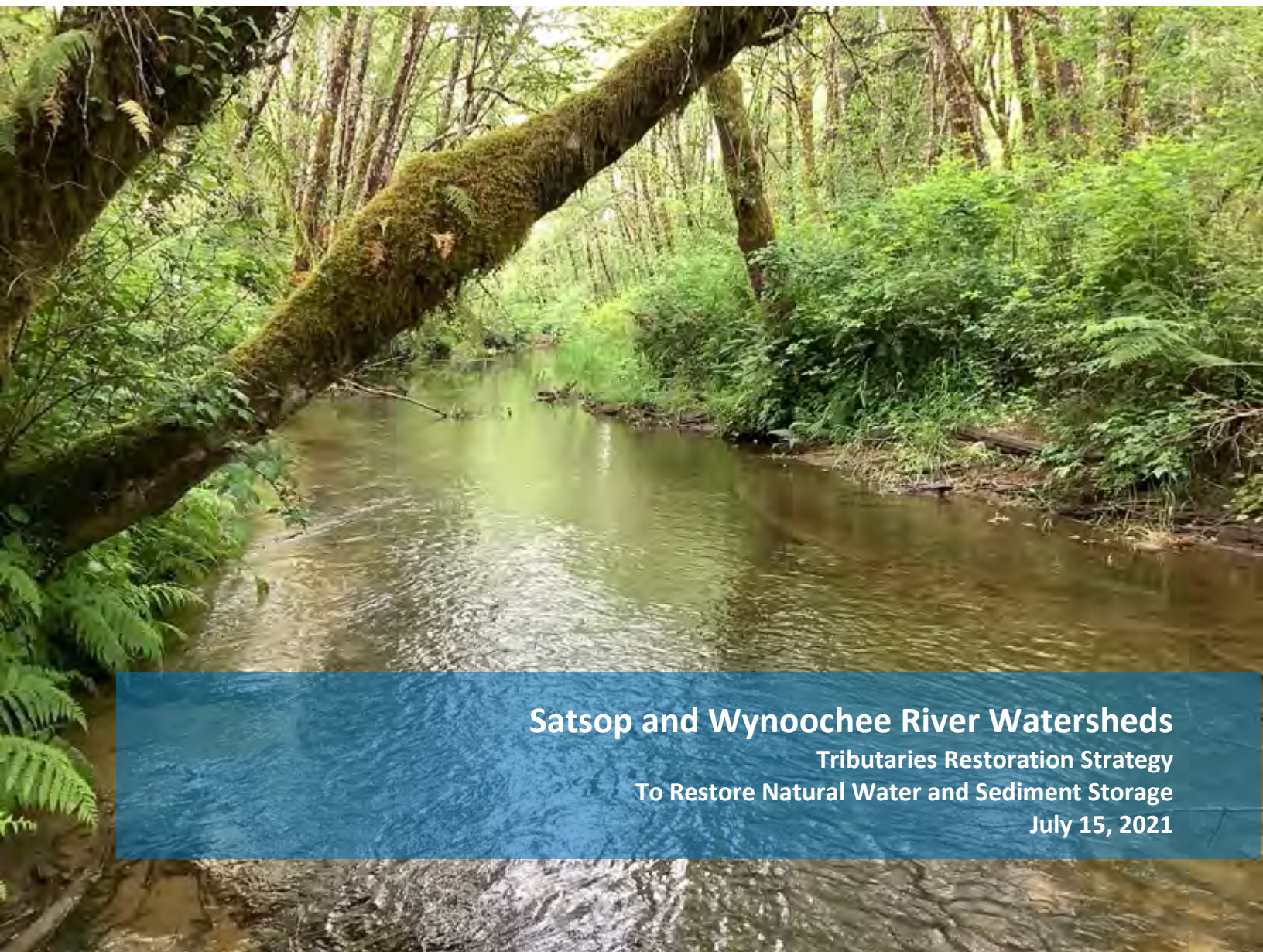




Satsop and Wynoochee River Watersheds

Tributaries Restoration Strategy
To Restore Natural Water and Sediment Storage
July 15, 2021



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TABLE OF CONTENTS

1	Introduction	1
2	Background	4
2.1	Local Context.....	4
2.2	Hydrologic and Geomorphic Effects of Channel Incision.....	5
2.3	Stream Restoration Design Techniques	6
3	Methods.....	8
3.1	Data Sources	8
3.2	Model Framework and Methods	9
3.2.1	Overview	9
3.2.2	Geospatial Analysis	9
3.2.3	Water and Sediment Storage Modeling	16
3.3	Field Validation of Modeled Values	20
4	Results.....	23
5	Restoration Strategy	30
5.1	Overarching Considerations.....	30
5.2	Prioritization.....	30
5.2.1	Prioritization Approaches	30
5.3	Restoration Approaches	31
5.3.1	Overview of Criteria	31
5.3.2	Machine-Built Instream Structure	32
5.3.3	Hand-Built Instream Structure.....	33
5.3.4	Valley Reset.....	37
5.3.5	Strategic Excavation	39
5.3.6	Humanscape Modifications	40
5.4	Application of Screening To Project Planning	40
5.4.1	Prioritization and Selection of a Pilot Project	40
5.4.2	Additional Project Identification Examples.....	41
5.4.3	Example Costs for Project Planning	44
5.5	Other Considerations for Project Planning	46
5.5.1	Invasive Species	46
5.5.2	Relation to Forest Management.....	47
6	Next Steps and Recommendations	48

6.1	Summation of Benefits from Extensive Restoration.....	48
6.2	Assessment For Potential and Approach at Reach-Scale.....	49
6.3	Data Availability and Future Use.....	50
7	References	51

LIST OF TABLES

Table 1.	Area of Satsop and Wynoochee River watersheds along with percent of management or ownership by USFS and commercial timber companies.	2
Table 2.	Data sources utilized in the modeling and analysis.	8
Table 3.	Model results summed by HUC-12 subwatershed and land ownership (for low order (1-4) and low gradient (<8%) reaches), presented in descending order by total restorable water storage potential.	26
Table 4.	Criteria for assignment of restoration approaches to individual stream reaches. See text for rationale and references associate with criteria.....	32
Table 5.	Bankfull depth and width estimation methods for two sub-categories of hand-built approach. Screening for both categories includes the absence of roads, stream crossings, and buildings from the valley bottom.	37
Table 6.	Example costs for a range of restoration approaches. Note that actual costs vary widely with project location, restoration approach, materials cost, etc.....	45
Table 7.	Example costs for a range of services associated with hand-built restoration approaches. Note that actual costs vary widely with project location, restoration approach, materials cost, etc.	46
Table 8.	Total modeled values for restorable water storage (acre-feet), potential sediment storage (cubic yards), and length of low order (1-4) streams with gradient < 8%, separated out by HUC-10 watershed and land ownership.	48
Table 9.	Total number of river miles with gradient < 8% that were classified into each restoration approach at the screening level. Note that numerous reaches are classified for more than one approach, and that the machine-built structures approach is assigned to every reach.	49

LIST OF FIGURES

Figure 1.	Map of the Wynoochee and Satsop River watersheds showing HUC-12 subwatersheds and land ownership. The focus of this project is on commercial timber lands owned by Green Diamond and Weyerhaeuser in the two watersheds.	3
Figure 2.	Illustration of the change in groundwater and surface water storage from re-aggradation of an incised channel.	5
Figure 3.	ArcGIS model builder workflow diagram, which provides a conceptual overview of the geospatial analysis component of the alluvial water storage model framework.	10
Figure 4.	Lidar DEM with hillshade showing example location along the Upper West Fork Satsop River.	11
Figure 5.	Stream network and associated drainage area derived from flow accumulation analysis on the DEM for the same example location along the Upper West Fork Satsop River illustrated	

	in Figure 4. Note that drainage area is computed for every pixel in the DEM, and pixels with a drainage area greater than 250,000 square feet (sf) (dark blue in the figure) are designated as the stream network.	11
Figure 6.	Stream reaches and associated catchments for an example location along the Upper West Fork Satsop River.	12
Figure 7.	Relative elevation along stream network for an example location along the Upper West Fork Satsop River.	13
Figure 8.	Valley bottom and channel extent polygons derived from the relative elevation raster for each reach for an example location along the Upper West Fork Satsop River.	13
Figure 9.	Relation between gradient (ft/ft) and average valley width (ft) for each stream segment in the Middle Wynoochee HUC-12. The vertical dashed line indicates the 8% gradient threshold used for restoration potential.	14
Figure 10.	Conceptual diagram of valley cross-section under existing (a) and restored (b) conditions. See text for symbol definitions.	16
Figure 11.	Conceptual diagram of the three triangles for which area is calculated.	18
Figure 12.	Conceptual diagram of the volume of water storage restored from channel aggradation.	18
Figure 13.	Wide alluvial valley around Decker Creek (HUC-12: Middle Fork Satsop) where Pleistocene continental glaciation resulted in low relief (photo taken looking downstream on June 12, 2020).	21
Figure 14.	Bedrock in the channel bed of a tributary to Still Creek (HUC-12: Lower West Fork Satsop), approximately 1.5 miles upstream of county road crossing (photo taken looking upstream on June 11, 2020). Bedrock was also observed in Still Creek and in Rabbit Creek (HUC-12: Middle Fork Satsop).	22
Figure 15.	Total restorable water storage (acre-feet) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed and by land ownership.	24
Figure 16.	Total potential in-situ sediment storage (cubic yards) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed and by land ownership.	25
Figure 17.	Total restorable water storage (acre-feet) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed, land ownership, and presence of infrastructure in the valley bottom.	27
Figure 18.	Quantile (i.e., 0 to 1, with 1 as the highest ranked) for normalized restorable water storage (acre-feet/mile) for each reach relative to the other values in its HUC-12 subwatershed, symbolized by the color of the reach-scale drainage area.	28
Figure 19.	Quantile (i.e., 0 to 1, with 1 as the highest ranked) for normalized restorable water storage (acre-feet/mile) for each reach relative to the other values in its HUC-10 watershed, symbolized by the color of the reach-scale drainage area.	29
Figure 20.	Conceptual diagram of the appropriateness of restoration approaches for a range of channel morphologies, defined by bankfull depth and bankfull width.	34
Figure 21.	Size ratios for instream wood pieces from the Queets River watershed, Washington. The horizontal axis is the ratio of log length to bankfull width and the vertical axis is the ratio of log diameter to bankfull depth. Note the minimum lower bound of the filled squares, which represent key (i.e., stable) piece is approximately 0.5. Reproduced from Figure 12 of Abbe and Montgomery (2003).	35

Figure 22.	Key piece volume as a function of bankfull width from a survey of key pieces in Washington. Note that the volume of a key piece steeply increases in channels > 5 m (approximately 15 ft) wide. Reproduced from Figure 5 of Fox and Bolton (2007).	35
Figure 23.	Conceptual sketch of valley reset approach, showing plan view (left) and cross-section view for the pre-restoration condition (upper right) and the post-restoration condition (lower right). In this approach an adjacent road (or other fill, such as a levee or berm) is used to fill an incised channel, and the floodplain is roughened through extensive placement of large wood. The cross section view also shows the increase in groundwater level that results from reducing the depth of the incised channel.....	38
Figure 24.	Conceptual diagram of the appropriateness of three machine-built restoration approaches to different reaches based on infrastructure intensity and geomorphic context. Infrastructure intensity is characterized by the number of buildings and stream crossings and the length of road in the valley bottom for a given reach. Geomorphic context is defined by valley width, confinement, and gradient.	39
Figure 25.	Map of Lower West Fork Satsop, showing modeled intrinsic potential for winter coho rearing, mapped to low order (1-4) stream segments that are in the top 50% for restorable water storage and are screened for a hand-built approach (based on criteria for possibly suitable, see Table 5).	42
Figure 26.	Restorable water storage (ac-ft/mi) versus projected 2080s stream temperatures for the Satsop River Watershed, broken out by HUC-12 subwatershed and symbolized by land ownership (color) and salmonid presence based on SWIFD (open versus fill circles). Each point represents a single reach in the model results.	43
Figure 27.	Map of low order (1-4) stream reaches with high 2080s projected stream temperature (≥ 20 °C) and are in the top 50% for restorable water storage potential.	44

LIST OF APPENDICES

Appendix A	Mapbook of Water Storage Potential
Appendix B	Restoration Cut Sheets
Appendix C	Mapbook of Instream Restoration Approaches
Appendix D	Mapbook of Geomorphic Modification Restoration Approaches
Appendix E	Pilot Project Basis of Design Memorandum
Appendix F	Mapbook of Hand-Built Reaches with Top 50% Restorable Alluvial Water Potential

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1 INTRODUCTION

The Satsop and Wynoochee Tributaries Assessment project aims to identify reaches within the tributary network of the Satsop and Wynoochee River watersheds where there is potential to restore natural water and sediment storage functions. For the purposes of this project, the entire watersheds were included in the modeling domain, with the analysis focused on smaller, low order streams (i.e., stream order ≤ 4) within commercial timber lands. Together, the commercial timber land represents 68% and 51% of the land area in the Satsop and Wynoochee River watersheds, respectively, and the majority of the tributary network is located in commercial timber lands or US Forest Service (USFS) managed lands (Table 1 and Figure 1).

Along with many other locations in the western United States, the natural water and sediment storage functions in the Satsop and Wynoochee Rivers tributary network have been diminished. A series of legacy impacts that include wood removal, splash damming to facilitate downstream log transport, beaver trapping, and road building resulted in simplified channel networks that have cut down (i.e., incised) relative to the alluvial valley, leaving the channel vertically disconnected from the floodplain. Although modern land management and timber harvest practices are protective of riparian forests and aquatic habitats, the legacy of entrenched and simplified channels persists and affects current geomorphic and hydrologic processes. The overly deep channels act as conduits to move sediment and water rapidly downstream rather than storing sediment and water in situ. From this conceptual basis, this project aims to use best available scientific understanding along with geospatial data and field verification to estimate the potential for water and sediment storage within the tributary network. These estimates can then be used to identify and prioritize reaches for further assessment and possible restoration treatment. Restoration of natural water and sediment storage functions has benefits for water quantity, water quality, habitat complexity, and climate change resilience, thus prioritizing the restoration of these functions along with local aquatic habitat or species-specific restoration goals supports a multi-benefit approach. The project also aims to leverage the geospatial analyses to provide screening-level guidance to practitioners on what restoration approaches may be viable for each reach, as well a framework for prioritization of restoration actions. The overarching goal is to galvanize widespread restoration in order to realize the benefits of distributed increases in local water and sediment storage.

This restoration strategy begins by reviewing background information relevant to the project area, as well as the scientific basis for restoring natural water and sediment storage functions (Section 2), followed by an in-depth review of modeling methods (Section 3), modeling results (Section 4), and the development of a restoration strategy that leverages the analysis (Section 5). Conclusions and recommendations are presented in Section 6, and maps of results and cut sheets summarizing four restoration approaches are appended to the strategy. The modeling results and spatially explicit restoration strategies are also provided as geospatial data and as a web map (See Section 6.3):

<https://coastsalmon.maps.arcgis.com/apps/webappviewer/index.html?id=ddd2f4dae4c5466d87657c59a3ccbec9>.

Table 1. Area of Satsop and Wynoochee River watersheds along with percent of management or ownership by USFS and commercial timber companies.

WATERSHED (HUC-10)	SATSOP RIVER	WYNOOCHEE RIVER
Total Watershed Area (mi ²)	300	196
USFS-managed Area (% of total)	18%	29%
Green Diamond-owned Area (% of total)	57%	26%
Weyerhaeuser-owned Area (% of total)	11%	25%

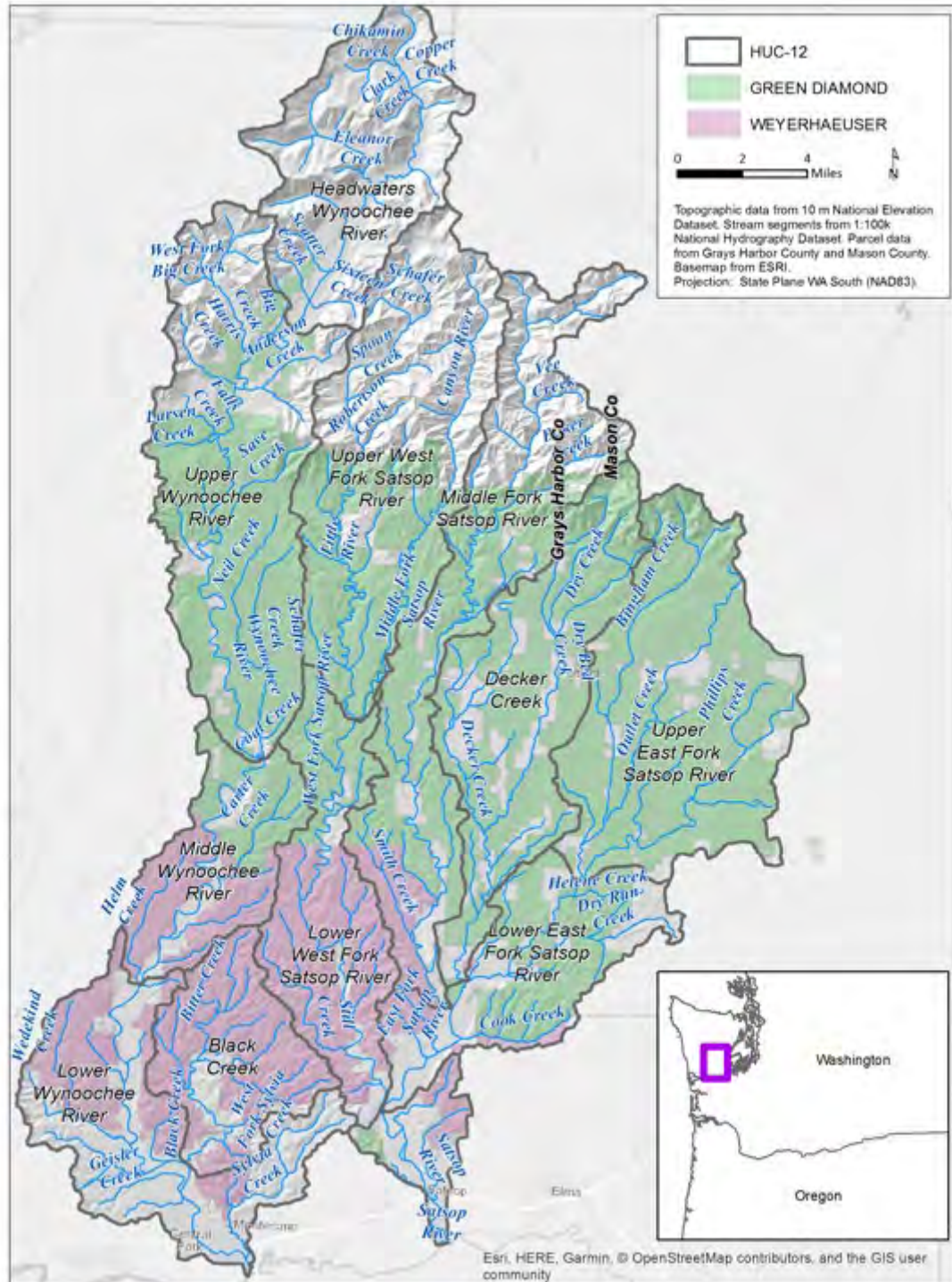


Figure 1. Map of the Wynoochee and Satsop River watersheds showing HUC-12 subwatersheds and land ownership. The focus of this project is on commercial timber lands owned by Green Diamond and Weyerhaeuser in the two watersheds.

2 BACKGROUND

2.1 Local Context

Several local investigations provide context for the historic and current hydrologic and geomorphic functions and features within the Satsop and Wynoochee watersheds. Two relevant geomorphic investigations were completed by scientists at the University of Washington. Collins and Dunne¹ quantified average annual gravel transport in the Wynoochee, Satsop, and Humptulips Rivers and demonstrated a degradational trend in bed elevation of ~0.1 foot/year during the 1950s through 1980s at nine USGS gages. Given gravel harvesting rates that far exceed the annual transport (i.e., replenishment) of gravel, the authors conclude that the channel degradation is linked to gravel removal from the systems. They also noted that the source material for gravel is primarily glacial outwash rather than erosion of the sandstones and siltstones of the Eocene-age Montesano Formation. Montgomery and others² completed geomorphic and riparian vegetation surveys in the West Fork Satsop River watershed to quantify the slope and drainage area threshold at which a stream reach converts from alluvial (i.e., retaining a bed of sediment) to bedrock. The authors reported observations of large diameter instream wood retaining alluvium, even for steeper reaches that would otherwise have a bedrock channel. In addition, they observed that the range of diameters for key instream wood pieces that were observed to hold grade (0.6-2.0 m) overlapped most closely with the range of old growth stump diameters (0.7-2.0 m), rather than the diameters of the second growth riparian forest (0.1-0.9 m). This suggests that selective harvest of larger riparian trees that occurred historically has reduced the number of alluvial reaches for which large wood is holding grade.

A key hydrologic feature of the study area is the presence of the Wynoochee Dam near River Mile 52 of the Wynoochee River. The dam was constructed in 1972 by the U.S. Army Corps of Engineers to provide flood control and water storage for the city of Aberdeen³. The dam can impound up to 70,000 acre-feet of water for approximately 4.4 miles as Wynoochee Lake, which is used recreationally. The drainage area to the lake represents approximately 20% of the drainage area of the Wynoochee River basin. In 1994, Tacoma Power built and began operating a 10,800-kilowatt power generation project at the dam.

Commercial timber harvest is a major land use in the study area. Although current best management practices (BMPs) are implemented to be protective of the riparian forest and aquatic habitat, historical practices set up a legacy of impacts from which natural processes are still recovering⁴. A Washington Department of Fish and Wildlife (WDFW) watershed analysis for the West Fork Satsop River was completed in 1996 based on the 1994 Forest Practices Act requirements and provides key local context for legacy impacts. The report synthesizes historical usage and the then current conditions of the watershed, and provides the following relevant context:

- ▶ A brief history of timber activities in the West Fork Satsop Watershed suggests that the river was used for the transport of logs by around 1900 but not for splash damming. Note that this contradicts Collins and Dunne (1996), who state that splash damming was common in the tributaries of the Satsop, citing Wendler and Deschamps (1955). Timber harvest in the watershed transitioned from sparse and selective cutting during the Depression and subsequent decade, to clear-cutting by the late 1940s and 1950s. In-channel wood was removed from the stream for stream 'cleaning', as well as for cedar salvage for shakes and shingles. Bulldozers were used to straighten channels at road crossings.
- ▶ Fish usage includes cutthroat and rainbow trout, coho, and steelhead.
- ▶ As a result of glaciation in only the upper watershed, the tributaries located in the lower, unglaciated portion of the watershed join at grade, whereas higher in the watershed tributaries are connected to main stems via steep sections of stream.
- ▶ The analysis notes a lack of large wood instream and that no new wood is being added, which affects sediment retention and grade.

2.2 Hydrologic and Geomorphic Effects of Channel Incision

The scientific literature provides numerous peer-reviewed studies that serve as the conceptual basis for the restoration strategy. Fundamental to the approach described herein is the concept that river valleys serve as critical reservoirs for both alluvial sediment and water. Historically, large wood was naturally recruited to stream channels where individual logs and log jams functioned as dams, creating a natural reservoir for sediment and storing water in the channel, underground in the surrounding floodplain sediments, and within floodplain water bodies^{5,6}. Streams across the Pacific Northwest have cut down (i.e., incised) relative to their historic valley bottoms due to the removal of in-channel wood, riverine transport of cut logs, near extirpation of beavers, channel straightening and other anthropogenic factors⁷⁻¹⁰. All of these drivers increase erosion and transport of sediment downstream¹⁰, either through reducing hydraulic resistance (e.g., wood removal)^{11,12} or increasing gradient (e.g., channel straightening). For example, over 12 miles of the West and Middle Forks of the Teanaway River have experienced almost complete evacuation of alluvial sediments and erosion into the underlying bedrock valley, with the timing of rapid erosion directly linked to splash-damming in the 1900s^{10,13,14}.

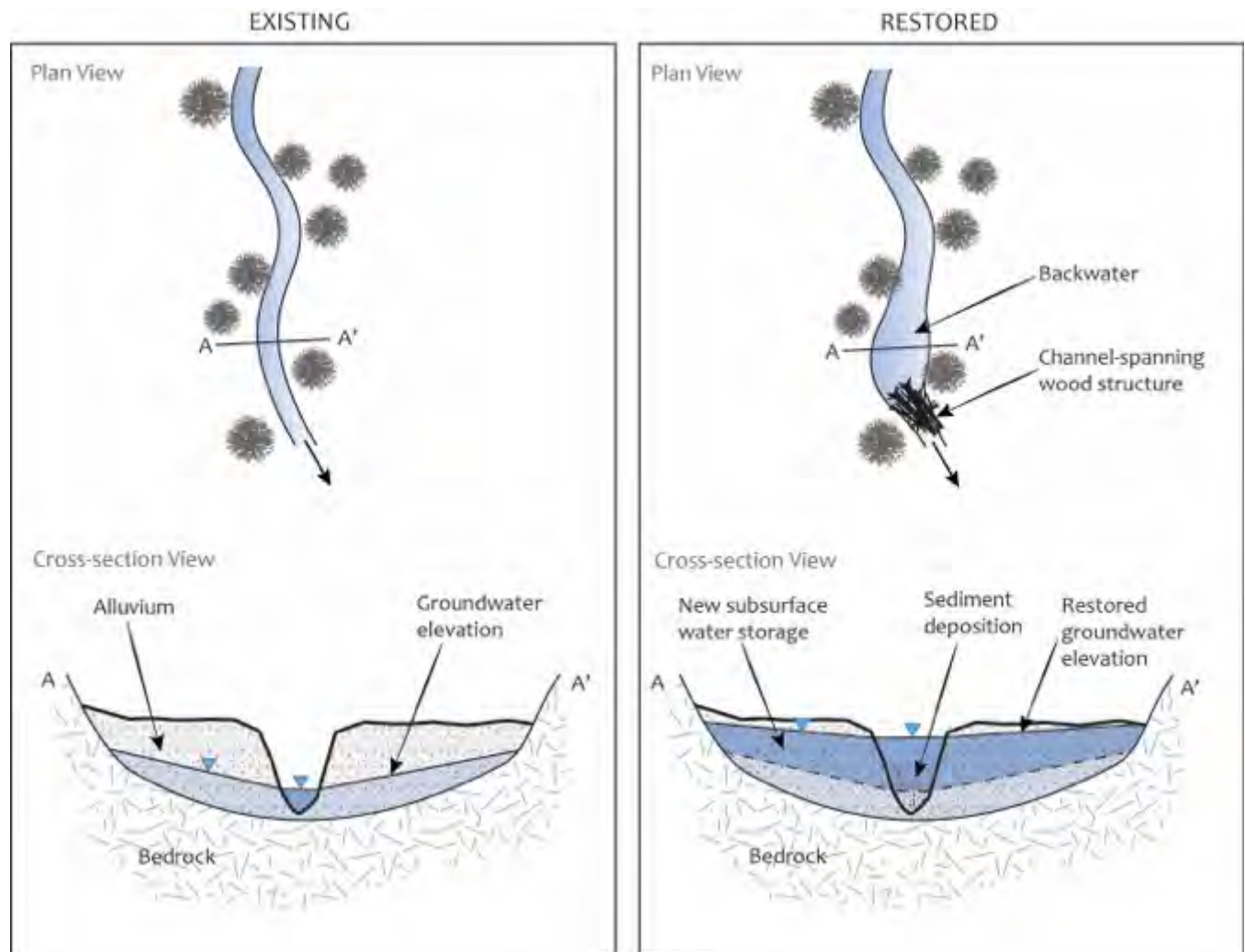


Figure 2. Illustration of the change in groundwater and surface water storage from re-aggradation of an incised channel.

The result is a simplified, vertically disconnected stream that has lost much of its historic capacity to store both sediment and water in-situ (Figure 2). For example, recent hydrogeomorphic analysis of the Teanaway River watershed suggests that over 5000 acre-feet of natural water storage has been lost from multiple episodes of channel incision and sediment evacuation¹⁵. In addition to the loss of water and sediment storage functions, stream incision sets up a positive feedback loop, in which the incised channel has more conveyance¹⁶. Larger flows are conveyed in the incised channel before overtopping the banks, which increases the local maximum stream power and therefore increases the erosion and transport of sediment. Increased stream power also increases the required size of a stable “key piece” of large wood¹⁷. Given the landscape-scale decrease in the diameter of riparian trees that occurred with old growth timber harvest, the likelihood of natural recruitment of a sufficiently sized ‘key piece’ of stable wood further decreases with channel incision. In addition, although trees in the riparian zone are currently protected from harvest, these riparian forests will require substantial time before trees grow large enough to provide stability and function when naturally recruited through bank erosion.

Channel incision reduces natural water storage within the stream network in two key ways: (1) Less water is stored during the spring freshet for later release, and (2) the water that is stored drains faster and earlier due to a locally steepened gradient between the groundwater table and the incised channel. The lowering of the channel bed steepens the local hydraulic gradient by increasing the difference between the groundwater table elevation and the in-channel water surface elevation. This steepened gradient drives faster and earlier drainage of the local groundwater into the stream, with field observations and subsurface modeling studies noting lowered groundwater elevations in conjunction with incised channels, as well as raised groundwater elevations in restored channels^{18–21}. An increase in shallow groundwater storage subsequently affects duration and elevation of soil saturation and soil water availability to support wetland and riparian vegetation, as well as the amount and timing of baseflow contribution from groundwater. Essentially, since the rate at which groundwater flows is more than four orders of magnitude slower than surface water²², the groundwater aquifer acts like a sponge, receiving water during high spring flows and returning water during low summer flows. For example, a field study in the Colorado Rockies demonstrated this sponge-like function, observing that a wide alluvial valley with a hydrologically connected, anabranching stream network (i.e., multiple interconnected channels versus a single incised channel) functions as a water “sink” during the spring freshet and switching to a water “source” during the baseflow period²³.

The effect on baseflow of restoring incised channels differs among groundwater modeling studies, with some studies showing an increase in downstream flow^{18,24} and some showing no change, which is attributed to site-specific groundwater recharge processes²⁵ or the reduction in lateral hydraulic gradient in re-aggraded streams²⁰. In contrast, for two studies in the Sierra Nevada region of California discharge was measured above and below a stream both before and after restoration actions that raised the channel bed elevation, the results indicated a 50 to >100% increase in summer baseflow that persisted for 1 to 4 months into the dry season^{19,21}. In addition, an investigation of the hydrologic effects from restoring an incised stream, Cottonwood Creek in Northern California, demonstrated that the increased surface water-groundwater interaction could reduce instream water temperatures by more than 3 °C²⁶. Lastly, unpublished results from a pilot project in the Mission Creek watershed (Chelan County, Washington) demonstrate the net retention of approximately 7 cubic yards of sediment behind a single large wood structure implemented with a series of structures to restore an incised 2nd order channel²⁷.

