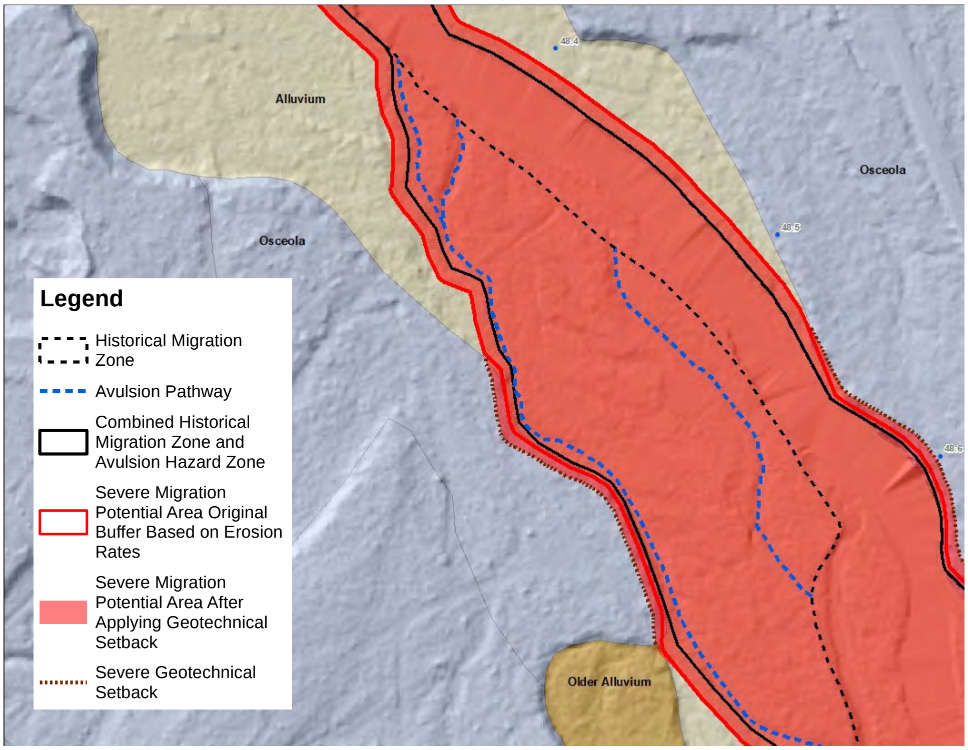

Illustration 1. Schematic showing the different boundaries associated with the generation of the severe migration potential area. The same concepts apply to the moderate and low migration potential areas.

3.2.5. Geotechnical Setback

The geotechnical setback accounts for mass wasting of a slope that either is currently being, or previously has been, eroded by the stream as it adjusts toward its preferred angle of repose. LiDAR data, aerial photographs and field observations provided the information needed to determine the angle of repose and estimated geotechnical setback. The geotechnical setback was determined by assuming a vertical slope at the migration potential area boundary and projecting the preferred angle of repose landward from the base of the vertical slope at the elevation of the stream bed.

Slope angles were obtained from within the GIS at transects (the same used for migration measurements) that intersect the Osceola Mudflow units where slopes are established; that is, at slopes that are not actively eroding and appear to have been stable for some time. Median slope values were calculated within each reach and converted to slope ratios. Elevations on the surface of the Osceola Mudflow units were obtained at approximately 10 to 30 feet landward from the top of the slopes along each transect and height differences between thalweg and Osceola Mudflow elevations were calculated. The slope ratio then was applied from the migration potential area boundary at the elevation of the thalweg landward according to the height difference. The geotechnical setback was visually interpolated between the transects. Modifications and corrections were made as necessary, with subsequent spot checking of elevations and distances.

3.2.6. Channel Migration Zone

The final CMZ is represented by the sum of the historical migration zone, the avulsion hazard zone, the migration potential areas and any geotechnical setbacks (Illustration 2).

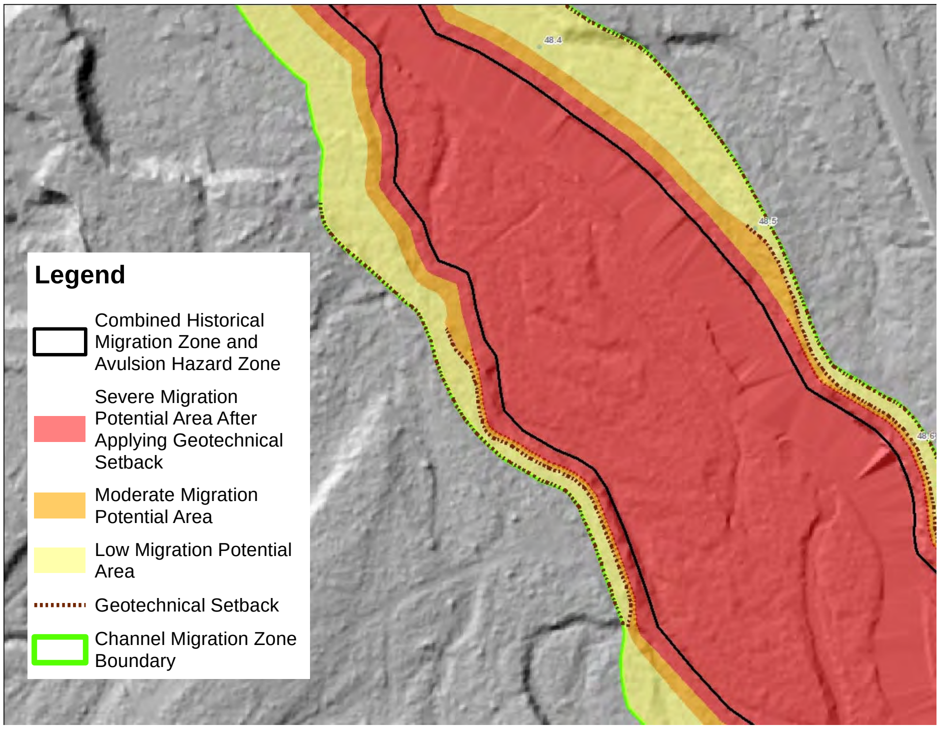

Illustration 2. Schematic showing the separate components of the Channel Migration Zone. The separate migration potential areas are at the specified distances landward of the combined historical migration and avulsion hazard zone with geotechnical setbacks where applicable.

4.0 CMZ ANALYSIS AND RESULTS

This section presents the results of the desktop evaluation, field observations and CMZ delineation.

4.1. Desktop Evaluation and Field Reconnaissance Findings

The desktop study and field observations inform the CMZ delineation. The desktop study helped focus the field reconnaissance, which took place over three days in mid July 2019 by two fluvial geomorphologists. Access to the river was continuous from RM 49 to 50.5, but sporadic throughout the rest of the project area. The purpose of the field reconnaissance was to confirm or differentiate observations from the desktop study. Two of the major goals of the desktop evaluation and field reconnaissance were to:

1. Identify reaches, and
2. Identify the interface of the alluvium and Osceola Mudflow or alluvium and other adjacent geologic units.

4.1.1. Reaches

The project area was segmented into six different reaches (Figure 4, Table 3), based on observations during the desktop analysis of geomorphic characteristics and review of the river profile (Figure 5). Historical channel migration in Reach 1 and Reach 2 appears to be topographically controlled by the valley width. Therefore, the valley bottom width and the mapped width of the Quaternary-age alluvium geologic unit was used to delineate the extent of these two reaches. Reach 3 extends from RM 47.8 upstream to the Crystal River Ranch Road Bridge near RM 48.8. Reach 3 is laterally controlled by the Osceola Mudflow geologic unit and contains a similar extent of alluvium along the valley floor. The Crystal River Ranch Road prism functions as a levee at the upstream end of Reach 3, artificially confining the flow in this area, which results in bed material deposition upstream of the bridge. Reaches 4, 5 and 6 were delineated on the basis of having similar:

- Lateral control by Osceola Mudflow
- Valley width confinement and topographic control
- Mapped width of alluvium on the valley floor

The reach delineations were used for evaluating the erosion rates that may vary among reaches based on the physical characteristics of each reach.

TABLE 3. INDENTIFICATION OF REACHES BY RM

Reach	From RM	To RM
1	44.5	46.5
2	46.5	47.8
3	47.8	48.8
4	48.8	49.4
5	49.4	50.4
6	50.4	51.5

4.1.1. Geomorphic Findings

The upper White River within the project area is a low-gradient, braided system with the exception of the lower reaches where the channel is somewhat straight and more closely resembles a single-thread channel with mid-channel and lateral bars. Sinuosity varies throughout the different reaches but is generally low. The average river slope over the project is approximately 1 percent (Figure 5), but varies locally among different reaches, and begins to slightly decrease close to and beyond the lower extent of the project at the confluence with the Greenwater River.

The upper White River is predominantly a riffle-glide bedform. Pools were indistinguishable as the visibility in the water column was minimal. Sediment in the channel was obscured by the cloudy water, but the gravel bars were observed to be extremely poorly sorted, consisting of all grain sizes from sand to large boulders (Photos 1 and 2, Appendix A).

As is typical of braided systems, the upper White River has numerous large gravel bars in many stages of vegetation growth. Developed floodplains generated from overbank deposits with established vegetation are present but discontinuous and at varying elevations above the gravel bars depending on the reach. Numerous high flow side channels are observed on the floodplains in Reaches 4 thru 6 (Photo 3, Appendix A). Additional channels were observed in the field or in the LiDAR imagery in Reaches 1 through 3, but they are not as plentiful.

Abundant large wood was observed throughout Reaches 4 through 6 (Photo 4, Appendix A), and the top third of Reach 1; a moderate amount was observed in Reaches 2 and 3 and lower portion of Reach 1. A massive log jam was observed near the confluence with the Greenwater River.

The river is controlled mainly by the Osceola Mudflow. The river has significantly incised into the Osceola Mudflow in the lower reaches and to a lesser, but still notable, extent in the upper reaches. The Osceola terraces are approximately 25 to 40 feet high in the lower reaches and closer to 10 to 15 feet high in the upper reaches (Photos 5 through 7 in Appendix A).

The river has widened since incision and generated floodplains at previous and current channel elevations. LiDAR imagery shows a number of high terraces where the surfaces have been reworked by fluvial action and alluvium is deposited on the surface (Photos 1 and 7, Appendix A). These terraces potentially suggest incremental incision and widening of the upper White River. Although the river has widened at the current elevation, it is still moderately confined as the local valley width (within the Osceola Mudflow) to channel width ratio is between 2 and 4 in most reaches. A ratio less than 2 defines a confined system and a ratio greater than 4 defines an unconfined system.

The braided nature of the White River in the upper reaches of the project area is commonly interpreted as an aggradational response, suggesting the river may be sediment transport-limited. However, examples of vertically stable, braided systems are described in Knighton (1998). Czuba (2012) characterizes the project area as transport reaches, which would suggest they are carrying out the sediment load that is being brought in without measurable long-term aggradation. These reaches could be responding to short-term fluctuations in transport rates related to episodic sediment pulses of bedload supplied from upstream reaches. In that case, the large, abundant depositional bar complexes are likely transient storage locations for bed material that form and disperse over timescales varying from sub-annual to multi-decadal. These are processes consistent with characteristics of braided channels.

The downstream reaches are more akin to a single-thread system with sporadic lateral and mid-channel bars. These bars have been constantly reworked and shifted locations over time, but the general planform pattern has remained constant throughout the timeframe of the study period.

The river is constrained by two standing bridges, the abutments of a bridge that no longer exists, and several levees (Figure 4, Photos 8 through 12, Appendix A). The bridge near RM 47 was in place by 1954, the bridge near RM 48.9 was in place by 1962, and the bridge near RM 51.5 was present in the 1944 through 1962 photos. The latter bridge no longer exists. The single levee near the town of Greenwater (RM 45) was owned and operated by the county at least from 2006 through 2013 (Pierce County 2013), and in place by 1985. A second significant levee not owned or operated by the county was placed near RM 46.7 according to aerial photo records in or around 1985.

The Crystal River Ranch Community built rock vanes within Reach 5 in 2012 in order to protect well heads associated with their drinking water source (Photo 13, Appendix A). These vanes were built to within 5 feet of ordinary high water so they were not interacting with the river at the time of installation. Erosion of the left bank has occurred since installment such that two of the vanes were partially exposed in 2017 and at least one was currently interacting with the river at the time of the field reconnaissance. Two rock vanes were placed in two separate emergency actions by a private landowner, in the channel near RM 49.5 between February 2008 and March 2008. The two vanes currently train the river toward the center of the active channel away from the left bank. Additionally, several private landowners along the river have put up ecology block or gabion revetments (Photos 14 and 15, Appendix A).

Pistol butt trees along left bank at Crystal River Ranch Community suggest that the slope has been relatively stable for some time (Photo 16, Appendix A). These field observations corroborate results from the desktop study, which found erosion took place between 1944 and 1962 along that bank but was arrested until recently. This provided time for the vegetation to grow on the bank. Fresh cut banks are evidence of recent erosion into the Osceola Mudflow along this bank.

A coarse clast-supported debris flow of unknown origin outcrops along the right bank near the Crystal Village. A 3- to 5-foot layer of alluvium is visible above this geologic unit (Photo 17, Appendix A). This bank has not migrated over the historical record within our review, but undercut banks suggest some recent erosion of the bank (Photo 18, Appendix A).

Alluvial fans along the left valley wall supply material to the river and encourage the river to flow toward the right bank.

4.2. CMZ Delineation

Delineation of the migration zone began with generation of active channel traces observed on the various years of photographic record, which are presented in Figure 6. Channel centerlines estimated from these channel traces and channel margins were used to measure migration rates at transects (Figure 7). Avulsion pathways and topographically low areas are identified and presented along with the historical migration zone and relative water surface elevation in Figure 8. Interpreted geologic mapping for the application of migration rates is presented in Figure 9. Finally, migration potential areas are provided in Figures 10 through 12. The elements comprising the CMZ are briefly described below.

4.2.1. Historical Migration Zone

The historical migration zone was derived by merging the active channel extents from 10 historical aerial photographs dated from 1944 to 2017 (Figures 6 and 8).

4.2.2. Avulsion Hazards and Topographically Low Areas

Based on the historical photo record, the process of avulsion within the upper White River usually occurs within the active channel, along back bar channels after relatively recent channel migration and bar building. Avulsion in the upper White River is typically a shifting of the thalweg within the active channel as sediment is locally deposited or removed. No avulsions, such as neck cut-offs, were observed nor were avulsions outside of recently active channels in floodplain areas where numerous avulsion pathways were identified (Figure 8). However, because of the dynamic nature of the river, it is assumed that localized aggradation of sediment and debris could occur during any given flood event, creating the necessary circumstances to reactivate a pathway leading to an avulsion.

A single, topographically low area was identified near RM 46.5 (Figure 8). This topographically low area is identified as an area that, because of the low topography, may experience migration during the timeframe of the CMZ even though it is outside of the applied migration potential area buffer. This area was subsequently included in the low migration potential area.

4.2.3. Calculation of Unconfined Erosion Rates

Erosion rates were measured at 144 transects over the six reaches using methods described above. Reach-averaged annual rates and the number of transects in each reach are presented in Table 4. Transect locations along with channel trace centerlines are shown in Figure 7. Migration distances measured at each transect are presented in Appendix B.

WAC section 173-26-221(3)(b) states that, "flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the CMZ unless demonstrated otherwise using scientific and technical information." Rapp and Abbe (2003) guidance states that "Man-made structures with no public commitment for maintenance and structures made of erodible materials (sugar dikes) are not effective barriers to channel migration." Even though structures meeting these criteria are not considered barriers to channel migration, rates may be influenced by them. Therefore, rates measured at these structures were not included in the calculation of reach averages. Thus, reach-averaged rates are representative of unconfined and anthropogenically unaltered conditions.

TABLE 4. TRANSECTS AND MEASURED MIGRATION RATES BY REACH

Reach	Number of Transects	Reach Averaged Rate in Alluvium (ft/yr)	Reach Averaged Rate in the Osceola Mudflow (ft/yr)
1	40	2	N/A
2	28	3	1
3	23	3	N/A
4	11	7	N/A
5	21	6	1
6	21	10	2

Bank materials within the project reach have varying degrees of erosion resistance, resulting in different channel migration rates for different locations depending upon the bank materials present. The least erosion resistant materials are colluvium, alluvium, alluvial fan material and landslide deposits. These rates were estimated using movement of the channel centerlines, which is applicable to measuring rates as the channel moves back and forth within the alluvium or similar erosion-resistant material.

Erosion resistance of the Osceola Mudflow deposits is higher than the erosion resistance of alluvium. The centerline method of Rapp and Abbe (2003), based on mapping of the active channel, works well for determining migration rates within the alluvium in the valley bottom as the channel commonly shifts rapidly (decadal time scale or less) from one side of the active channel to the other. This method, however, misrepresents new erosion into Osceola Mudflow, where observations indicate that erosion of these landforms occur over much longer time scales. Therefore, the centerline method results in higher migration rates within alluvium that do not represent lower migration rates found separately within Osceola Mudflow deposits. For this reason, rates for the Osceola Mudflow were measured as described in Section 3.2.2.

Three transects were reviewed at the location of the coarse-grained debris flow adjacent to a portion of Crystal Village. No measurable movement beyond analyst-biased photo georeferencing error could be distinguished. Therefore, movement was estimated based on field observations and applied over the timeframe since the last clear cutting was documented at the latest in 1962, with the assumption that the trees have been growing since that time. Bank erosion of approximately 10 to 20 feet was estimated based on overhanging tree roots where the bank has receded (Photo 18, Appendix A). This provides less than a rate of 0.5 foot per year, and less than what can be measured and applied with statistical significance. Therefore, a migration rate of 0.5 foot per year was applied to this unit.

The river is not in contact with the bedrock of the valley walls; therefore, no rates were measured for that material. Because bedrock is typically highly resistant to erosion, the same rate found for the coarse-grained debris flow unit was applied to the bedrock.

4.2.4. Migration Potential Areas

Reach-averaged erosion rates specific to the different bank materials present were used to generate the migration potential areas within each reach. Reaches with no measurable migration rates into the Osceola Mudflow (1, 3 and 4) were assigned the average rate of reaches with measurements, 1 foot per year, for the Osceola Mudflow. Measured rates were used for the remaining reaches as shown in Table 4.

If the migration potential buffer crossed a boundary between geologic units, the associated rate for each unit is applied separately. The geology interpreted for the purpose of applying rates is presented in Figure 9. The migration potential areas are shown in Figures 10 through 12 and are briefly described below. Figure 10 shows the migration potential areas and CMZ with a LiDAR base map and the interpreted geology; Figure 11 has a 2017 aerial photograph as the base; and Figure 12 shows the 2017 aerial with the inclusion of property lines for reference.

4.2.4.1. Severe Migration Potential Areas

The severe migration potential area in the project reach is represented by the reach-averaged migration rate estimated within each reach, multiplied by 10 years, applied to the combined historical migration and avulsion hazard zones boundary. Rates vary depending on the material present at the combined historical migration and avulsion hazard zones boundary and beyond A geotechnical setback was added to the severe migration potential area at the high bank locations to account for bank failure after toe erosion of the Osceola Mudflow deposits.

4.2.4.2. Moderate Migration Potential Areas

The moderate migration potential area in the project is the reach-averaged migration rate estimated within each reach multiplied by 20 years applied to the combined historical migration and avulsion hazard zones boundary. Again, different reach-averaged rates for the different geologic units apply where they are present. The moderate migration potential area does not encompass the severe migration potential area; although the moderate is applied from the historical migration and avulsion hazard zones out to 20 years, it only begins at the outside edge of the severe migration potential area. A geotechnical setback was added to the moderate migration potential area at the high bank locations to account for bank failure after toe erosion of the Osceola Mudflow deposits.

4.2.4.3. Low Migration Potential Areas

The low migration potential area is the reach-averaged migration rate estimated within each reach multiplied by 50 years applied to the combined historical migration and avulsion hazard zones boundary. A geotechnical setback was added to the low migration potential area at the high bank locations to account for bank failure after toe erosion of the Osceola Mudflow deposits. The low migration potential area does not encompass the severe or moderate migration potential areas; although the low migration potential area is applied from the combined historical migration and avulsion hazard zones out to 50 years, it only begins at the outside edge of the moderate migration potential area.

The low migration potential boundary intersected bedrock in several locations after accounting for erosion into colluvium or Osceola Mudflow. The boundary was delineated using an estimated location of the bedrock under the colluvium or Osceola at the elevation of the current thalweg, based on slopes derived from LiDAR, and then adjusted for the number of years remaining and rate of migration to reach the 50-year boundary.

4.2.4.4. Disconnected Migration Areas

A disconnected migration area is the area that includes, and is landward of, human infrastructure that has the ability to limit channel migration, including avulsion. Two locations are mapped along Highway 410 as disconnected migration areas: the first is just downstream of the confluence with the Greenwater River, near RM 44.5; the second is a half mile upstream of the confluence with the Greenwater River, around RM 45.1 (Figures 10-A, 11-A and 12-A).

Several criteria help define a disconnected migration area:

- A disconnected migration area includes a public commitment for maintenance that would keep a structure intact (Rapp and Abbe 2003).
- WAC section 173-26-221(3)(b), which states that "flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the channel migration zone unless demonstrated otherwise using scientific and technical information." In other words, flood control structures or other revetted infrastructure built to above the 100-year floodplain elevation could be considered a barrier to migration and mapped as disconnected migration areas, depending on degree of revetment and potential to restrict channel migration.
- WAC section 173-26-221(3)(b) also states that "All areas separated from the active channel by a legally existing artificial structure(s) that is likely to restrain channel migration, including transportation facilities, built above or constructed to remain intact through the one hundred-year flood should not be considered to be in the channel migration zone."

The disconnected migration areas in this study, although not technically flood control structures, are based on infrastructure built above the 100-year floodplain and, being along a state route, have a public commitment that would keep the infrastructure intact. The remaining structures in the study area do not meet these criteria:

- The levee at RM 45.5 is discontinuous and could be flanked; the area behind it is still connected to the river and, therefore, does not constitute a disconnected migration area.
- The levee at RM 46.5 is discontinuous and has no public commitment associated with it.
- The bridge at RM 47 is above the 100-year floodplain, but it is privately owned. Therefore, there is no public commitment for maintenance to keep it intact. Additionally, an avulsion hazard zone flanks the bridge to the east.