2.3 Stream Restoration Design Techniques

The primary geomorphic goal of stream restoration design in incised channels is to re-aggrade the channel bed elevation to a reference condition, for which the stream is hydrologically connected to its floodplain via both surface water (i.e., overbank) and groundwater flow¹⁶. In particular, there are two ways to bring the incised channel back up: (1) by increasing hydraulic resistance through placement of instream wood or rock structures,

or (2) by filling the channel with alluvium. The placement of wood or rock structures raises water surface elevation²⁸, slows streamflow velocities and triggers deposition of sediment, thus re-aggrading the stream over time^{11,12}. This method depends on functional obstructions to flow that are either stable over a long-term range of peak flows (e.g., engineered log jams¹⁷ or rock filter dams²⁹) or are replaced on a semi-regular maintenance schedule (e.g., beaver dam analogs³⁰). The approach of filling the channel³¹, also referred to as the “Stage 0” or “valley reset” method, aims to restore to a Stage 0 reference condition (using the terminology from the Cluer and Thorne channel evolution model¹⁶). Physically filling in the incised channel, typically utilizing native alluvium from the floodplain, reduces stream power and raises channel bed elevation and surface water elevation almost immediately.

3 METHODS

3.1 Data Sources

Numerous geospatial datasets were used in this modeling and analysis effort (Table 2). In addition, this effort benefited from collaboration with Green Diamond and Weyerhaeuser, the two commercial timber landowners in the project area. Each landowner maintains their own data inventories related to roads, road crossings, harvest planning, habitat conditions, and fish use and expressed willingness to provide these proprietary data at a reach or project scale to support project development.

Table 2. Data sources utilized in the modeling and analysis.

CATEGORY	DATA TYPE	SOURCE
Boundaries	Watershed boundary dataset (HUC-10; HUC-12)	USGS WBD dataset
	Counties	WA State
	National Park and National Forest boundaries	USFS and NPS
	Parcels including land use designations	Grays Harbor Co and Mason Co
Soils	Grays Harbor County and Mason County soil surveys	NRCS Web Soils Survey
Land Cover	Vegetation type and height (Existing Vegetation Type (EVT), Existing Vegetation Height (EVH)) – 30 m	LANDFIRE
	National Land Cover Database - 30 m Canopy Cover	USDA NLCD
Water Quality	303d list of impaired waters	WA DOE
	Chehalis Thermalscape results (local improvement to NorWest ³² dataset), with modeled stream temperatures under current and future conditions	WDFW (John Winkowski)
Geology	Landslides	WA DNR
	100k Geologic maps (no 24k digital maps for this domain)	WA DNR
Fish Distribution and Passage	Statewide Washington Integrated Fish Distribution (SWIFD)	WDFW
	Barrier inventory (Fish Passage and Diversion Screening Inventory database)	WDFW
	Intrinsic potential modeling data – quantifies potential for salmonid habitat based on physical characteristics such as gradient and valley confinement	UW Olympic Natural Resources Center
Hydrology	Stream gages	USGS and WA DOE
	FEMA mapped floodplains	FEMA
	River miles	USGS/WDFW
	National Hydrography Data 100k and 24K flowlines	USGS
	National Wetland Inventory	USFWS
	National Dam Inventory	USACE
	PRISM 30-year climate normals (total annual precipitation)	OSU ³³
Roads	Grays Harbor County Roads	Grays Harbor Co
	Mason County Roads	Grays Harbor Co

	WDNR Roads	WDNR
Elevation	LiDAR data for Satsop and Wynoochee Watersheds	WA DNR lidar Portal
	National Elevation Dataset 10m DEMs	USGS
Infrastructure	Microsoft Building Footprints Dataset	Microsoft/ESRI

3.2 Model Framework and Methods

3.2.1 Overview

The tributaries assessment model is a geospatial and computational workflow that uses high resolution topographic data, relevant spatial datasets, geomorphic analysis, and field validation to:

1. Estimate the volume of restorable surface and subsurface water storage at a reach-scale;
2. Estimate the volume of in-channel sediment storage potential from restoration actions at a reach-scale;
3. Determine reach-scale characteristics related to geomorphology, hydrology, vegetation, and infrastructure that are relevant for determining potential restoration approaches; and
4. Document spatial relationships to relevant geospatial datasets that may contribute to restoration prioritization.

The model workflow components are described below.

3.2.2 Geospatial Analysis

Stream Network and Valley Bottom Delineations

The foundation of the model framework is the characterization of the stream network and alluvial valley bottoms based on geospatial analysis of high-resolution topographic data. The initial steps determine the accurate location of the stream network and estimate the geomorphic and hydrologic characteristics of each reach, such as gradient and drainage area. The resulting reach-scale data are critical for accurate valley bottom delineation, as well as for quantification of water and sediment storage potential and classification of each reach for appropriate restoration approaches. Estimating the size of the alluvial valley bottom is a key step for characterizing the shallow alluvial aquifer, as well as determining valley confinement to support development of restoration approaches.

The stream network and valley bottom delineations are derived from a lidar digital elevation model (DEM) run through a series of ArcGIS spatial analysis tools run in the ArcGIS model builder framework. The DEM is derived from a mosaiced set of lidar digital elevation models (data from Puget Sound lidar Consortium, 2012; US Forest Service, 2017; US Geological Survey, 2012, 2017, 2019; all accessed via the WA Department of Natural Resources lidar portal, <https://lidarportal.dnr.wa.gov/>) which are then clipped to the extent of each of the twelve HUC-12 subwatersheds within the study area.

The model framework maps the flow network, stream reaches, and catchments of each stream reach, as well as the elevation relative to the flow line within each catchment, and channel and valley bottom extents (Figure 3). Through the processing, surface and stream network attributes for each stream reach are written to a stream reach attribute table. Stream reach attributes include minimum and maximum elevation, stream length, stream

order, and total drainage area. These attributes are used to calculate average gradient and estimated mean bankfull depth, based on regional regression equations for Pacific Maritime Streams ³⁴.

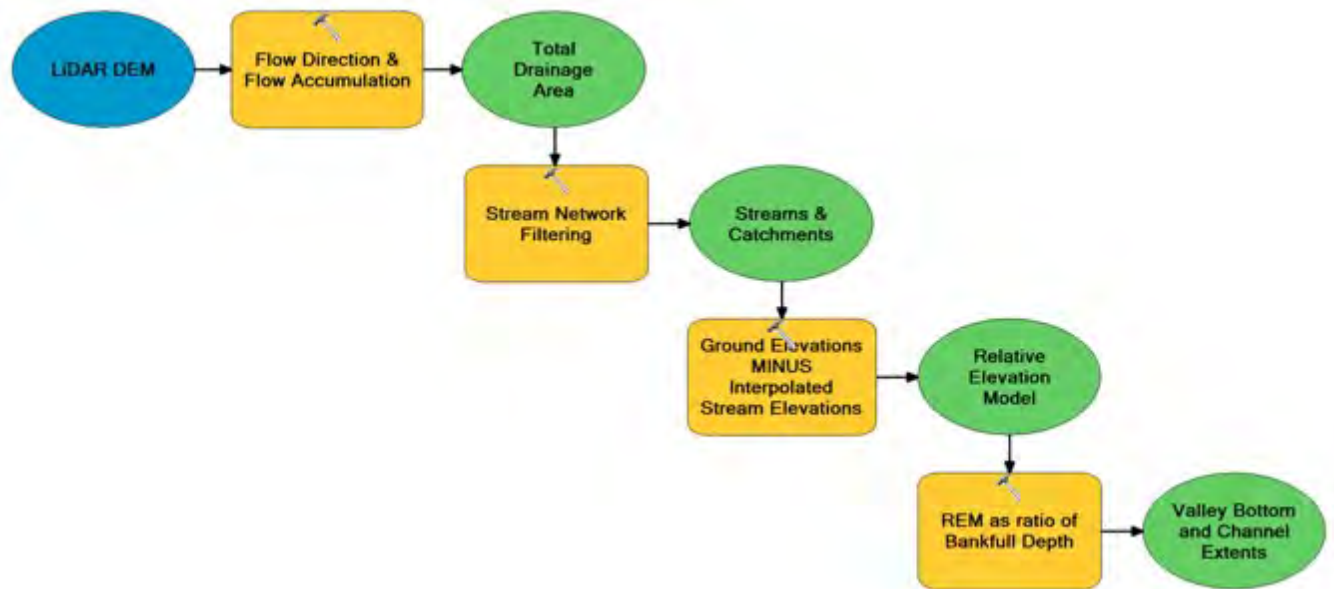


Figure 3. ArcGIS model builder workflow diagram, which provides a conceptual overview of the geospatial analysis component of the alluvial water storage model framework.

Data input to the geospatial analysis component of the model is limited to the lidar DEM, which is re-sampled from 3 ft to 9 ft pixels to increase computational efficiency (Figure 4). Outputs from initial flow direction and accumulation analysis steps are fed back into subsequent model steps to ultimately derive stream network lines, and the channel and valley bottom polygons. To delineate the approximate channel extents and then compute channel width, the region within each catchment below the relative elevation equal to the estimated bankfull depth is delineated as the channel extent. Valley bottom extents are derived from the relative elevation at twenty times the estimated bankfull depth above each stream segment's flowline. A more detailed description of the processing with illustrative figures follows.

The stream network is derived from a steepest flowpath analysis of the re-sampled 9-foot resolution lidar DEM, with depressions filled to provide a continuous flowpath (Figure 5). A minimum drainage area threshold of 250,000 square feet (0.009 square miles) is used for classification as a stream, which results in a headwater extent roughly similar to the 1:24K National Hydrography Dataset (NHD) flowlines ³⁵. While the extent and general pattern of the stream network is consistent with the NHD data, there is not a one-to-one correlation between streams.

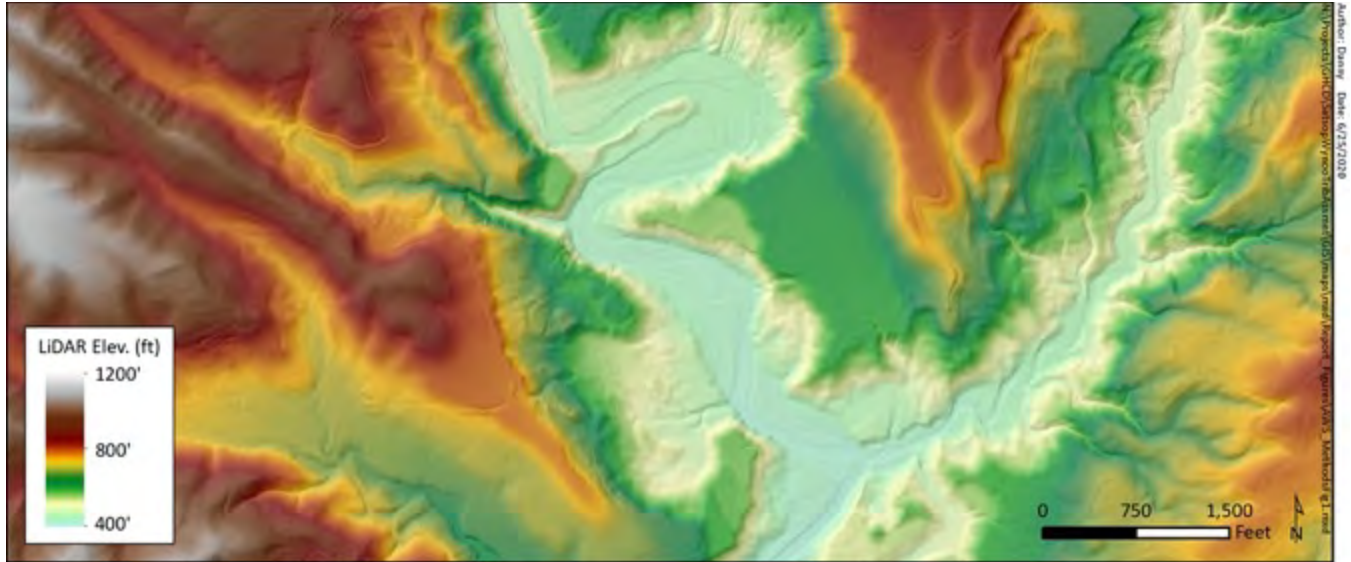


Figure 4. Lidar DEM with hillshade showing example location along the Upper West Fork Satsop River.



Figure 5. Stream network and associated drainage area derived from flow accumulation analysis on the DEM for the same example location along the Upper West Fork Satsop River illustrated in Figure 4. Note that drainage area is computed for every pixel in the DEM, and pixels with a drainage area greater than 250,000 square feet (sf) (dark blue in the figure) are designated as the stream network.

The lidar-derived flow paths more accurately follow visible channels in the 9-foot resolution lidar DEM hillshade as compared to the NHD 1:24K, which is derived from the 10 m (30 ft) national elevation dataset DEM. The more accurate flow path locations are critical to development of relative elevation rasters from which valley bottoms are delineated. However, the lidar-derived flow path locations are different than the commonly used NHD datasets so there is not an exact spatial match when joining reach-scale characteristics. For example, the Statewide Fish Distribution dataset (SWIFD) maps salmonid usage based on the NHD 1:100K flowlines, and the mapped SWIFD stream segment may be close, but not overlapping with the lidar-derived flow paths. Thus, to overcome these differences in flow path locations the spatial datasets are joined via proximity because the stream lines are not coincident (discussed further below).

Minor adjustments to the derived stream network are made in order to filter the preliminary network, and to limit the length of stream reaches. First order streams less than 500 feet long are excluded as they likely do not represent true channels. Stream reaches generally extend from one confluence to the next, unless the reach is longer than 2500 feet, in which case the reach is divided at 2500-foot intervals along the overall flow path. The 2500-foot threshold is used to keep stream reach lengths shorter so that they are more likely to be geomorphically similar throughout.

Each stream reach is assigned a unique identification number and exported as a polyline file with stream order, elevation, and geometry attributes ascribed to the data table. The catchment area of each stream reach is defined, which delineates the area draining directly to each stream reach across the entire subwatershed (Figure 6). The total drainage area of a stream reach is the sum of all catchment areas upstream of that reach. The extent of each stream reach catchment defines the analysis extent for determining relative elevation and delineating valley bottom of each reach.

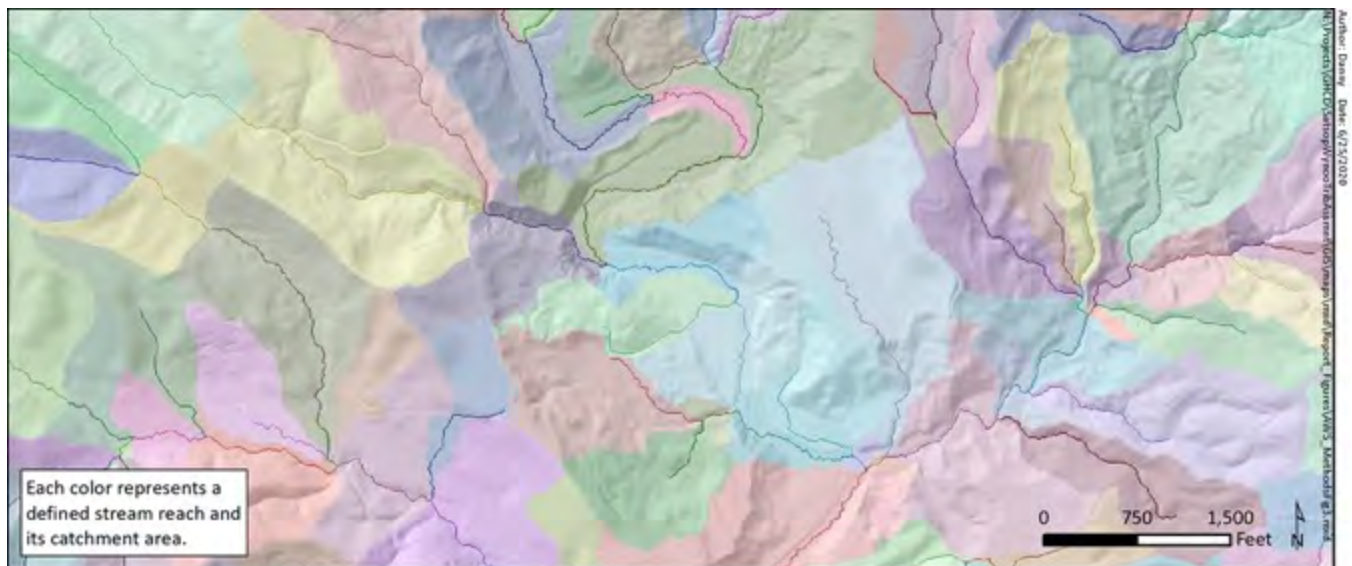


Figure 6. Stream reaches and associated catchments for an example location along the Upper West Fork Satsop River.

Elevation values along the flow lines are exported as a point dataset. The elevation values of each stream reach's flowpath are then interpolated to generate a water surface elevation raster that spans the extent of the stream segment catchment. These rasters, which represent the elevational trend of the water surface elevation in each catchment, are then mosaiced into a single raster coverage for each HUC-12 subwatershed. The water surface elevation raster is then subtracted from the values of the 9-foot lidar DEM to generate a relative elevation model for each HUC-12 subwatershed. The relative elevation model represents the elevation of each pixel in terms of a height above the local water surface (Figure 7). Using the previously estimated bankfull mean depth for each reach, the relative elevation values are then divided by the estimated bankfull mean depth within each stream reach's catchment area to derive a raster coverage representing values as a ratio of relative elevation to bankfull depth (REM:BFD). Channel extents are mapped as all areas of REM:BFD less than or equal to 1. The valley bottom is then mapped as all areas where REM:BFD was less than or equal to twenty. The multiplier for valley delineation is a calibrated parameter that is determined iteratively from visual review of results.

The area of the derived channel extent and valley bottom is then divided by the length of the stream reach to estimate the reach-average channel width and valley width (Figure 8). These values are added to attribute table for each stream segment.

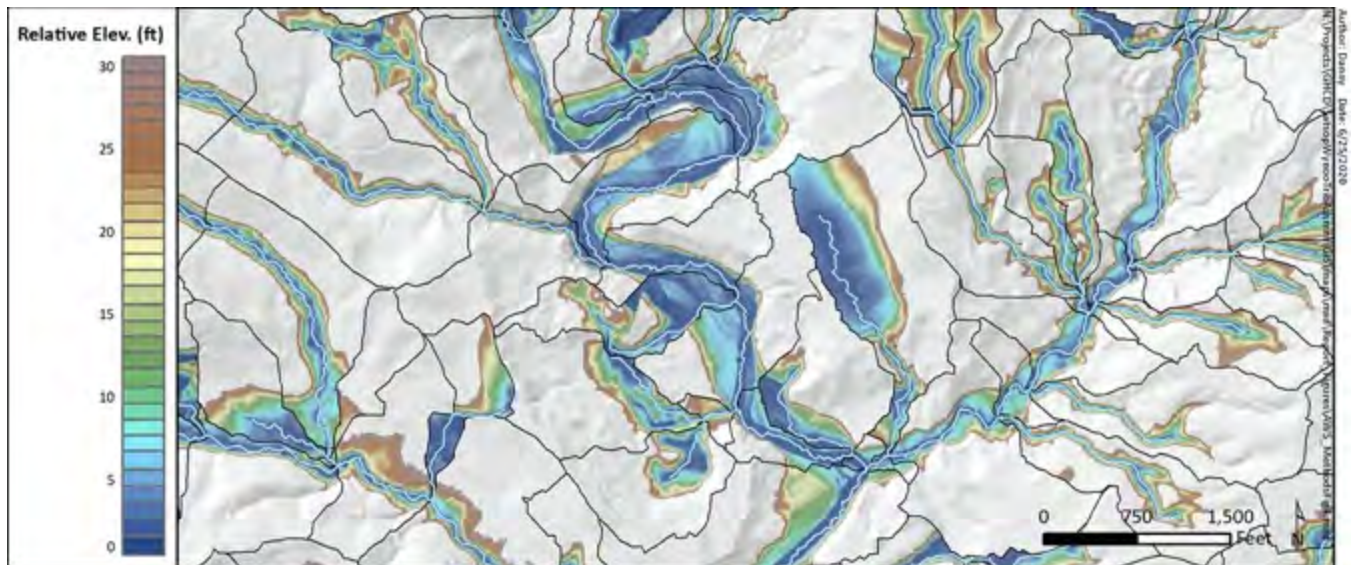


Figure 7. Relative elevation along stream network for an example location along the Upper West Fork Satsop River.



Figure 8. Valley bottom and channel extent polygons derived from the relative elevation raster for each reach for an example location along the Upper West Fork Satsop River.

Classifying Geomorphic and Hydrologic Setting

Reach-scale stream gradient, channel width, and valley width are used to classify reaches into geomorphic settings for use in the development of the restoration strategy. Reaches with gradient less than 3% are classified as response reaches, as compared to transport or source reaches, which are steeper^{36,37}. Response reaches are more likely to be situated in an alluvial valley with a floodplain. For the purposes of analyzing the potential for increased water storage due to restoration actions, 8% gradient is used as the upper threshold for summing alluvial water storage potential (see Results) and for identifying top-ranking reaches for the restoration

strategy. An 8% gradient is generally the upper limit for the transition from step-pool morphology (i.e., lower gradient) to a steeper-gradient cascade morphology. Whereas step-pool reaches tend to have some local sediment storage capacity potential, cascade reaches tend to be primarily transport reaches³⁷. Thus, from a practical standpoint, restoration actions in lower gradient reaches are likely to have more effect on water and sediment storage processes than in steeper reaches. In addition, higher valley widths are generally associated with lower gradient reaches in the Satsop and Wynoochee River watersheds (e.g., Figure 9). Therefore while 8% gradient is used as a general threshold for higher restoration potential, note that natural processes in reaches that are steeper than 8% are commonly impaired due to legacy impacts, and stable large wood has been observed to affect local gradient and sediment deposition and scour in reaches up 20%^{38,39}. Stream segments with greater than 20% gradient are removed from future analysis in this model framework.

Valley confinement is classified based on the ratio between valley width and channel width. Reaches with a ratio of greater than or equal to 2 are classified as unconfined or moderately confined, and below 2 as confined.

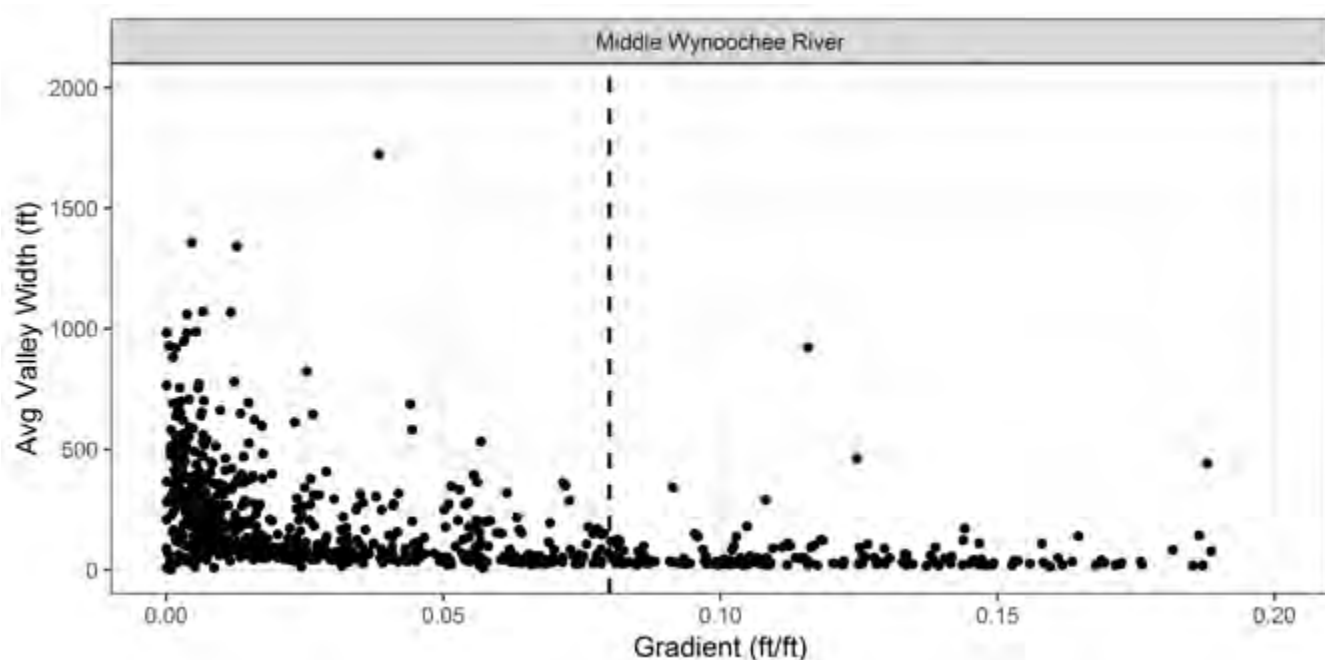


Figure 9. Relation between gradient (ft/ft) and average valley width (ft) for each stream segment in the Middle Wynoochee HUC-12. The vertical dashed line indicates the 8% gradient threshold used for restoration potential.

Drainage area and average annual precipitation data, extracted at the HUC-12 subwatershed level from PRISM⁴⁰, are used to estimate peak flow magnitudes for a range of recurrence intervals based on regional regression equations⁴¹. The peak flow with a recurrence interval of 2-year, the Q2, is then used to estimate bankfull width and bankfull depth using Pacific Maritime empirical relations³⁴.

Joining with Relevant Spatial Data

Numerous additional data sources are relevant to the water and sediment storage modeling and the development of the restoration strategy. Identifying information including county, watershed (HUC-10), subwatershed (HUC-12), land ownership, landcover, soils, and geology data are added to stream data tables based on location. Attributes from other stream network-based datasets, including stream name, intrinsic fish habitat potential, fish presence, and modeled temperature are added to the stream data table when a

corresponding line segment occurs within 100 feet of the reach midpoint. Attributes from other polygon-based datasets, including the USFWS National Wetland Inventory and FEMA flood maps, are added to stream data table where a stream reach intersects the polygon.

The fish distribution data (SWIFD) is distilled to a binary flag (i.e., yes/no) for salmonid presence, based on querying the species attribute for Coho Salmon, Chinook Salmon, Chum Salmon, Kokanee Salmon, Steelhead Trout, and Bull Trout. The overlapping SWIFD reach ID is also included in the model results to allow for linking the two datasets in future analyses.

Spatial analysis of reach-scale infrastructure intensity leverages the delineated valley bottom polygons to determine the number of or length of infrastructure features within a stream's valley bottom. In particular, for each reach, the analysis extracts the total number of existing buildings, road crossings, and dams, and the total miles of existing road present. In addition, the LANDFIRE dataset is analyzed for each valley bottom polygon and for a 100-ft buffer around each stream segment to estimate the percent forest cover in the valley bottom and in the riparian zone.

The compiled data tables, with unique identifiers for each stream reach, are then exported for water and sediment storage modelling. Results and prioritization resulting from that modelling is later reconnected to the stream and catchment geometry for mapping purposes (Appendix A).

Incision Analysis

Channel incision has occurred throughout Washington as a result of the removal of instream wood due to splash-dam log transport, efforts to remove wood known as “stream cleaning”, and the trapping and near extirpation of beaver, among other reasons. In particular, numerous splash-dams have been mapped in the Wynoochee and Satsop River watersheds⁴². Accurately detecting the degree of channel incision at the reach-scale is a challenge since channel incision does not simply equate to channel depth, but rather, involves analysis of current and relict floodplain surfaces and comparison of geomorphic bankfull depth (i.e., where water flows overbank) to hydrologic bankfull depth (i.e., the peak flow that does the most channel formation through time, which has an average recurrence interval of approximately 1.2 years in the region of Satsop and Wynoochee River Watersheds^{34,43}).

Given the large spatial domain of the analysis, we completed an ad hoc investigation of incision to determine the incision depth values to use as inputs in the water and sediment storage modeling. We found field evidence for the incision (discussed in Field Validation, below). We also found geomorphic evidence for incision, including relict channel features in the alluvial valley that are high above the current active floodplain, and geomorphic bankfull channels that are 2-4x deeper than the estimated hydrologic bankfull depth. We also observed several reaches with no evidence of incision in the field, which generally had evidence of current and/or previous beaver activity. Quantitative estimates of incision depth range from 0-6 feet, with a mean value of 3 feet.

We assessed the option to use spatially variable incision depths estimated at the spatial unit of a HUC-12 and then extrapolated to all reaches therein, but we generally found that incision varied more by stream order and drainage area than by location within the model domain with higher incision values in higher order streams. Thus, we opted to use the mean value of 3 ft as a constant estimate of incision in the water and sediment storage modeling framework to avoid introducing a spatial variable that would create difficulties for comparison between reaches and interpretation. The development of spatially explicit incision estimates is an opportunity for future improvement of the model framework.

3.2.3 Water and Sediment Storage Modeling

Alluvial Water Storage

We use the data tables compiled from geospatial modeling described above to estimate potential for water storage and low flow augmentation in the Satsop and Wynoochee basins. In particular, we estimate how much subsurface and surface water could be stored *in situ* in each reach, assuming a fixed level of channel bed aggradation from existing conditions. These reach-scale estimated volumes are then summarized to describe storage on a subwatershed and watershed scale.

Subsurface Water Storage

The potential change in subsurface alluvial storage is estimated based on simplified valley geometry, building off an approach described by Emmons (2013). In cross-sectional area, the current zone of **unsaturated** sediments is approximated as two triangles, which extend horizontally from the valley edges to the channel edge, and vertically from the channel edge to the depth of the incised channel (Figure 10). The construction of these unsaturated triangles assumes that the elevation of the incised channel is approximately the same as the water surface elevation in the channel. By implementing restoration actions that raise the channel bed elevation and the water surface elevation in the channel, the vertical dimension of the unsaturated triangle is shortened (Figure 10).