- The bridge at RM 48.9 is owned by Pierce County, but there is not enough information about the bridge to confirm either if it would remain intact through a 100-year RI flood, or that the revetments at the abutments would restrain channel migration over the timeframe of the CMZ delineation.

With respect to the CRR Homeowners' Association vanes, GeoEngineers (2019), following best practices in bank protection design, determined that there is insufficient engineering and design documentation to conclude that they are above the 100-year floodplain or that they are an effective barrier to channel migration. Therefore, the vanes are not included as a deterrent to channel migration for this study. Evaluation of the effectiveness of the rock vanes is beyond the scope of work for the project and would require significant engineering analysis. GeoEngineers, therefore, makes no comment or judgment regarding the effectiveness of the rock vanes with respect to the potential mechanisms of bank failure and avulsion at the CRR Homeowners' Association river reach.

4.2.5. Geotechnical Setbacks

Because the Osceola Mudflow forms high banks in this study area and the unit is unconsolidated with variable cohesion, this geologic unit is considered likely to erode to a preferred angle of repose. Therefore, a geotechnical setback was added to each migration potential area where it intersects the Osceola Mudflow. Bedrock, although steep and crops out well above the channel bed, is highly erosion-resistant and would not require a geotechnical setback should the river come in contact with the bedrock. Likewise, the mudflow of unknown origin was categorized as erosion-resistant and, therefore, no geotechnical setback was applied where it was mapped.

According to Engineering Geology in Washington (Koloski, et al. 1989), the preferred angle of repose for volcanic lahars is between 25 to 40 degrees. This is equivalent to a slope ratio range of 1:1.18 to 1V:2.13H (vertical to horizontal). Median slope ratios for reaches 1 through 3 all were very similar, ranging from 1:1.45 to 1:1.54. Median slope ratios for reaches 4 through 6 also were very similar, ranging from 1:1.94 to 1:2.04 (V:H). All ratios are within the range presented in Koloski, et. al. (1989). Reaches 1 through 3 averaged a 1:1.5 (V:H) slope ratio, while reaches 4 through 6 averaged a 1:2 (V:H) slope ratio. These average values were applied to the associated reaches according to the local elevations identified at each transect. Geotechnical setbacks are presented in Figures 10-A through 12-F.

4.2.6. Comparison of CMZ with FEMA Floodway and Pierce County Deep and Fast Flowing Floodway

Figure 13 presents the CMZ and the 2017 FEMA Floodway and the Pierce County Deep and Fast Flowing Floodway. The FEMA-regulated floodplain is available for approximately the lower half of the project. The FEMA floodway extends landward beyond the CMZ over a significant portion of the river. However, in some locations the CMZ extends beyond the floodway. It appears that some of those areas have been more recently eroded or occupied, suggesting the FEMA floodway may not have been generated using the recent topography reflected in the LiDAR. In the upper half of the project area, the severe migration potential area generally is included within the existing Deep and Fast Flowing Floodway.

4.2.7. Regulatory Effects

Pierce County regulates adopted CMZs identified at severe risk of migration as floodways. Several buildings in the surrounding communities are within the severe migration potential areas delineated in this study, as shown on Plates 1 through 3.

5.0 DISCUSSION

Channel migration on the upper White River throughout the historical record has been substantial. Most of that migration takes place within the historical migration zone within alluvium and areas that have already been occupied by the river. Migration into Osceola Mudflow surrounding the alluvium is a much slower process.

Many of the adjacent terraces well above the current floodplain elevation suggest periodic incision has occurred over time, followed by channel widening and floodplain development. These terraces have the sediment and surface morphology indicative of fluvial action but these fluvial surfaces rest atop Osceola or other debris flows of unknown origin. Osceola at the base slows migration into these terraces relative to locations consisting of alluvium.

A primary driver of channel migration is the storage and episodic transport of bedload sediment in a river channel in an undisturbed system. The majority of the sediment feeding the White River comes from Mt. Rainier, as the glaciers deposit moraines from which sedimentary material is commonly carried to the fluvial system by debris flows (Czuba, et al. 2012). Landslides, soil creep and alluvial fans contribute sediment to the system to a lesser degree. Commercial logging along the entire project area in the 1950s through 1960s likely destabilized the floodplain in areas with a lack of bank cohesion, thereby contributing sediment to the channel as the banks receded. As sediment builds up in the system, bank erosion and channel widening occurs. Riparian vegetation can improve stability with root reinforcement of soils along riverbanks. With improved riparian protection from evolving logging practices, the forest can recover faster and provide that stabilizing force again (WSDOT 2007).

Considerable large wood on bars throughout the project contribute to sediment accumulation. Aerial photographs illustrate the fact that large floods have eroded alluvium that once supported moderately mature second or third growth forests in the project recruiting significant large wood to the channel.

Incision has been a primary process within the project area in the past, but the abundant sediment in the channel suggests different processes are currently at work. Braiding, as seen in the upper reaches of the study area, is commonly associated with high sediment loads and aggradation. However, Czuba, et al. (2012) describe this section of the White River as comprising transport reaches, where resident time for sediment is fairly short and vertical changes are small. These observations seem contradictory, but examples of vertically stable, braided systems are described in Knighton (1998). It is clear these upper reaches are responsive to sediment input. Because sediment resident times appear to be short, occupation time for the various channel locations within the active channel also tend to be short. This means the channel changes location often in response to local erosion and deposition of sediment as it moves rather quickly through the reach. Hence, the upper reaches of this study currently area appear to be vertically stable (i.e. neither aggrading nor eroding vertically), braided channels.

According to Czuba et. al (2012), however, the braided reaches upstream of the West Fork White River have some of the lowest transport capacity and stream power along the White River, making this area more prone to sedimentation. Modeling by Czuba, et al. (2012) of future hydrologic conditions under similar transport capacity as currently exists shows the potential for aggradation over the next 50 years. Implications include continued spatial variation in bar formation and channel location within the active channel, more occurrence of avulsions, and likely ongoing migration into the Osceola Mudflow deposits.

6.0 GREENWATER RIVER CMZ AT THE CONFLUENCE WITH THE UPPER WHITE RIVER

A CMZ delineation was published for the Greenwater River in Pierce County, on November 9, 2017 (GeoEngineers). That delineation extended from approximately RM 1.2 downstream to the SR 410 Bridge near the town of Greenwater, at approximate RM 0.1. A CMZ delineation of the 0.06-mile river section between the SR 410 Bridge and the confluence with the active channel of the White River was originally omitted from the November 9, 2017 CMZ report because, at that time, it was anticipated that the future upper White River CMZ delineation would capture that section of the Greenwater River. However, because the outer limits of the delineated Severe Migration Potential Area on the Upper White River CMZ did not reach the 2017 delineation limits of the Greenwater River, a gap in the delineation of the CMZ along the Greenwater River near the confluence remained. Consequently, an addendum to the Greenwater River CMZ Delineation Report, attached herein as Appendix C, was completed recently to complete the delineation of the CMZ on the Pierce County side of the Greenwater River, for a distance of about 300 feet.

7.0 LIMITATIONS

This report has been prepared for Pierce County Planning Public Works for the upper White River Channel Migration Zone Analysis.

Within the limitations of scope, schedule and budget, services by GeoEngineers have been executed in accordance with generally accepted practices in the field of geomorphology and hydrology/hydraulics in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

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

Please refer to the appendix titled “Report Limitations and Guidelines for Use” for additional information pertaining to the use of this report.

8.0 REFERENCES

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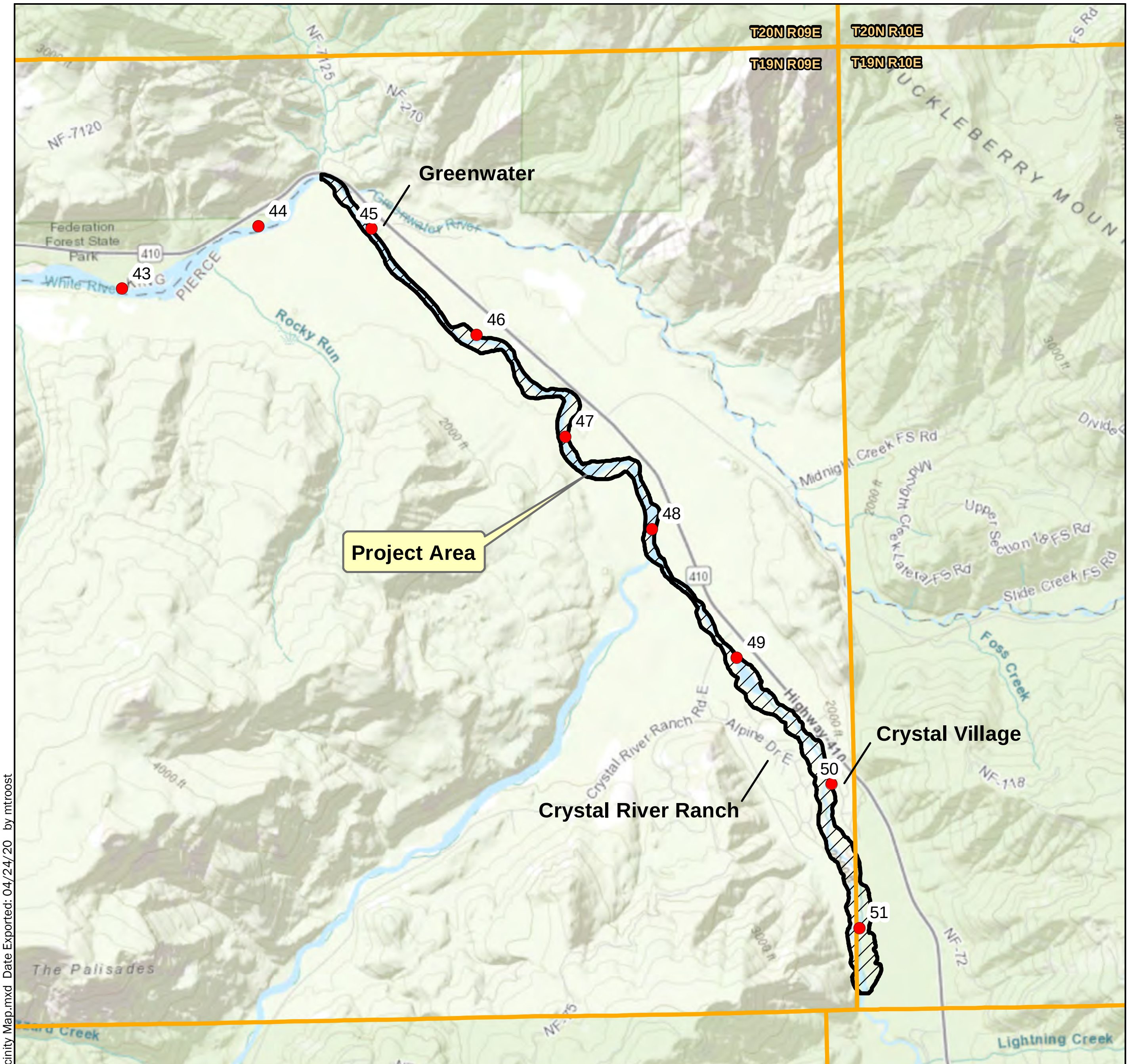
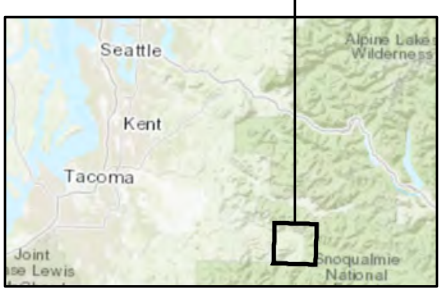
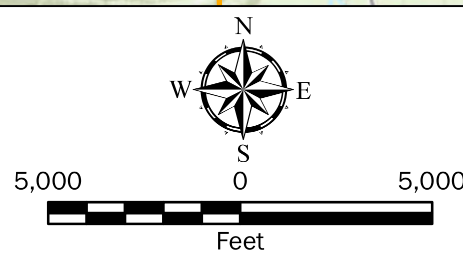




Legend

- River Miles
- Project Area
- Township



Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: Mapbox Open Street Map, 2017,
Township and section lines from PLSS, 2017
Projection: NAD 1983 UTM Zone 10N

Vicinity Map

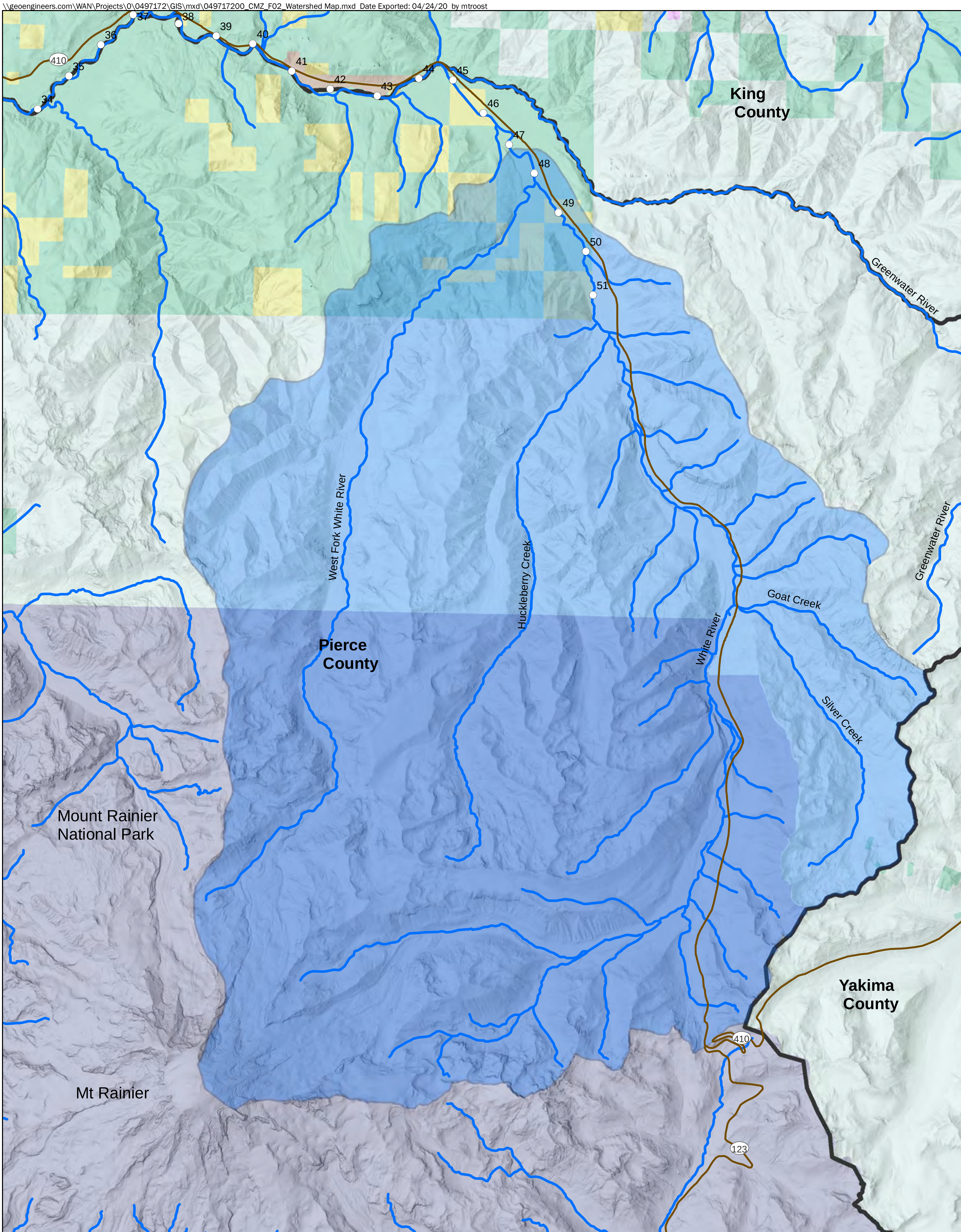
Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 1

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F01_Vicinity Map.mxd Date Exported: 04/24/20 by mtroost

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F02_Watershed Map.mxd Date Exported: 04/24/20 by mtroost



Legend

- River Miles
- Roads
- Streams and Rivers
- Upper White River Watershed
- County Boundary
- WA Department of Natural Resources
- National Park Service
- Private Land
- US Forest Service
- WA State Parks and Recreation Commission

N W E S

2 0 2

Miles

Notes:

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Data Source: Roads and watershed boundary downloaded from Pierce County 2017, Land ownership, streams, and county boundaries downloaded form Washington Department of Natural Resources 2017.
Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Watershed Map

Upper White River CMZ Delineation
Pierce County, Washington

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Figure 2

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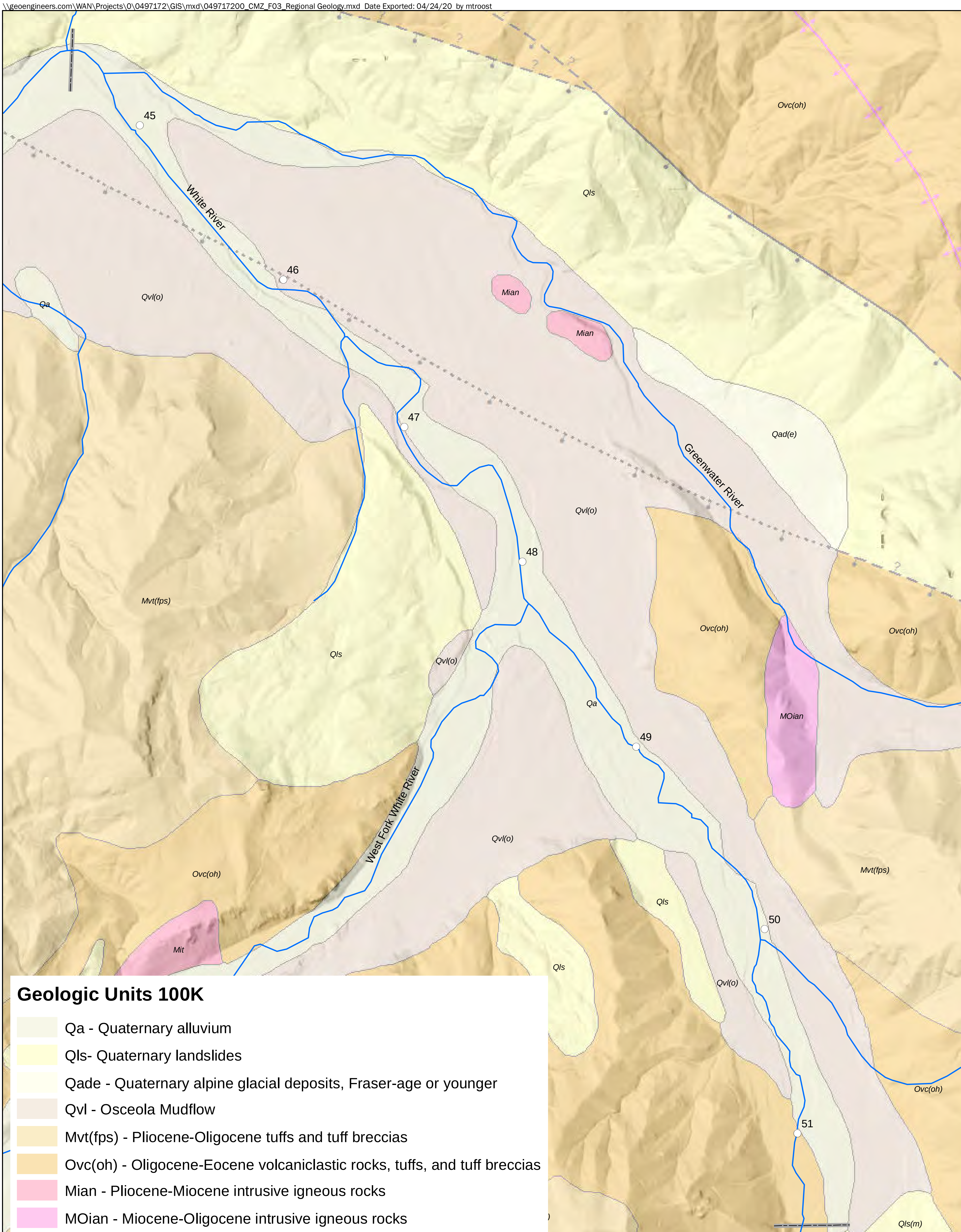

Legend

- River Miles
- Project Area Extents
- Streams and Rivers

N W E S

2,225 0 2,225

Feet

Regional Geology

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 3

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: Geology, Washington State Department of Natural Resources

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

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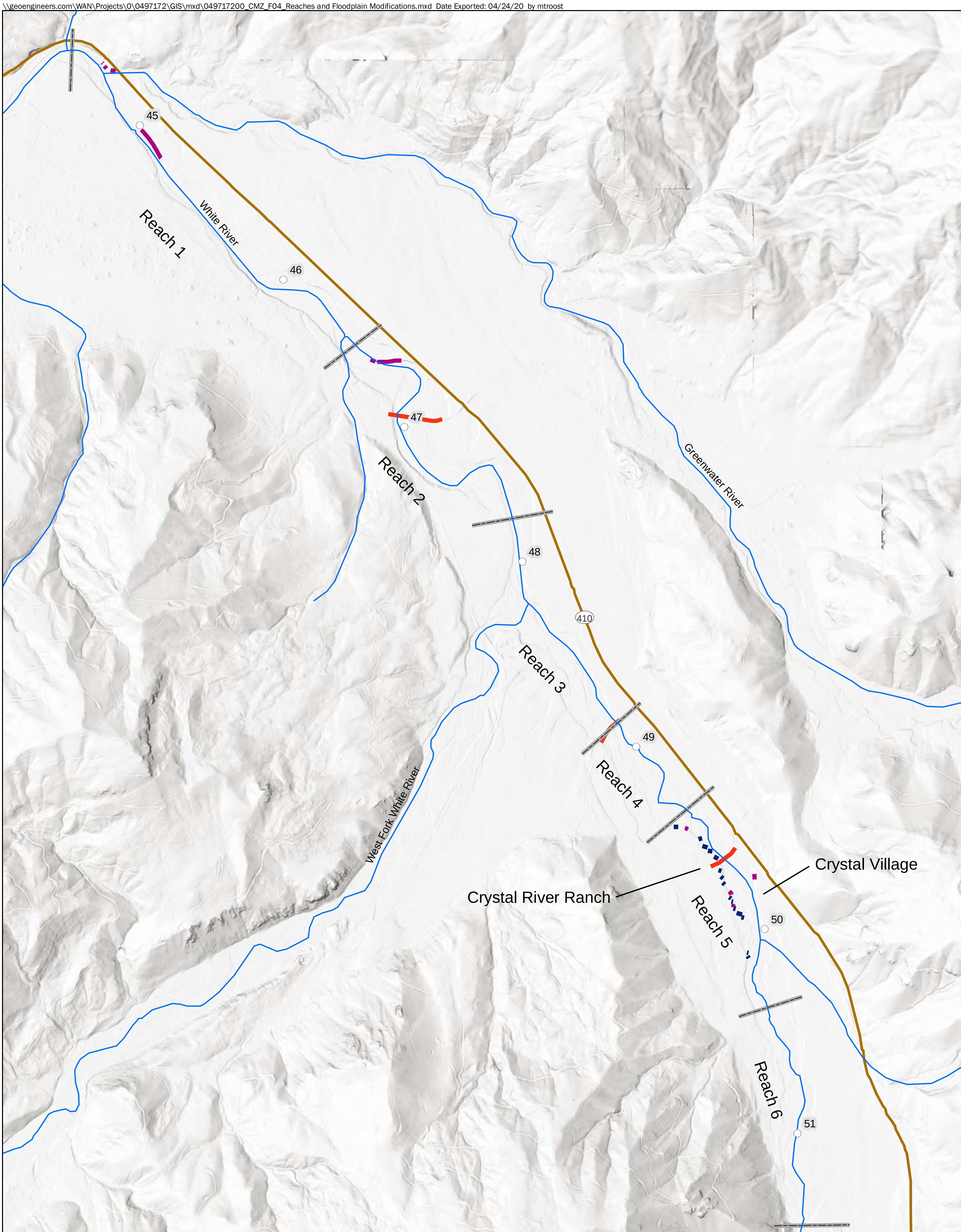

Legend

- River Miles
- Streams and Rivers
- Reach Breaks
- Levees or Revetments
- Vanes
- Bridges
- Major Road

N W E S

2,225 0 2,225

Feet

Reaches and Floodplain Modifications

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 4

Notes:
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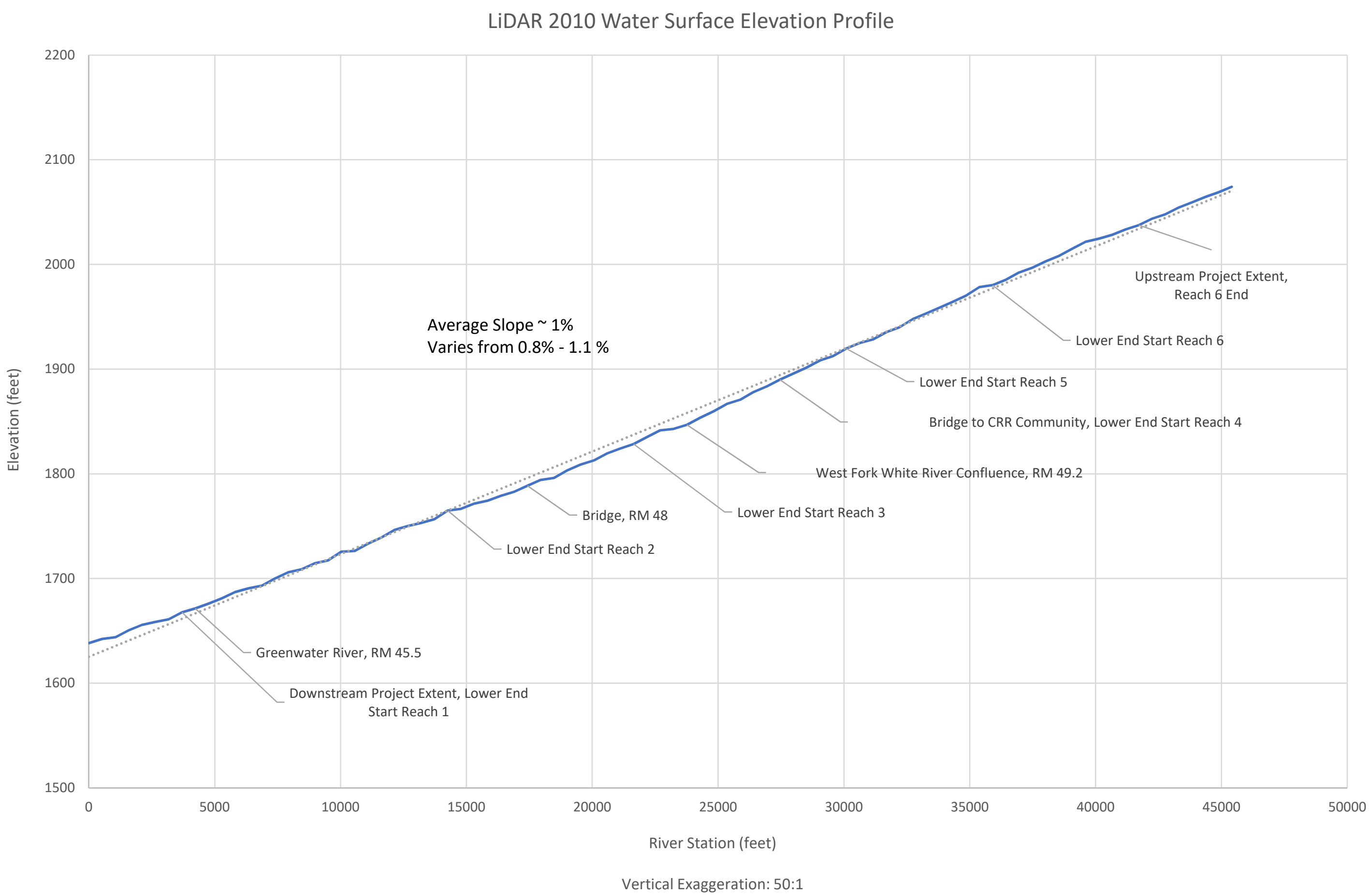
Data Source:

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet



Notes:
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Data Source: 2010 LiDAR from Pierce County

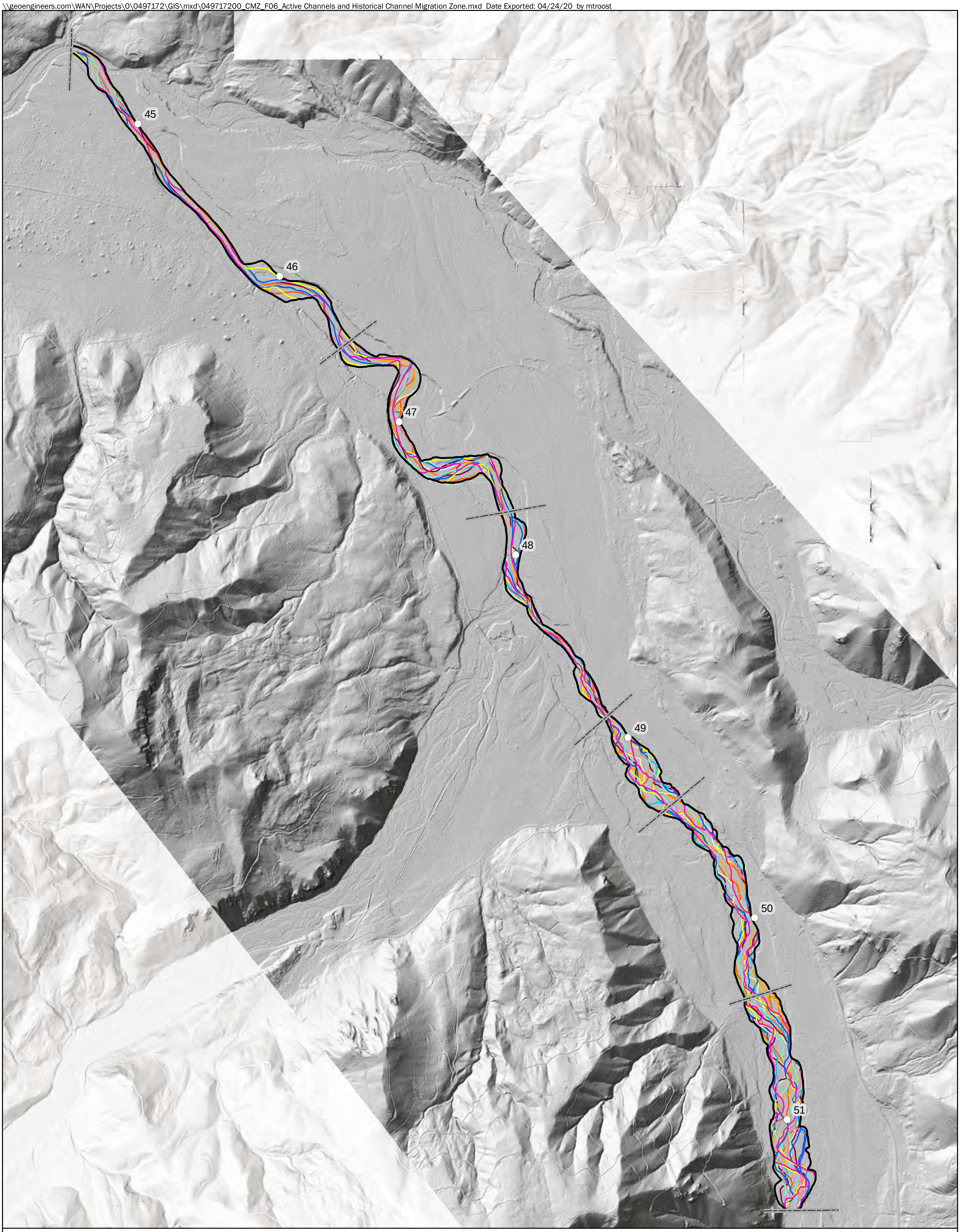
River Profile

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 5

0497-172-00 Date Exported: 10/13/2019



Legend

- River Miles
- Reach Breaks
- Historical Migration Zone
- Active Channel 2017
- Active Channel 2011
- Active Channel 2002
- Active Channel 1993
- Active Channel 1985
- Active Channel 1978
- Active Channel 1970
- Active Channel 1962
- Active Channel 1954
- Active Channel 1944

N W E S

2,225 0 2,225

Feet

Notes:
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Data Source: Geology, Modified by GeoEngineers based on WADNR 1:100,000 Geologic Mapping

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Active Channel Traces and Historical Migration Zone

Upper White River CMZ Delineation
Pierce County, Washington

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Figure 6

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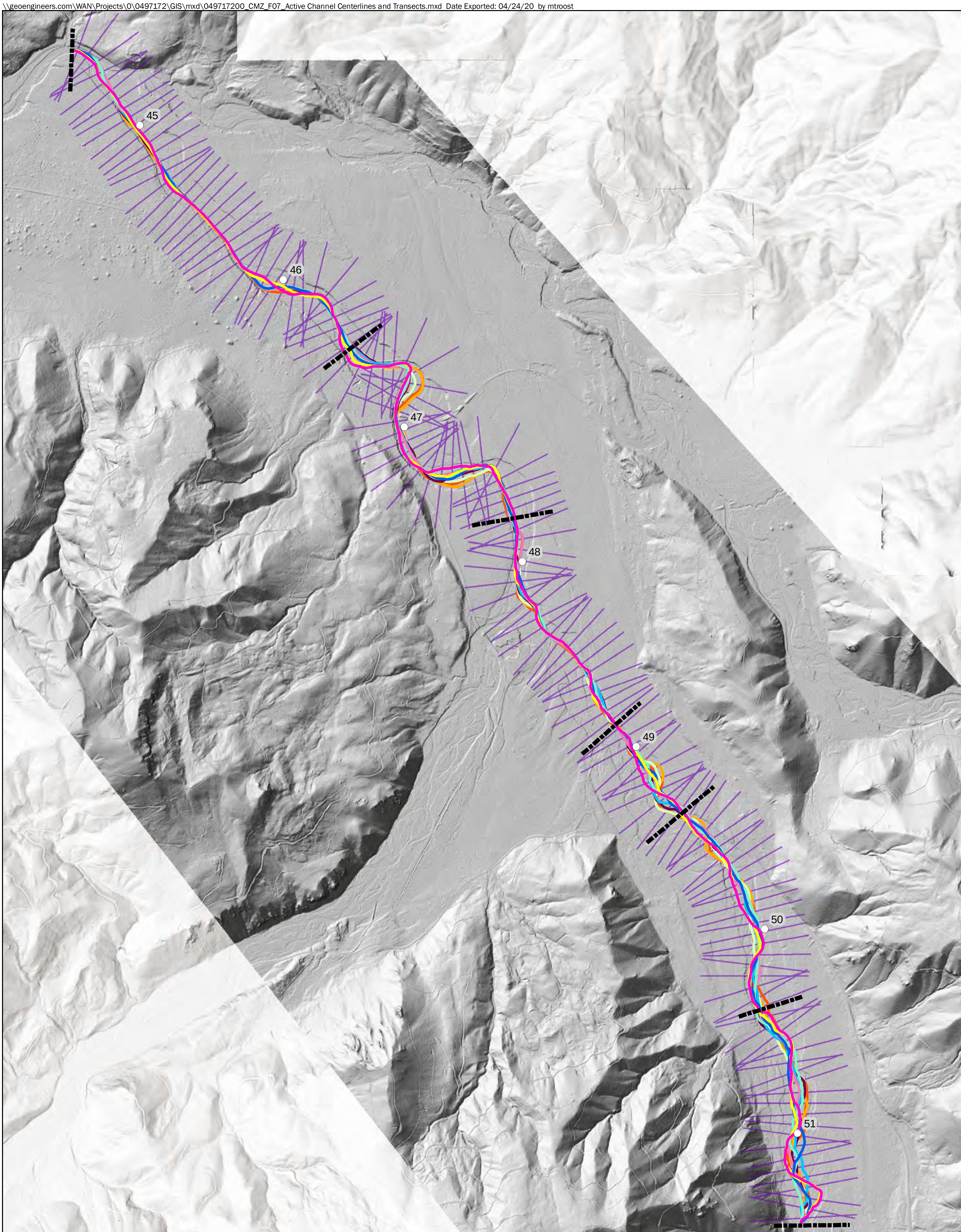


Legend

- River Miles
- Transect
- Reach Breaks

Channel Centerlines

2017
2011
2002
1993
1985
1978
1970
1962
1954
1944

N
W E
S

2,225 0 2,225

Feet

Active Channel Centerlines and Transects

Upper White River CMZ Delineation
Pierce County, Washington

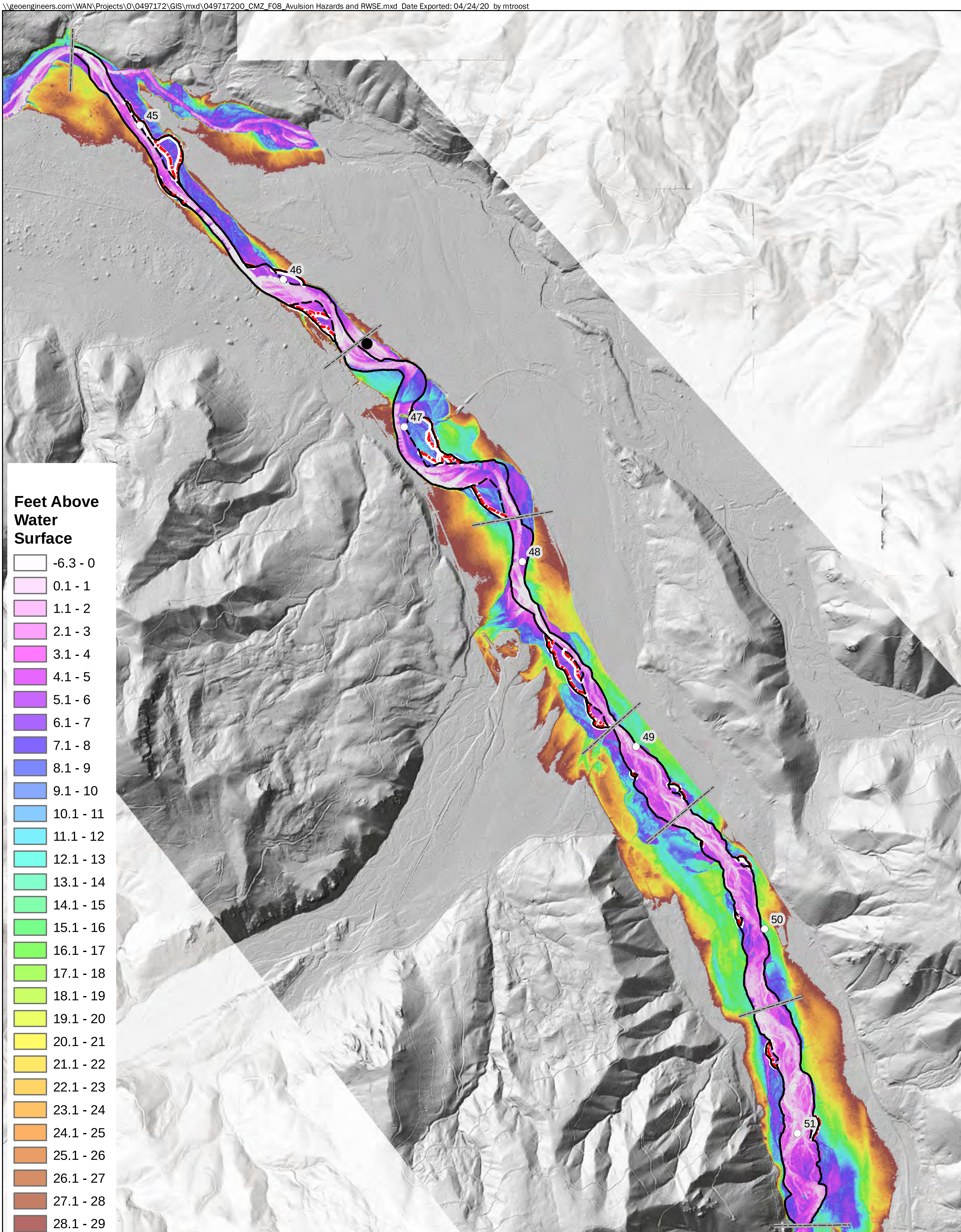
GEOENGINEERS

Figure 7

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: Centerlines and Transects - GeoEngineers

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet



Legend

- River Miles
- Topographically Low Area
- Historical Migration Zone
- Reach Breaks
- Potential Avulsion Pathway
- Combined Historical Migration Zone and Avulsion Hazard Zone

N W E S

2,225 0 2,225

Feet

Notes:
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Data Source: Geology, Modified by GeoEngineers based on WADNR 1:100,000 Geologic Mapping

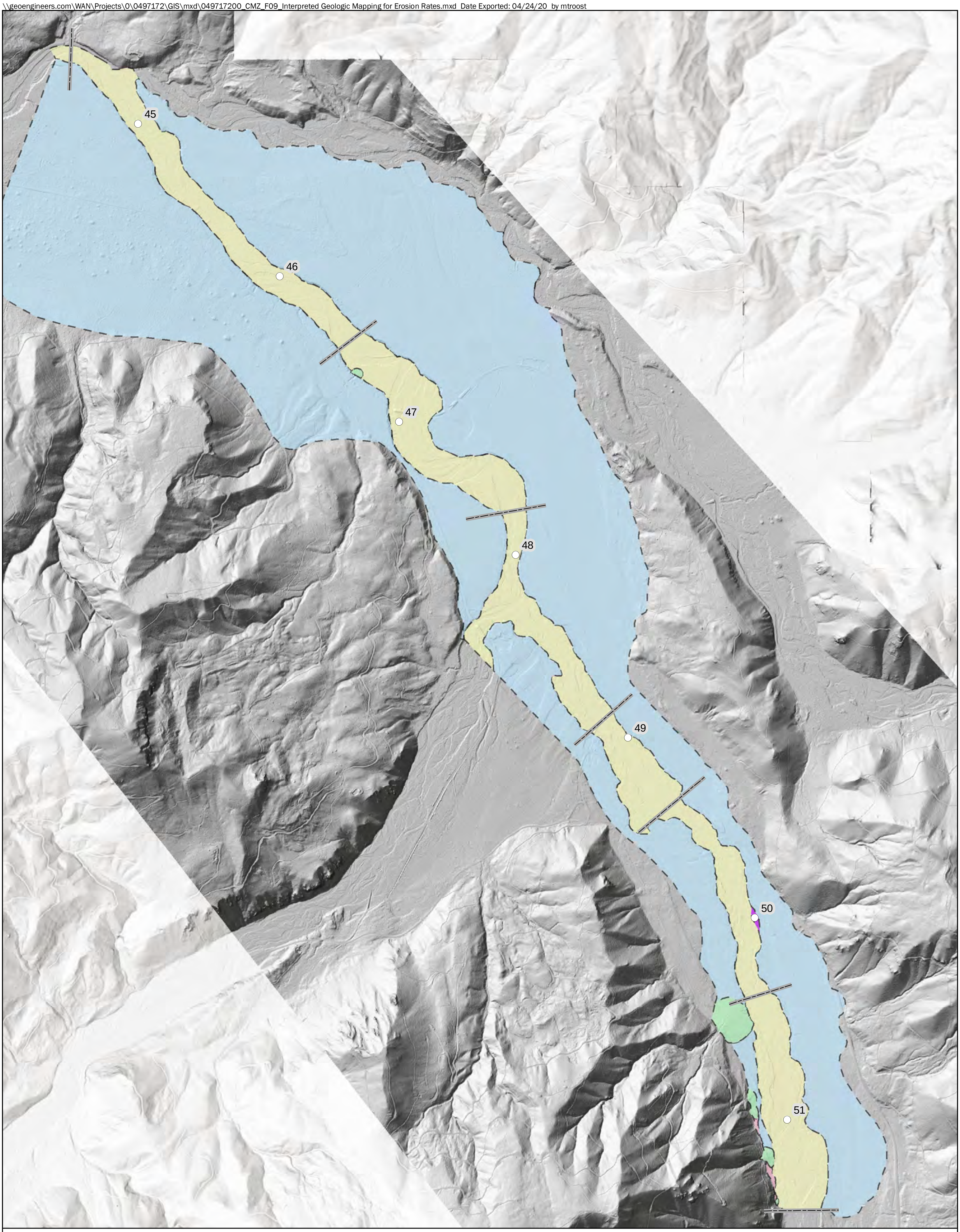
Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Relative Water Surface Elevation and Avulsion Hazards