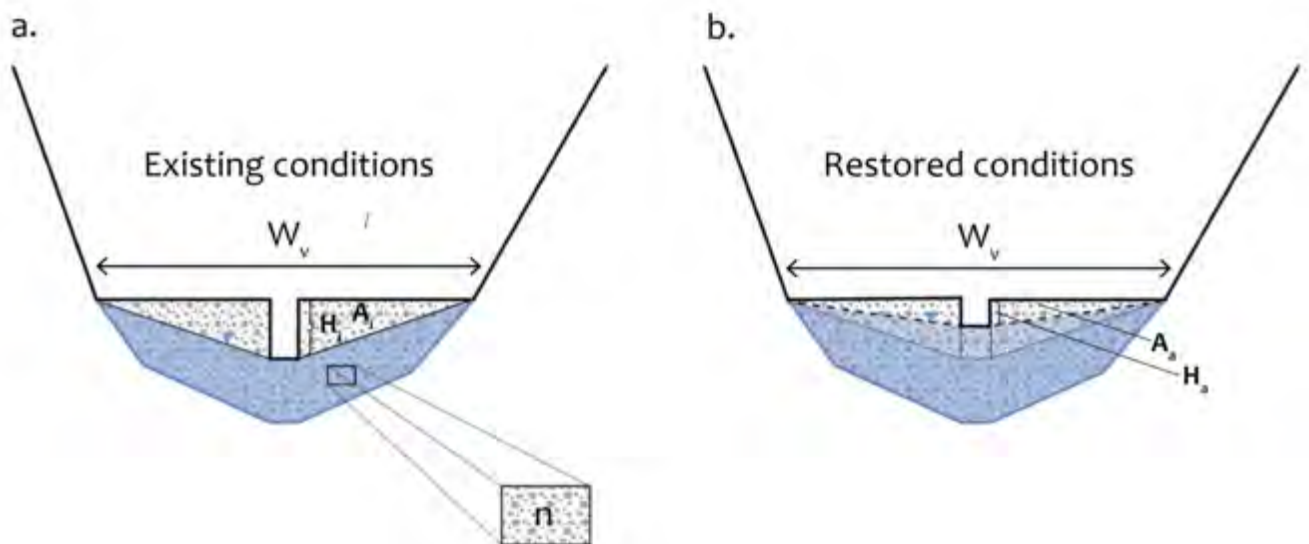


Figure 10. Conceptual diagram of valley cross-section under existing (a) and restored (b) conditions. See text for symbol definitions.

Under both existing and restored conditions, this conceptualization assumes that the alluvial valley is a gaining reach based on the analysis domain focused on low order streams⁴⁵. The simplified groundwater surface (i.e., the groundwater flow line) is sloped from the valley edges, where local groundwater elevation is influenced primarily by hillslope water inputs (surface and subsurface), and by the channel, where the local groundwater elevation is influenced primarily by the water surface elevation in the channel. Thus, the slope of this surface becomes less steep between existing and restored conditions because the water elevation at the channel is controlled by the channel bed elevation and water surface elevation, both of which shift upward with

aggradation and backwatering. When calculating the increased subsurface water storage from re-aggradation of the channel bed, we ignore the elevation of the water surface in the channel and use the channel bed elevation as the water surface elevation (e.g., Figure 10, where there is no water shown in the channel). Additional in-channel surface water storage due to impoundment is considered separately from the restored subsurface storage (see *Surface Water Storage*, below).

The change in subsurface alluvial water storage is approximated from the geometry of the cross-sectional area of the alluvial valley. The areal difference between the two unsaturated triangles on either side of the channel under existing conditions and under restored conditions represents a newly saturated area under restored conditions. The newly saturated subsurface area is effectively an increase in alluvial groundwater storage (i.e., the light blue area in Figure 10).

The following equations are therefore used to compute the change in water storage from restoration in a single reach.

The area of half of the unsaturated zone (i.e., one triangle) under existing, incised conditions, A_i (Figure 11a), is given as half of the product of the height from bed elevation to floodplain elevation, H_i , and half of the valley width, $W_v/2$:

$$A_i = \frac{H_i \times \frac{W_v}{2}}{2}$$

The area of half of the unsaturated zone (i.e., one triangle) in aggraded conditions, A_a (Figure 11b), is given as half of the product of the height from aggraded bed elevation to floodplain elevation, H_a , and half of the valley width, $W_v/2$:

$$A_a = \frac{H_a \times \frac{W_v}{2}}{2}$$

The newly saturated area, A_s (Figure 11c), is the difference between the two unsaturated triangles:

$$A_s = A_i - A_a$$

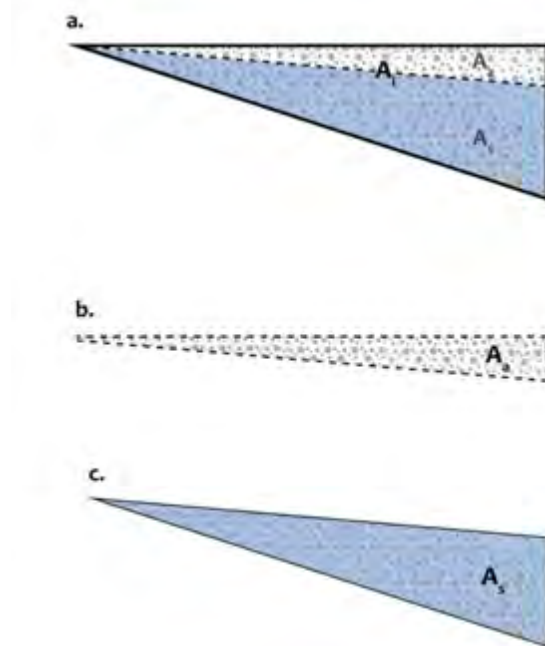


Figure 11. Conceptual diagram of the three triangles for which area is calculated.

The volume of water storage in the newly saturated wedge of alluvial sediments, V_s (Figure 12), is computed as the newly saturated area (A_s), multiplied by the specific yield (n) of the sediments (i.e., the interstitial space between the sediment grains which fills with water under saturated conditions and can be drained by gravity, also referred to as the drainable porosity), multiplied by the reach length (L_r):

$$V_s = 2A_s \times n \times L_r$$

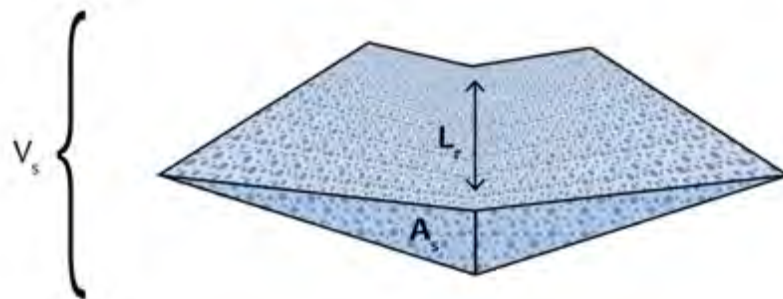


Figure 12. Conceptual diagram of the volume of water storage restored from channel aggradation.

Although the specific yield of sediments is naturally variable, we used 20% specific yield (i.e., $s_y = 0.20$) for all of the calculations. This simplification is based on published values for sand and gravel ⁴⁶ and limited field observations of floodplain sediments.

For the purposes of applying this calculation to every stream segment within the Satsop and Wynoochee basin, the potential amount of channel aggradation under restored conditions is fixed at 3 ft for all stream segments. This is based on estimates of average incision depth, discussed above.

Streamflow Contribution from Subsurface Alluvial Storage

We estimate the magnitude of the streamflow contribution from the restoration of additional subsurface alluvial storage in each study reach. Robust quantification of groundwater-surface water interactions requires a sophisticated numerical model to account for time-varying flow rates and multi-dimensional subsurface flow paths. In previous implementations of this model framework, we have used a simplified approach to characterize the drainage of the subsurface storage volume and subsequent contribution to baseflow based on a simplified Darcy's equation approach. Darcy's equation estimates subsurface flow based on the type of sediments (i.e., saturated hydraulic conductivity, porosity) the hydraulic gradient that drives flow (i.e., the slope of the water table). However, this approach is highly sensitive to the hydraulic parameter values (i.e., saturated hydraulic conductivity) and the lateral and longitudinal hydraulic gradients. The watershed-scale model has highly uncertain values for these inputs, especially lateral gradient which is determined by a constant incision assumption.

To avoid these uncertainties, we further simplify the approach by considering the additional flux from alluvial water storage as a function solely of the restored storage volume. We assume that all the additional water storage drains back to the stream – whether locally or down-valley - during the approximately four-month transition period from higher spring flows to lower summer flows. The additional flux is therefore calculated as the estimated volume of additional water storage draining at a constant rate over four months. This simplification provides a straightforward and easily repeatable way to translate alluvial water storage into an estimated flux contribution.

The water storage and flux calculations approximate the change in soil water usage by riparian vegetation by assuming a 50% evapotranspiration loss from the increased alluvial water storage. An increase in water storage is associated with an increase in the elevation of the water table, therefore making water available to plants for longer in the season and possibly increasing total atmospheric water loss due to transpiration. Previous studies have noted this effect after the restoration of incised channels in wet meadow environments ^{19,21}; additional study to determine the magnitude of this effect in forested alluvial corridors is needed.

Surface Water Storage

To estimate the additional surface water storage from backwatered areas triggered by in-channel wood structures (e.g., Figure 2), we compute the ideal density of structures along the reach and estimate a water storage volume per structure. Ideal density of structures is determined by estimating each structure's backwater influence based on channel gradient and the fixed aggradation potential estimate of 3 ft using the following equation where S is channel slope and $(H_i - H_a)$ is the difference between incised and aggraded channel depth:

$$L_b = \frac{(H_i - H_a)}{S}$$

The length of backwater influence is then used as ideal spacing between channel-spanning structures. Surface storage volume per structure is then estimated as the volume of a simple rectangular prism where L_b is length of backwater influence, W is channel width, and H_a is estimated aggraded channel depth which for simplicity is fixed at 1 ft throughout the study area. Channel width is multiplied by a 1.1 coefficient to account for the

expected widening of the channel due to obstruction. The calculation of surface storage volume per structure ($V_{surf,struct}$) uses the following equation:

$$V_{surf,struct} = L_b \times 1.1W_c \times H_a$$

Thus, the volume of surface water storage at a reach-scale ($V_{surf,reach}$) is estimated by:

$$V_{surf,reach} = V_{surf,struct} \times (L_r \div L_b)$$

Similar to an artificial impoundment, surface water storage volume from in-channel wood structures is positively correlated to valley width and structure spacing (i.e., area of potential storage) and negatively correlated with valley slope. Thus, low-relief reaches with wider valley bottoms will have greater storage potential per in-channel wood structure versus steeper channels with naturally confined valleys where storage potential is low.

In-Channel Sediment Storage

The process of aggradation of the incised channel also increases *in-situ* sediment storage, which can be quantified using a similar approach to surface water storage. The determination of structure spacing as described above assumes that channel spanning structures will cause sediment aggradation for the length of their backwater influence. The additional volume of in-channel sediment storage from each channel-spanning structure ($V_{sed,struct}$) can be imagined as a wedge of sediment built up to the height of aggradation against the upstream side of the structure and tapering back to grade over the length of influence (L_b). The in-channel sediment storage per structure can therefore be calculated as:

$$V_{sed,struct} = \frac{L_b \times W_c \times (H_i - H_a)}{2}$$

Thus, sediment storage at a reach-scale ($V_{sed,reach}$) is estimated by:

$$V_{sed,reach} = V_{sed,struct} \times (L_r \div L_b)$$

Note that this additional sediment storage engenders additional in-channel subsurface storage as well. However, this quantity is not calculated separately as it is folded into the overall subsurface water storage calculation.

3.3 Field Validation of Modeled Values

On June 11 and 12, 2020 we visited approximately 20 reaches to measure channel morphology and valley width, characterize floodplain sediments, and observe geomorphic setting. In addition, Anthony Waldrop (Grays Harbor Conservation District) visited Schafer Creek on May 4, 2020, and provided channel measurements at 5 locations, which were incorporated into field validation. Given the large domain of the analysis, field visit locations were chosen to represent a range of tributary types in locations with easy road access along a relatively efficient travel path. Thus, of the 12 total HUC-12 subwatersheds in the analysis domain, field locations covered a subset including: Upper Wynoochee River, Middle Fork Satsop, Lower West Fork Satsop, and Decker Creek.

In general, we found that modeled channel width and valley width are similar to the field observed values. Where the values diverge, the difference is largely attributed to difficulty in measuring valley width in the field with a laser range finder, given dense forest cover and the difficulty in identifying valley walls. Where field values and model values disagree, we checked the model values against topographic analysis of the lidar DEM and found that the model values are more accurate than the field values in characterizing the width of the alluvial valley bottom. In some cases, the model overestimated valley bottom in the proximity of road crossings,

where the stream network and subsequent valley bottom delineation, are influenced by road-side drainage pathways.

We focused a portion of field time on reaches within the Decker Creek watershed, where the modeled valley bottom delineations are very wide and not well defined by topography due to a low relief landscape formed by continental glaciation. Multiple valley bottoms are adjacent where more than one stream drains the flat plain with few topographic watershed divides. We found that although the valley width values seem high, field observations suggest that the model representation of adjacent valley bottoms is accurate (Figure 13). In particular, the goal of delineating valley bottoms in the model is to define the size of the shallow alluvial aquifer and characterize the lateral extent of hydrological influence from raising channel bed elevation. With this goal in mind, field observations suggest that hydrologic influence is nearly continuous between different drainages due to undefined valley topography.

Lastly, field observations provided additional evidence for previous channel incision, which was estimated in the model framework. In addition to the evidence for incision history and amount determined from topographic and hydrologic analysis (described above), we observed a 3.5 ft head cut in a tributary to Still Creek and bedrock present in an otherwise alluvial channel in 3 locations: Still Creek, a tributary to Still Creek (both in the Lower West Fork Satsop HUC-12; Figure 14), and Rabbit Creek (Middle Fork Satsop HUC-12).



Figure 13. Wide alluvial valley around Decker Creek (HUC-12: Middle Fork Satsop) where Pleistocene continental glaciation resulted in low relief (photo taken looking downstream on June 12, 2020).



Figure 14. Bedrock in the channel bed of a tributary to Still Creek (HUC-12: Lower West Fork Satsop), approximately 1.5 miles upstream of county road crossing (photo taken looking upstream on June 11, 2020). Bedrock was also observed in Still Creek and in Rabbit Creek (HUC-12: Middle Fork Satsop).

4 RESULTS

Modeled values suggest high potential for restoring water storage and sediment storage within the tributary network of the Satsop and Wynoochee watersheds. Results for the tributary assessment include only reaches with stream orders of 1-4, which are generally smaller streams located higher up in the stream network. Normalized water storage potential ranges from 0.2 to almost 100 acre-feet of water storage per mile of restored stream, and normalized sediment storage potential ranges from 300 to more than 7,000 cubic yards per mile.

Since results are spatially explicit, values for each stream segment can be mapped to understand location and spatial relationships (see Appendix A). In addition, the reach-scale values can also be aggregated to compute total water storage potential or sediment storage potential at the scale of a HUC-12 subwatershed (Figure 15 and Figure 16; Table 3). Although the potential restorable water storage of a single 0.5-mile reach may be on the order of a few acre-feet, the benefits scale with extent of treatment. For example, model results suggest the potential to restore over 500 acre-feet of natural water storage on Green Diamond and Weyerhaeuser lands in the West Fork Satsop River subwatershed (Table 3).

In addition, the numerous attributes that are joined or derived during the modeling process are potentially useful for applying these results to the identification and prioritization of stream reaches for restoration. For example, the valley bottom polygons are used to extract infrastructure information, which can then be used as a variable across which to sum the results. By doing so, the results suggest, for example, that there is substantial restorable water storage with minimal adjacent infrastructure on Green Diamond lands within the East Fork Satsop HUC-12 subwatershed (Figure 17). The applications of these results to project planning are discussed further in Section 5.4.

Another perspective for understanding the results is to map drainage areas by their quantile for restorable water storage, scaled by reach length (i.e., normalized). Quantile (i.e., rank relative to total number of reaches) depends on the context for comparison, so therefore the quantile for each reach was computed relative to its HUC-12 subwatershed (Figure 18) and its HUC-10 watershed (Figure 19). Within comparisons relative to the HUC-12 subwatershed, the highest values generally occur along the highest order tributaries where alluvial surfaces are widest and gradient is lowest. Within comparisons relative to the HUC-10, the highest potential for restorable water storage occurs in the lower and middle Wynoochee, Decker Creek, and the upper East Fork Satsop. These higher values are also associated with wider, lower gradient valleys.

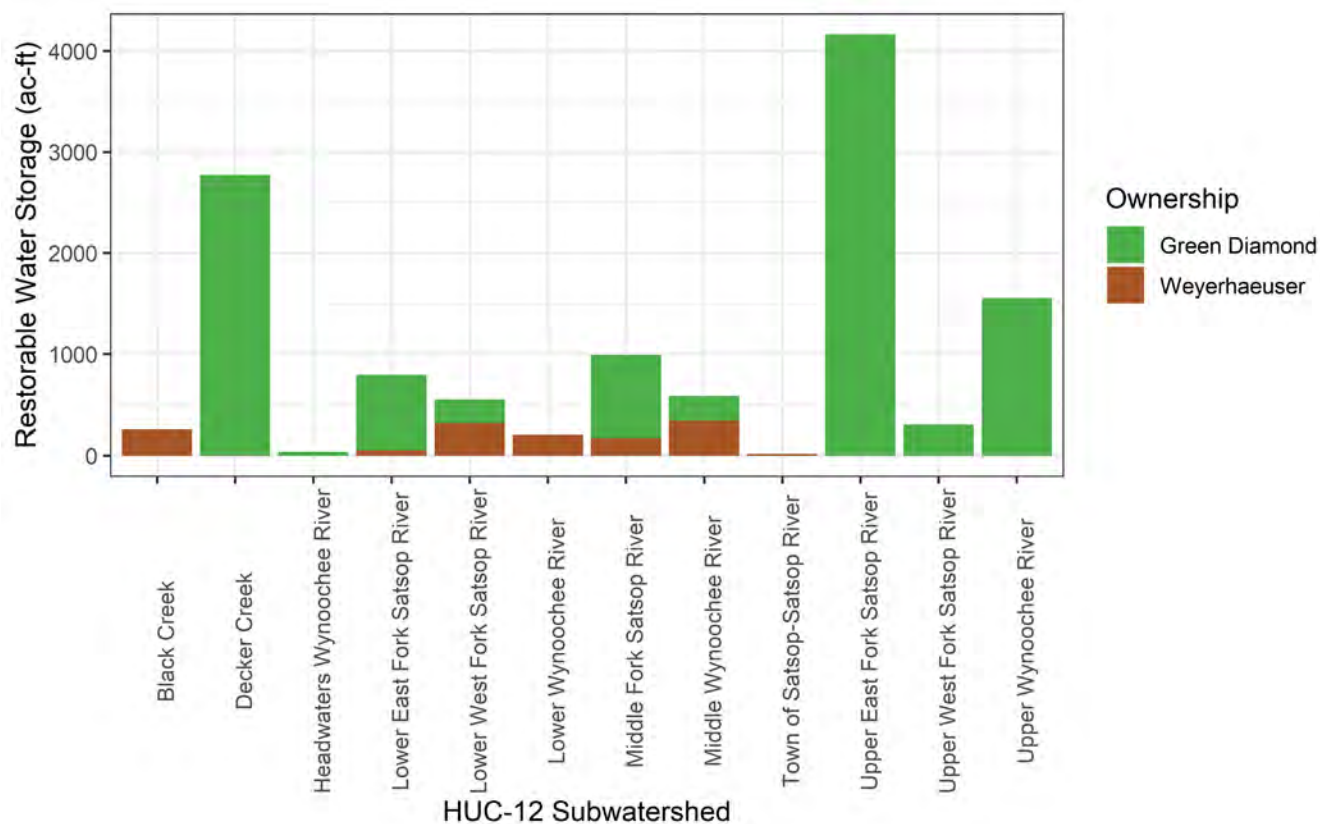


Figure 15. Total restorable water storage (acre-feet) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed and by land ownership.

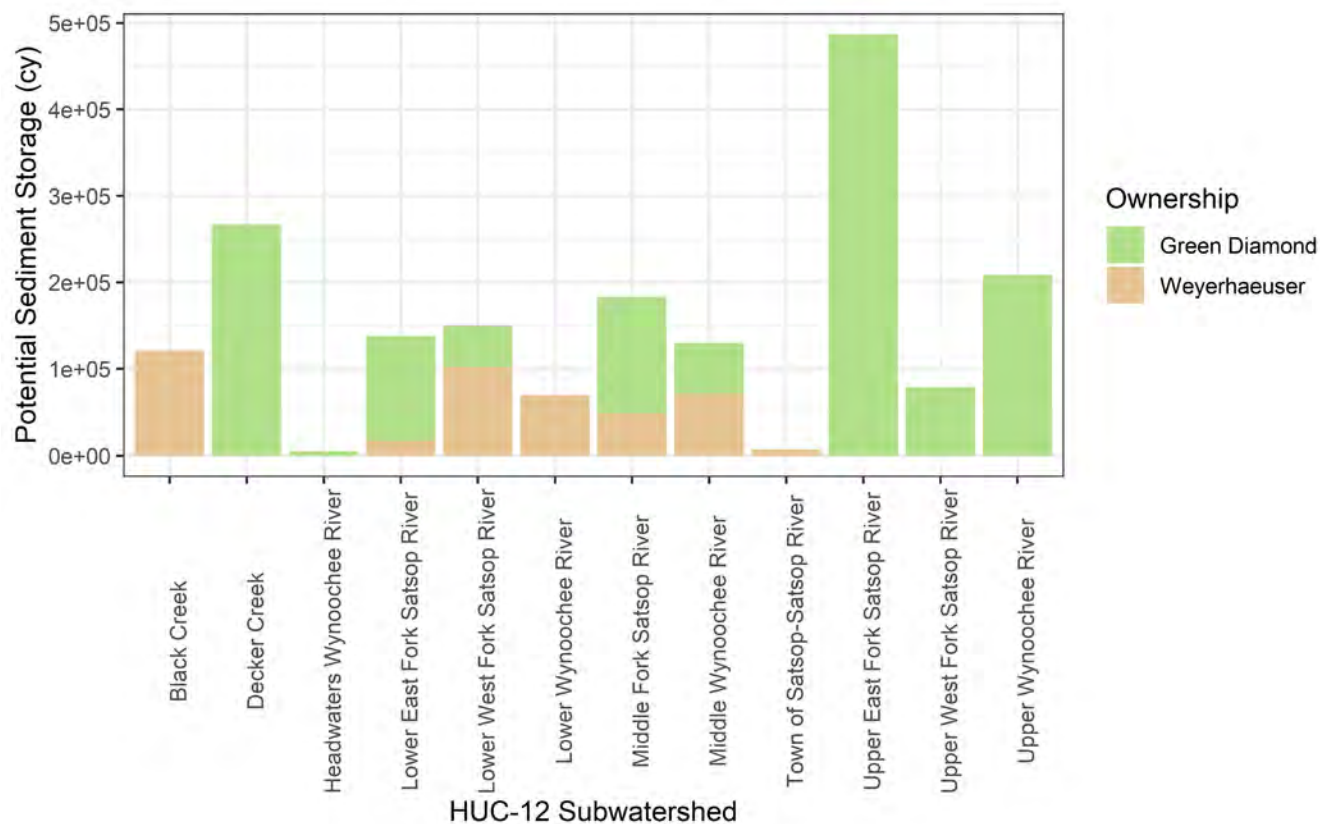


Figure 16. Total potential in-situ sediment storage (cubic yards) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed and by land ownership.

Table 3. Model results summed by HUC-12 subwatershed and land ownership (for low order (1-4) and low gradient (<8%) reaches), presented in descending order by total restorable water storage potential.

HUC-12 Subwatershed	Ownership	Total Restorable Water Storage (ac-ft)	Total Potential Sediment Storage (cy)	Total Length of Streams < 8% Gradient (mi)
Upper East Fork Satsop River	Green Diamond	4,163	486,520	350
Decker Creek	Green Diamond	2,769	266,480	224
Upper Wynoochee River	Green Diamond	1,556	208,397	196
Middle Fork Satsop River	Green Diamond	817	134,923	111
Lower East Fork Satsop River	Green Diamond	741	120,418	84
Upper West Fork Satsop River	Green Diamond	342	71,182	49
Lower West Fork Satsop River	Weyerhaeuser	318	102,043	58
Middle Wynoochee River	Weyerhaeuser	303	78,612	61
Lower West Fork Satsop River	Green Diamond	255	120,907	64
Middle Wynoochee River	Green Diamond	243	58,669	38
Black Creek	Weyerhaeuser	234	48,291	37
Lower Wynoochee River	Weyerhaeuser	208	69,412	41
Middle Fork Satsop River	Weyerhaeuser	174	48,126	27
Lower East Fork Satsop River	Weyerhaeuser	52	17,420	10
Headwaters Wynoochee River	Green Diamond	40	5,403	5
Town of Satsop-Satsop River	Weyerhaeuser	16	6,830	5
Decker Creek	Weyerhaeuser	2	132	0
Town of Satsop-Satsop River	Green Diamond	1	677	1

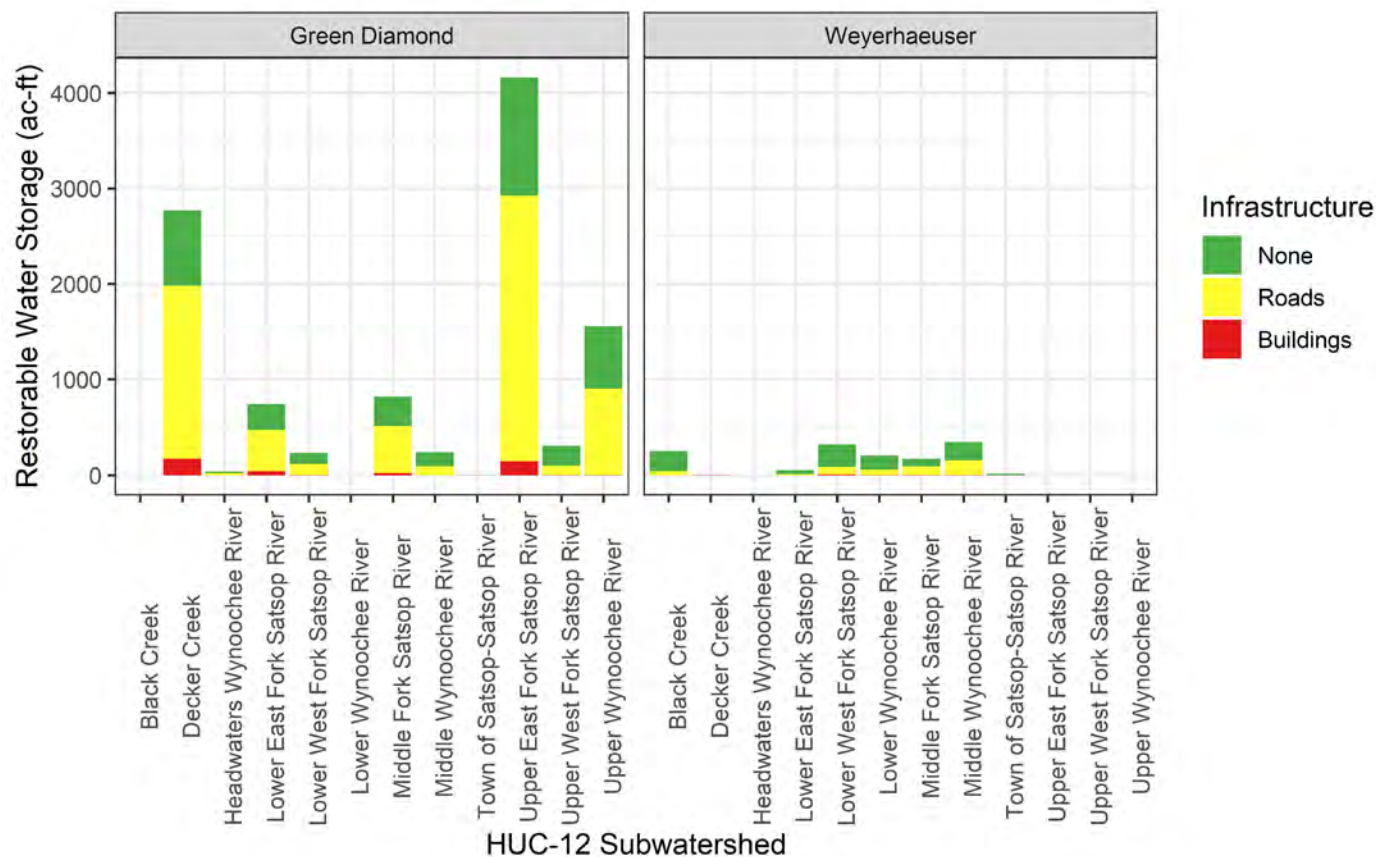


Figure 17. Total restorable water storage (acre-feet) in low order stream reaches (order 1-4) summarized by HUC-12 subwatershed, land ownership, and presence of infrastructure in the valley bottom.

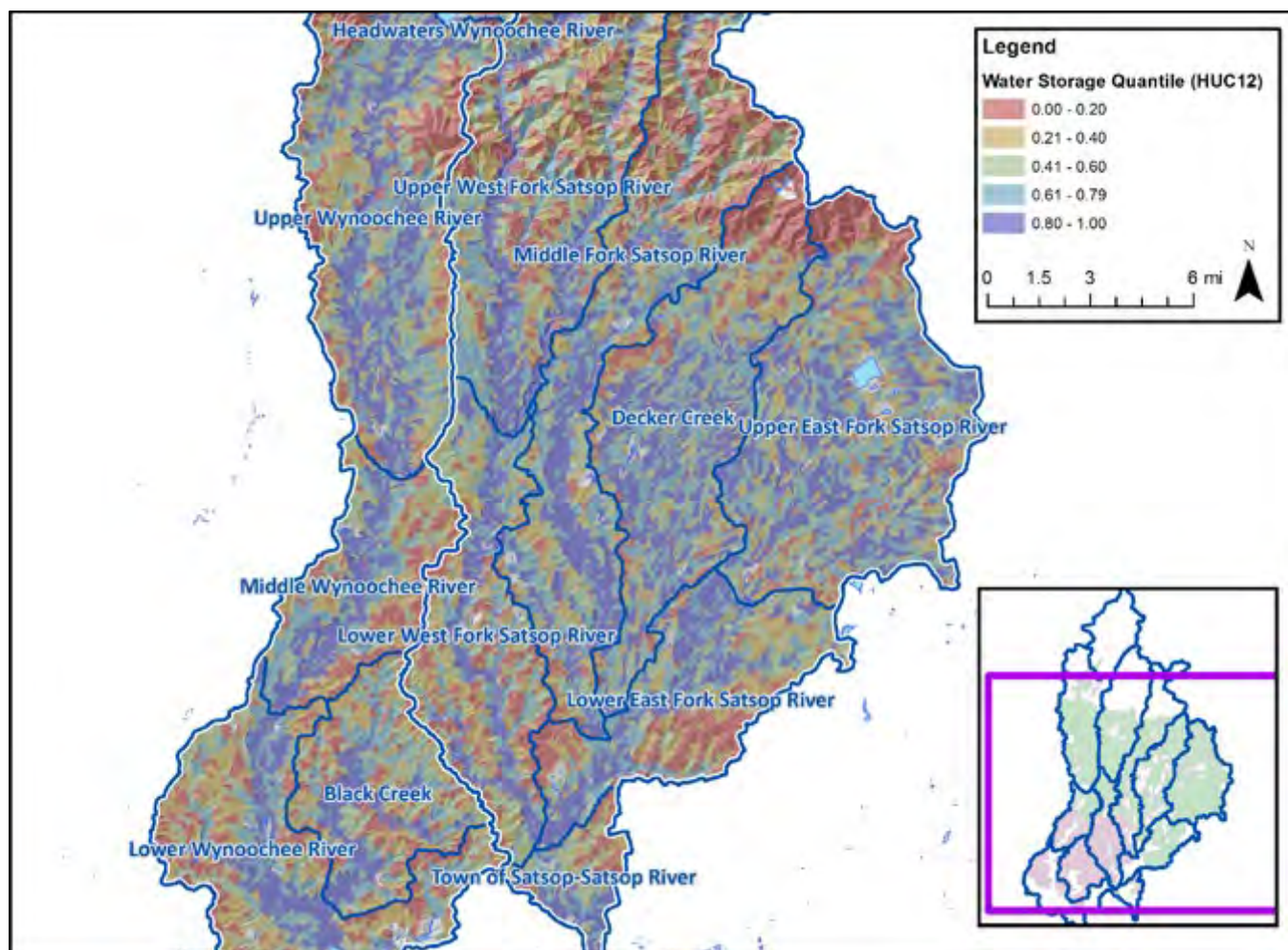


Figure 18. Quantile (i.e., 0 to 1, with 1 as the highest ranked) for normalized restorable water storage (acre-feet/mile) for each reach relative to the other values in its HUC-12 subwatershed, symbolized by the color of the reach-scale drainage area.