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 8



Legend

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

- River Mile
- Reach Breaks

N
W E
S

2,225 0 2,225

Feet

Notes:
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Data Source: Geology, Modified by GeoEngineers based on WADNR 1:100,000 Geologic Mapping

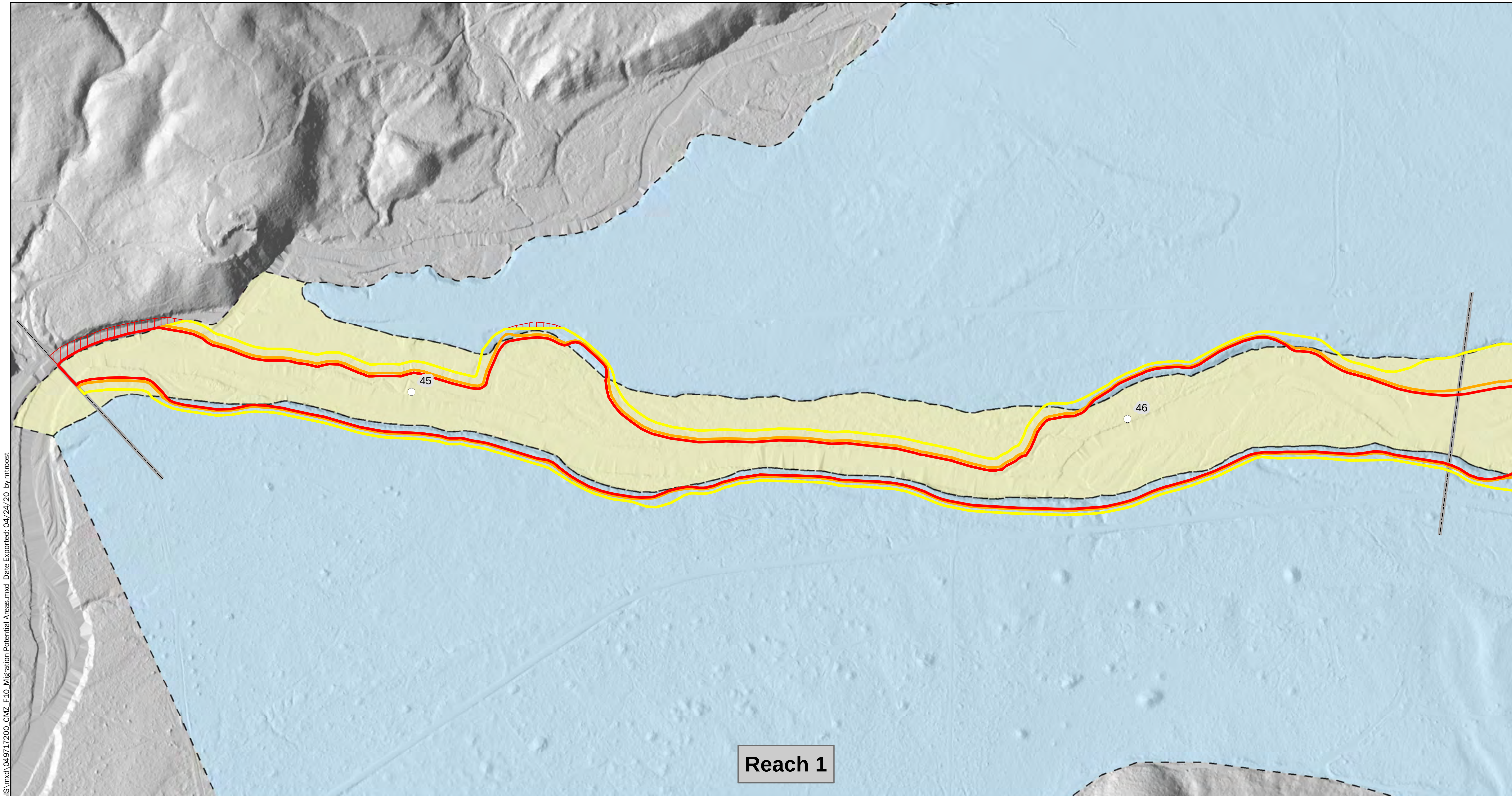
Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Interpreted Geology for Application of Erosion Rates

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 9



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Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

400 0 400

Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 10-A
Reach 1

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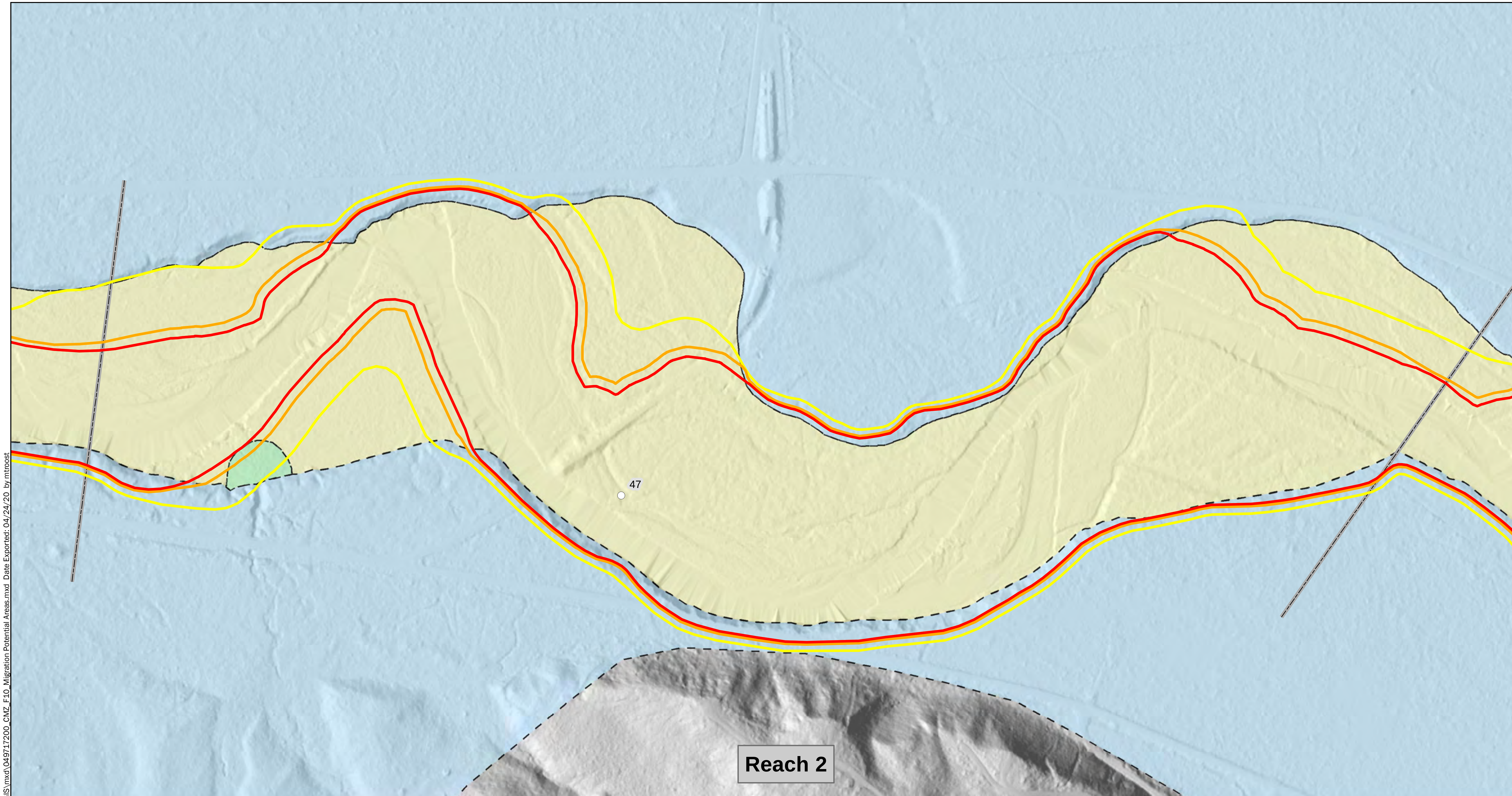

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Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

400 0 400

Feet

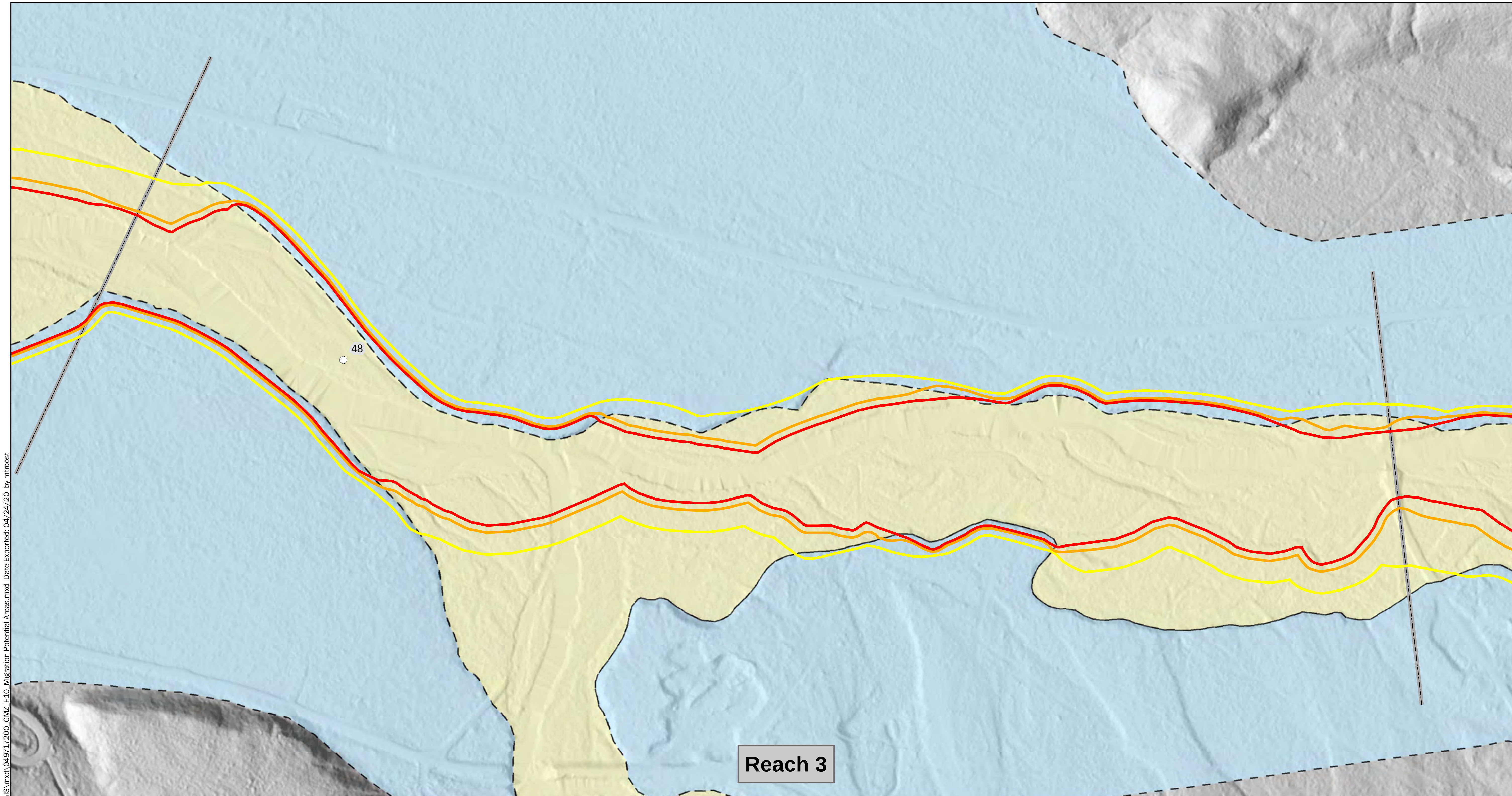
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 10-B
Reach 2

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F10_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost



Notes:
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Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

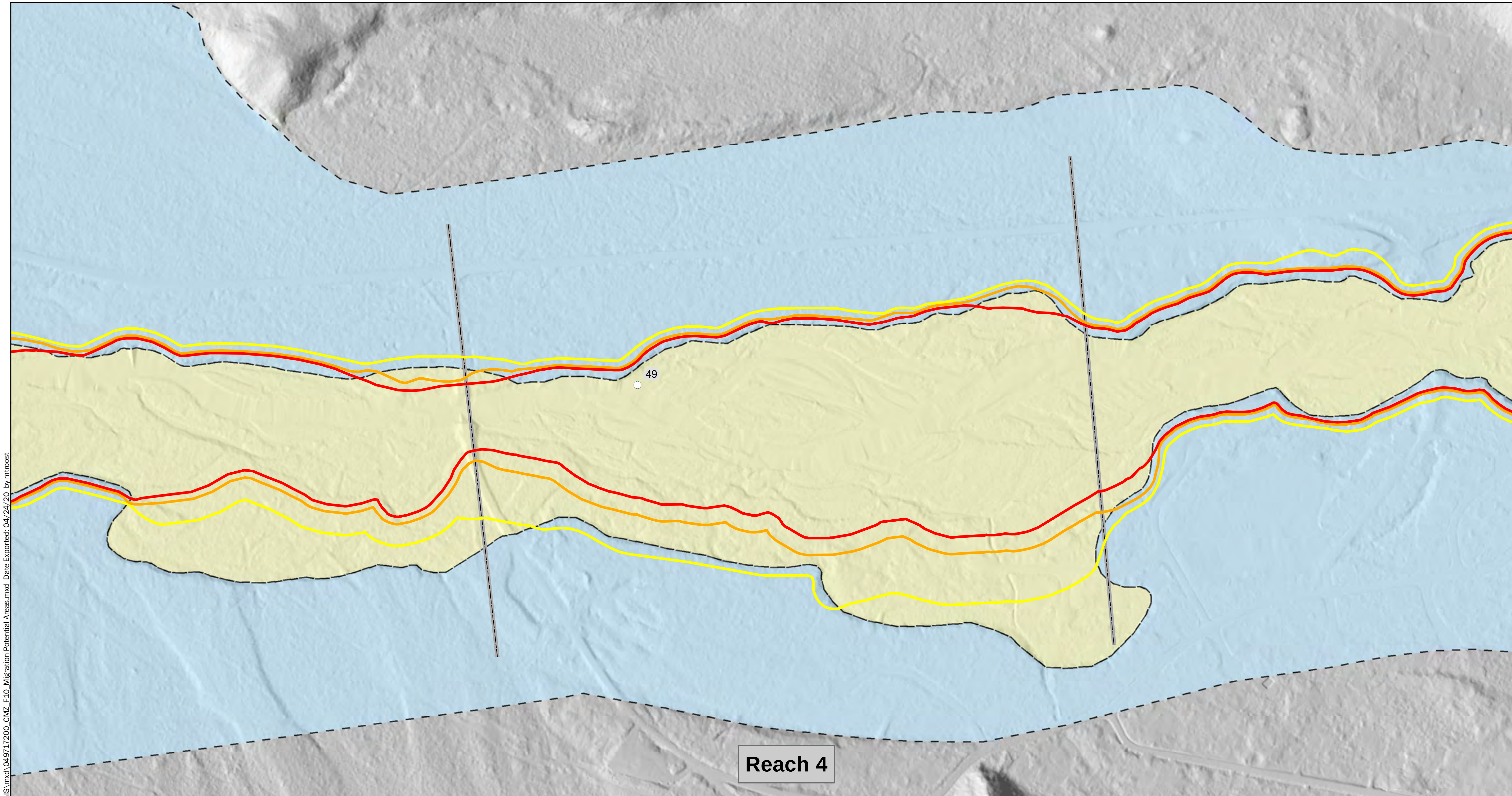
400 0 400
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 10-C
Reach 3



Notes:

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Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

400 0 400

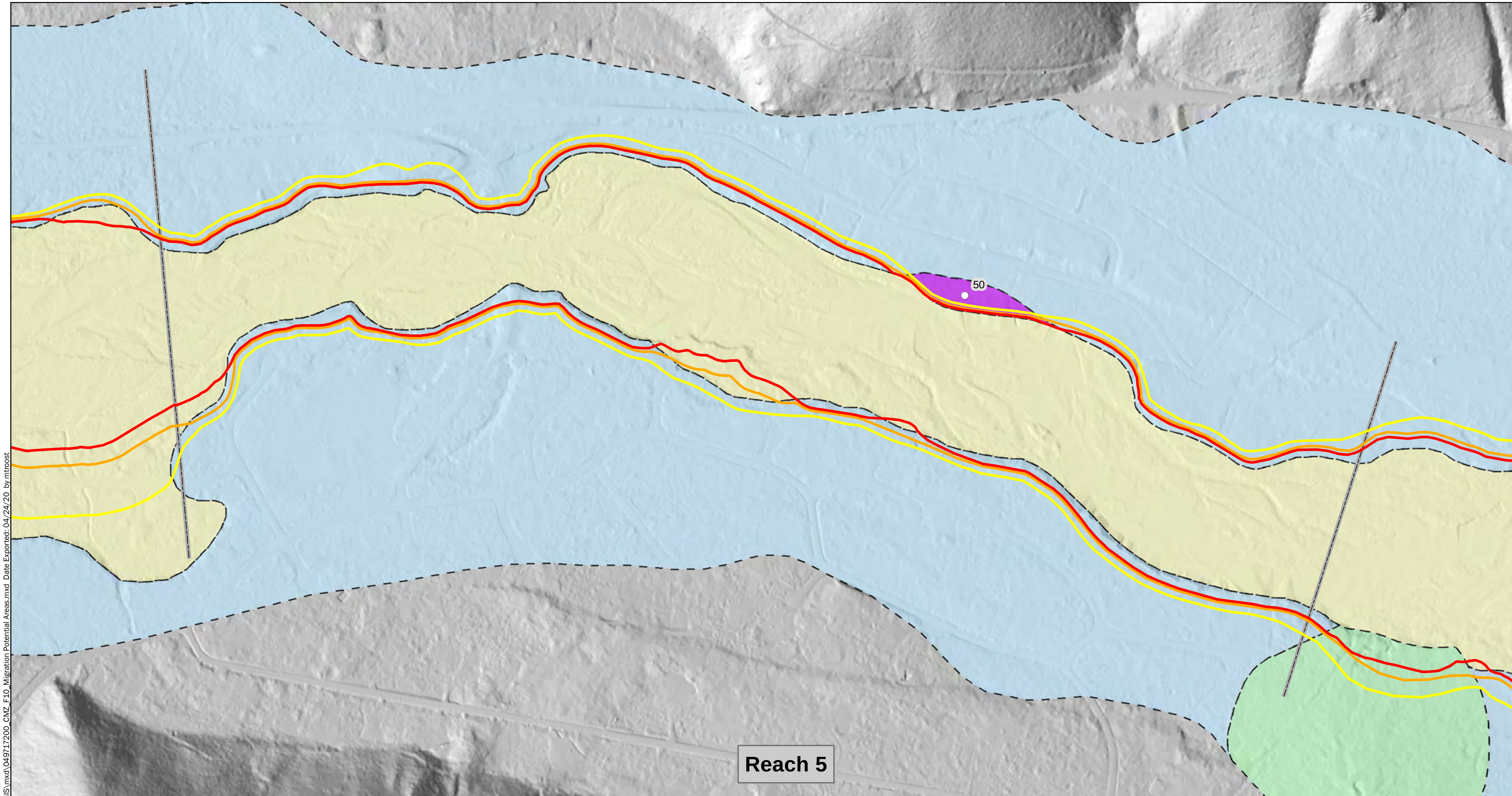
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 10-D
Reach 4



Notes:
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Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

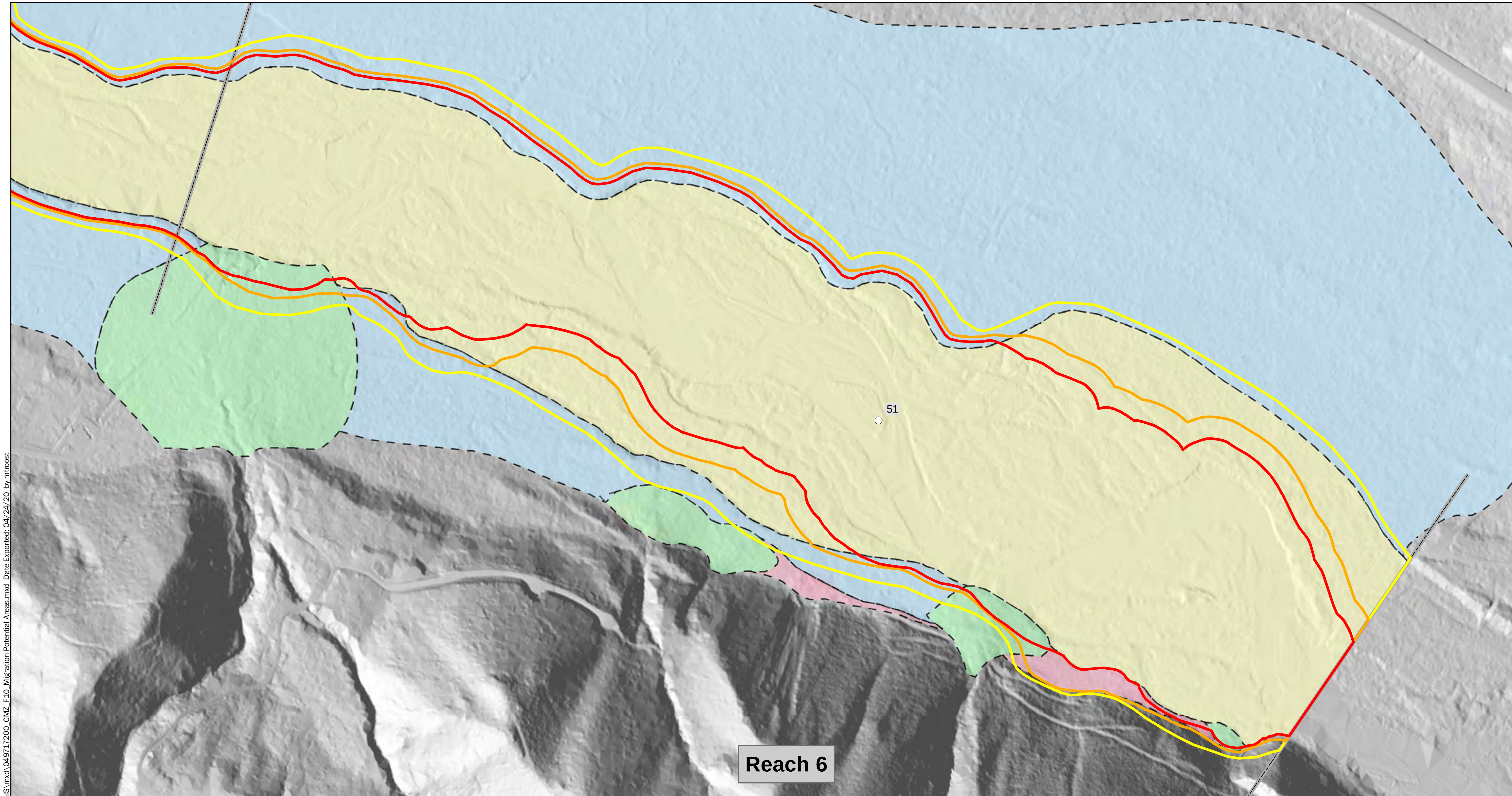
400 0 400
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 10-E
Reach 5



Notes:
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2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend
- River Miles
- Reach Breaks
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit
- Quaternary Alluvium
- Alluvial Fan
- Colluvial Slope
- Debris Flow of Unknown Origin
- Osceola Mudflow

N E S W

400 0 400
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 10-F
Reach 6

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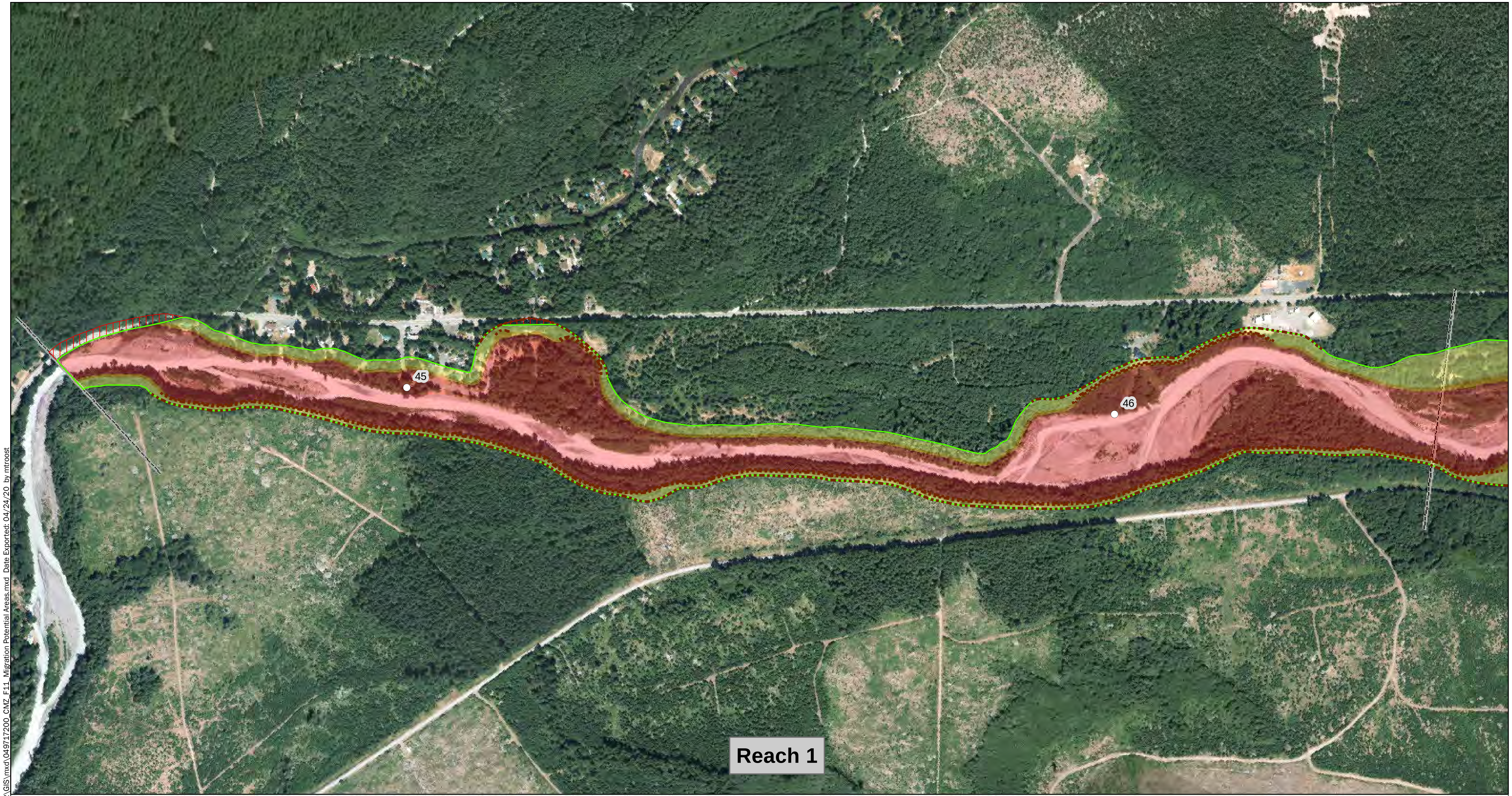

Notes:
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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

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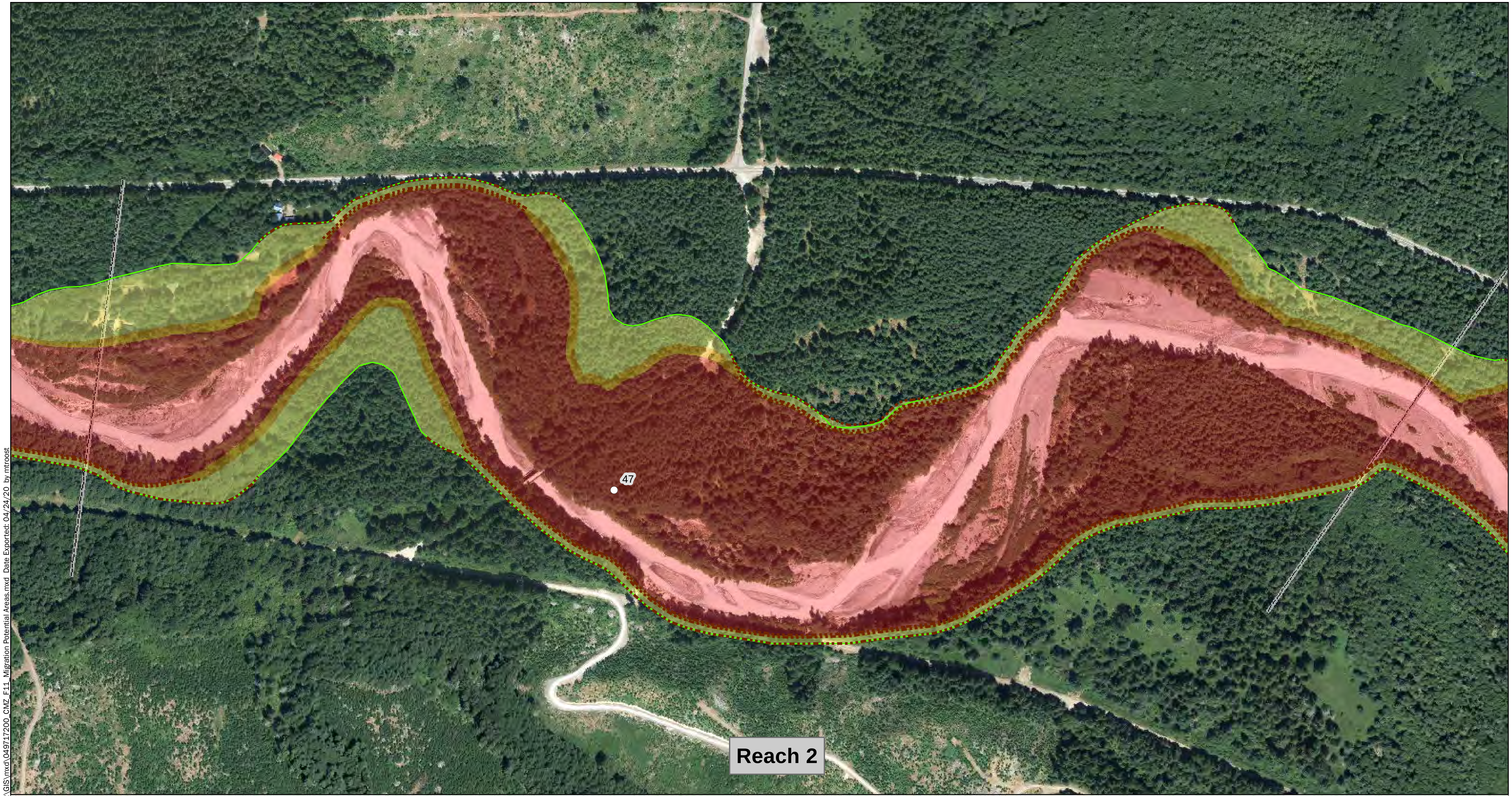
Figure 11-A
Reach 1

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F11_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost



Notes:
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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400

Feet

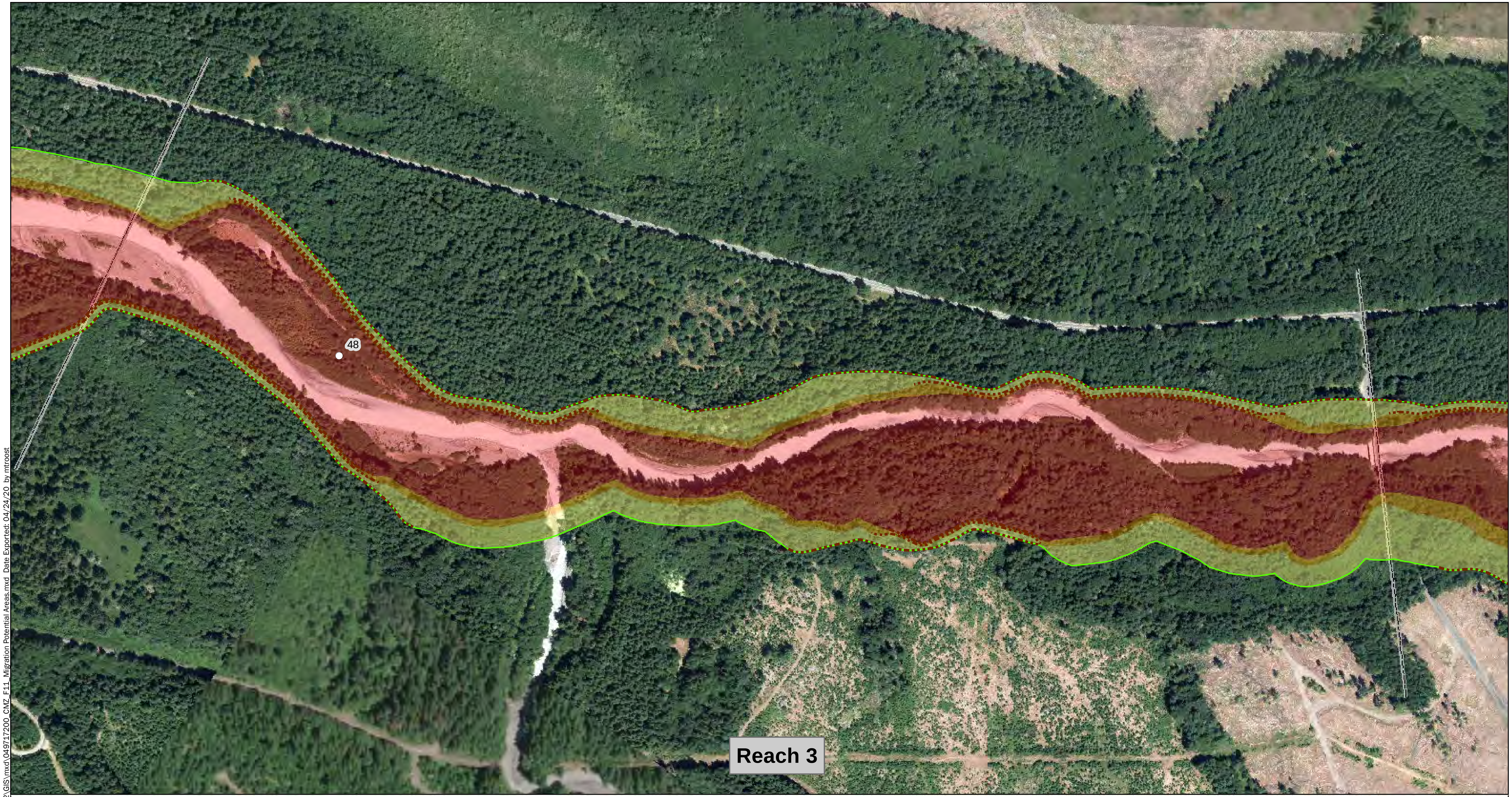
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 11-B
Reach 2

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F11_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost



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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

400 0 400

Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 11-C
Reach 3

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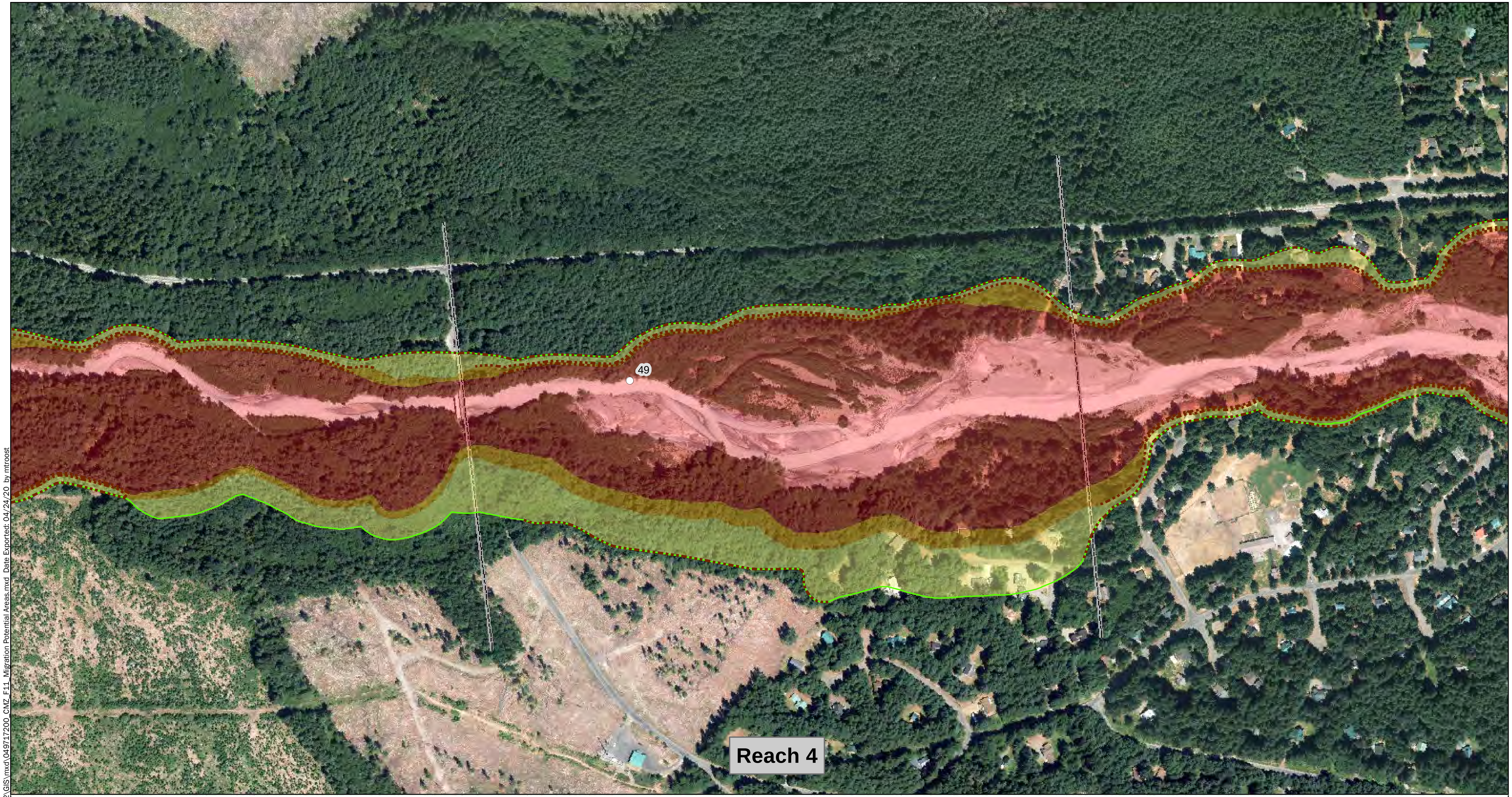

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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400

Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 11-D
Reach 4

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F11_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost

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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

400 0 400
Feet

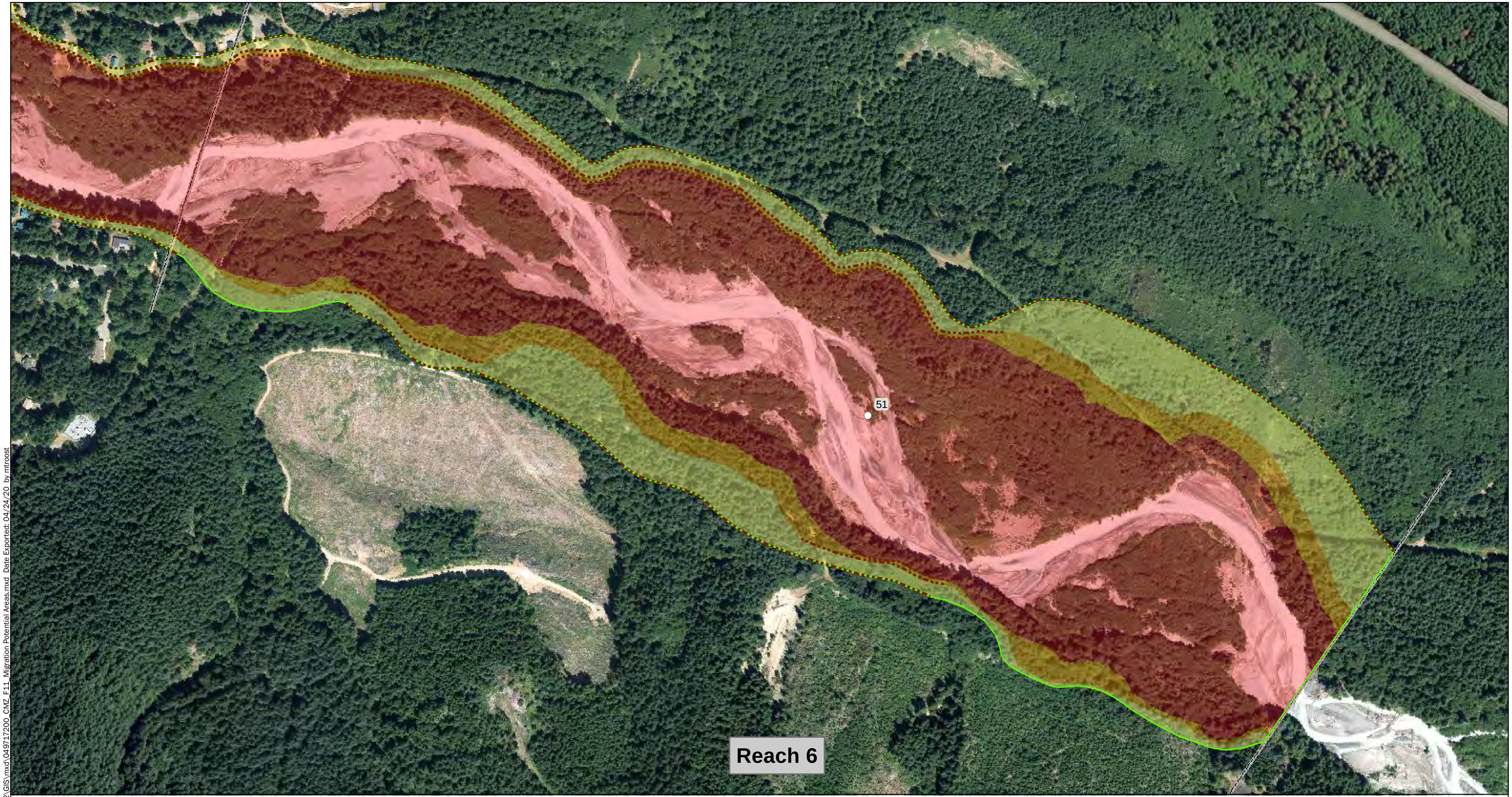
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 11-E
Reach 5

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F11_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost



\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F11_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost

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Data Source: 2017 Aerial Photograph from Pirece County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Reach Breaks
- Geotechnical Setback
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