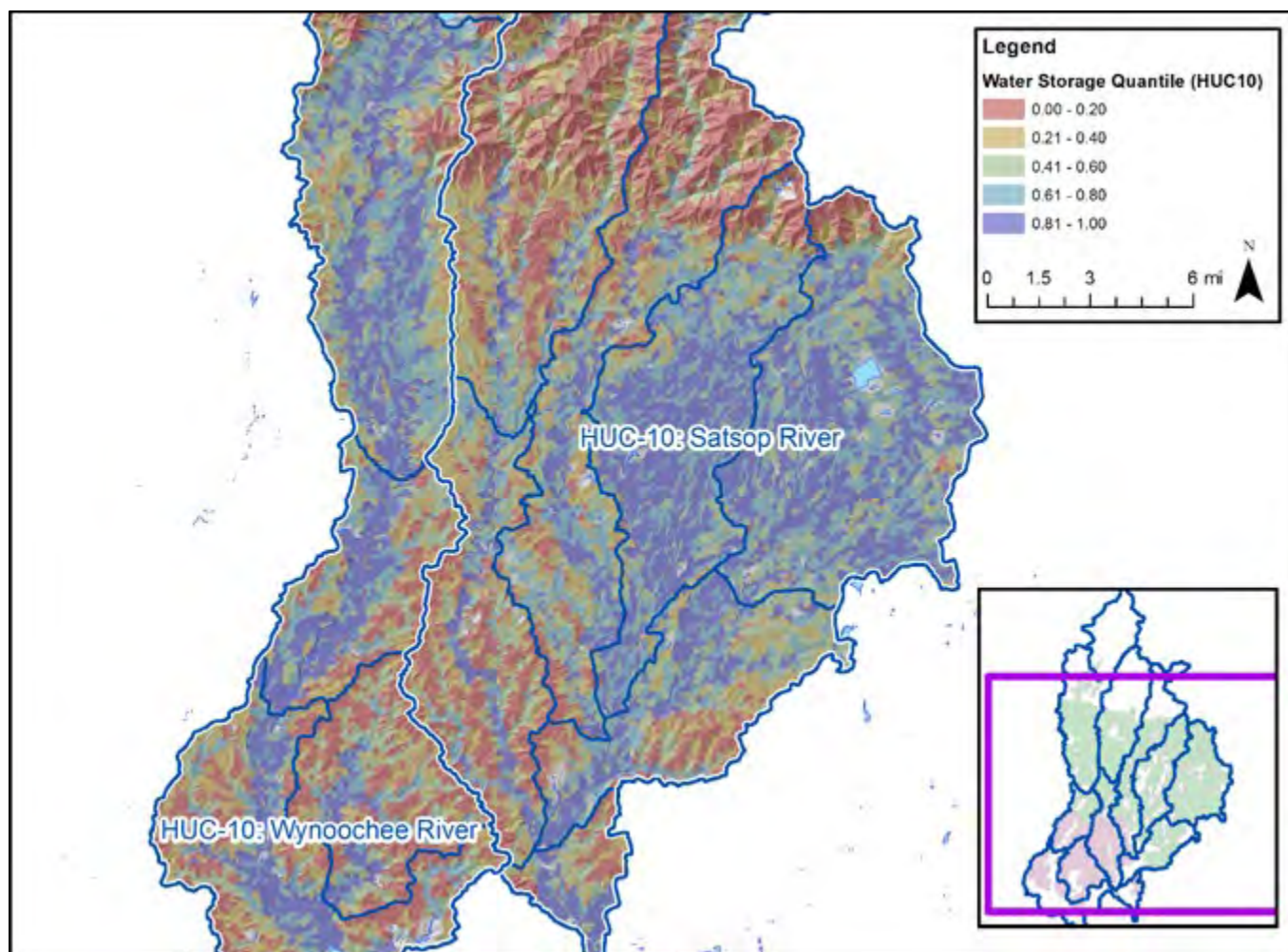


Figure 19. Quantile (i.e., 0 to 1, with 1 as the highest ranked) for normalized restorable water storage (acre-feet/mile) for each reach relative to the other values in its HUC-10 watershed, symbolized by the color of the reach-scale drainage area.

5 RESTORATION STRATEGY

5.1 Overarching Considerations

The focus of this restoration strategy is to use the model framework as a screening tool to identify potential opportunities to restore natural water and sediment storage functions to increase instream water quantity and quality. Because the domain of the model framework is a watershed-scale, the output must subsequently be vetted through additional reach- and site-specific criteria and data collection to determine project viability. These criteria include, but are not limited to, site-specific level of existing alluvial water storage and ecological function, implications to existing habitats and sensitive species, design considerations (e.g., stability, longevity, risk, budget schedule), regulatory requirements, and construction feasibility.

Collection of site-specific field data will be required to verify site conditions, particularly the assessment of the level of existing function or degradation, which informs the decision to restore versus protect. Consideration of ecological sensitivity to increases in alluvial water storage/elevation of the water table may affect the choice of restoration treatment or support a decision that protection is a more viable strategy. Similarly, use of the reach by sensitive species (e.g., salmonid spawning; freshwater mussel beds) and/or presence of unique/rare/sensitive habitats (e.g., bogs, mature forests, rare plant habitats) should also influence project viability considerations.

5.2 Prioritization

5.2.1 Prioritization Approaches

Using the model framework, each individual stream reach is ranked for restorable water storage potential, normalized by stream length (acre-feet/mile) to identify top-ranked reaches for further consideration of appropriate restoration actions. Rankings and the associated quantile are computed for all the commercial timber land located within two spatial units: the Satsop and Wynoochee River watersheds (i.e., HUC-10s), and for each of the HUC-12 sub-watersheds within them. Thus, the top-ranking reaches are identified for further consideration of restoration actions.

In addition to ranking on the basis of restorable water storage potential, each stream segment within the project domain includes numerous attributes that can be used to filter or rank reaches for possible restoration actions, including:

- ▶ Location in a watershed of interest
- ▶ Location upstream of impairment due to low flows or suspended sediment
- ▶ Sediment storage potential (cubic yards per mile)
- ▶ Appropriateness of a specific restoration approach
- ▶ Fish use or intrinsic fish habitat potential
- ▶ Current and/or future summer stream temperatures
- ▶ Infrastructure intensity

The specific attributes of interest are likely to vary with restoration goals, stakeholders, and funding sources and can be used to establish specific ranking/weighted criteria.

Regardless of how stream segments are identified and prioritized for restoration actions, there are several overarching considerations when implementing projects identified with this screening tool:

1. **Prioritize projects that restore processes.** Numerous restoration frameworks point to the need for re-initiating natural processes that sustain ecological recovery, rather than targeting local improvements only^{47,48}. This restoration strategy lays the foundation for identifying projects that can achieve hydrologic and ecologic uplift, but the next step is a reach-scale analysis of geomorphic processes, which is critical to understand what processes may be impaired in order to implement process-based restorative actions that achieve a net-benefit condition and can support climate change resiliency.
2. **Consider value versus cost of working lower in the watershed.** Higher order streams tend to fall into more expensive and higher risk restoration categories due to their larger size and stream power. However, there are numerous benefits from starting at the bottom and working up the watershed. In particular, channel incision propagates upstream, which is often visible as head cuts, and can result in stream network-wide incision and subsequent loss of gravel storage and water table lowering on a much greater scale. Raising the base level of the channel bed elevation downstream provides a foundation for upstream restoration.
3. **Consider density when using non-engineered methods.** One of the advantages of “low tech” restoration is that less cost for design and construction means more funds available for restoration. Because individual structures are not designed for long-term stability, this approach relies on high density of structures, both in space and in time, to let the stream do the work but to continue to nudge it toward recovery of natural process. Multiple years of implementation should be an expectation for this approach.
4. **Restore and enhance natural water storage functions.** Channel incision is one of the root causes of loss of alluvial water storage throughout Washington. Incision is the target impairment to be treated through this work because large amounts of natural storage capacity have been lost due to the down-cutting and subsequent evacuation of alluvium from stream channels. However, even in reaches that are not vertically incised, restoration actions with the intent to increase sediment storage and reduce rates of surface and groundwater drainage can enhance water quantity, water quality, and climate change resilience. Reaches that have been flooded by beaver activity provide a natural analog for increasing natural storage functions, with concomitant ecological benefits, even where there is not an incised channel.
5. **Consider the risks associated with restoring natural processes.** Re-aggrading channels and raising water surface elevations affects the extent and duration of overbank inundation, as well as channel migration rates and the width of the active channel corridor. Every project needs to assess whether there is infrastructure or private property that would be subject to increased flooding or erosion as a result of restoring natural processes, which are often inherently dynamic and stochastic.

5.3 Restoration Approaches

5.3.1 Overview of Criteria

To support the restoration strategy, we considered several restoration approaches and developed criteria for an initial screening of which restoration approaches may be appropriate for a given reach based on spatially explicit data. In particular, we leveraged the spatially explicit analysis of channel morphology, stream power, and presence of valley bottom infrastructure to assign one or more restoration approaches that may be applicable for each reach (Table 4). Each approach and its threshold criteria are discussed below. Summary “cut sheets” with examples of each approach are provided in Appendix B. Map books displaying the restoration approaches that were identified for each reach within the model domain are presented in Appendix C (instream restoration

approaches, including machine-built and hand-built instream structures) and Appendix D (geomorphic modification restoration approaches, including valley reset, strategic excavation, and humanscape modification).

For criteria related to infrastructure intensity we used presence/absence of buildings or stream crossings in the valley bottom polygon, and we used length of road in the valley bottom as a percentage of the total stream length to account for differing reach lengths.

Table 4. Criteria for assignment of restoration approaches to individual stream reaches. See text for rationale and references associate with criteria.

RESTORATION TREATMENT	GRADIENT	BANKFULL DEPTH (FT) ¹	BANKFULL WIDTH (FT) ¹	CONFINEMENT	INFRASTRUCTURE INTENSITY
Machine-built wood or rock structures	<i>Machine built is an option to consider at all reaches; no reaches were excluded</i>				
Hand-built wood or rock structures		< 1.8	< 15		No buildings or stream crossings in valley bottom AND Length of road in valley bottom < 0.10 × stream length
Valley Reset	< 3%			Valley Width: Channel Width > 2	No buildings in valley bottom AND Length of road in valley bottom ≥ 0.20 × stream length
Strategic Excavation	< 3%			Valley Width: Channel Width > 2	
Humanscape Modification	< 3%			Valley Width: Channel Width > 2	At least one stream crossing or dam present in valley bottom OR Length of road in valley bottom ≥ 0.05 × stream length

¹See discussion in hand-built section on range of input data for these criteria.

5.3.2 Machine-Built Instream Structure

Overview of Approach

In the context of restoring natural water and sediment storage functions, a machine-built structure is designed to re-initiate or sustain the same hydro-geomorphic processes that are triggered by naturally formed logjams, landslides, and geologic constrictions, including retention of alluvium and raising water surface elevation^{12,28,49}. To do so, machine-built structures must obstruct a substantial portion of the channel and therefore slow streamflow velocity and trigger deposition of sediment^{11,50}. Channel-spanning machine-built structures can be constructed from wood or rock or a combination thereof and are intended to halt incision and maintain channel bed elevation (i.e., grade control) or to re-aggrade the incised channel. When combined with intact riparian forests or riparian forest restoration these structures ultimately help to restore the floodplain-large wood cycle, which relies on natural recruitment of large riparian trees to the channel via floodplain reconnection, bank erosion, landslides, and beavers to maintain the dynamic fluvial processes that provide natural water and sediment storage functions and form and maintain habitat⁵. Stable logjams create and maintain deep pools, side channels, and forested islands, and redirect flow from a single-threaded channel into side channels and sloughs^{11,12,28,51}.

Given the widespread channel incision and simplification resulting from a legacy of wood removal coupled with conversion of mature forest to immature (i.e., small diameter) riparian forests, machine-built wood structures can simulate the natural stability of large-diameter trees falling into the channel. This approach can be designed for any stream where access is adequate but is usually applied to higher order streams or areas with infrastructure or private property at risk because machine construction methods provide multiple options to design for stability and intended effects. Larger channel size and stream power require engineering analysis to overcome greater forces, and proximity to infrastructure and private property requires greater certainty in the project outcome and more predictable response of the channel system.

Criteria for Approach

Machine-built structures can be designed to fit a wide range of stream sizes and infrastructure constraints. Machine built structures can also repair greater levels of impairment or degradation to a stream channel relative to hand-built or other, more passive approaches such as riparian restoration. As such, all reaches included in the assessment were categorized for a potential machine-built approach, but this approach is typically more appropriate where degradation is greater, stream power is higher, or infrastructure risk is higher.

5.3.3 Hand-Built Instream Structure

Overview of Approach

A hand-built wood structure is designed to re-initiate or sustain the same hydro-geomorphic processes that are triggered by naturally formed logjams and beaver dams, including retention of alluvium, raising water surface elevation, creation and maintenance of deep pools and side channels, and overbank connectivity with floodplain water bodies^{9,12,52}. The resulting vertical and lateral hydrologic connectivity increases groundwater and surface water storage^{9,53}.

Hand-built structures can range from “low tech” beaver dam analogs (BDAs) and post-assisted log structures (PALS, Wheaton *et al.*, 2019) for which the expectation of frequent blow-outs and adaptive maintenance is counter-balanced by the low cost and minimal design requirements, to site-specific engineered structures built by hand-crews for longer-term stability. Hand-built construction methods range from projects for which wood is carried, placed, and stabilized with hand tools to projects that utilize machine delivery methods such as cable riggings and a yoadler and hand placement of the cable-delivered large wood. Hand-built wood structures can be installed when there is limited to no machine access and are often applied in lower-order streams where channels are smaller and infrastructure intensity, and thus risk to infrastructure, in the valley bottom is lower.

Screening Criteria

Screening for the feasibility of a hand-built approach is determined by the size of the stream to be treated since a larger stream requires larger wood for stability. A hand crew must be able to build a structure that obstructs all or most of the channel width to re-initiate sediment deposition and channel bed aggradation. A hand-built wood structure is feasible on many small, low order streams, so we classify based on the upper limit of where hand-built wood structures may be appropriate. However, the construction method, design, and size of materials all contribute to defining the upper threshold for stability, so a hand-built BDA that utilizes posts and small diameter branches will have a lower threshold than larger diameter wood delivered to the channel via cable rigging (Figure 20).

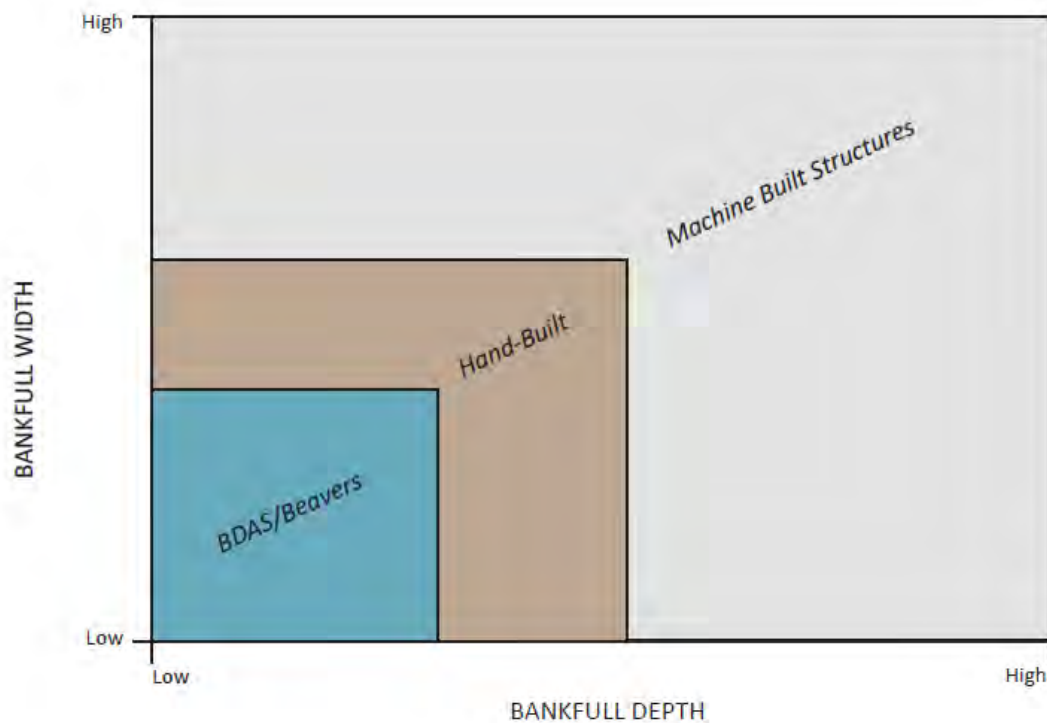


Figure 20. Conceptual diagram of the appropriateness of restoration approaches for a range of channel morphologies, defined by bankfull depth and bankfull width.

Based on previous research in the Queets River, on the Olympic Peninsula, Washington, the diameter of a stable key piece that spans the channel (i.e., log length/bankfull width = 1) ranges from approximate 0.5x to 1.8x the depth of the channel (Figure 21; from Abbe and Montgomery, 2003). Based on our restoration implementation experience, a 16" diameter log is the upper limit for manipulation and placement by a hand crew. Thus, using 16" diameter as the maximum key piece size along with a guideline of 0.75x the depth of the channel (i.e., a more conservative multiplier than 0.5, and one which represents the middle of the range rather than the minimum value), the maximum depth of a channel in which hand-built wood structures will be stable is 1.8 ft. In addition, based on surveys of key pieces in Washington, the required size of a key piece starts to drastically increase at a channel width greater than 15 ft (Figure 22, from Fox and Bolton, 2007).

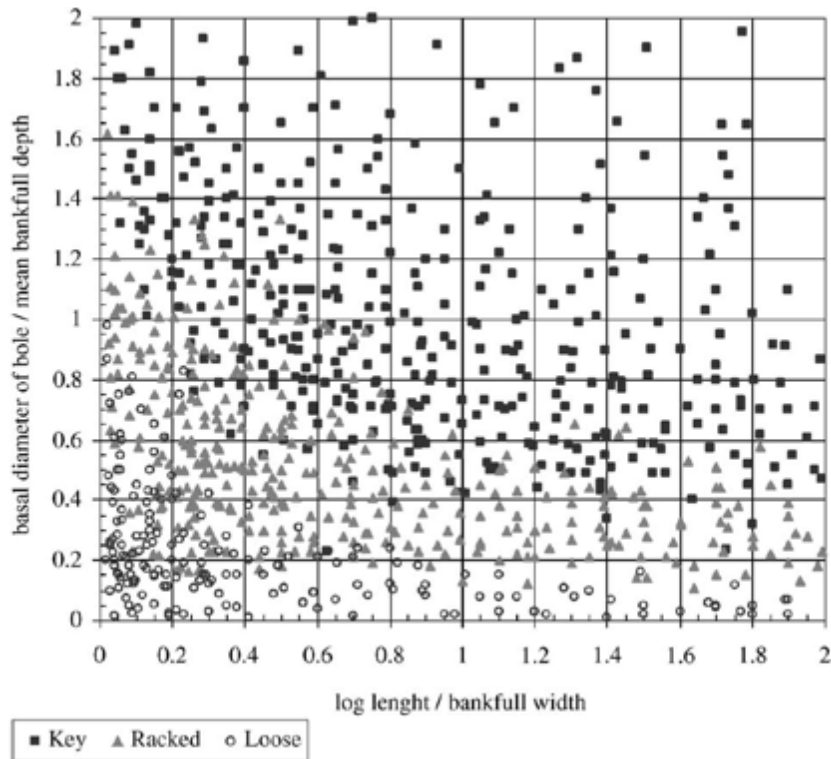


Figure 21. Size ratios for instream wood pieces from the Queets River watershed, Washington. The horizontal axis is the ratio of log length to bankfull width and the vertical axis is the ratio of log diameter to bankfull depth. Note the minimum lower bound of the filled squares, which represent key (i.e., stable) piece is approximately 0.5. Reproduced from Figure 12 of Abbe and Montgomery (2003).

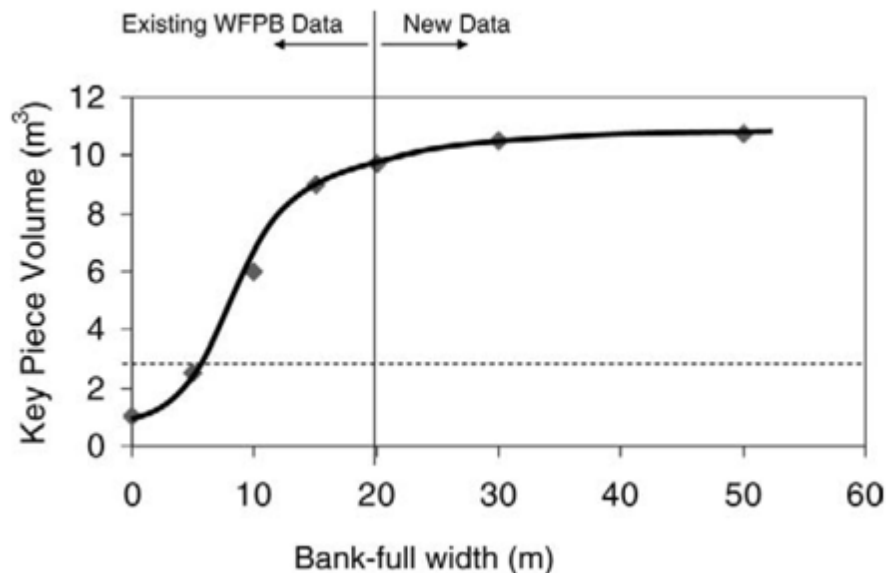


Figure 22. Key piece volume as a function of bankfull width from a survey of key pieces in Washington. Note that the volume of a key piece steeply increases in channels > 5 m (approximately 15 ft) wide. Reproduced from Figure 5 of Fox and Bolton (2007).

A hand-built wood structure approach was assigned as a restoration option to reaches for which bankfull depth is < 1.8 ft, bankfull width < 15 ft, and there are no roads, stream crossings, or buildings in the valley bottom. However, given that bankfull depth and width are estimated from other input data, we used two sets of values for channel morphology to provide some bounds on this category (Table 5). In particular, bankfull depth and width estimates are lower when estimated from regional regression equations³⁴ that utilize drainage area. They are higher when estimated from the equation based on mean average precipitation and the associated Q2 (i.e., the peak flow with a 2-year recurrence interval⁴¹) for bankfull depth, and the approach described in Section 3 for using relative elevation to define the channel width. The different methods lead to vastly different numbers of stream segments classified for a hand-built approach (400 versus 1700 miles of stream length, see Table 9). Therefore, both are provided as an indication of a more conservative versus a more liberal screening. The resulting reaches from the more conservative screening criteria (i.e., higher threshold values) are considered to be likely suitable for hand-built methods whereas the resulting reaches from the more liberal screening (i.e., lower threshold values) are considered to be possibly suitable.

Both sets of the screening criteria for a hand-built approach are based on estimated values, which provides an indication of the size of channel in which a stable, hand-built structure can be built. However, at a reach-scale, the actual channel depth should be assessed via cross section analysis in the field or via high resolution topographic data because the observed depth may be substantially deeper than the modeled condition due to incision. Where the actual channel is approximately 3-4 ft deep, a hand-built structure could reasonably re-aggrade the channel to within the un-incised (i.e., reference) condition, which would be closer to the modeled value of < 1.8 ft than the observed value of 3-4 ft. However, a hand-built structure is less likely to be functional or stable in a channel that is deeper than 3-4 ft.

Lastly, given that there are inherently less options for stabilizing hand-built structures than for machine-built structures, the hand-built approach tends to be more appropriate where infrastructure intensity, and thus risk to infrastructure, is lower. In fact, in many cases stability is not a key design goal of such structures. In locations where risk to infrastructure is low and willingness to adaptively manage is high the hand-built approach may be more widely applicable than is indicated by these criteria.

Table 5. Bankfull depth and width estimation methods for two sub-categories of hand-built approach. Screening for both categories includes the absence of roads, stream crossings, and buildings from the valley bottom.

HAND-BUILT APPROACH SUB-CATEGORY	BANKFULL DEPTH (BFD) ESTIMATION METHOD	BANKFULL WIDTH (BFW) ESTIMATION METHOD	INTERPRETATION
Hand-built approach lower threshold (Possibly suitable)	$BFD = 0.66 * DA^{0.39}$	$BFW = 12.39 * DA^{0.43}$	Many more segments are included in the hand-built category using these criteria, which estimate low values for BFD and BFW. There is less likelihood that a hand-built approach will be appropriate for these stream segments based on reach-scale analysis.
Hand-built approach higher threshold (Likely suitable)	$BFD = 0.15 * Q^{0.45}$	BFW defined by relative elevation raster, inclusive of all pixels for which relative elevation $\leq$ BFD, where BFD is defined as, $BFD = 0.66 * DA^{0.39}$	Many less segments are included in the hand-built category using these criteria, which estimate higher values for BFD and BFW. There is more likelihood that these streams are actually smaller, and that a hand-built approach will be appropriate.

¹ All equations for Pacific Maritime Mountain Streams in Table 4 of Castro and Jackson (2001).

² Q estimated as Q2 using average annual precipitation values from PRISM for each HUC-12 subwatershed, with regional regression equation from Mastin *et al.* (2017).

Working with Beavers

An additional subset of the hand-built category involves relying on beavers to leverage the positive hydrologic and geomorphic effects of dam-building where compatible with infrastructure and land ownership⁵⁵. Beavers create and maintain impoundments that have a significant impact on the hydraulics of a stream by slowing water velocities, triggering aggradation, raising surface and subsurface water elevations, and improving the robustness of the riparian corridor which provides source of wood and shade to the channel^{9,23,56,57}. This approach ranges from relocating or reintroducing beavers to a reach with the aim of long-term residence, to building beaver dam analogs as “starter” dams in areas where beavers are likely to move in on their own. This approach can also include adaptive management to maintain structures until beavers move in or to frequently replant riparian vegetation to sustain beaver populations and encourage long-term occupation.

For this approach to be effective, a stream must have sufficient streamflow during the dry season and also not exceed stream power criteria for stability⁵⁶, along with sufficient and appropriate species of riparian vegetation for both food and construction materials⁵⁸. Geospatial models that have been developed to specifically screen for the potential for beaver to reside in a given reach based on hydrology, vegetation, and infrastructure are recommended for screening for integrating beavers in restoration approaches^{59,60}.

5.3.4 Valley Reset

Overview of Approach

A valley reset, sometimes referred to as a “stage 0” approach after the channel evolution model updated by Cluer and Thorn (2014)¹⁶, aims to return a valley bottom and channel(s) to its pre-disturbed condition, which in lower gradient settings of western Washington, commonly consisted of a network of shallow, anabranching channels in a complex floodplain which supported an interspersed of upland forests and wetland communities⁵. The approach relies on the use of earthwork machinery to fill incised stream channels with alluvium and grade

down artificially perched floodplains, loading the floodplain with large wood, and installing native vegetation and then allowing the stream to form new channels and ultimately develop wetlands across the “reset” valley bottom³¹. In doing so, channel depths are decreased and floodplain width is increased, which reduces stream power, and therefore the export of sediment from the reach, and reconnects the channel hydrologically to both the alluvial groundwater table and to floodplain water bodies and wetlands. The net effect is to raise groundwater elevations and increase in-situ water and sediment storage⁶¹.

The key advantages of this approach for incised channels are that (1) there is no delay in geomorphic effect since floodplains are reconnected immediately rather than relying on natural aggradation processes which can take years or decades, and (2) stream power is drastically reduced after converting a reach from a single thread incised channel to a network of shallower and longer channels, thus inherently increasing the stability of wood, sediment, and the riparian corridor. Vegetation restoration is a key component to facilitate the development of native vegetation communities across the valley bottom and thwart invasive species colonization particularly in the period immediately after ‘reset’.

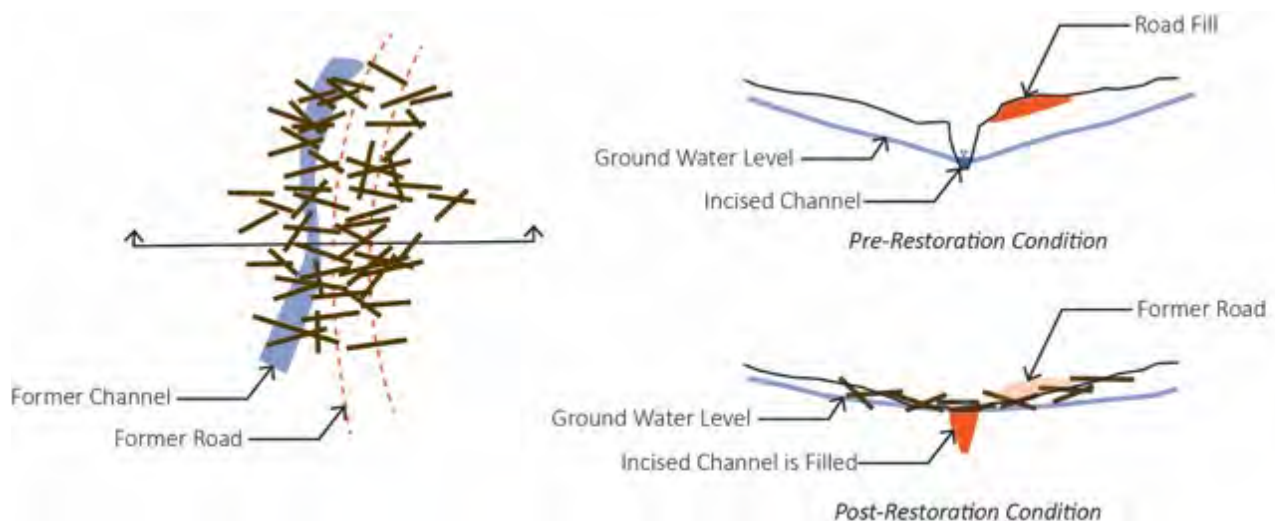


Figure 23. Conceptual sketch of valley reset approach, showing plan view (left) and cross-section view for the pre-restoration condition (upper right) and the post-restoration condition (lower right). In this approach an adjacent road (or other fill, such as a levee or berm) is used to fill an incised channel, and the floodplain is roughened through extensive placement of large wood. The cross section view also shows the increase in groundwater level that results from reducing the depth of the incised channel.