400 0 400

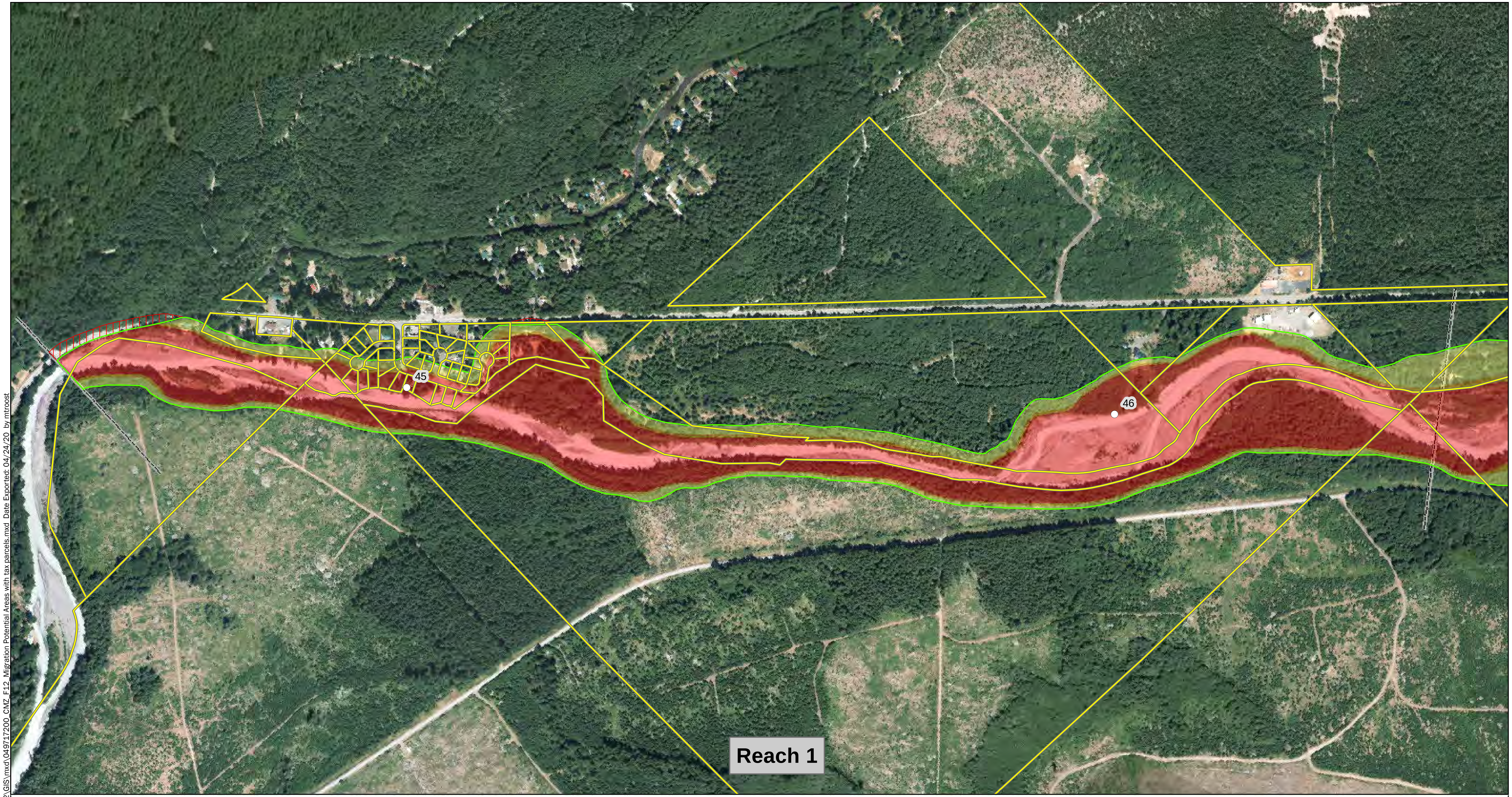
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 11-F
Reach 6



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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400

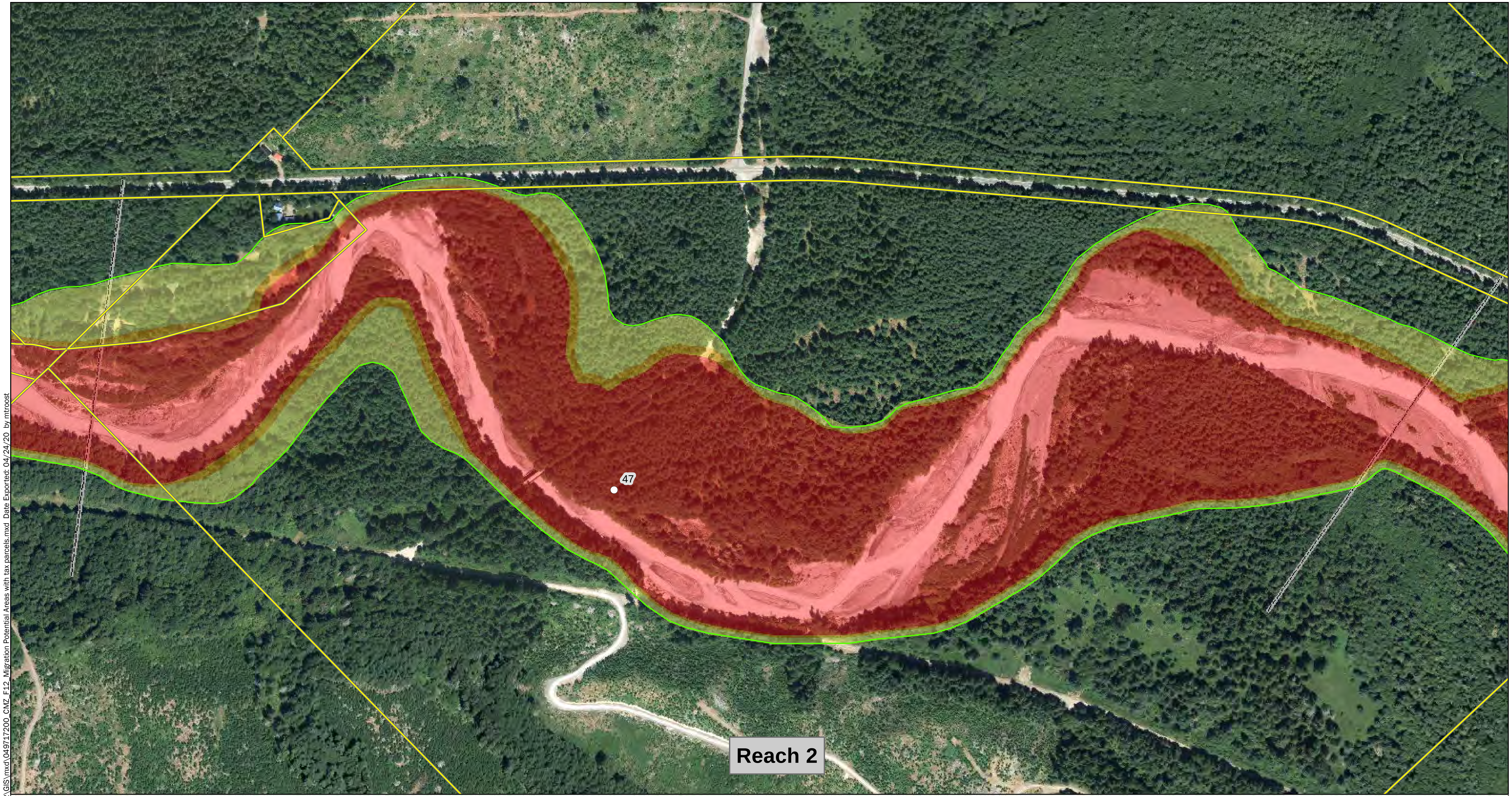
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-A
Reach 1



Notes:

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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400

Feet

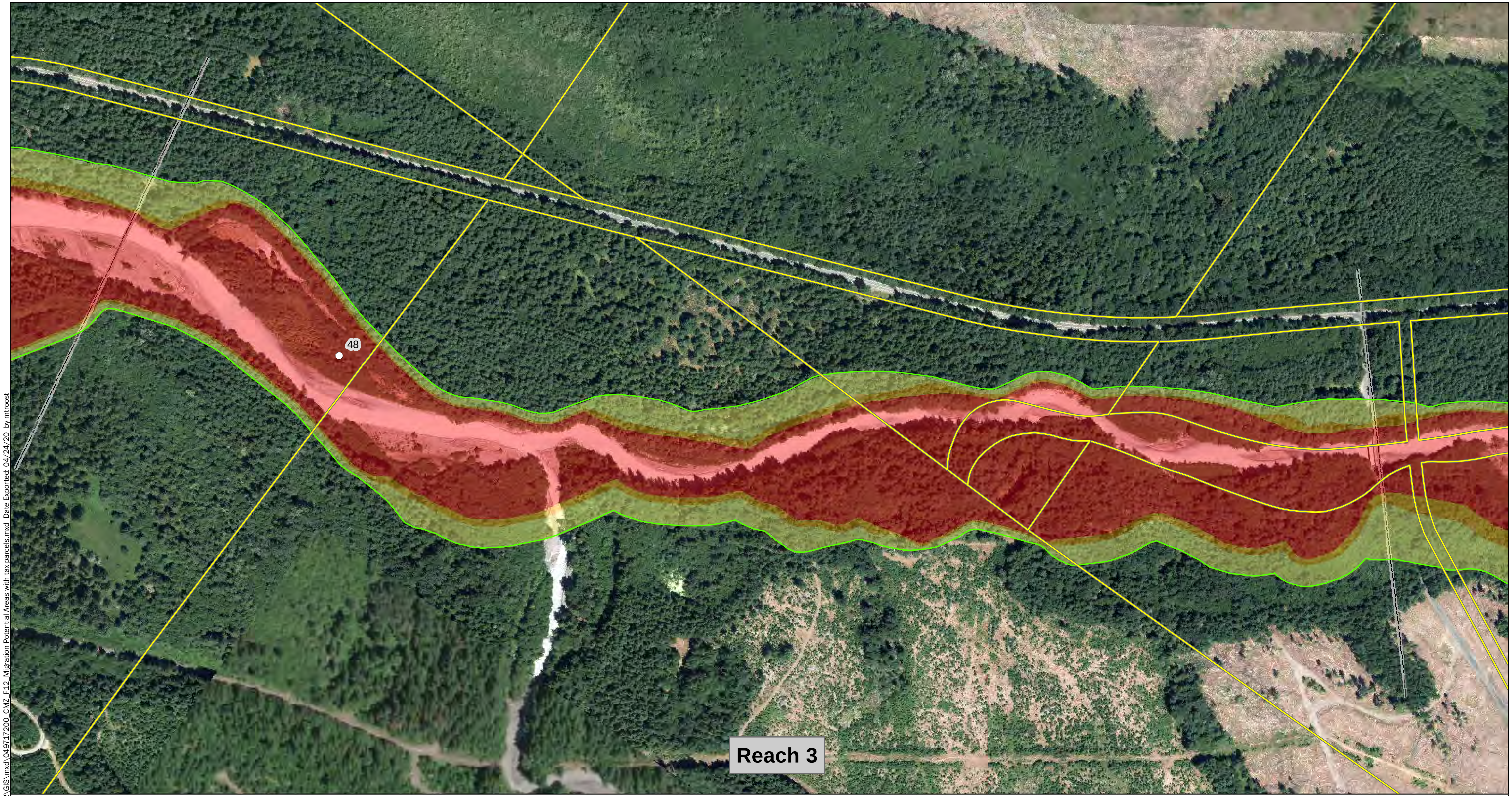
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-B
Reach 2

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F12_Migration Potential Areas with tax parcels.mxd Date Exported: 04/24/20 by mtroost



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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

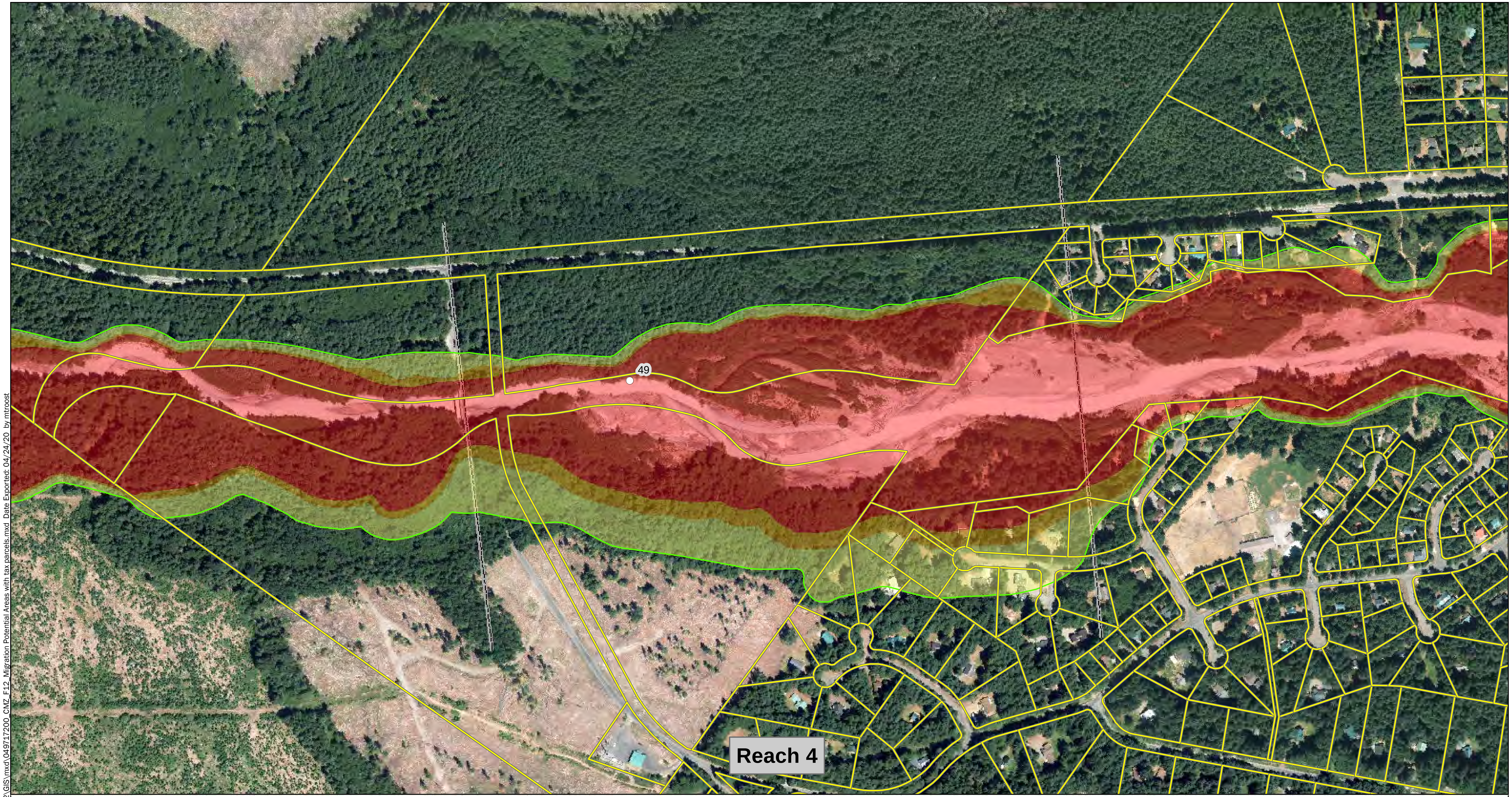
400 0 400
Feet

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-C
Reach 3



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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-D
Reach 4

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F12_Migration Potential Areas with tax parcels.mxd Date Exported: 04/24/20 by mtroost

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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

N E S W

400 0 400

Feet

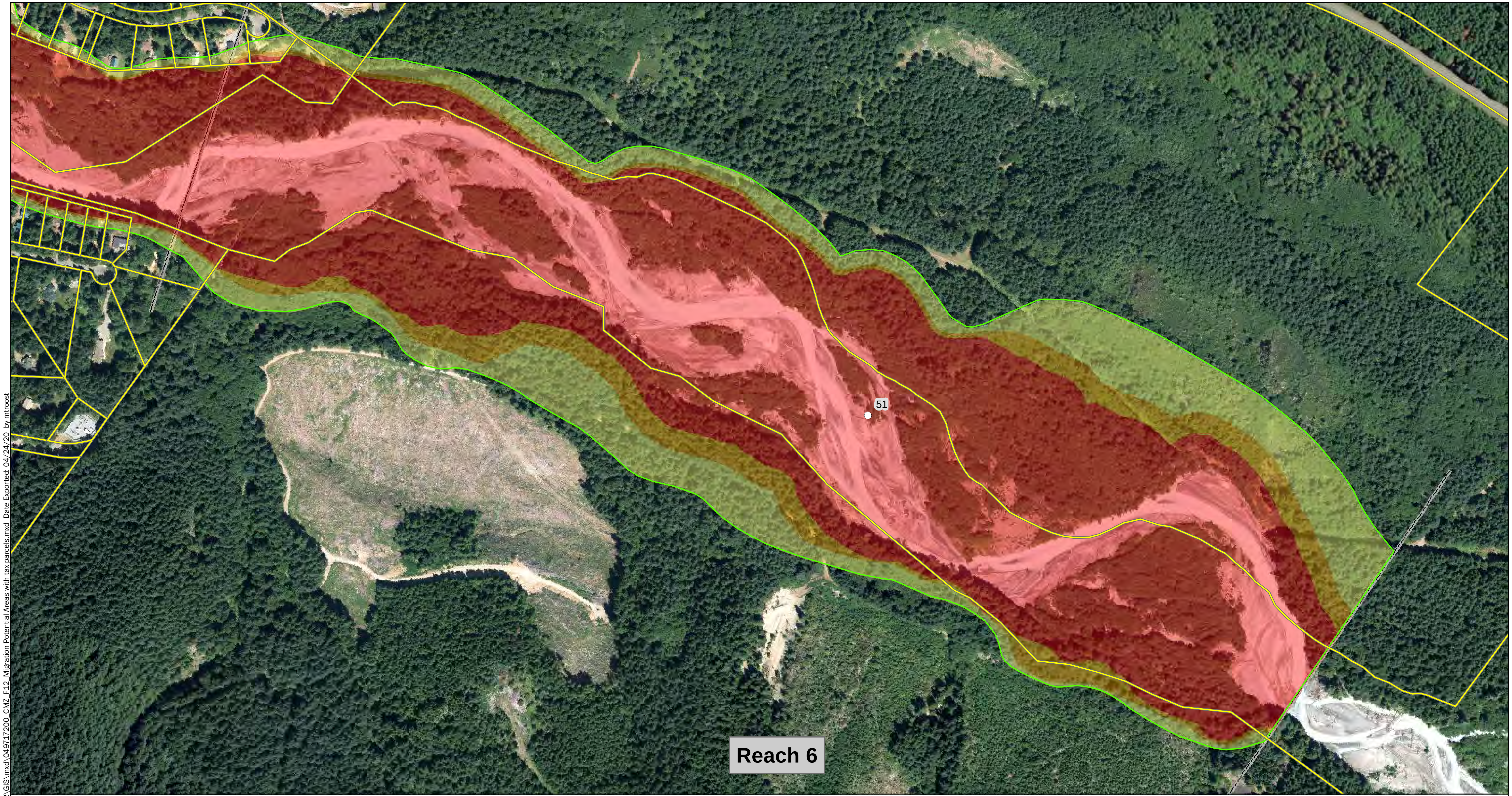
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-E
Reach 5

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F12_Migration Potential Areas with tax parcels.mxd Date Exported: 04/24/20 by mtroost



\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F12_Migration Potential Areas with tax parcels.mxd Date Exported: 04/24/20 by mtroost

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Data Source: 2017 Aerial Photograph and Parcels from Pierce County

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- River Miles
- Reach Breaks
- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

400 0 400
Feet

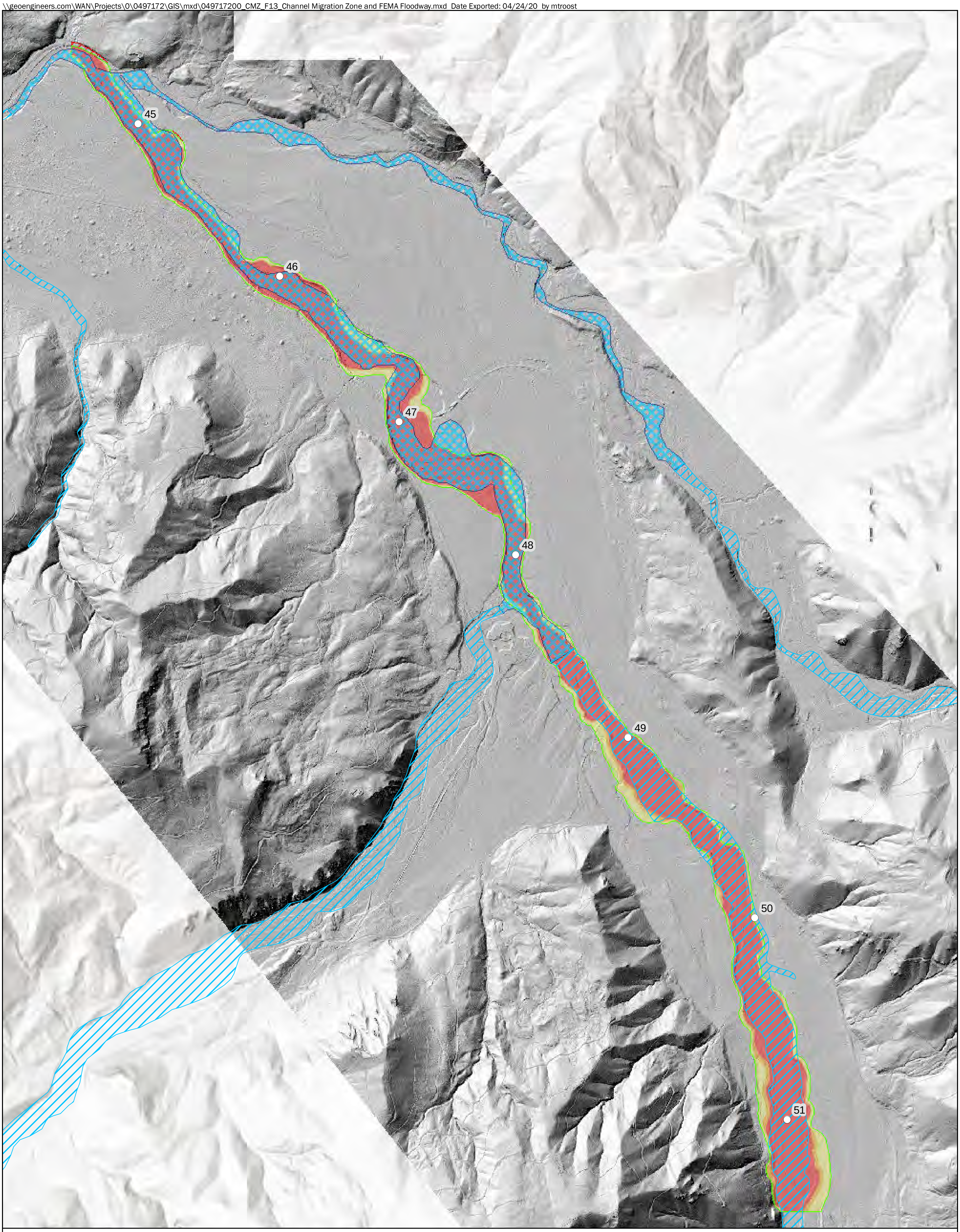
Channel Migration Zone and Migration Potential Areas