Screening Criteria

The valley reset approach is only appropriate for lower gradient response reaches rather than source or transport reaches^{31,62}, and requires machine access, as well as a source of native fill material to place within the incised channel. Rebuilding of channel beds is possible with imported streambed material, but at much greater costs. Commonly a road prism or levee that originally utilized native alluvium is identified as the source. We therefore assigned this as a possible approach based on three criteria: gradient less than 3%^{36,37}, unconfined valley, and the presence of a road in the valley bottom. Although it is possible to apply this approach in a higher gradient reach (e.g., Table 2 of Powers *et al.*, 2019), 3% is a commonly defined threshold for a response reach.

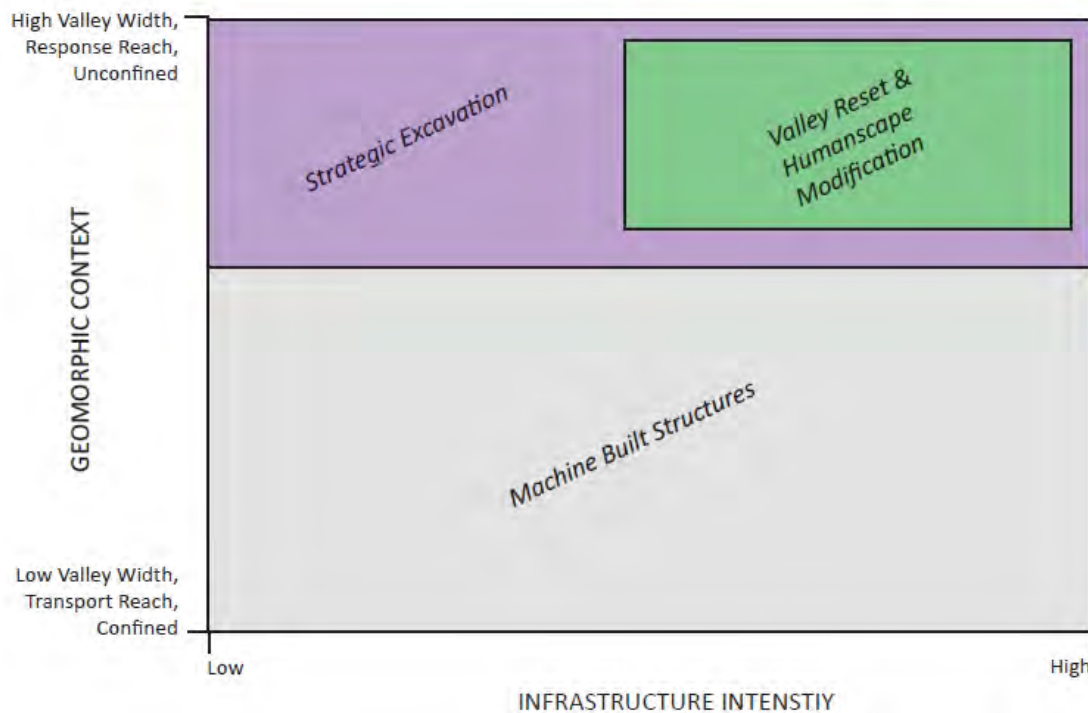


Figure 24. Conceptual diagram of the appropriateness of three machine-built restoration approaches to different reaches based on infrastructure intensity and geomorphic context. Infrastructure intensity is characterized by the number of buildings and stream crossings and the length of road in the valley bottom for a given reach. Geomorphic context is defined by valley width, confinement, and gradient.

5.3.5 Strategic Excavation

Overview of Approach

When a channel becomes disconnected from its floodplain either through direct human intervention or through degradation via incision over time, much of the sediment and water storage benefits of an active floodplain are lost. Often the remnants of an active floodplain, such as abandoned channels or disconnected wetlands, remain visible in the topography and can be re-engaged or recreated by strategically removing fill, excavating connections to the mainstem, or redirecting the mainstem from an artificially straightened path to a more natural meander planform. By doing so, the hydrologic connection across the floodplain can be restored, which results in increased groundwater and surface water storage.

There can be overlap between this approach and humanscape modifications (discussed below) since the disconnection between a stream and floodplain is often maintained by anthropogenic structures such as roads or levees. However, strategic excavation can also be appropriate for lowering an abandoned floodplain surface to create an inset surface, or to reconnect to side channels and wetlands that became disconnected due to incision in the main channel.

Screening Criteria

This approach is most appropriate in moderately confined to unconfined response reaches in which anabranching or meandering planforms are most likely to develop. We therefore assigned this as a possible

approach based on two criteria: gradient less than 3% and unconfined valley. Infrastructure intensity was not used as screening criteria for this approach because the risk to infrastructure is highly variable based on the specific site conditions and intended effects of excavation.

5.3.6 Humanscape Modifications

Overview of Approach

Since European colonization, humans have built static infrastructure that interferes with the naturally dynamic flow paths of rivers and streams, often resulting in channel incision. Channel incision, as well as impairment of natural processes such as channel migration, channel avulsion, and overbank flow, result in the lowering of the alluvial groundwater table, reduction in connectivity to the floodplain, and evacuation of alluvial sediments ^{10,21,63,64}.

A straightforward way to reverse the impacts of structures such as roads, levees, bridges, culverts, dikes, and dams, is to remove or modify them to allow the stream to return to its natural planform and flooding regime. There is often overlap between this approach and the strategic excavation approach, discussed above, as areas of earthwork may be needed in addition to infrastructure removal to fully restore natural processes the riverine system.

Screening Criteria

This approach is most appropriate in semi-confined to unconfined response reaches in which anabranching or meandering planforms are most likely to develop when constraints are removed. We therefore assigned this as a possible approach based on three criteria: gradient less than 3%, unconfined valley, and presence of at least one stream crossing or section of road for which the length of road in valley bottom $\geq 0.05 \times$ stream length.

5.4 Application of Screening To Project Planning

5.4.1 Prioritization and Selection of a Pilot Project

For the purpose of identifying a pilot project to restore natural water and sediment storage function, the stream segment attributes were used to identify a short list of potential sites, which then guided field reconnaissance and selection of a site. The criteria used to query the modeled data and winnow the results to a short list include:

- ▶ High-ranking for restorable water storage and sediment storage
- ▶ Located on Green Diamond land, in Grays Harbor County
- ▶ Salmonid-bearing stream, for habitat benefit and to step through permitting pathway
- ▶ Straightforward road access, for easier monitoring
- ▶ Hand-built restoration approach, due to implementation budget

In practice, identification and selection of the site involved querying the data for the attributes above, desktop review of 252 stream segments returned by the query, and a field visit to the top 5 sites. The query of the modeled data utilized the following logical statement:

"StreamOrder"<5 AND "Slope"<0.05 AND ("GHCo_Owner" = 'GREEN DIAMOND RESOURCE COMPANY' OR "GHCo_Owner" = 'GREEN DIAMOND RESOURCE CO') AND "acft_p_mi"> 2 AND "HandStr" = 'Yes'

The SWIFD data was queried for presence of salmonids, and the resulting dataset was spatially joined to the model results based on location within a distance of 100 ft. The resulting dataset included 252 stream segments. During desktop review, each segment was assessed for road access, fish use, channel morphology, channel plan form, and valley morphology. Exclusion of segments that did not meet base criteria (e.g., straightforward road access) along with professional judgement related to appropriate stream size and valley confinement for a hand-built project, resulted in a short list of 7 sites. These 7 sites were prioritized based on limited field time and 5 sites were visited for field reconnaissance.

The field assessment focused on access, signs of channel incision, morphology, options for restoration approaches, and presence of invasive species. A single reach was chosen for pilot project design and implementation (Schafer Creek, on Green Diamond Land in the Wynoochee basin). Additional details on the pilot project are summarized in the Basis of Design memorandum included as Appendix E.

5.4.2 Additional Project Identification Examples

Results for every reach in the model domain are displayed in the mapbooks in Appendix A. The results can also be queried for water storage ranking, physical attributes or restoration approaches, using the geospatial data or web-based mapping application (see Section 6.3). For example, the mapbook presented in Appendix F displays tributary reaches that were modeled to be in the top 50% of reaches within a given HUC-12 subwatershed for potential alluvial water storage and were identified for hand-built restoration approach. In addition, several examples are provided below to illustrate how the model results can be used to identify, prioritize, and select reaches for restoration.

Multi-Benefit Habitat and Alluvial Water Storage Project

One example application of model results is to identify location where high potential for restoring water storage intersects with reaches that have been identified for the potential for high quality salmonid habitat. For example, we queried the model results to map the spatial co-occurrence of two attributes (Figure 25):

- ▶ Top 50% (by HUC-12) for restorable water storage potential
- ▶ Reaches that meet the criteria for hand-built structures (low threshold)

The resulting stream segments are then symbolized by modeled intrinsic potential for coho winter rearing to help identify potential hand-built restoration projects that would have both habitat and water quality and quantity benefits. Once the reaches are identified at the watershed scale, other relevant attributes can be considered via geospatial analysis, including land ownership, road access to the reach, and position relative to other habitat or water quality concerns.

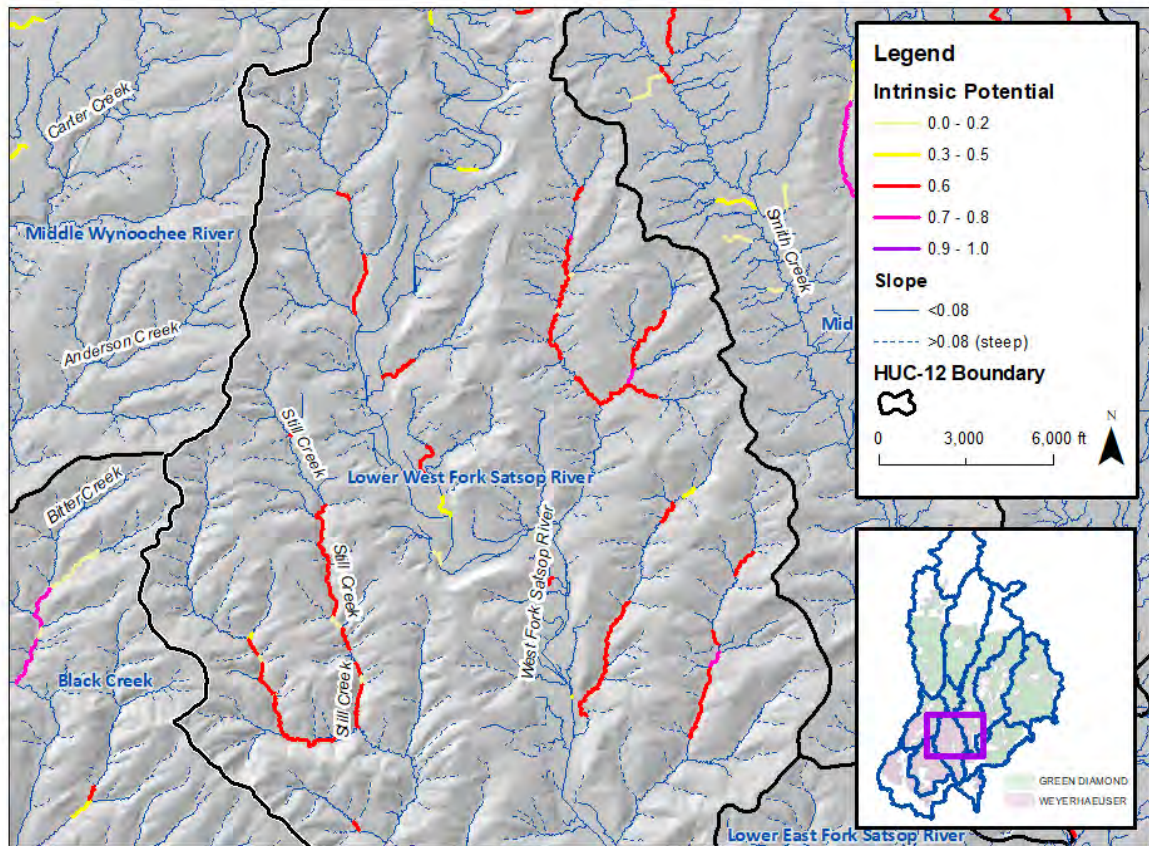


Figure 25. Map of Lower West Fork Satsop, showing modeled intrinsic potential for winter coho rearing, mapped to low order (1-4) stream segments that are in the top 50% for restorable water storage and are screened for a hand-built approach (based on criteria for possibly suitable, see Table 5).

Climate Change Resilience Project

Another application of the modeling results is multi-benefit restoration that targets critical reaches in which to improve resilience to projected increases in stream temperature. The Chehalis ThermalScape data (Table 2) maps projected stream temperatures to stream segments at the same scale of the NHDPlusV2 1:100k stream network. These data are spatially joined to the model results via proximity of reaches. By querying the data and plotting projected stream temperature in the 2080s as a function of restorable water storage, along with land ownership and salmonid presence (Figure 26) we identify a cluster of reaches in the Lower West Fork Satsop HUC-12 that have relatively high restorable water storage potential along with high projected future stream temperatures and salmonid presence.

Next, we map the locations of this cluster of reaches, by mapping segments for which the projected 2080s stream temperature is ≥ 20 °C and the modeled restorable water storage is ≥ 8 ac-ft/mi (Figure 27). The resulting map helps to identify tributary reaches where restoration may improve climate change resilience by restoration water storage along with groundwater-surface water interactions, which has been demonstrated to have a cooling effect on stream temperatures²⁶.

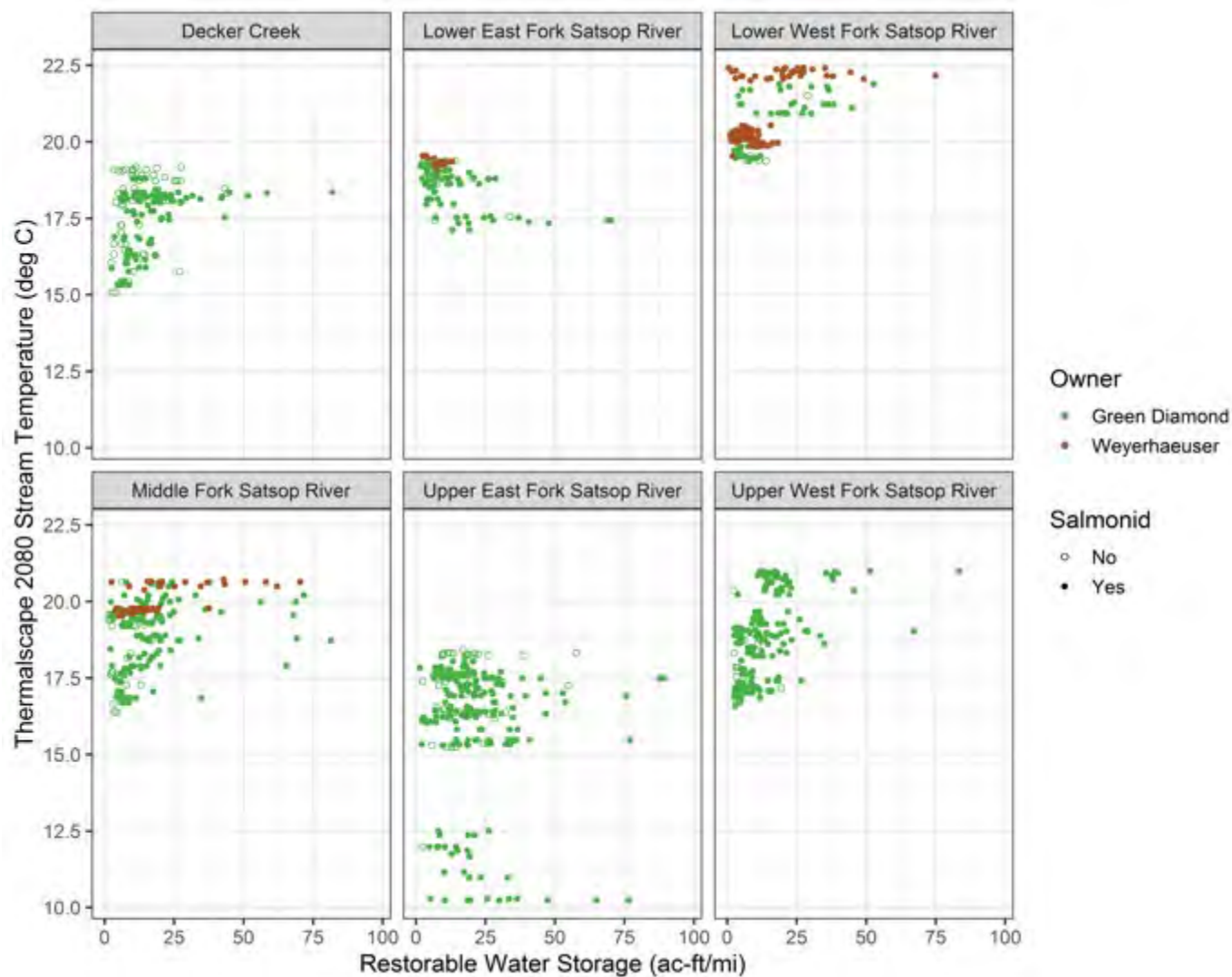


Figure 26. Restorable water storage (ac-ft/mi) versus projected 2080s stream temperatures for the Satsop River Watershed, broken out by HUC-12 subwatershed and symbolized by land ownership (color) and salmonid presence based on SWIFD (open versus fill circles). Each point represents a single reach in the model results.

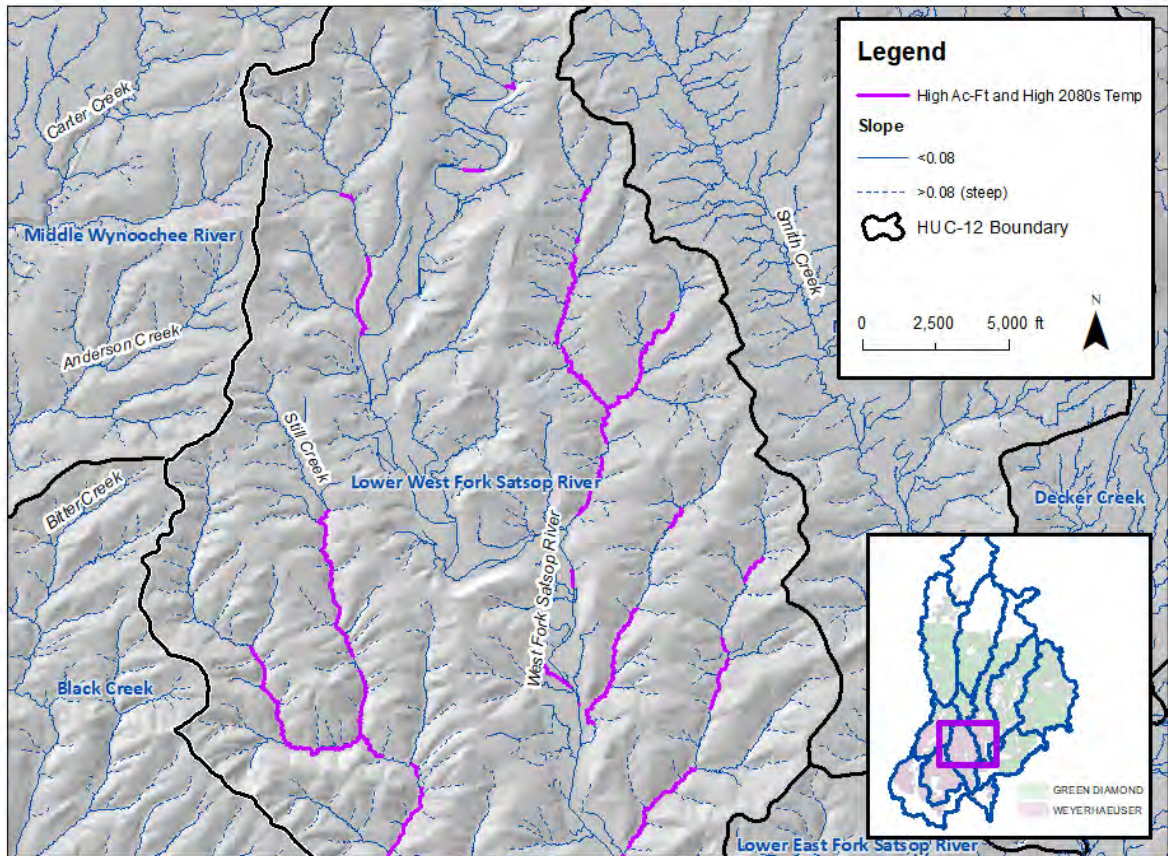


Figure 27. Map of low order (1-4) stream reaches with high 2080s projected stream temperature ($\geq 20^{\circ}\text{C}$) and are in the top 50% for restorable water storage potential.

5.4.3 Example Costs for Project Planning

Implementation costs vary widely with design effort, material quantities, construction methods, access, timing of construction, permitting requirements, dewatering requirements, and fish exclusion. However, approximate costs can be a useful tool for restoration planning, with some caution regarding relying on select examples too heavily. Example costs for a range of restoration approaches are provided below, primarily based on Natural Systems Design data and experience, except where noted (Table 6). In addition, hand-built restoration approaches range from hand-delivered and hand-placed to machine- or cable-delivered and hand-placed or hand-directed. Example costs for services associated with hand-built construction methods are also provided (Table 7).

Table 6. Example costs for a range of restoration approaches. Note that actual costs vary widely with project location, restoration approach, materials cost, etc.

TYPE OF PROJECT	COUNTY (STATE)	COST PER UNIT	CONSIDERATIONS
Hand-built engineered log jams, 2 nd order stream	Chelan (WA)	\$3,500/structure	Constructed by wildland fire fighting crew in the shoulder season; does not include riparian revegetation. All wood sourced on-site at no cost per agreement with landowner to harvest standing trees < 8" DBH and to buck and use logs perched over the entrenched channel
Machine-built engineered log jams, 3 rd order stream	Chelan (WA)	\$7,200/structure	Estimated, project not yet constructed, includes design, construction, and materials. Does not include riparian revegetation.
Machine-built engineered logjams on 5 th order river	Lewis (WA)	\$170,000/structure	Constructed. Includes design, construction and dewatering, materials, and significant channel and floodplain excavation component within a large and dynamic river.
Machine-built engineered logjams 4 th order river	Lewis (WA)	\$100,000/structure	Constructed. Includes design, construction and dewatering, and materials for large ELJs (~100 ft wide) within a large and dynamic river.
Machine excavation to re-meander 2 nd and 3 rd order channels	Kitsap (WA)	\$32/cubic yard Total of \$900,000 for channel and floodplain excavation component of a 30-acre restoration project.	Excavation of 30,000 cubic yards as part of re-meandering of 4000 linear ft of channel, two improved road crossings, and installation of 500 logs. Excavation spoils were mounded on site. Estimated cost includes excavation only, not the road or bridge work.
Valley reset on 3 rd and 4 th order river	Lane (OR)	\$13,000-\$17,000/acre	Valley reset on South Fork McKenzie River; estimate provided by USFS. Note that cost per log is approximately \$100/log, which is 3-10x lower than commercial logs for restoration.
Valley reset on 3 rd order stream	Chelan (WA)	\$55,000/acre	Estimated, not yet constructed. Includes excavation, all wood sourcing, wood placement, and extensive re-vegetation.

Table 7. Example costs for a range of services associated with hand-built restoration approaches. Note that actual costs vary widely with project location, restoration approach, materials cost, etc.

SERVICE	BALLPARK COST	NOTES
Excavator with attachment for cable-placement of logs	\$2500/day for excavator with attachment, plus \$2200/day for excavator to supply logs	Operator and equipment. Excavator options include a yoader, which is an excavator with a tower arm that can be used as a cable yarder, a greater than 70 horsepower excavator with a cable attachment, or a truck with a winch/hoist combined with block and tackle. Maximum carry distances and hauling efficiencies vary with equipment.
Hauling	\$1000/day	For materials within close proximity (a mile or less) to restoration site
Hand crew	\$1800/day	Assuming 6 people. Construction of 4 structures/day if materials are machine-delivered. Hand crew can move approximately 1 log every 15 minutes assuming 100 ft carry distance and log <30' long and 10" dbh.
Hand skyline	\$6000 – \$8000/day	Approximately 1 day to install, then can move 50-200 logs/day depending on size, length, and building. If delivering to distributed sites, may need to reset the line, which takes ½ to 1 day.

5.5 Other Considerations for Project Planning

5.5.1 Invasive Species

The presence and type of invasive riparian plant species is a consideration for any restoration project, since colonization or expansion by invasive species can offset some benefits of habitat enhancement and invasive species seldom die out or decline in density without management and control efforts. Raising the channel bed elevation and the groundwater elevation and enhancing floodplain connectivity are explicit goals when restoring natural water and sediment storage functions. However, these natural functions also have the potential to increase favorable conditions for some invasive species. For example, if the groundwater table rises and the duration and depth of surface water inundation increases will reed canarygrass (*Phalaris arundinacea*) establish? Alternatively, will existing populations expand across the floodplain or diminish the area of in-channel habitat? Increased deposition of alluvium may support expansion or colonization of the many species of knotweed now prevalent in western Washington. Although every site has specific characteristics to consider, some overarching questions to consider related to invasive species include:

- ▶ Which invasive species are prevalent in the watershed?
- ▶ What species are present in the project reach and to what extent?
- ▶ What are the conditions that favor the invasive species, and will the expected effects of increasing water and sediment storage create more favorable or less favorable conditions? Expected hydrogeomorphic effects from restoration approaches for alluvial water storage include:
 - Shallower channels
 - Increased channel length and/or increase in side channels
 - Increased groundwater table elevation (or, conversely, decreased depth to groundwater)

- Increased frequency and duration of floodplain inundation and/or persistence of floodplain water bodies and wetlands
- Increased deposition of alluvium, in bars and channel bed
- ▶ Is there a known threshold at which the conditions flip from favorable to unfavorable, e.g., based on inundation duration and frequency?
- ▶ Does the presence of invasive species alter the efficacy of different restoration approaches?
- ▶ What restoration actions could be taken or adjusted to reduce or remove the invasive species?
- ▶ Does the invasive species provide any functions that are limiting in the watershed (e.g., sediment retention and water quality improvement)?
- ▶ How does the presence of invasive species affect construction budget? Construction timing? Permitting?

5.5.2 Relation to Forest Management

Given the land ownership domain of this effort within commercial timberlands, both Forest Practice Act (FPA) regulations and local forest management practices are key considerations for project implementation. FPA rules define the size and extent of the regulated riparian buffer and dictate the conditions under which riparian trees may be harvested.

Timber landowners may be willing to provide or sell wood harvested from pre-commercial thin, commercial thin, and harvest efforts. In particular, exploring the use of non-commercially viable materials such as pre-commercial thin, misshapen trees, or stumps may be an opportunity for collaboration between restoration efforts and forest management practices. Such collaboration can reduce project materials costs and offer commercial timberland owners a mechanism to support local water storage and habitat restoration efforts.

6 NEXT STEPS AND RECOMMENDATIONS

6.1 Summation of Benefits from Extensive Restoration

The results of this analysis indicate that there are over 1300 miles of tributary stream reaches in the Satsop and Wynoochee River watersheds that could be restored or protected to provide natural water and sediment storage functions. The restoration of these natural functions has both local and downstream benefits to water quality, water quantity, and habitat, including increased water availability, decreased water temperature, and increased instream habitat complexity. Whereas the water and sediment storage benefit of restoration of a single reach is relatively small, total storage volume is large when 10s to 100s of miles are treated (Table 8). The benefits scale with length of stream treated, particularly if the reaches with the highest potential are prioritized for treatment. The screening for restoration approaches further suggests that there are 100s to 1000s of miles of low order streams that could be appropriate for each approach, allowing for opportunities for restoration that fit a range of budgets and planning constraints (Table 9).

We anticipate that the design, implementation, and monitoring of the pilot project will provide additional proof of concept and help further refine practical aspects of the project prioritization and selection approach, and construction considerations for alluvial water storage projects in Western Washington.

Table 8. Total modeled values for restorable water storage (acre-feet), potential sediment storage (cubic yards), and length of low order (1-4) streams with gradient < 8%, separated out by HUC-10 watershed and land ownership.

HUC-10 WATERSHED	OWNERSHIP	TOTAL RESTORABLE WATER STORAGE (AC-FT)	TOTAL POTENTIAL SEDIMENT STORAGE (CY)	TOTAL LENGTH OF STREAMS < 8% GRADIENT (MI)
Satsop River	Green Diamond	9,028	1,135,921	869
	Weyerhaeuser	563	174,550	101
Wynoochee River	Green Diamond	1,839	272,469	238
	Weyerhaeuser	805	261,501	154

Table 9. Total number of river miles with gradient < 8% that were classified into each restoration approach at the screening level. Note that numerous reaches are classified for more than one approach, and that the machine-built structures approach is assigned to every reach.

HUC-10 WATERSHED	RESTORATION APPROACH	TOTAL RIVER MILES (GRADIENT <8%)
Satsop River	Machine-Built Structures	970
	Hand-Built Structures – low threshold of channel morphology	886
	Hand-Built Structures – high threshold of channel morphology	176
	Valley Reset	324
	Strategic Excavation	707
	Humanscape Modifications	430
Wynoochee River	Machine-Built Structures	392
	Hand-Built Structures – low threshold of channel morphology	360
	Hand-Built Structures – high threshold of channel morphology	134
	Valley Reset	53
	Strategic Excavation	214
	Humanscape Modifications	73

6.2 Assessment For Potential and Approach at Reach-Scale

This analysis and the alluvial water storage workflow model provide numerous options for selecting reaches to prioritize for restoration based on a variety of goals, or for compatibility with a particular restoration approach, with 10s to 1000s of miles of stream classified for each approach at a screening level. The watershed-scale screening uses the best available geospatial data to designate possible restoration approaches for each reach. However, by design the screening does not incorporate many important reach-scale characteristics that are poorly resolved at the watershed-scale; spatially continuous data that the screening relies upon. Thus, the intention of the modeling results and classification into restoration approaches is to provide a first order screening, to be followed by reach-scale assessment that can include additional geospatial analyses (e.g., using aerial photographs) and field-based assessment.

After applying the model results to support identification and prioritization of a subset of reaches for further assessment, the next step is to consider the following questions:

- ▶ Are there properly functioning geomorphic processes and landscape features?
 - Are there existing high functioning wetlands, side channels, forested floodplains, beaver dams, or log jams?
 - If so, focus on protection and consider options for enhancement.
- ▶ Are there impaired geomorphic processes?