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure 12-F
Reach 6

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_F13_Channel Migration Zone and FEMA Floodway.mxd Date Exported: 04/24/20 by mtroost



Legend

- RiverMile
- Pierce County Deep and/or Fast Flowing Floodway Unverified
- FEMA Floodway
- Channel Migration Zone Boundary
- Disconnected Migration
- Severe Migration Potential
- Moderate Migration Potential
- Low Migration Potential

N
W E
S

2,225 0 2,225

Feet

FEMA Floodway and Pierce County Deep and/or Fast Flowing Floodway

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure 13

Notes:
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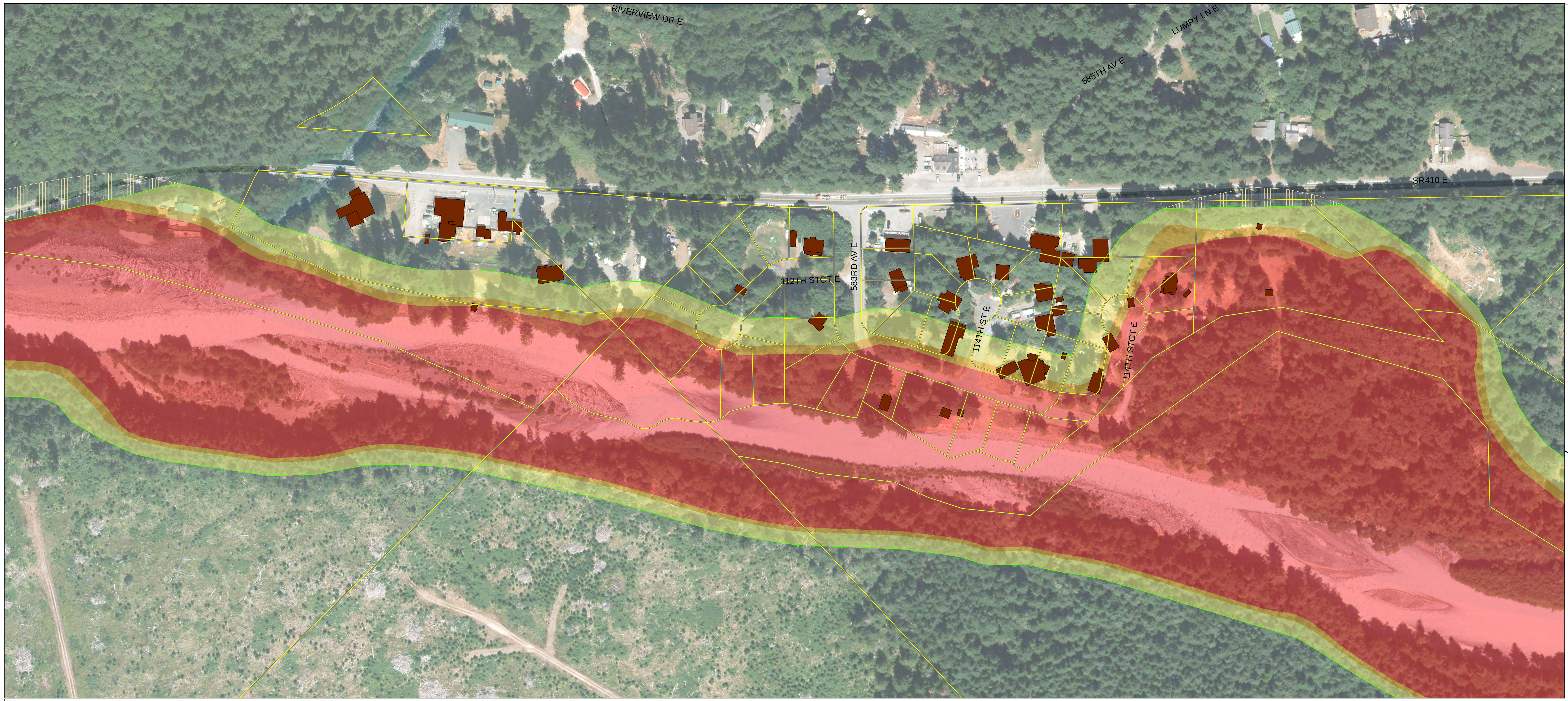
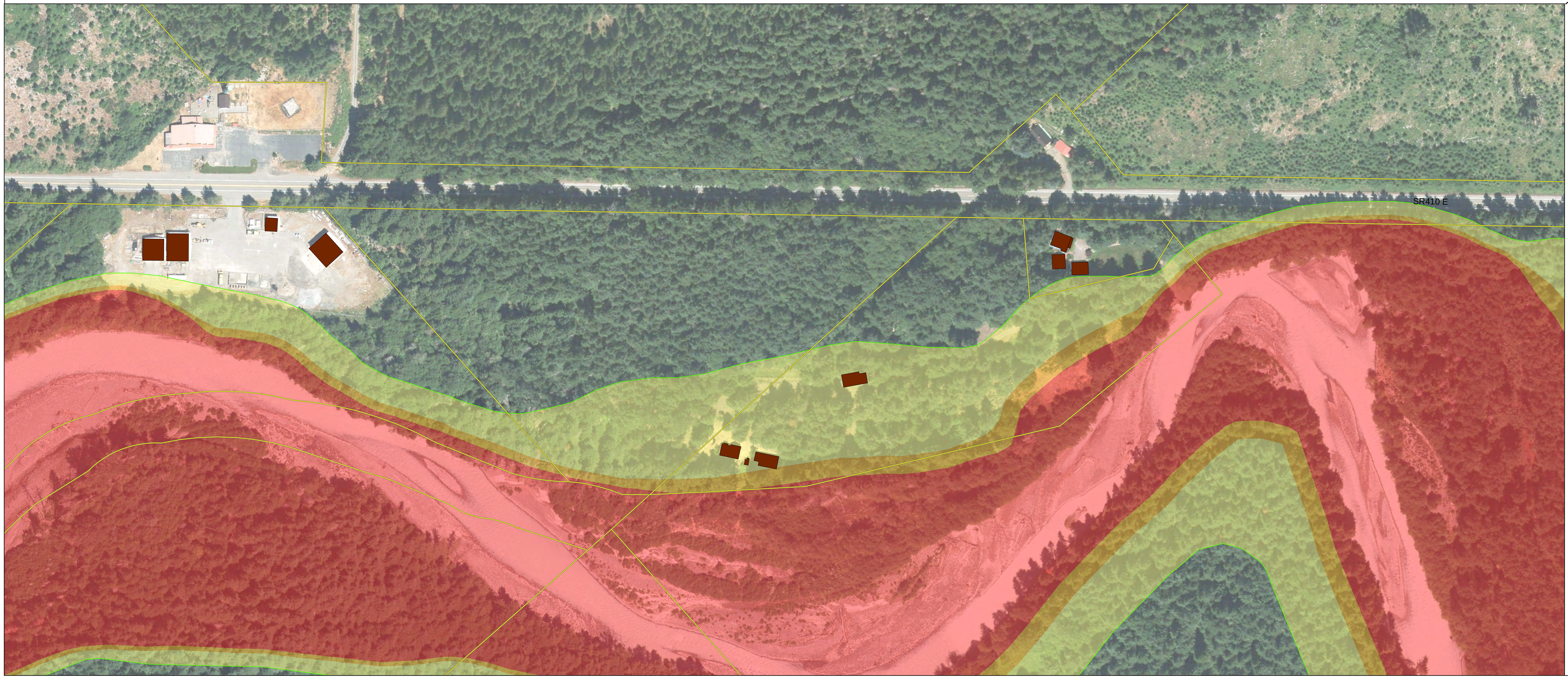
Data Source: Geology, Modified by GeoEngineers based on WADNR 1:100,000 Geologic Mapping

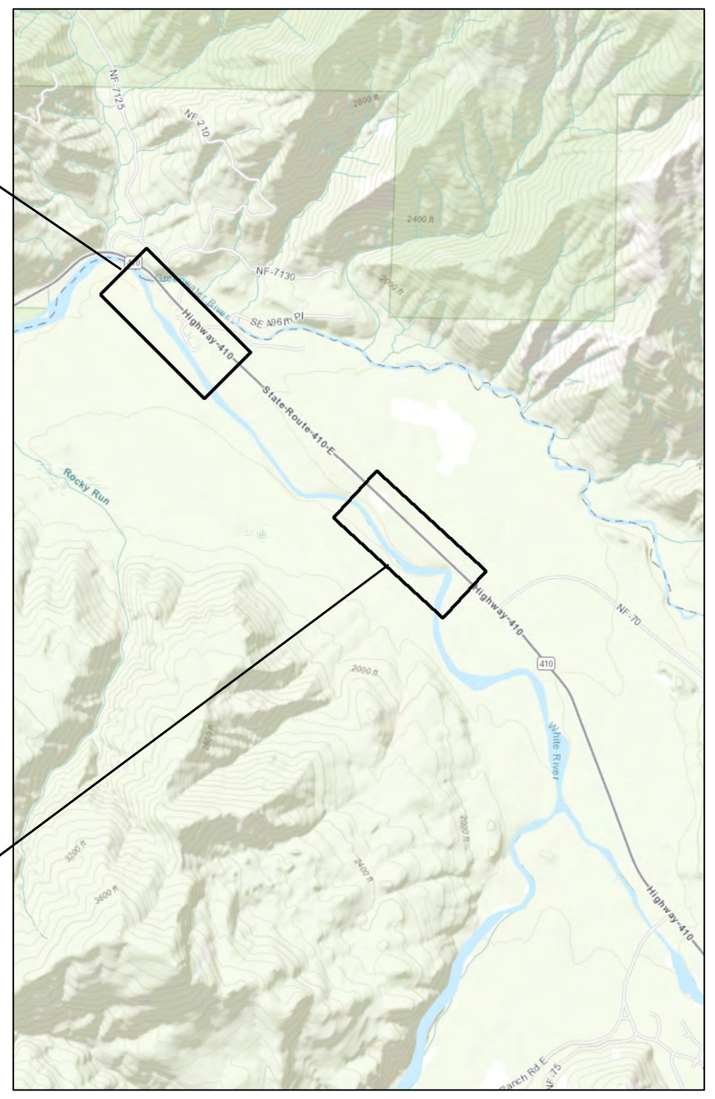
Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet





Legend

- Tax Parcels
- Channel Migration Zone Boundary
- Disconnected Migration Area
- Roof and/or Deck
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area



100 0 100
Feet

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Data Source: 2017 Aerial and parcels from Pierce County

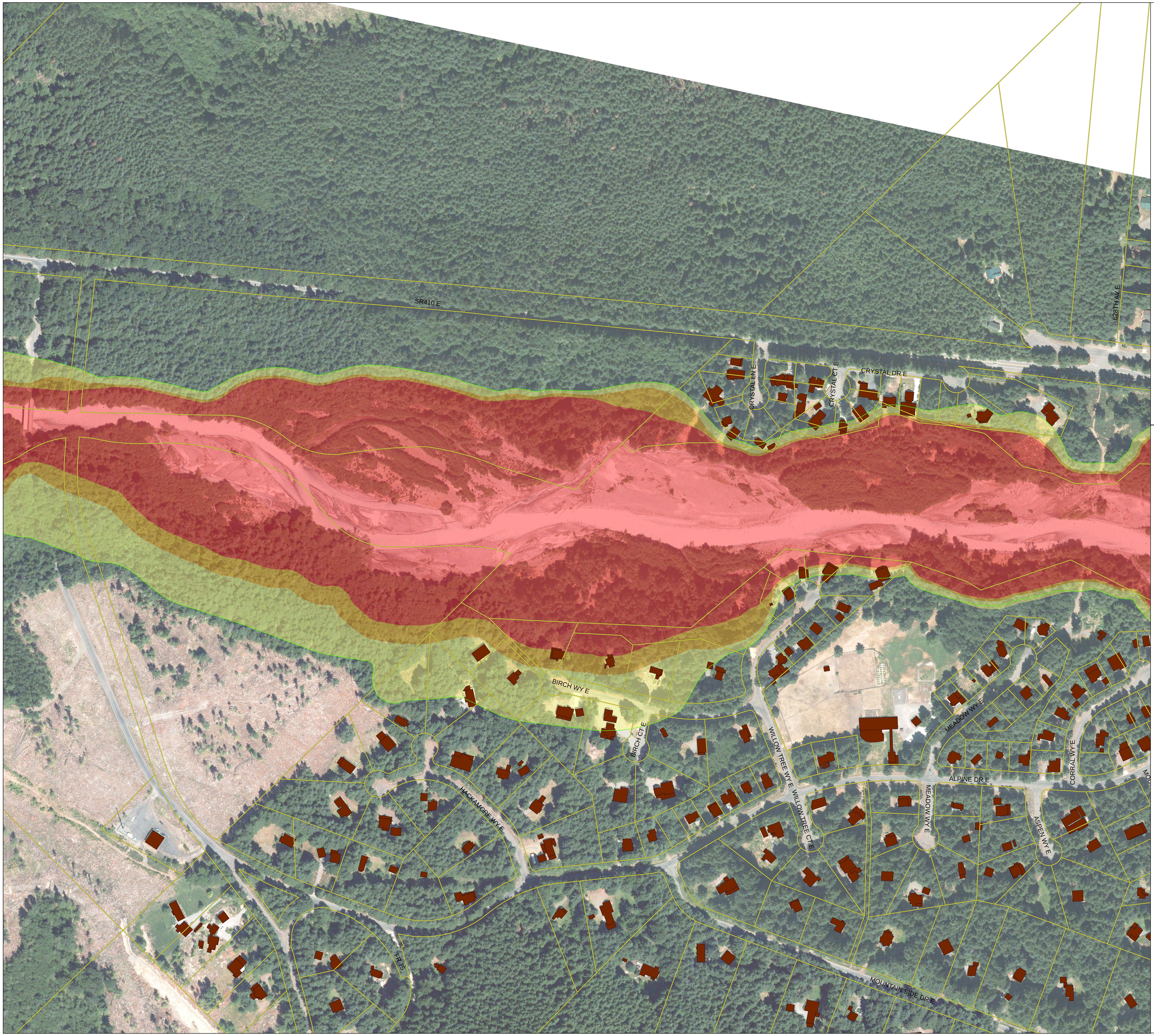
CMZ with Migration Potential Areas
Town of Greenwater

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

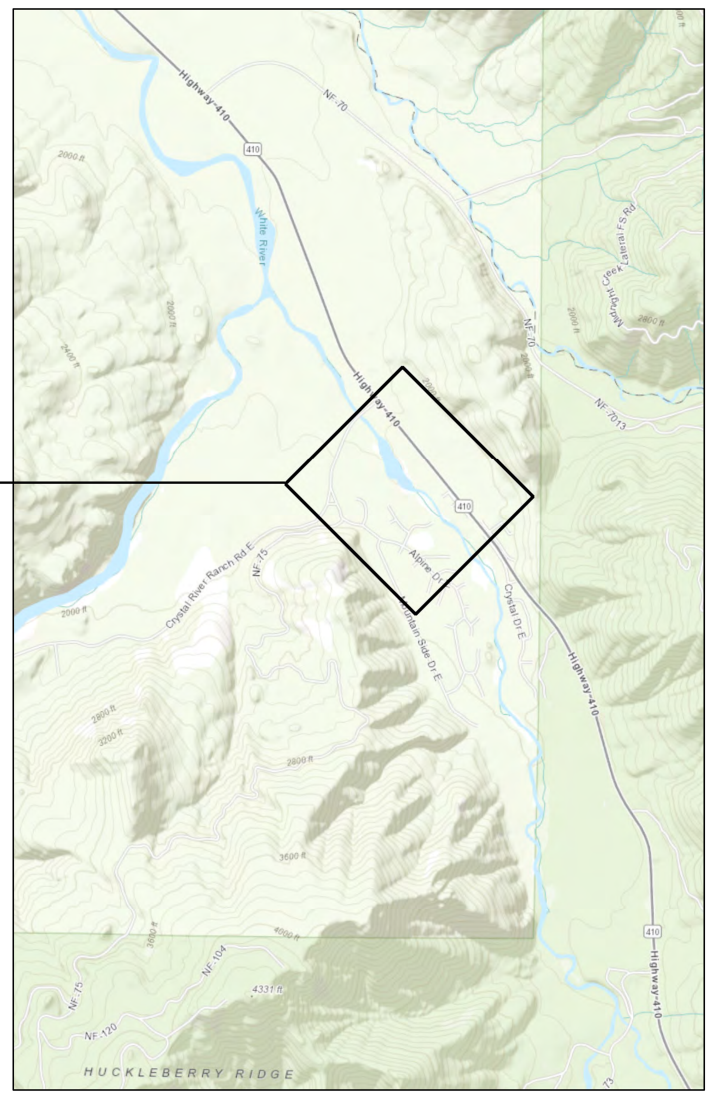
Pierce County

Plate 1



Legend

- Tax Parcels
- Channel Migration Zone Boundary
- Roof and/or Deck
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area



125 0 125

Feet

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Data Source: 2017 Aerial and parcels from Pierce County

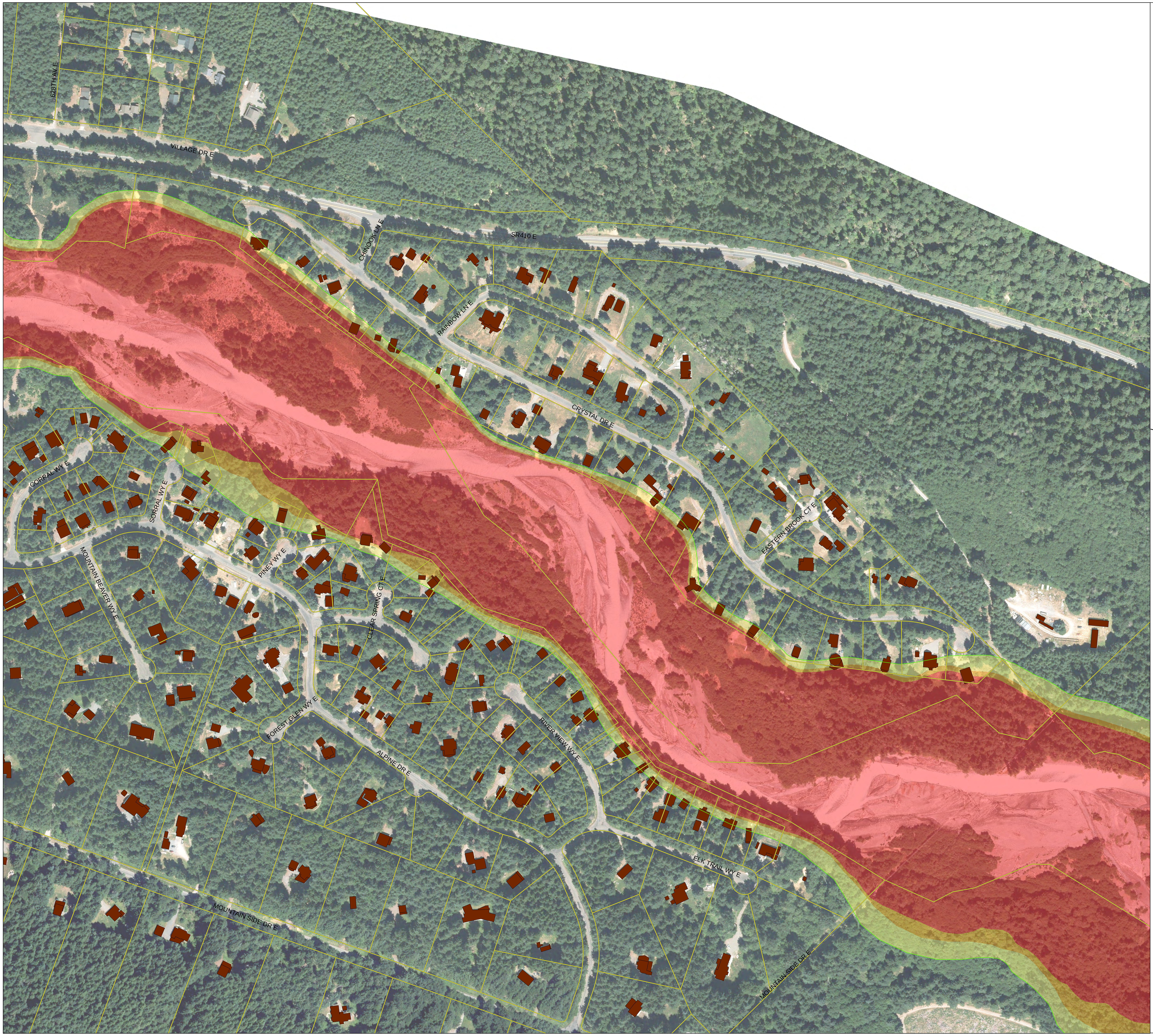
CMZ and Migration Potential Areas
Crystal River Ranch and Crystal Village HOAs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

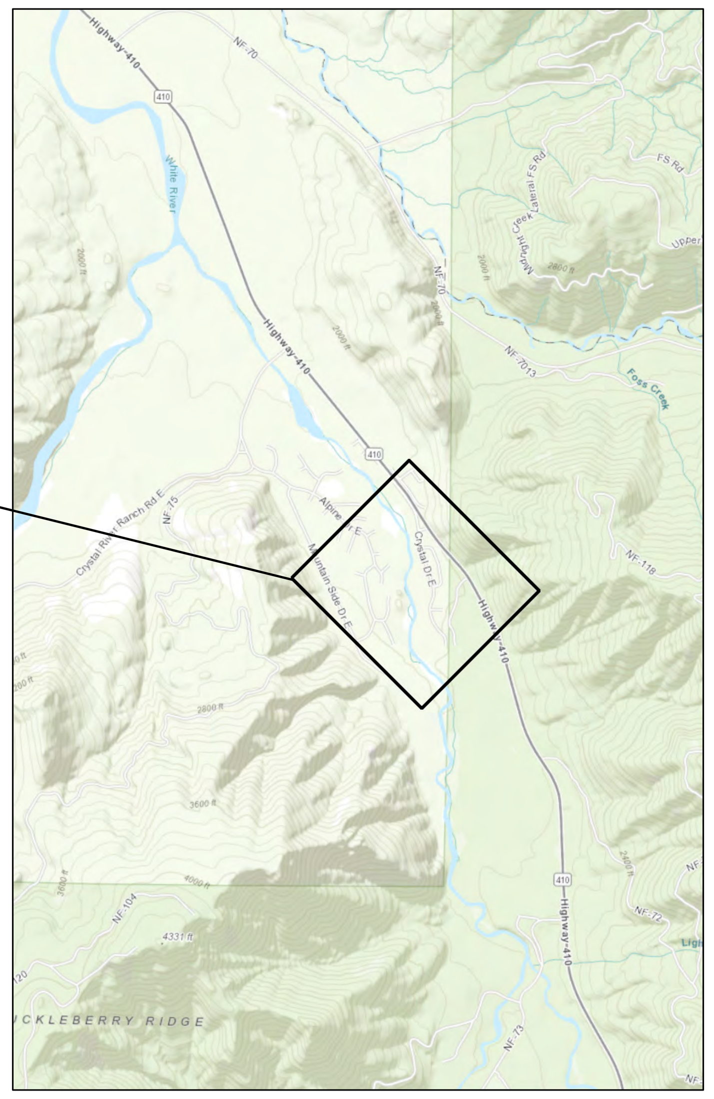
Pierce County

Plate 2



Legend

- Tax Parcels
- Channel Migration Zone Boundary
- Roof and/or Deck
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area



125 0 125

Feet

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Data Source: 2017 Aerial and parcels from Pierce County

CMZ and Migration Potential Areas
Crystal River Ranch and Crystal Village HOAs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Pierce County

Plate 3

APPENDICES

Appendix A
Site Photographs

Photograph 1. Bar material and Osceola Mudflow with a dark soil layer above and interface with alluvium at center of photo. Soil layer covers both units. Near RM 47.5.