- Evidence of impaired processes includes lack of native riparian vegetation, regulated stream flow, straightening or artificial confinement, bank armoring, lack of instream wood, lack of complexity.
- If so, consider restoration.
- ▶ Is the channel incised and potentially vertically disconnected from its floodplain?
 - Evidence of incision includes observed channel depth greater than predicted channel depth (based on hydrology modeling), exposed bedrock in the channel, position of bed sediments visible in bank stratigraphy.
 - What are the drivers of incision (e.g., downstream incision, lack of wood, confinement, legacy of splash damming)?
 - Is channel depth appropriate? Hand-built structures are generally recommended for channels < 4 ft deep. Machine-built structures can be designed for deeply incised channels (i.e., > 6 ft).
- ▶ Is there room for the channel corridor to expand across the valley bottom (consider infrastructure, vegetation, habitat)?
- ▶ Is there a road, berm, or other fill in the floodplain?
- ▶ What is the quality of the riparian corridor? Will it be possible to avoid impacts to intact mature riparian trees?
- ▶ Are there invasive plants present and what are the potential implications for design?
- ▶ Is beaver reintroduction a viable alternative or supplement to engineered structures based on physical characteristics, vegetation, and landowner willingness?
- ▶ What is the extent and ownership of adjacent lands that could be affected by restoration?
- ▶ Which fish and wildlife species are currently using and historically used the reach?
 - Can design address habitat limiting factors for at risk or imperiled species?
 - Is maintaining or improving fish passage a design criterion?
- ▶ What regulated features and species could be affected by the project (e.g., wetlands, ESA-listed species, cultural resources, FEMA zones)?
 - What regulatory permits may be needed?
 - Can advance regulatory agency engagement be accomplished at federal, state, and local levels during project development?
 - Is the anticipated in-water construction window of sufficient duration?

An abbreviated list of the most relevant criteria for each restoration approach is also included on the cut sheets (Appendix B).

6.3 Data Availability and Future Use

The modeling and analysis effort described herein provides the foundation for identifying, prioritizing, and assessing reaches for restoration. The results consist of georeferenced stream segments, each of which is associated with numerous attributes which include input data (e.g., length), geographic data (e.g., HUC-12 subwatershed), modeled data (e.g., water storage potential), and restoration approach(es) (e.g., valley reset). The table of attributes can be used to symbolize the stream segments, sort or filter by a particular set of attributes, or summarize values over the dataset. These data are provided as a geodatabase to Grays Harbor Conservation District and can be made available to stakeholders/practitioners, and Coast Salmon Partnership and Grays Harbor Conservation District contributed to the development of a web-based mapping platform to view and query the results of this assessment:

<https://coastsalmon.maps.arcgis.com/apps/webappviewer/index.html?id=ddd2f4dae4c5466d87657c59a3ccbec9>

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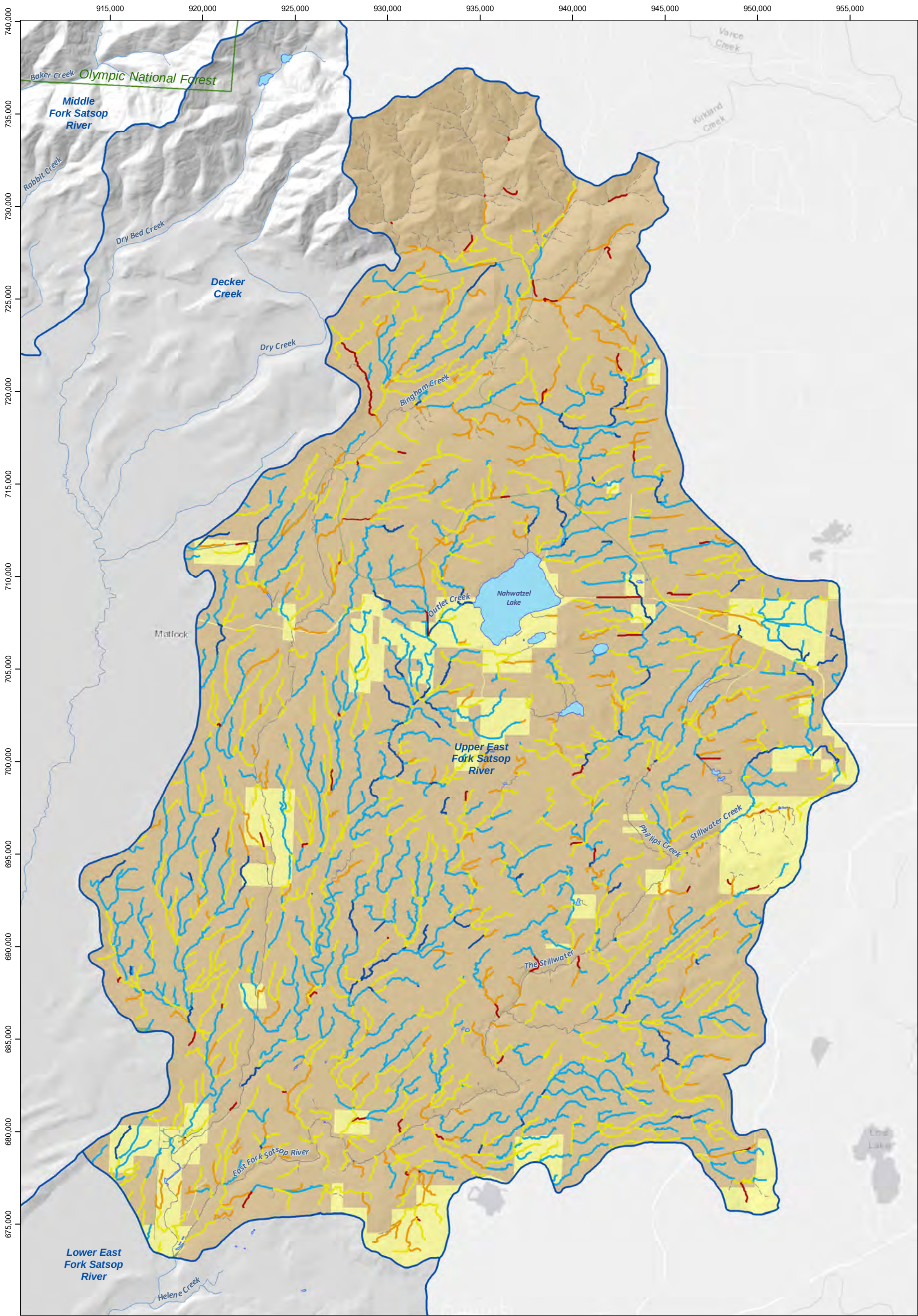
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APPENDIX A. MAPBOOK OF WATER STORAGE POTENTIAL



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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 1 of 12

Upper East Fork Satsop River

Alluvial Water Storage Potential
(acre ft/mi)

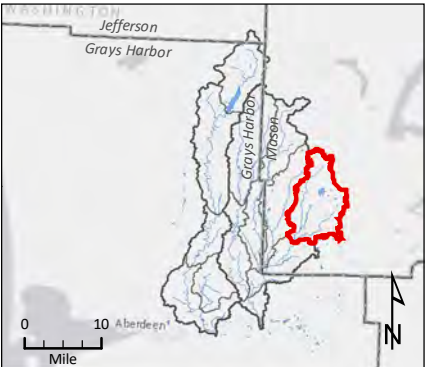
- < 3
- 3 - 6
- 6 - 12
- 12 - 24
- > 24

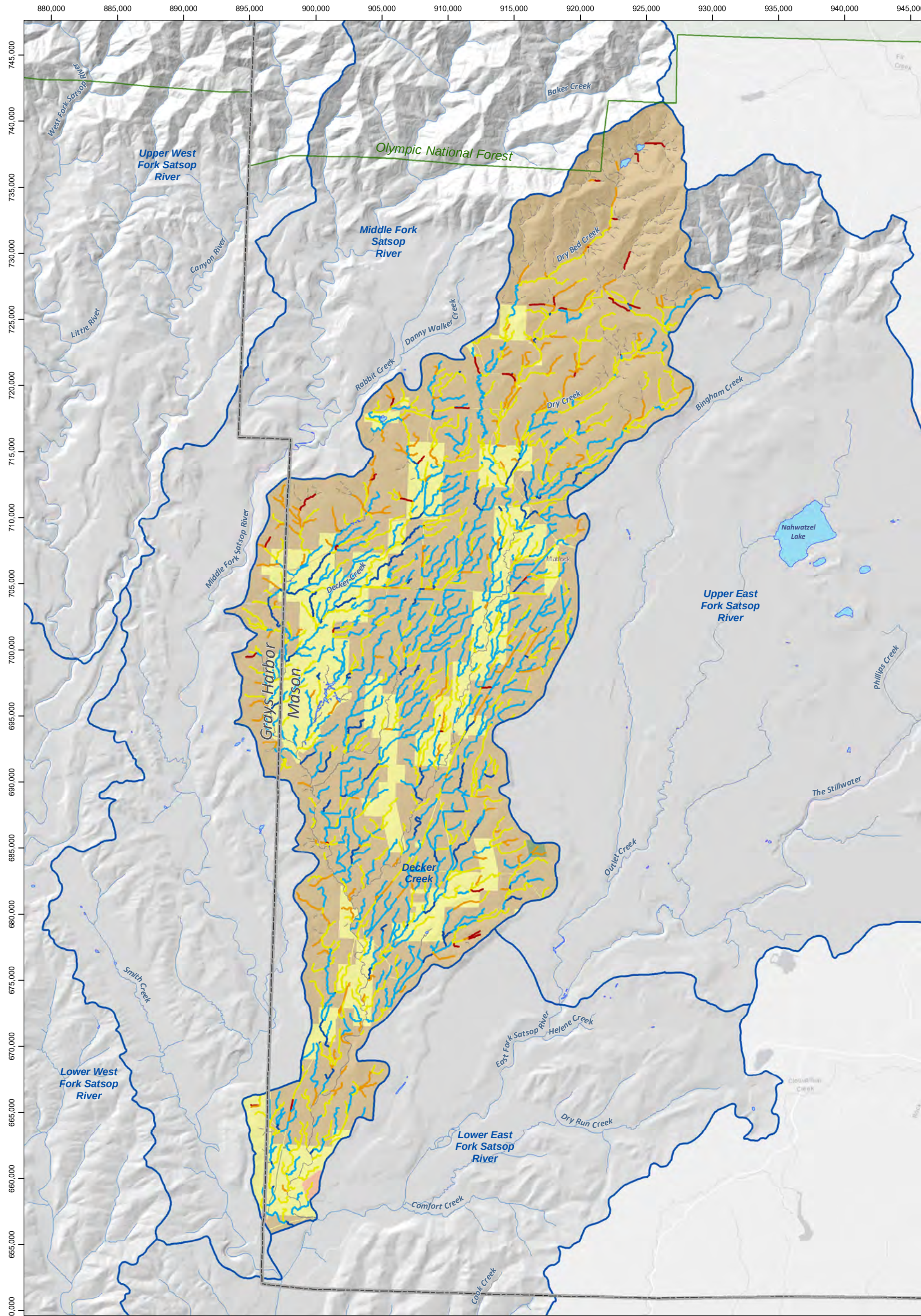
Land Owner

- Federal Land
- Green Diamond Resource Co.
- Weyerhaeuser Co.
- Other
- Unassessed Stream Reach (<8% slope)
- Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 2 of 12

Decker Creek

Alluvial Water Storage Potential
(acre ft/mi)

— < 3

— 3 - 6

— 6 - 12

— 12 - 24

— > 24

Land Owner

■ Federal Land

■ Green Diamond Resource Co.

■ Weyerhaeuser Co.

■ Other

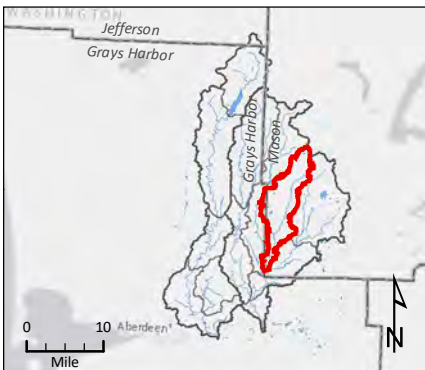
— Unassessed Stream Reach (<8% slope)

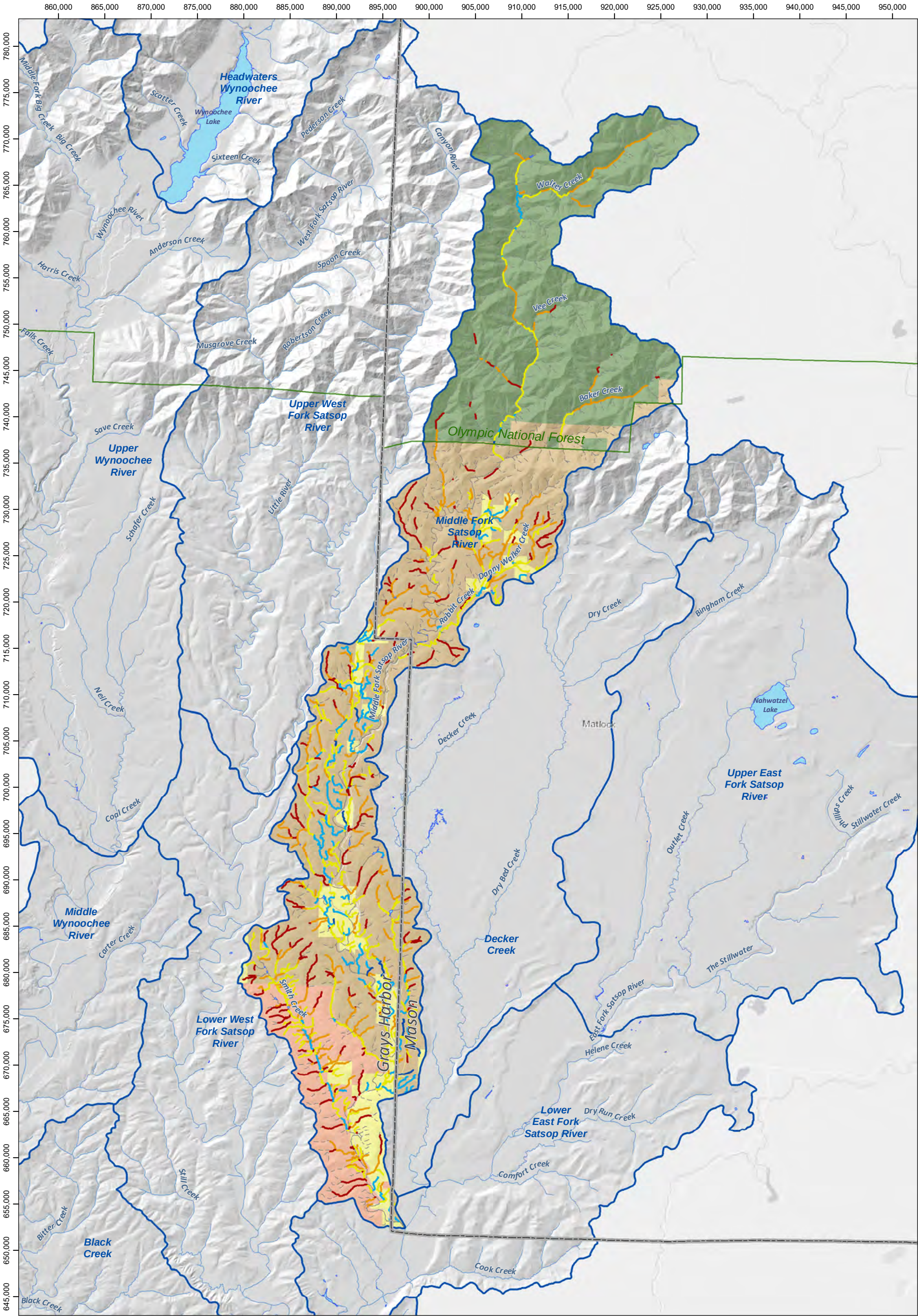
--- Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)

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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 3 of 12

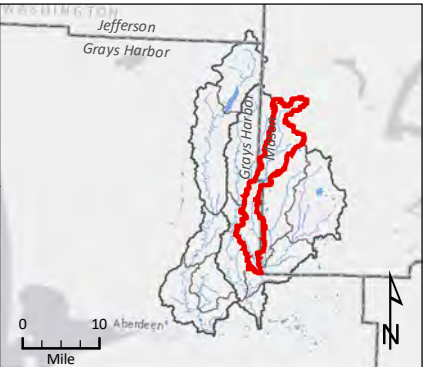
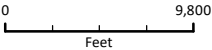
Middle Fork Satsop River

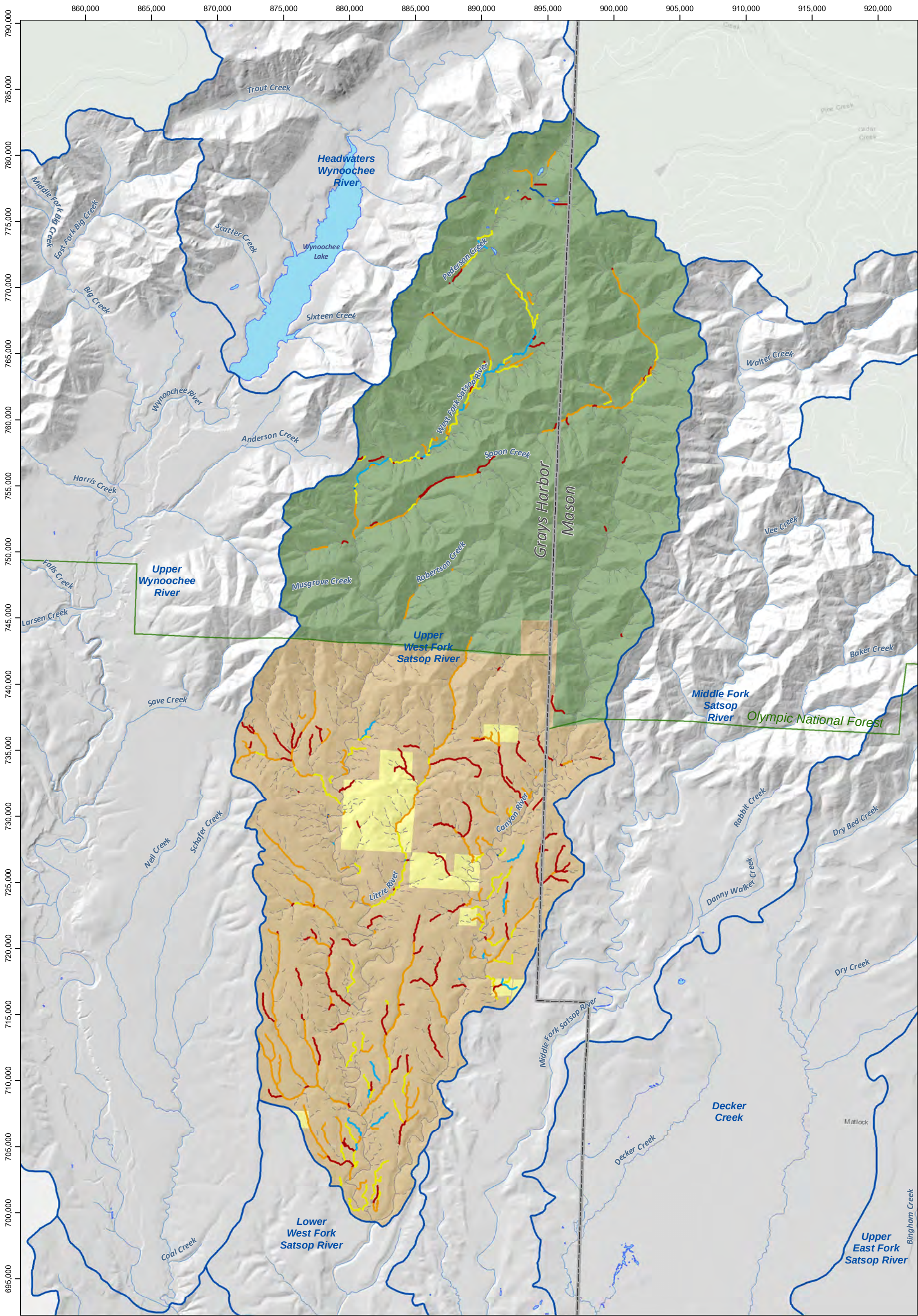
- Alluvial Water Storage Potential
(acre ft/mi)
- < 3
 - 3 - 6
 - 6 - 12
 - 12 - 24
 - > 24

- Land Owner
- Federal Land
 - Green Diamond Resource Co.
 - Weyerhaeuser Co.
 - Other
 - Unassessed Stream Reach (<8% slope)
 - Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

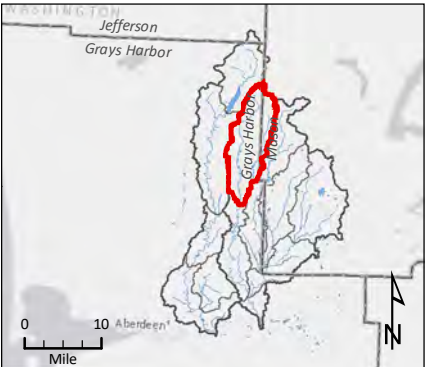
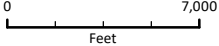
Map 4 of 12

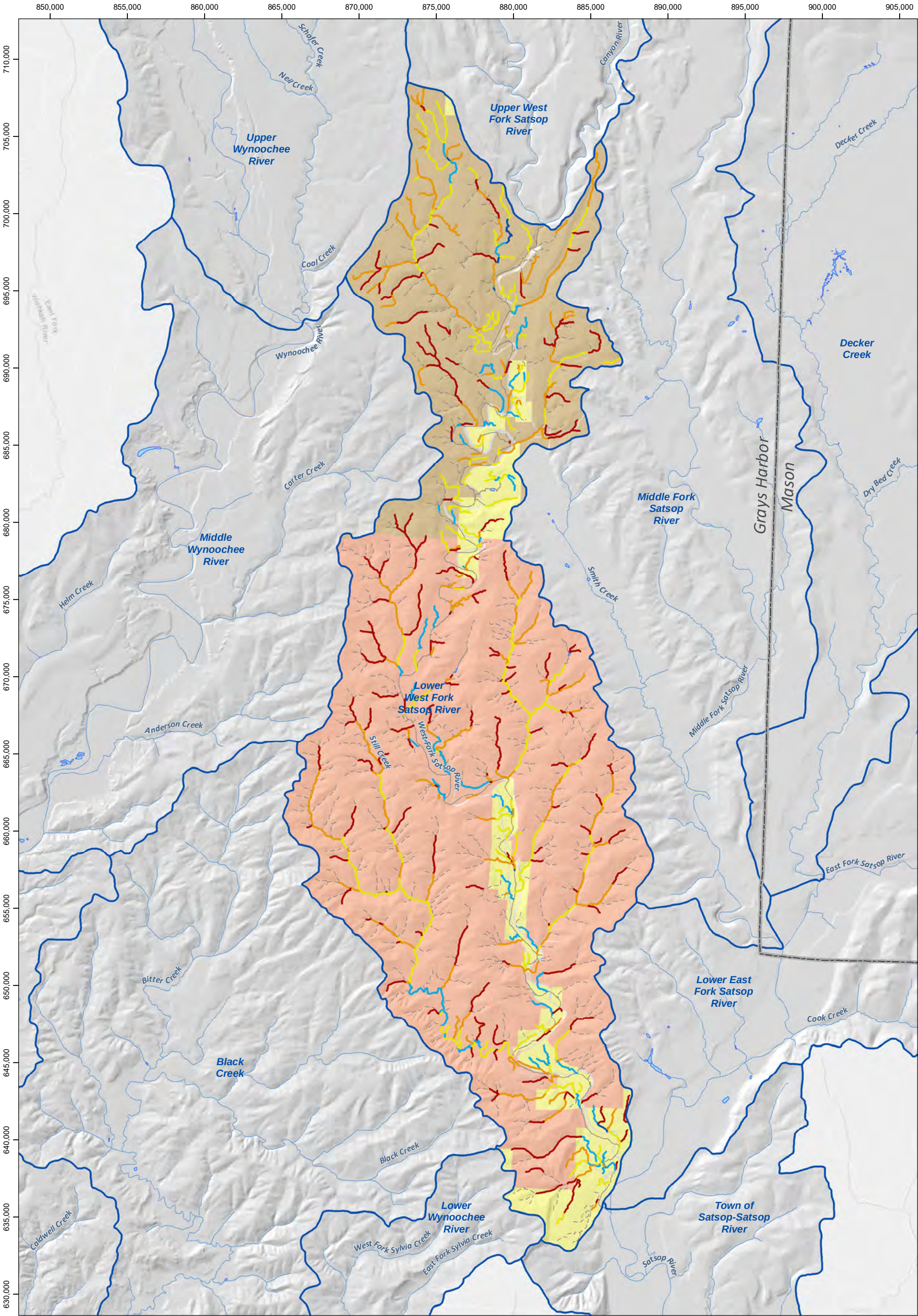
Upper West Fork Satsop River

- Alluvial Water Storage Potential (acre ft/mi)
- < 3
 - 3 - 6
 - 6 - 12
 - 12 - 24
 - > 24
- Land Owner
- Federal Land
 - Green Diamond Resource Co.
 - Weyerhaeuser Co.
 - Other
 - Unassessed Stream Reach (<8% slope)
 - Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

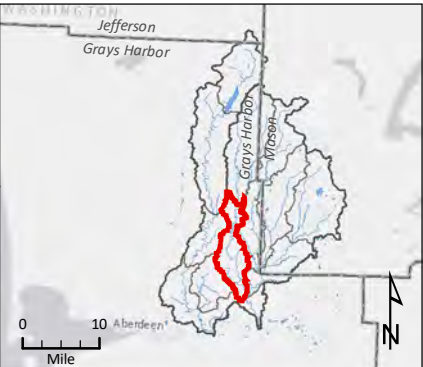
Map 5 of 12

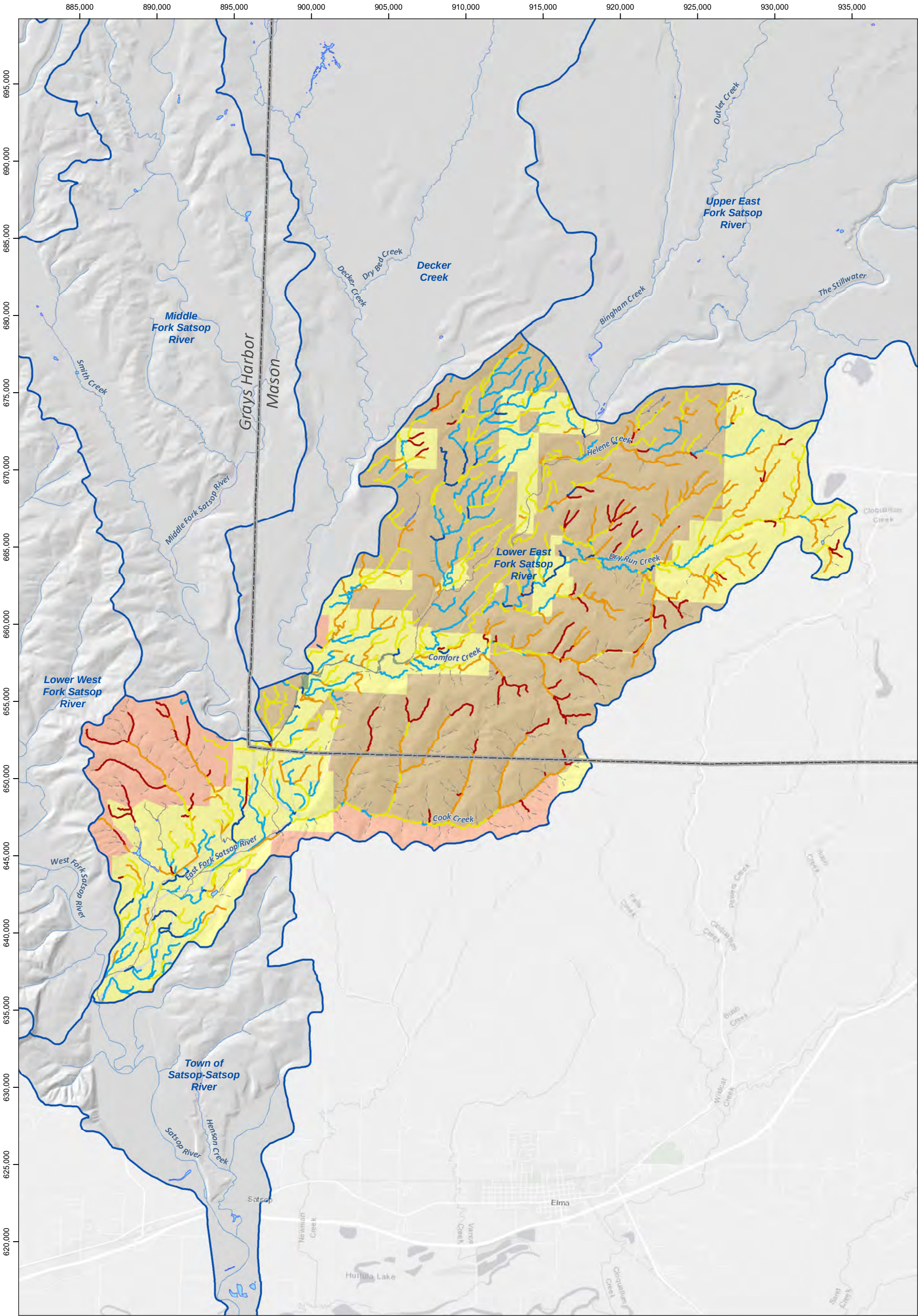
Lower West Fork Satsop River

- Alluvial Water Storage Potential**
(acre ft/mi)
- < 3
 - 3 - 6
 - 6 - 12
 - 12 - 24
 - > 24
- Land Owner**
- Federal Land
 - Green Diamond Resource Co.
 - Weyerhaeuser Co.
 - Other
 - Unassessed Stream Reach (<8% slope)
 - Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 6 of 12

Lower East Fork Satsop River

Alluvial Water Storage Potential
(acre ft/mi)

< 3

3 - 6

6 - 12

12 - 24

> 24

Land Owner

Federal Land

Green Diamond Resource Co.

Weyerhaeuser Co.

Other

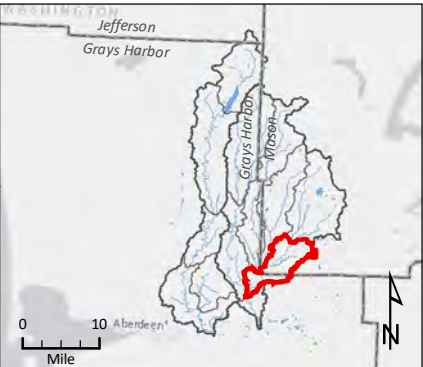
Unassessed Stream Reach (<8% slope)

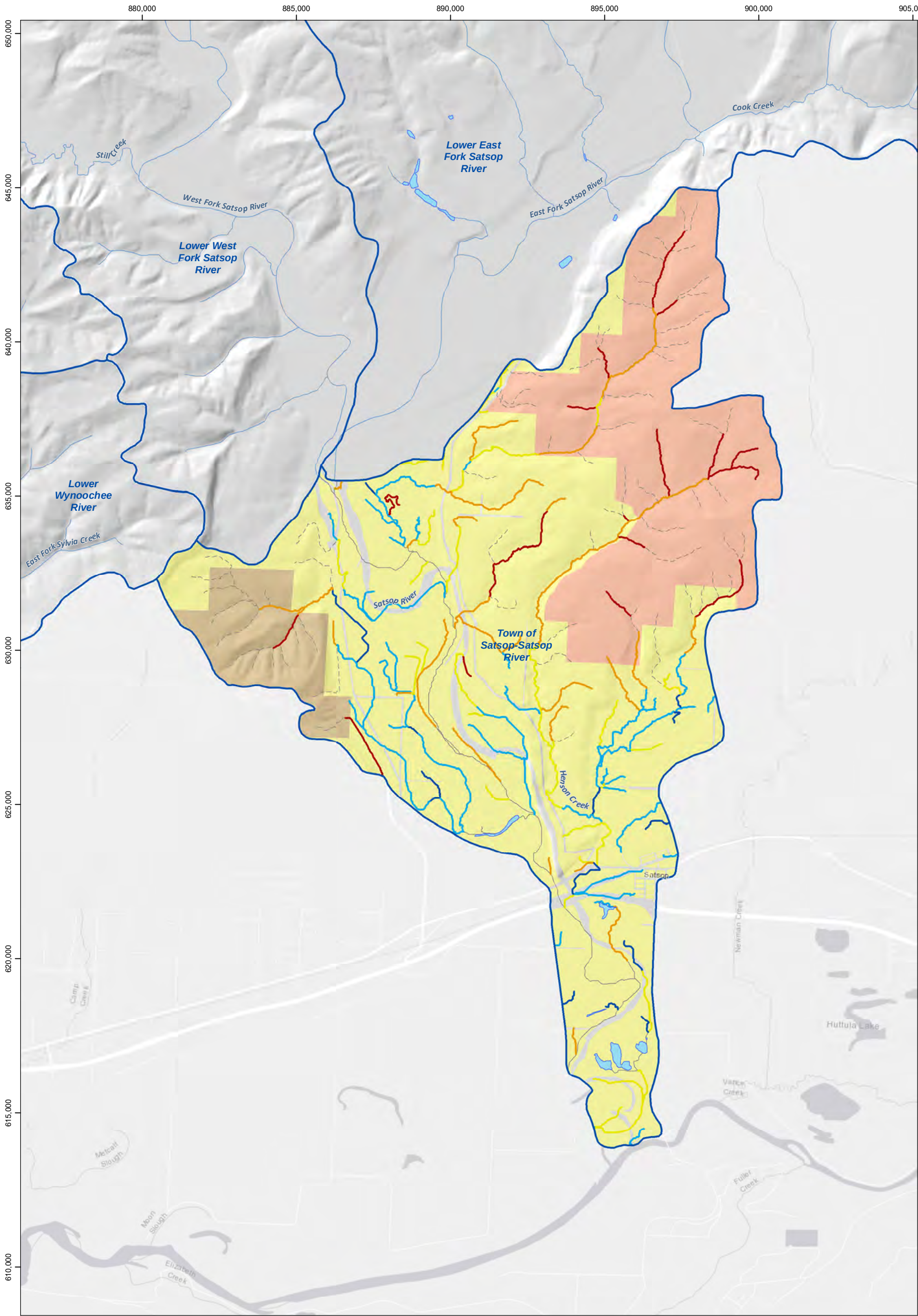
Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington
Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)

0 6,000
Feet





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 7 of 12

Town of Satsop-Satsop River

Alluvial Water Storage Potential
(acre ft/mi)

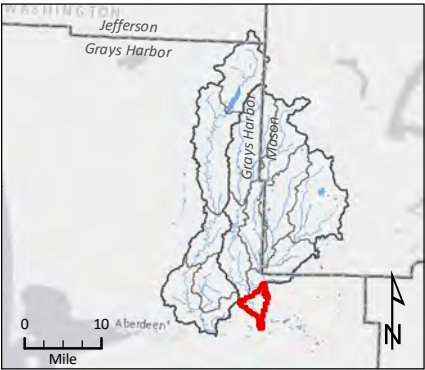
- < 3
- 3 - 6
- 6 - 12
- 12 - 24
- > 24

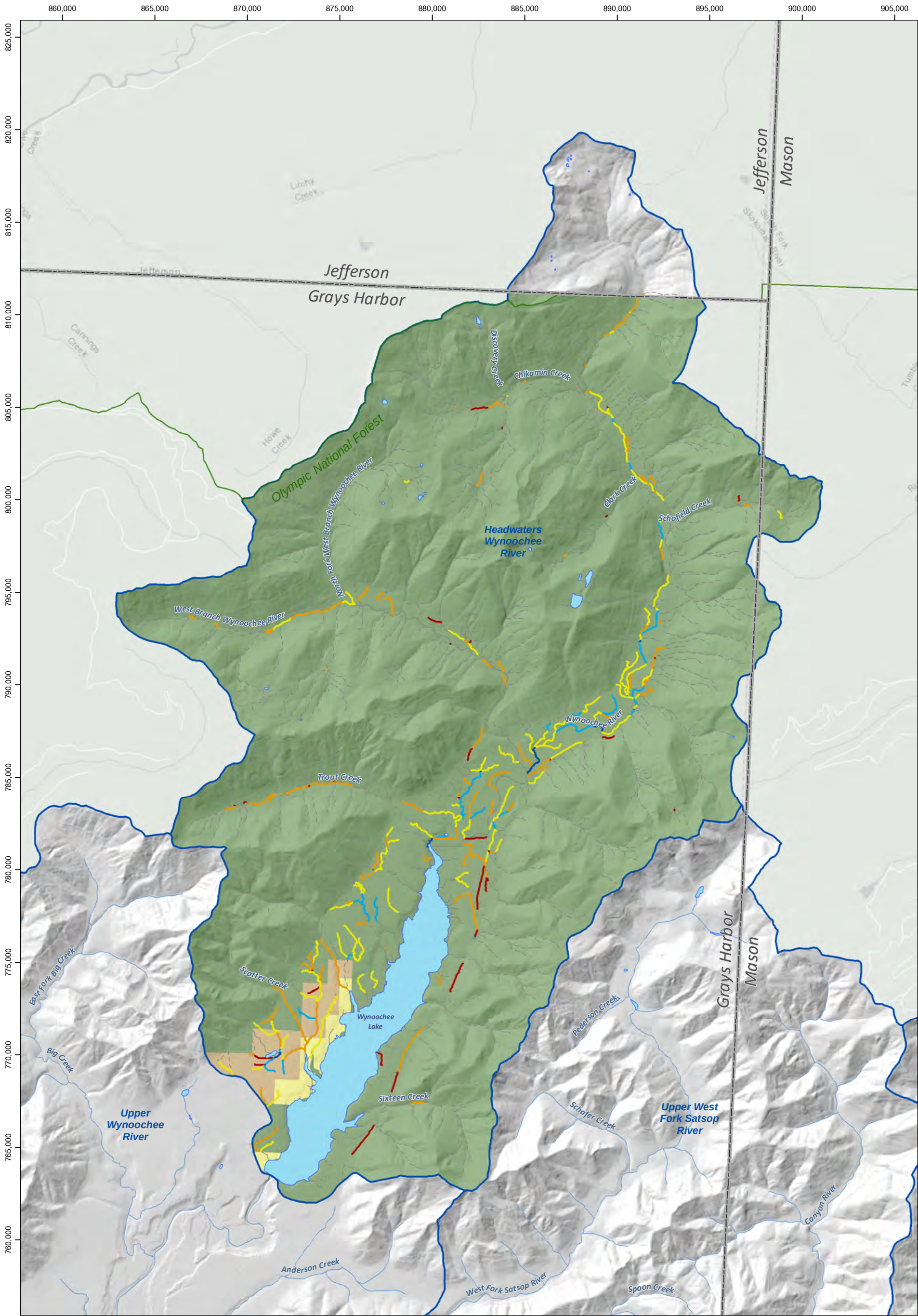
Land Owner

- Federal Land
- Green Diamond Resource Co.
- Weyerhaeuser Co.
- Other
- Unassessed Stream Reach (<8% slope)
- Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington
Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 8 of 12

Headwaters Wynoochee River

Alluvial Water Storage Potential
(acre ft/mi)

< 3

3 - 6

6 - 12

12 - 24

> 24

Land Owner

Federal Land

Green Diamond Resource Co.

Weyerhaeuser Co.

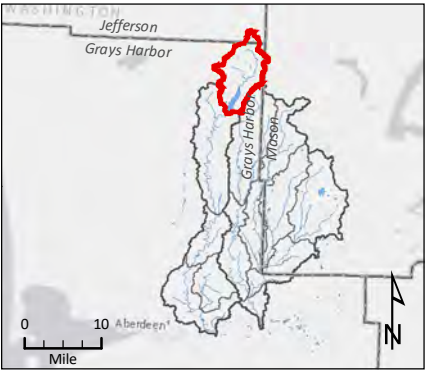
Other

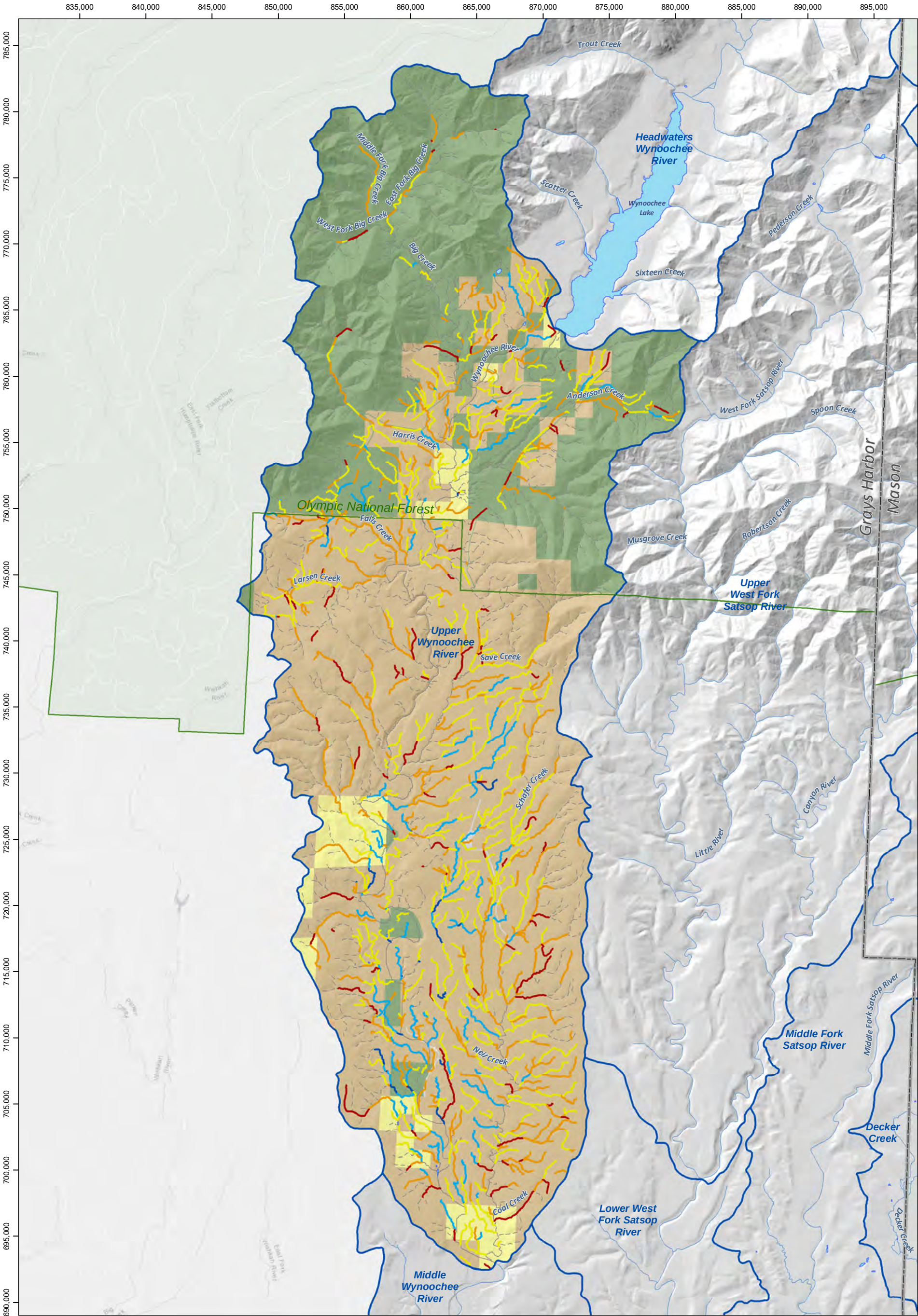
Unassessed Stream Reach (<8% slope)

Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

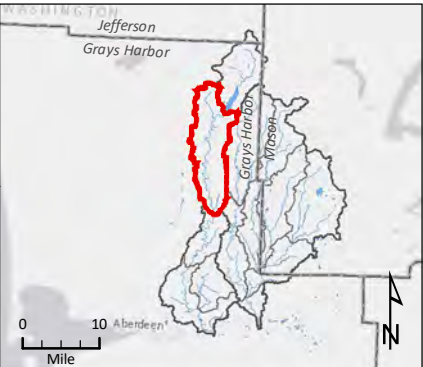
Map 9 of 12

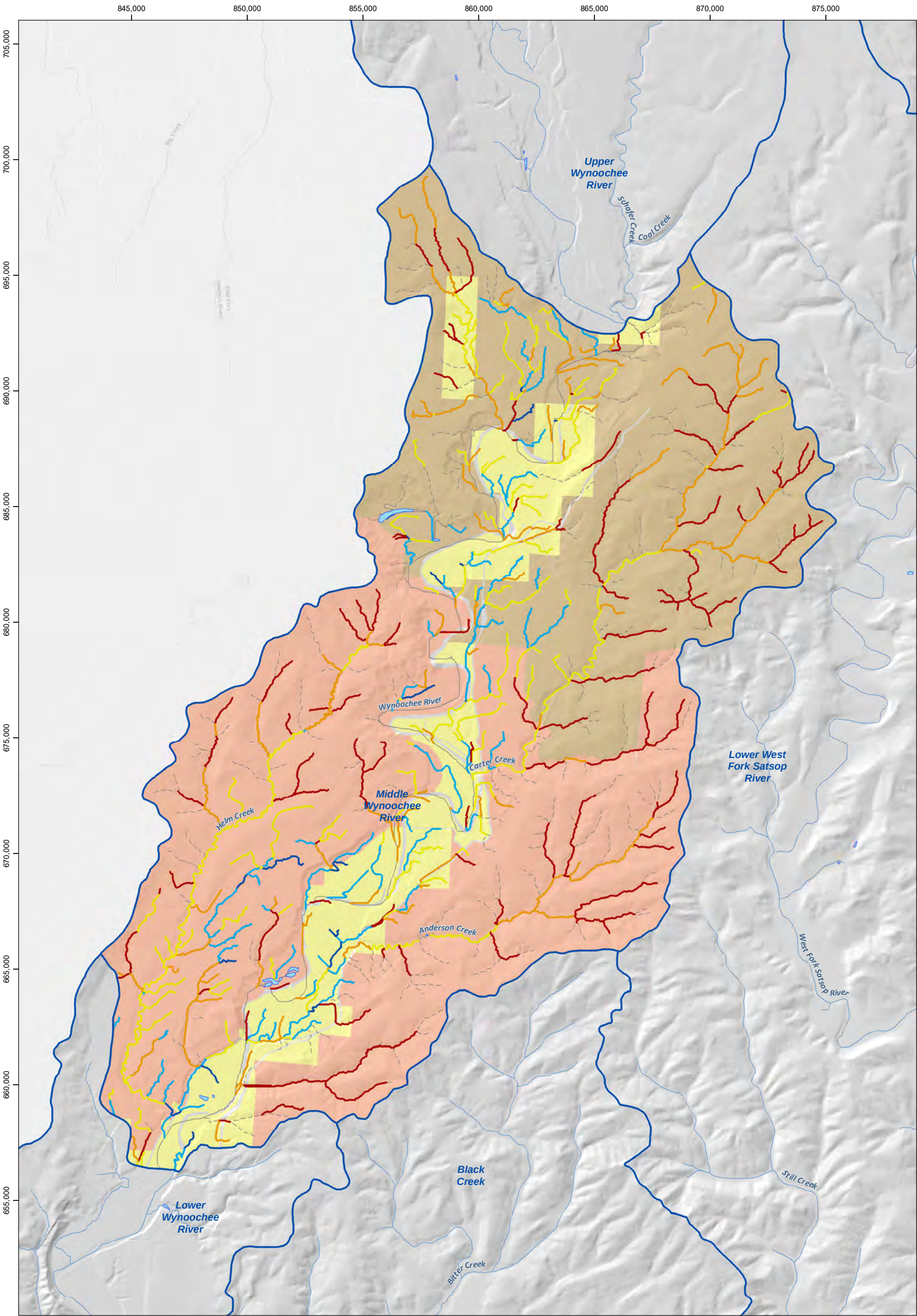
Upper Wynoochee River



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)

- | Alluvial Water Storage Potential
(acre ft/mi) | Land Owner |
|--|--|
| — < 3 | Federal Land |
| — 3 - 6 | Green Diamond Resource Co. |
| — 6 - 12 | Weyerhaeuser Co. |
| — 12 - 24 | Other |
| — > 24 | Unassessed Stream Reach (<8% slope) |
| | Unassessed Stream Reach (>8% slope) |





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 10 of 12

Middle Wynoochee River

Alluvial Water Storage Potential
(acre ft/mi)

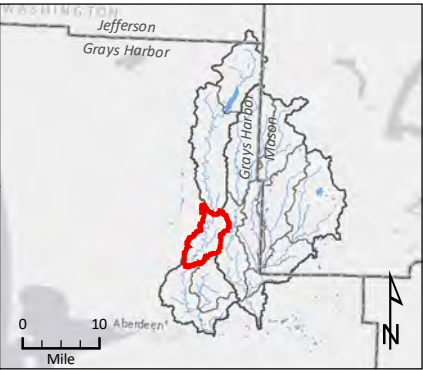
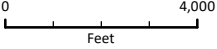
- < 3
- 3 - 6
- 6 - 12
- 12 - 24
- > 24

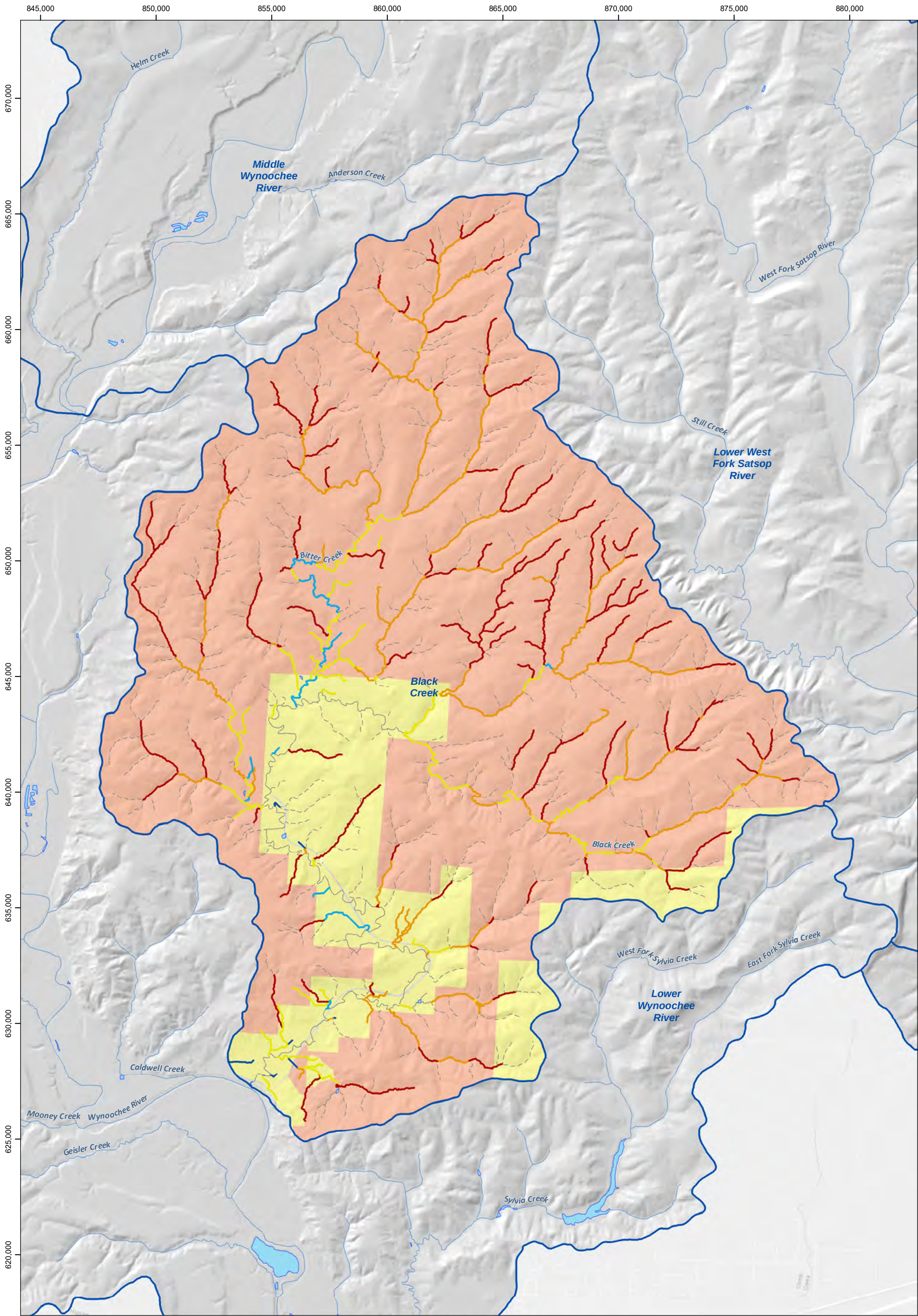
Land Owner

- Federal Land
- Green Diamond Resource Co.
- Weyerhaeuser Co.
- Other
- Unassessed Stream Reach (<8% slope)
- Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 11 of 12

Black Creek

Alluvial Water Storage Potential
(acre ft/mi)

- < 3
- 3 - 6
- 6 - 12
- 12 - 24
- > 24

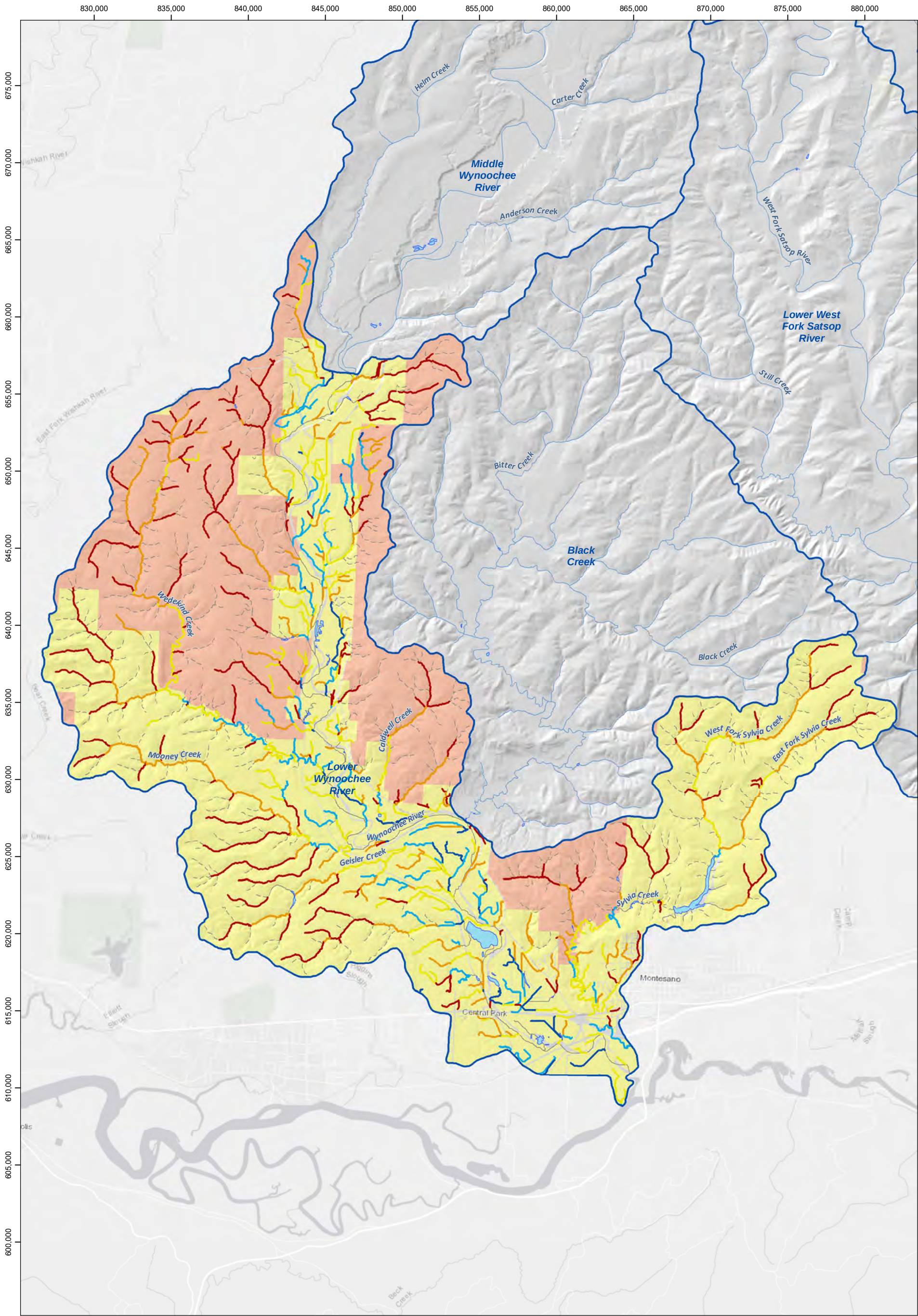
Land Owner

- Federal Land
- Green Diamond Resource Co.
- Weyerhaeuser Co.
- Other
- Unassessed Stream Reach (<8% slope)
- Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington
Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)





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Satsop and Wynoochee Tributary Restoration Strategy

Modeled Storage Potential and Land Ownership

Map 12 of 12

Lower Wynoochee River

Alluvial Water Storage Potential
(acre ft/mi)

— < 3

— 3 - 6

— 6 - 12

— 12 - 24

— > 24

Land Owner

■ Federal Land

■ Green Diamond Resource Co.

■ Weyerhaeuser Co.

■ Other

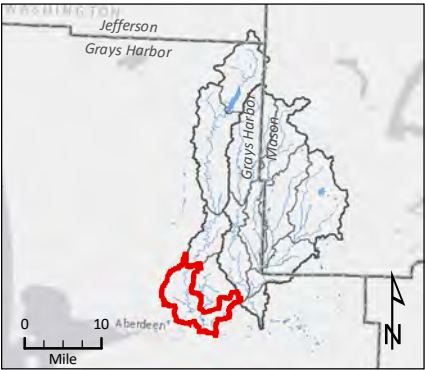
— Unassessed Stream Reach (<8% slope)

- - - Unassessed Stream Reach (>8% slope)



Lambert conformal conic projection, NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW 2019)

0 6,000
Feet



APPENDIX B. RESTORATION CUT SHEETS



Machine-Built Instream Structure

Increase instream hydraulic roughness to capture and store sediment and raise surface and groundwater elevations



Grays Harbor
Conservation
District



Watershed-Scale Screening Criteria

- Applicable to all stream segments since design and methods can be adjusted to account for size, level of degradation, and infrastructure intensity.

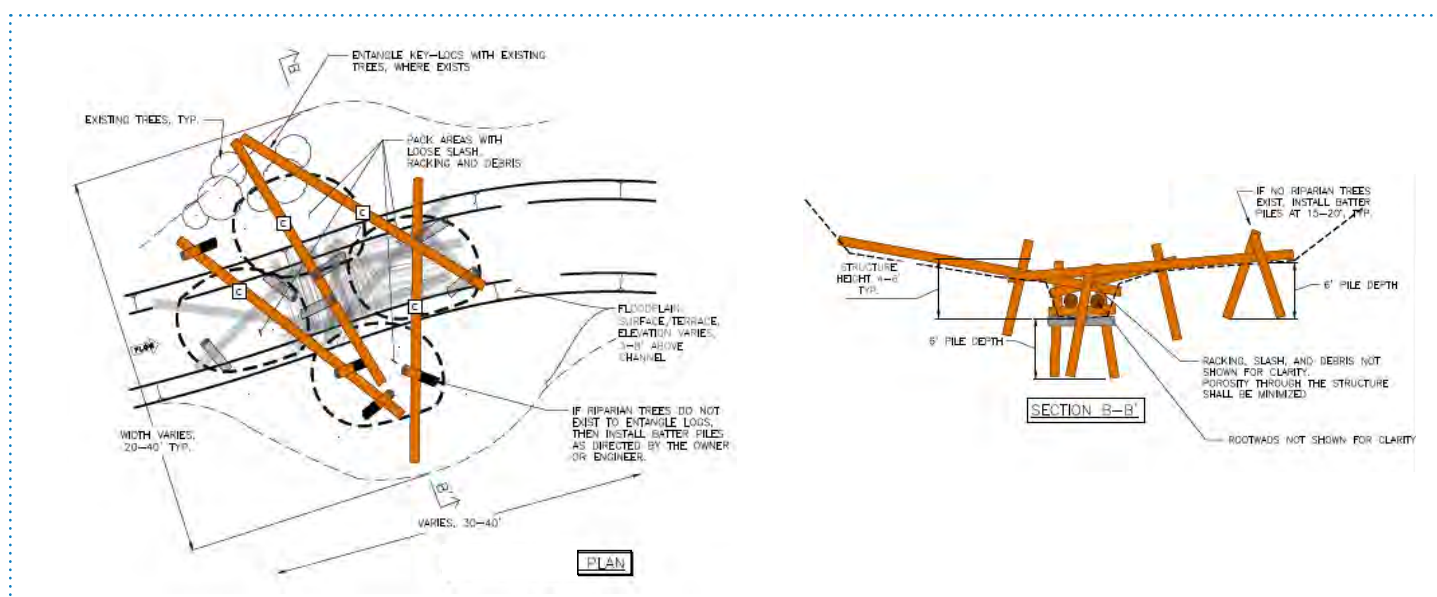
Recommended Reach-Scale Assessment Criteria

- Are there properly functioning geomorphic processes and landscape features (e.g., log jams, beaver dams, side channels)? If so, focus on protection and consider options for enhancement.
- Are there impaired geomorphic processes (e.g., bank armoring, artificial confinement, lack of instream wood)? If so, consider restoration.
- Is the channel incised and potentially vertically disconnected from its floodplain?
 - What are the drivers of incision and the current channel depth?
 - Structure stability is a key consideration for deeply incised channels (i.e., > 6 ft) due to high stream power, and machine-built approaches are typically required.
- What is the extent and ownership of adjacent lands that could be affected by restoration?
- Which fish and wildlife species are currently using and historically used the reach and how does this influence design goals?
- What regulated features and species could be affected (e.g., wetlands, cultural resources)? What regulatory permits may be needed? What is the anticipated in-water construction window?