Photograph 2. Bar material and Osceola Mudflow along left bank near RM 50.4 and south end of Crystal River Ranch Community

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure A-1

0497-172-00 Date Exported: 10/17/19

Photograph 3. One of numerous side channels within floodplain.

Photograph 4. Abundant large wood within Reach 5.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure A-2

Photograph 5. Osceola Mudflow along left bank near RM 47, approximately 30 to 35 feet high.

Photograph 6. High bank in Osceola Mudflow that is actively eroding.

0497-172-00 Date Exported: 10/17/19

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure A-3

Photograph 7. Lower terrace of Osceola Mudflow at Crystal River Ranch. Osceola Mudflow at base of slope is overlain by approximately 4 to 6 feet of alluvial sediments with two different distinct layers; the lower is brown, the upper is gray.

Photograph 8. Bridge near RM 48.9.

Site Photographs	
Upper White River CMZ Delineation Pierce County, Washington	
GeoEngineers	**Figure A-4**

Photograph 9. Bridge near RM 46.8.

Photograph 10. Abutment to old bridge near RM 49.7 consists of massive riprap and wood.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure A-5

Photograph 11. Pierce County levee along right bank near RM 45.1.

Photograph 12. Levee along right bank near RM 46.6.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GEOENGINEERS

Figure A-6

Photograph 13. Crystal River Ranch rock vane exposed.

Photograph 14. Large ecology block revetment near RM 49.8.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers | **Figure A-7**

Photograph 15. Gabion basket revetment near RM 49.5.

Photograph 16. Eroding Osceola Mudflow bank near Crystal River Ranch with pistol butt tree.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure A-8

Photograph 17. Debris flow of unknown origin with alluvium and topsoil on top (arrow marks boundary).

Photograph 18. Debris flow of unknown origin and significantly undercut bank. Tree growing atop of undercut with overhanging roots and other vegetation.

Site Photographs

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure A-9

APPENDIX B
Transect Information

Table B-1

Measured Migration Distances in Alluvium

Upper White River Channel Migration Zone Delineation

Near the Town of Greenwater in Pierce County, Washington

Reach	Transect	Migration Distance (feet) from Previous Aerial Photo Record in Alluvium								
		1954	1962	1970	1978	1985	1993	2002	2011	2017
1	1	3	4	3	1	4	1	1	3	22
	2	2	16	3	15	6	1	4	51	20
	3	10	24	1	0	2	5	66	12	10
	4	11	9	1	14	8	23	106	2	4
	5	13	27	0	0	2	62	51	0	3
	6	17	15	3	0	6	23	4	2	4
	7	33	0	6	1	1	8	50	14	11
	8	40	15	16	18	9	31	22	1	7
	9	31	53	12	22	54	5	8	47	39
	10	1	26	14	5	26	19	1	2	34
	11	21	10	0	15	4	3	1	0	43
	12	27	10	0	41	3	0	3	2	45
	13	36	26	1	27	8	0	1	0	19
	14	24	36	1	0	4	0	2	4	7
	15	7	33	2	1	0	1	0	54	2
	16	17	40	2	0	7	12	8	47	52
	17	21	32	6	4	11	31	25	21	56
	18	3	28	5	5	4	14	3	10	2
	19	1	33	5	2	5	3	0	0	0
	20	1	23	4	2	4	3	0	8	10
	21	0	25	0	7	5	2	1	12	21
	22	6	21	1	1	4	1	0	4	11
	23	9	13	4	3	7	0	0	4	10
	24	4	10	4	4	0	0	1	7	14
	25	9	16	2	0	0	1	2	15	10
	26	6	15	2	4	1	1	3	14	12
	27	1	14	4	8	8	6	3	17	17
	28	8	15	9	10	8	5	0	36	72
	29	4	14	8	11	11	8	2	146	60
	30	37	9	7	3	13	33	10	134	43
	31	100	10	3	15	3	22	2	13	96
	32	61	4	0	18	3	16	5	92	61
	33	25	4	2	21	4	11	12	100	34
	34	3	0	0	12	1	12	10	30	49
	35	13	3	3	12	8	4	8	39	67
	36	7	4	9	7	10	16	17	50	35
	37	4	10	14	1	6	7	14	6	4
	38	1	17	5	2	2	8	9	44	12
	39	3	16	1	1	4	12	36	57	45
	40	4	19	0	4	5	40	52	43	105

Reach	Transect	Migration Distance (feet) from Previous Aerial Photo Record in Alluvium								
		1954	1962	1970	1978	1985	1993	2002	2011	2017
2	41	9	20	2	39	25	47	31	77	110
	42	8	19	12	30	34	53	21	74	67
	43	9	16	1	28	37	10	6	28	23
	44	17	37	5	14	22	2	4	17	5
	45	17	37	2	31	39	27	8	3	1
	46	6	30	4	10	3	13	71	2	24
	47	11	145	74	18	12	12	26	5	1
	48	15	184	149	27	8	19	50	0	5
	49	58	138	121	36	12	17	53	1	0
	50	57	160	35	22	0	4	19	2	1
	51	24	43	1	19	0	7	0	0	3
	52	2	6	2	7	8	0	2	5	0
	53	29	25	15	6	14	38	2	3	6
	54	21	7	16	7	16	94	3	4	2
	55	15	3	3	38	8	113	15	5	7
	56	46	9	8	6	6	81	9	9	36
	57	36	6	4	13	3	8	8	3	6
	58	7	28	29	82	11	0	15	15	58
	59	9	69	24	93	9	11	29	70	170
	60	54	117	121	70	9	52	66	94	161
	61	91	115	122	93	54	3	10	53	99
	62	55	36	113	45	10	21	1	4	34
	63	3	18	102	6	47	4	3	16	4
	64	18	3	30	14	3	20	7	1	92
	65	12	8	1	2	0	2	1	13	42
	66	4	8	5	7	5	1	14	7	3
	67	54	7	7	1	1	5	4	40	16
	68	45	5	3	9	0	14	11	65	9
3	69	16	4	0	7	5	29	19	48	6
	70	70	2	2	67	18	63	4	30	2
	71	145	3	2	157	6	157	3	18	0
	72	112	0	11	130	1	134	0	7	3
	73	78	7	42	45	5	97	7	0	2
	74	51	89	39	5	8	10	17	30	39
	75	23	58	21	10	29	29	11	84	33
	76	37	3	20	27	49	47	3	21	1
	77	2	21	90	12	6	20	1	4	8
	78	60	2	10	13	8	6	12	4	14
	79	9	3	2	0	1	0	41	16	25
	80	1	0	2	0	8	2	50	6	12
	81	6	7	2	6	2	11	8	6	3
	82	22	4	5	5	20	36	10	5	0
	83	29	10	1	4	13	27	12	9	3
	84	14	12	0	7	16	15	9	5	2
	85	4	3	6	2	15	13	2	3	10
	86	10	6	2	11	13	5	33	39	9

Reach	Transect	Migration Distance (feet) from Previous Aerial Photo Record in Alluvium								
		1954	1962	1970	1978	1985	1993	2002	2011	2017
3 (continued)	87	43	115	101	9	9	11	47	14	1
	88	116	24	131	2	58	6	67	26	20
	89	63	69	105	16	68	1	58	0	47
	90	24	15	29	6	0	1	26	2	0
	91	39	22	35	17	1	4	8	14	2
4	92	23	23	6	21	4	9	8	5	0
	93	41	64	4	6	17	102	24	7	0
	94	95	98	5	30	8	72	22	26	0
	95	36	19	22	69	14	11	114	71	51
	96	69	35	22	29	12	41	79	56	150
	97	152	90	139	93	5	69	19	35	179
	98	75	95	187	55	18	0	149	22	261
	99	123	50	106	5	46	18	94	17	100
	100	49	4	82	11	171	5	28	2	1
	101	16	15	77	132	58	13	44	80	21
	102	8	33	75	84	52	15	84	28	5
5	103	47	5	37	6	90	27	51	53	69
	104	119	70	51	2	8	49	30	135	41
	105	26	7	10	15	40	86	41	152	19
	106	77	115	63	2	24	24	25	86	11
	107	33	141	30	43	37	16	25	42	10
	108	6	56	47	9	52	6	4	26	13
	109	5	6	77	4	1	20	31	17	17
	110	40	52	52	16	14	57	75	69	18
	111	66	30	34	36	30	66	0	167	1
	112	44	38	105	6	25	79	61	166	2
	113	2	59	83	21	106	5	75	170	1
	114	36	58	10	20	113	0	71	106	11
	115	27	132	126	4	19	33	24	116	7
	116	25	108	136	51	10	36	36	70	83
	117	41	115	174	51	4	4	42	8	78
	118	34	55	85	15	19	14	17	22	41
	119	24	3	6	35	91	37	80	74	14
	120	22	18	104	13	144	78	118	8	8
	121	115	25	122	1	2	16	80	41	3
	122	102	2	28	8	73	9	2	43	6
	123	117	56	93	60	11	72	86	69	35
6	124	107	53	134	73	5	74	106	26	153
	125	125	44	78	18	87	3	2	59	61
	126	66	20	2	19	60	1	13	81	30
	127	11	37	101	4	23	38	33	144	5
	128	38	27	130	62	34	132	125	82	18
	129	8	64	12	42	22	124	173	49	0
	130	13	27	5	13	50	112	212	84	6
	131	80	85	19	128	30	96	262	42	24
	132	98	17	26	95	19	62	265	0	11

Reach	Transect	Migration Distance (feet) from Previous Aerial Photo Record in Alluvium								
		1954	1962	1970	1978	1985	1993	2002	2011	2017
6 (continued)	133	21	167	0	25	32	112	198	48	94
	134	17	131	8	107	28	13	48	10	113
	135	104	9	3	115	16	32	154	65	82
	136	154	46	47	60	50	56	288	289	29
	137	84	56	5	3	155	63	302	411	7
	138	55	40	11	167	203	145	65	350	1
	139	135	31	69	136	216	42	24	125	29
	140	143	108	37	215	183	143	28	57	45
	141	17	18	20	119	185	58	111	300	20
	142	123	56	8	4	133	13	216	212	32
	143	100	50	50	82	43	5	158	51	21
	144	3	1	28	10	41	61	110	34	5

Notes:

Did not use in reach average because of anthropogenic influence

Distances are rounded to the nearest whole number

Table B-2

Measured Migration Distances in the Osceola Mudflow

Upper White River Channel Migration Zone Delineation

Near the Town of Greenwater in Pierce County, Washington

Reach	Transect	Migration Distance (feet) From Previous Aerial Photo Record in Osceola Mudflow								
		1954	1962	1970	1978	1985	1993	2002	2011	2017
2	46	4	23	6	17	0	21	3	0	8
	51	0	1	1	9	3	3	20	0	0
	52	0	0	0	0	0	0	0	0	0
	53	0	0	0	0	0	0	0	0	0
	54	NA	NA	NA	6	10	4	27	11	0
	55	NA	NA	NA	21	3	12	26	9	4
	56	NA	NA	1	18	6	0	18	3	3
	57	0	0	0	0	0	0	20	12	12
	58	0	0	18	0	0	0	9	5	0
	59	0	0	2	0	NA	NA	NA	3	0
5	110	0	0	17	11	18	0	19	0	3
	121	19	28	0	0	0	0	0	0	0
	122	23	34	0	5	0	0	0	0	9
	123	26	37	0	24	0	0	0	0	0
6	124	19	52	0	44	0	0	0	3	0

Notes

NA - Active channel was not in contact with the Osceola Mudflow

APPENDIX C
Greenwater CMZ at the Confluence with the Upper White River

APPENDIX C
LOWER GREENWATER RIVER CHANNEL MIGRATION ZONE DELINEATION
SR 410 BRIDGE TO THE CONFLUENCE WITH THE UPPER WHITE RIVER, GREENWATER, PIERCE COUNTY, WASHINGTON

Introduction

A Channel Migration Zone (CMZ) delineation was published for the Greenwater River in Pierce County, on November 9, 2017 (GeoEngineers). That delineation extended from approximately River Mile (RM) 1.2 downstream to the SR 410 Bridge near the town of Greenwater, at approximate RM 0.1. This addendum extends the CMZ delineation from the SR 410 Bridge downstream to the confluence with the active channel of the upper White River, a distance of about 300 feet. The CMZ delineation of this 0.06-mile river section was originally omitted from the November 9, 2017 CMZ report because, at that time, it was anticipated that the future upper White River CMZ delineation would capture that section of the Greenwater River. However, because the outer limits of the delineated Severe Migration Potential Area on the Upper White River CMZ did not reach the 2017 delineation limits of the Greenwater River, a gap in the delineation of the CMZ along the Greenwater River near the confluence remained. Consequently, this addendum addresses the Pierce County (i.e., south) side of the Greenwater River in the remaining reach to be delineated.

Data Sources and Methods

The data sources for this delineation are provided in the November 9, 2017 report, Table 3. The methodology used to complete this delineation are documented under the Methods section of the 2017 report.

Setting

This short section of the Greenwater River is bounded on both sides by the town of Greenwater development. SR 410 extends northwest to southeast just upstream of the confluence with the Upper White River, bisecting the town of Greenwater. The Greenwater River demarcates the boundary between King and Pierce counties: the north bank of the Greenwater River is within King County; the south bank is within Pierce County.

Topography and Geology

The reach is located at the confluence with the upper White River. The banks of the reach are formed in alluvium.

Desktop Evaluation and Field Reconnaissance

Field reconnaissance was completed in mid-July 2019 by two fluvial geomorphologists concurrent with the fieldwork for the upper White River CMZ delineation. The desktop evaluation, including delineation of the Historical Migration Zone (HMZ) and avulsion hazards were completed in early to mid-February 2020. Rates calculated for the Greenwater River during the 2017 CMZ analysis were applied to this section of the Greenwater River.

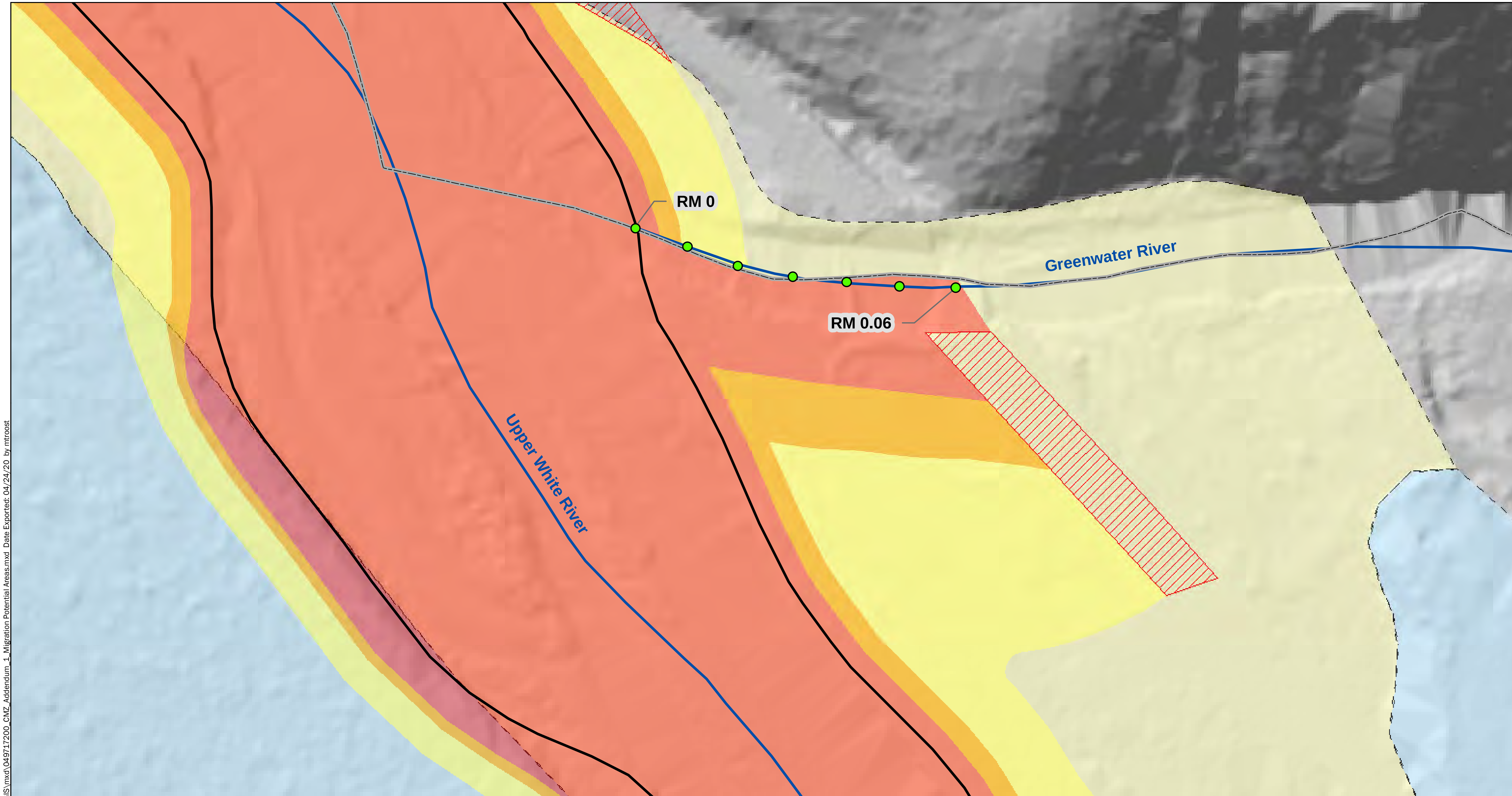
Hydrology and Climate

Please refer to the November 9, 2017 report for a summary of the hydrology and climatic conditions of the site.

Discussion

The CMZ for the upper White River did not extend laterally to the SR 410 Bridge over the Greenwater River, just upstream of the confluence. However, this section of the Greenwater River has been highly influenced by the upper White River. Currently, flow of the Greenwater River abruptly turns north where it intersects the upper White River active channel and runs parallel to it for approximately 650 feet. The location where the waters join had been upstream (relative to the White River flow) of the current location as late as 2015, but has since migrated downstream because of the influence of a gravel bar that has been building between the two rivers within the upper White River active channel. Because this gravel bar is within the active channel of the upper White River, the CMZ delineated for the White River applies here (see Figure C-1).

Although the confluence area is fairly dynamic within the active channel of the upper White River, the SR 410 bridge limits the mobility of the Greenwater River just upstream of the confluence. SR 410 also represents a barrier to lateral migration in a northeasterly direction.



Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: LiDAR, Pierce County 2010

Projection: NAD 1983 HARN StatePlane Washington South FIPS 4602 Feet

Legend

- Pierce County Boundary
- Disconnected Migration Area
- Severe Migration Potential Area
- Moderate Migration Potential Area
- Low Migration Potential Area

Geologic Unit

- Quaternary Alluvium
- Osceola Mudflow

N W E S

100 0 100

Feet

Channel Migration Zone and Migration Potential Areas Lower Greenwater River Downstream of SR 410

Upper White River CMZ Delineation
Pierce County, Washington

GeoEngineers

Figure C-1

\\geoengineers.com\WAN\Projects\0\0497172\GIS\mxd\049717200_CMZ_Addendum_1_Migration Potential Areas.mxd Date Exported: 04/24/20 by mtroost

APPENDIX D
Report Limitations and Guidelines for Use

APPENDIX D
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 of Pierce County Planning & Public Works and their authorized agents. 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 report has been prepared for a portion of the Upper White River. 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.

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, wildfires, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

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

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 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.

A Geotechnical Engineering or Geologic Report Could Be Subject to Misinterpretation

Misinterpretation of this report by others 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.

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.