Design Considerations

Consideration	Questions
Design and Stability	• Hydraulic conditions (depth, velocity, shear stress, flood elevations) within the channel under a range of peak flows? • Geologic properties (substrate, bank materials, depth to bedrock) of the channel and floodplain? • Required design flood event (recurrence interval) factor of safety and project lifespan, as determined by project owner and risk level? • Feasibility of methods to stabilize the structure(s) (piles, posts, burial, rock, or other anchoring methods)? • Are helicopters, steep-terrain machinery, forestry equipment, pile drivers, or other specialty equipment needed to install the project elements? • Any limitations to access and staging (e.g. proximity of road for heavy equipment)?
Infrastructure and Risk	• Type and sensitivity of infrastructure adjacent, upstream, and downstream? • How will the channel respond laterally and vertically in response to instream structure(s)? What are the resulting risks? • Are there risks to recreational river users from instream structures?
Cost and Implementation	• Is the construction budget sufficient for the treatment extent, level of degradation, level of risk, and construction approach? • Are there local options for sourcing timber and aggregate materials? • Cost can vary from less than \$5,000 to more than \$100,000 per structure. • Limited or difficult machine access can substantially increase cost.

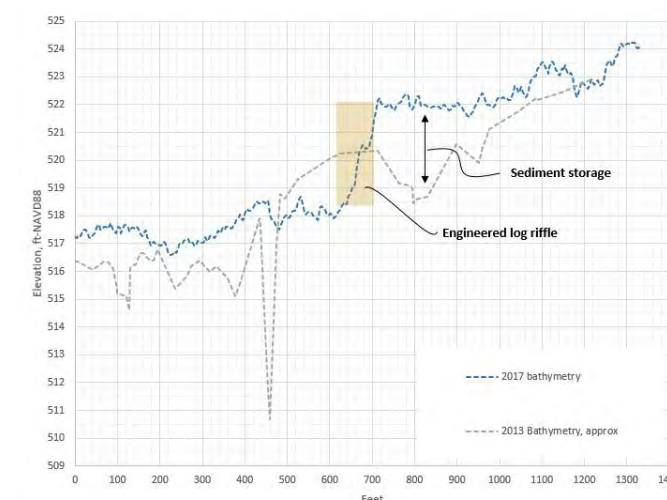
Examples



Plan and cross-section of channel-spanning machine-built log structure proposed for an alluvial water storage project on Eagle Creek (Sponsor: Chelan County Natural Resource Department).



Clustered machine-built ELJs on the South Fork Nooksack River in Whatcom County, WA.



A profile of South Fork Nooksack bathymetry shows the increase in sediment storage directly upstream of the structures.



Hand-Built Instream Structure

Increase instream hydraulic roughness to capture and store sediment and raise surface and groundwater elevations



Grays Harbor
Conservation
District



Watershed-Scale Screening Criteria

- Modeled channel width < 15 ft
- Modeled channel depth < 1.8 ft
- Low to medium infrastructure risk

Recommended Reach-Scale Assessment Criteria

- Are there properly functioning geomorphic processes and landscape features (e.g., log jams, beaver dams, side channels)? If so, focus on protection and consider options for enhancement.
- Are there impaired geomorphic processes (e.g., bank armoring, artificial confinement, lack of instream wood)? If so, consider restoration.
- Is the channel incised and potentially vertically disconnected from its floodplain?
 - What are the drivers of incision and the current channel depth?
 - Hand-built structures have less options for stabilization and therefore are recommended for channel depths of less than 2-3 feet.
- Is the quality of the riparian corridor sufficient for entanglement and future recruitment of wood?
- Is beaver reintroduction viable based on physical characteristics, vegetation, and landowner willingness?
- What is the extent and ownership of adjacent lands that could be affected by restoration?
- Which fish and wildlife species are currently using and historically used the reach and how does this influence design goals?
- What regulated features and species could be affected (e.g., wetlands, cultural resources)? What regulatory permits may be needed? What is the anticipated in-water construction window?

Design Considerations

Consideration	Questions
Design and Stability	• What is expected structure lifespan and level of stability required? Hand-built structures may be appropriate in larger streams depending on project goals and constraints. • Is function created by the cumulative effect or density of structures, or can individual structures provide discrete function? • What method(s) are feasible to stabilize structures (hand-driven posts, existing boulders, entanglement, etc.) if long-term stability is required? • Does riparian corridor land ownership, regulation, and condition support a riparian tree tipping approach? • How can construction materials (cable lining, hand carts, small off-road equipment, pack animals carrying, etc.) be delivered to the site?
Infrastructure and Risk	• Type and sensitivity of infrastructure adjacent, upstream, and downstream? • How will the channel respond laterally and vertically in response to instream structure(s)? What are the resulting risks? • Are there risks to recreational river users from instream structures? • Where will a failed structure end up and what is the result of this failure (erosion or flood damage or an immediate return to degraded conditions)?
Cost and Implementation	• Is the construction budget sufficient for the treatment extent, level of degradation, level of risk, and materials delivery and construction approach? • Are there local options for sourcing timber and aggregate materials? • Structures can range from less than \$1,000 to more than \$10,000 per structure.

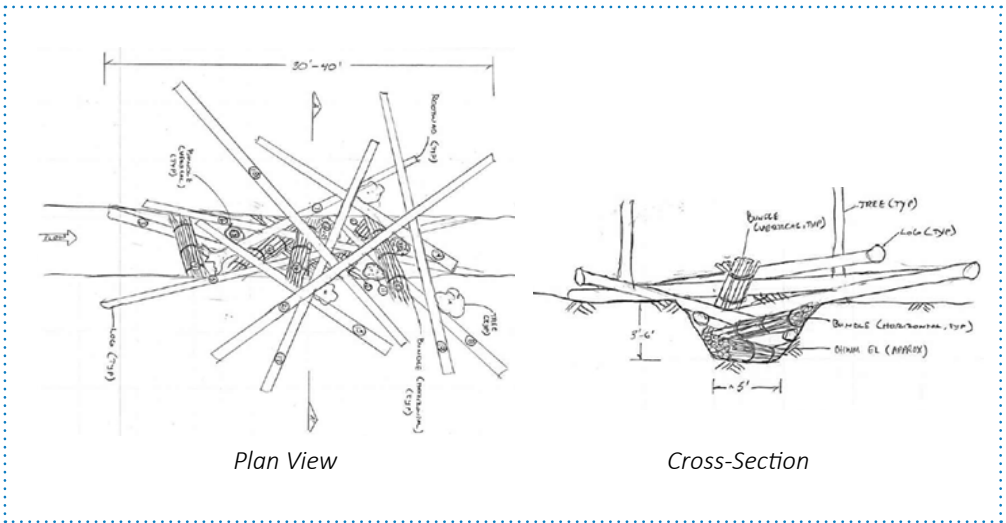
Examples



Conceptual drawing of a channel-spanning post-assisted log structure (PALS), from figure 26 of Wheaton et al. (2019). Figure reproduced here under the terms of the Creative Commons Attribution 4.0 International License. The referenced Low-Tech manual provides guidance and numerous conceptual drawings for similar hand-built, non-engineered structures.



2-3 foot of channel aggradation upstream of hand-built structure in Poison Creek (Sponsor: Chelan County Natural Resource Department).



Typical cross section and plan view sketch of hand-built engineered log structure.



Valley Reset (Stage 0)

Fill incised channel with floodplain road and berm material to raise water surface elevation and reconnect channel to floodplain



Grays Harbor
Conservation
District



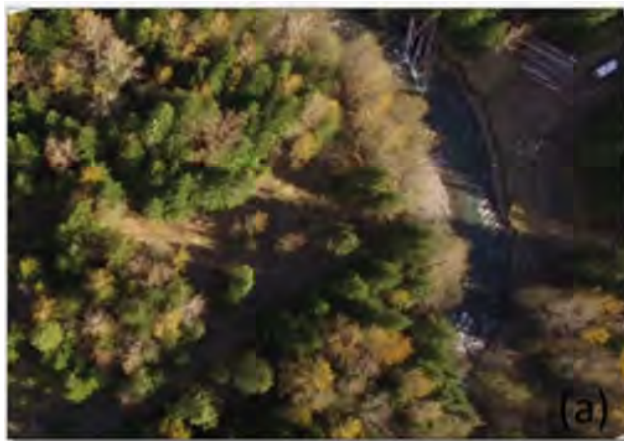
Watershed-Scale Screening Criteria

- Response reach (i.e., channel gradient < 3%)
- Valley confinement ratio of unconfined or moderately confined (i.e., valley width:channel width > 2)
- Road present in valley bottom with a length $\geq$ 20% of the reach length
- No buildings present in the valley bottom

Assessment Criteria

- Are there properly functioning geomorphic processes and landscape features (e.g., log jams, beaver dams, side channels)? If so, focus on protection and consider options for enhancement.
- Are there impaired geomorphic processes (e.g., bank armoring, artificial confinement, lack of instream wood)? If so, consider restoration.
- Is the channel incised and potentially vertically disconnected from its floodplain?
 - What are the drivers of incision and the current channel depth?
 - Depth of incision that can be treated through valley reset depends on upstream and downstream conditions, such that the channel can maintain an equilibrium profile through the reach.
- Is there room for the channel corridor to expand across the valley bottom (consider infrastructure, vegetation, habitat)?
- What is the quality of the riparian corridor? Will it be possible to avoid impacts to intact riparian trees?
- Is there a road, berm, or other fill in the floodplain to serve as material to fill the incised channel?
- What is the extent and ownership of adjacent lands that could be affected by restoration?
- Which fish and wildlife species are currently using and historically used the reach and how does this influence design goals?
- What regulated features and species could be affected (e.g., wetlands, cultural resources)? What regulatory permits may be needed? What is the anticipated in-water construction window?

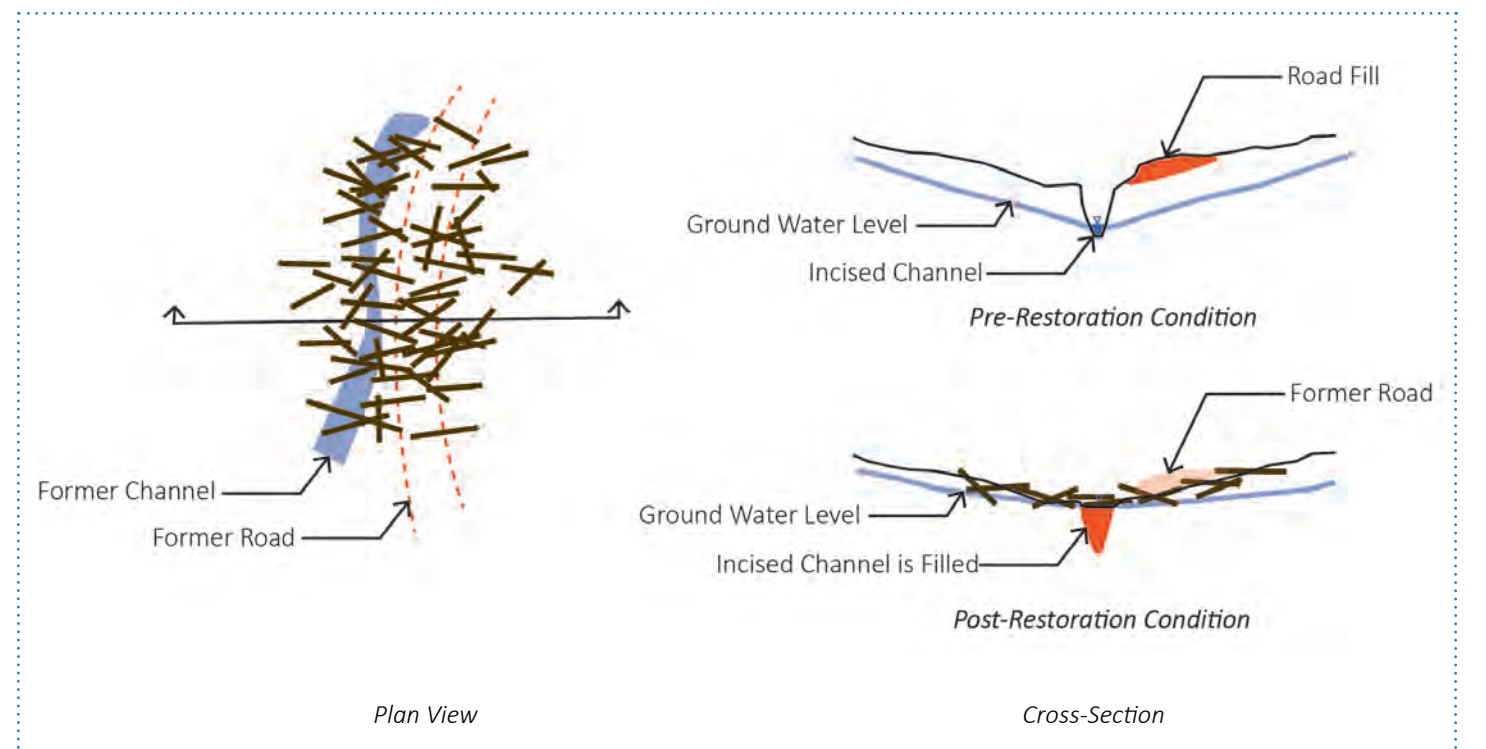
Examples



Aerial photographs of (a) pre- and (b) post-treatment with valley reset approach in Staley Creek, eastern Oregon from Figure 8 of Powers et al. (2018). Note single thread channel in (a) as opposed to multiple flow paths and high wood loading in (b).

Design Considerations

Consideration	Questions
Design and Stability	• Is there an adequate source of accessible fill in the valley bottom, such as an abandoned road prism, levee, or berm? • How will roughness be added to reduce risk of developing a single, entrenched channel through the newly reset areas? • Does downstream grade control exist or can it be constructed to protect against future headcutting?
Infrastructure and Risk	• What infrastructure is adjacent and downstream and what are the risks to this infrastructure from restoration natural processes? • What are the risks to river-recreation associated with transforming the reach to a wood-rich and multi-channel floodplain?
Cost and Implementation	• Is the construction budget sufficient for the treatment extent, level of degradation, and level of risk? • Are regulatory agencies aware and supportive of valley reset approach and temporary changes to flow paths? • Are there local options for sourcing alluvial fill and large wood? • Valley reset can range from approximately \$10,000/acre to \$60,000/acre.



Concept drawings for valley reset approach.



Strategic Excavation and/or Humanscape Modifications

Remove impairments to natural water and sediment storage functions and reconnect floodplain



Grays Harbor
Conservation
District



Watershed-Scale Screening Criteria

- For Strategic Excavation and Humanscape Modifications:
 - Response reach (i.e., channel gradient < 3%)
 - Valley confinement ratio of unconfined or moderately confined (i.e., valley width:channel width > 2)
- For Humanscape Modifications only:
 - Presence of road with a length $\geq$ 5% of the reach length OR a dam OR a stream crossing in valley bottom.

Recommended Reach-Scale Assessment Criteria

- Are there culverts, fill, or other features that alter surface and subsurface hydraulic gradients?
- Has the channel been straightened or is lateral migration constrained via infrastructure?
- Is the channel incised and potentially vertically disconnected from its floodplain?
 - What are the drivers of incision and the current channel depth?
 - Is incision actively occurring? Consider instream treatments to halt incision prior to floodplain excavation.
 - Will removal of infrastructure trigger incision? Is the infrastructure providing a grade control function?
- Are there abandoned channel scars or wetland areas that could be reconnected?
- Has the valley bottom been modified such that natural depressions or channels have been filled?
- Is there room for the channel corridor to expand across the valley bottom (consider infrastructure, vegetation, habitat)?
- What is the extent and ownership of adjacent lands that could be affected by restoration?
- Which fish and wildlife species are currently using and historically used the reach and how does this influence design goals?
- What regulated features and species could be affected (e.g., wetlands, cultural resources)? What regulatory permits may be needed? What is the anticipated in-water construction window?

Examples



For the Clear Creek restoration project (Kitsap County, WA), completed in 2016, 6 acres of perched floodplains were lowered by an average of 5 feet, a ¼ mile of road was removed and replaced with a pedestrian path, wide bridge crossings replaced two blocking culverts, and channels were re-meandered into the lowered floodplain to restore floodplain connectivity and re-introduce complex habitat features.

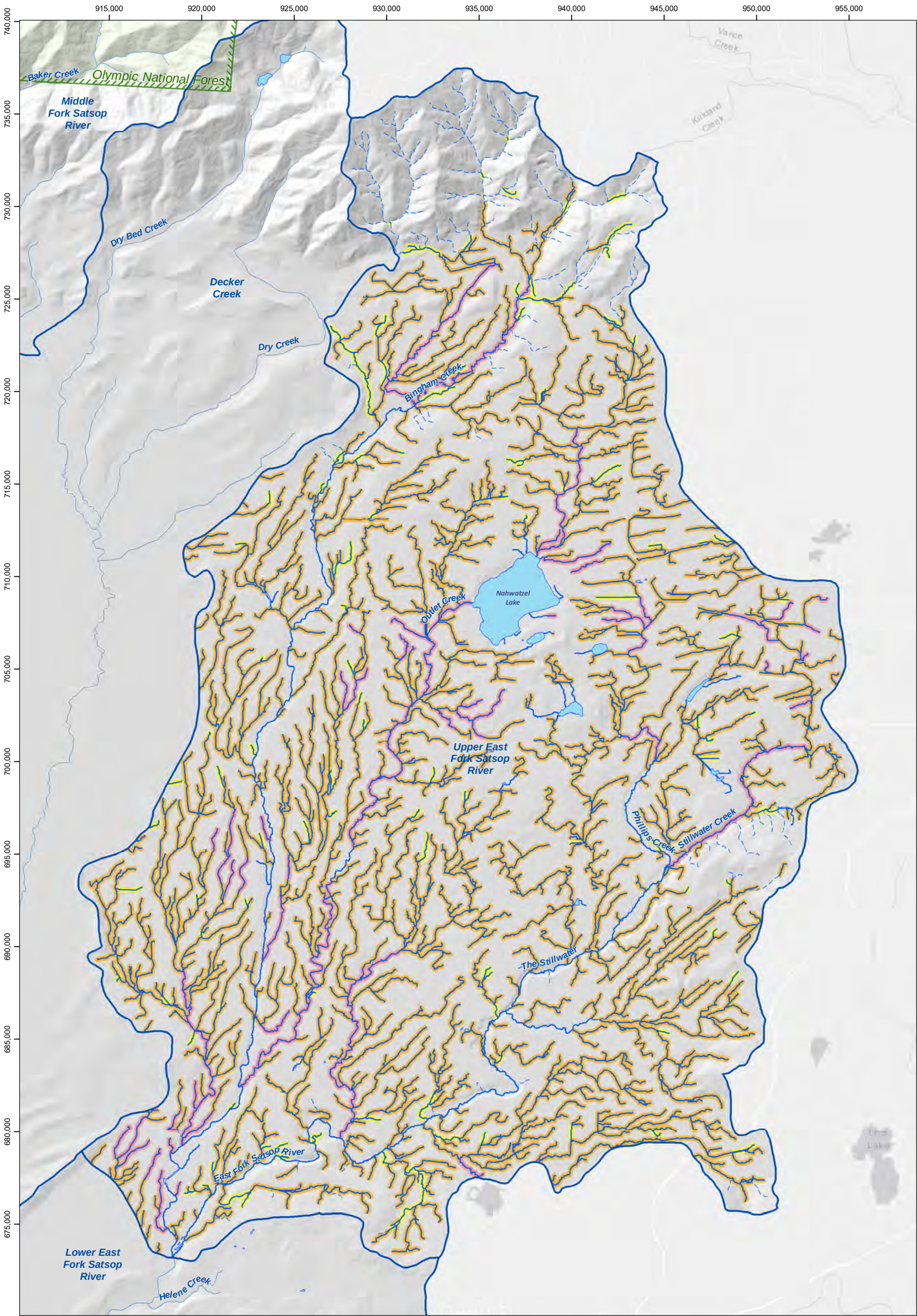
Design Considerations

Consideration	Questions
Design and Stability	- What will be the hydraulic and sediment transport response to restoration actions? - How will roughness be used to limit avulsion risk and prevent return to a simplified state? - Is there machine access? If not, strategic excavation via hand tools may still be possible for small volumes of material.
Infrastructure and Risk	- Type and sensitivity of infrastructure adjacent, upstream, and downstream? - How will the channel respond laterally and vertically in response to instream structure(s)? What are the resulting risks? - Are there public recreation usage risks with the designed channel planform and added roughness?
Cost and Implementation	- Is the construction budget sufficient for the treatment extent, level of degradation, excavation extent, volume of material disposal, and level of risk? - What are the local options for sourcing roughening features such as large wood or rock, and for disposal of excavated material? - Are regulatory agencies aware and supportive of approach, particularly if excavation will alter floodplain wetlands? - Strategic excavation and/or humanscape modifications range widely based on infrastructure.



Large wood being placed to provide stabilizing roughness in a newly excavated side channel to Sullivan Creek in Pend Oreille County, WA.

APPENDIX C. MAPBOOK OF INSTREAM RESTORATION APPROACHES



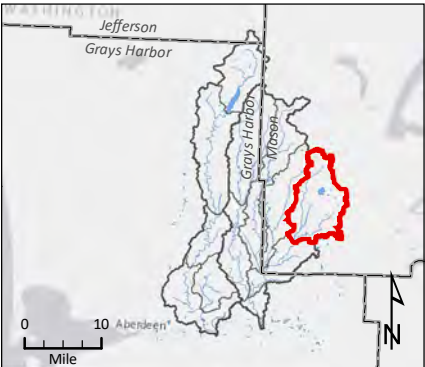
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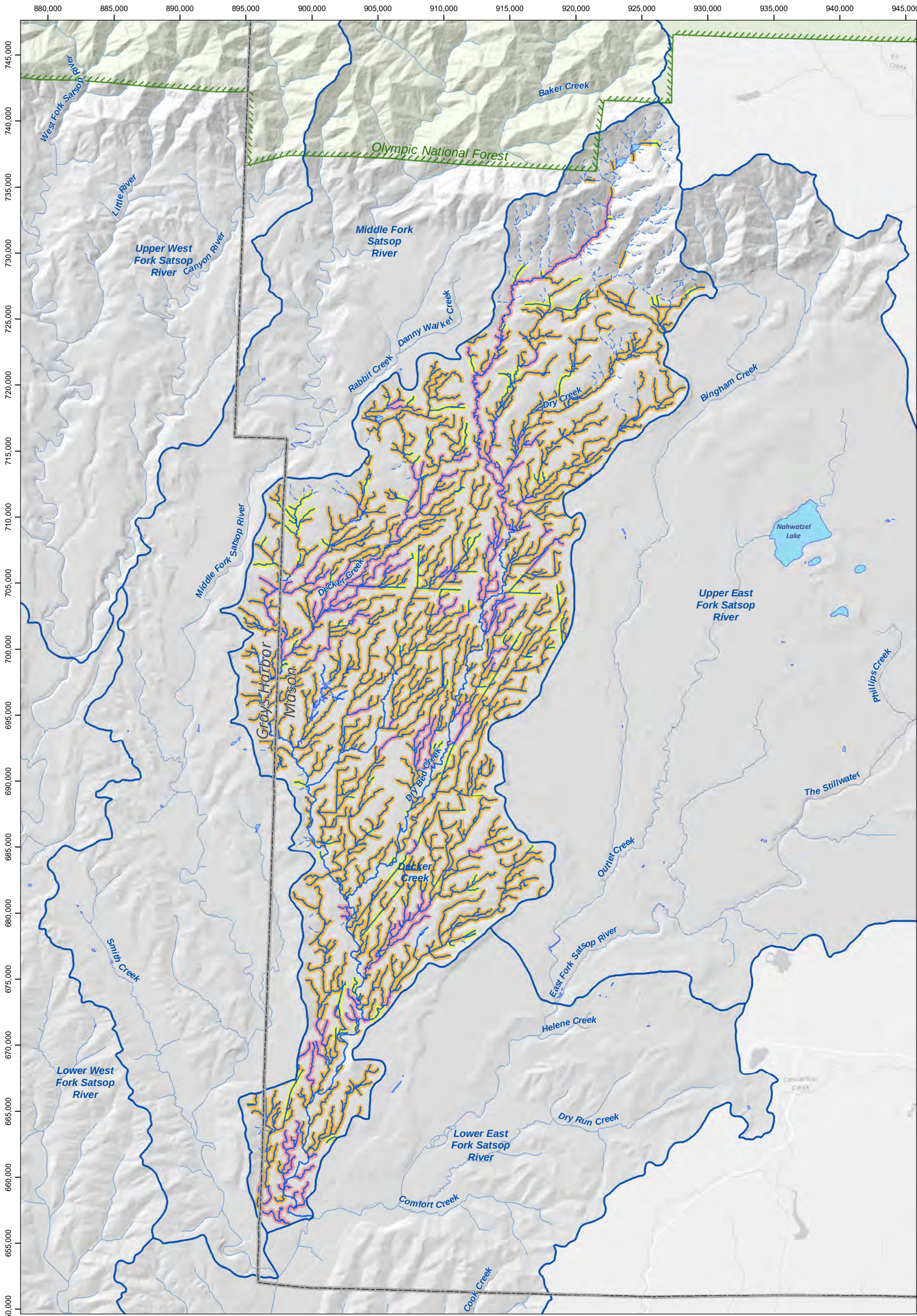
Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 1 of 12
Upper East Fork Satsop River

- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.





Author: Stratton Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

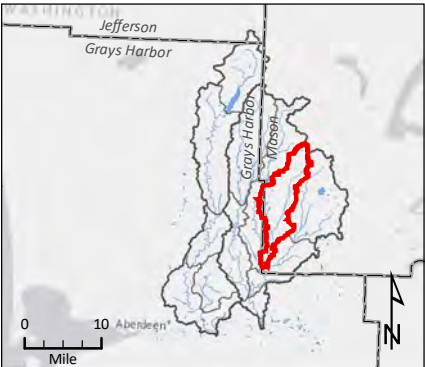
In-Stream Restoration Approaches
Map 2 of 12
Decker Creek

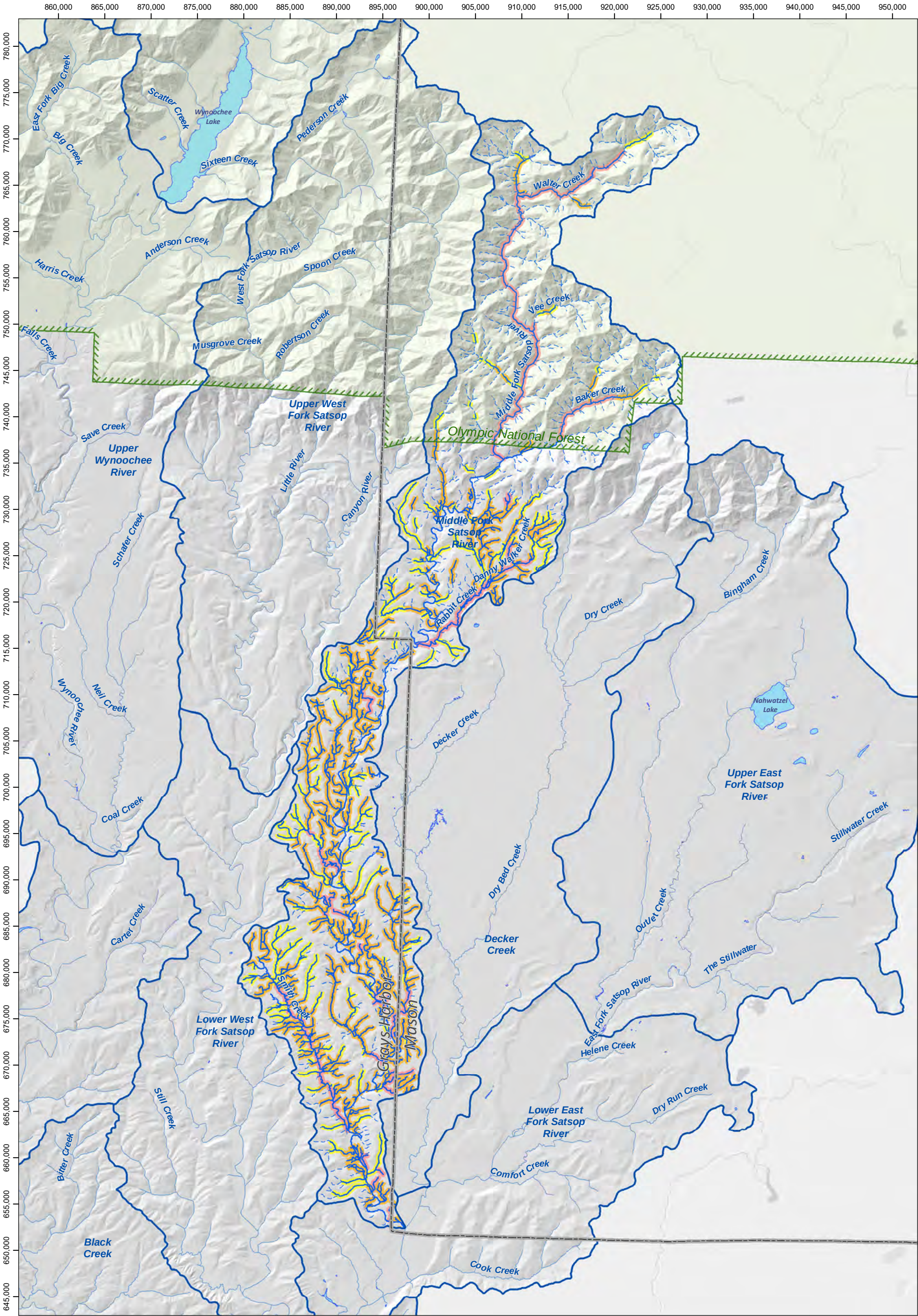
- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 3 of 12
Middle Fork Satsop River

Streams (Unassessed if not Highlighted)

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

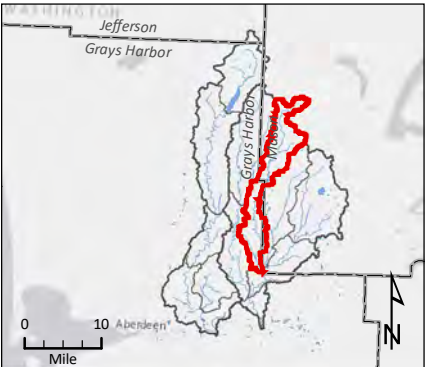
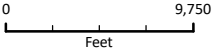
In-Stream Structures

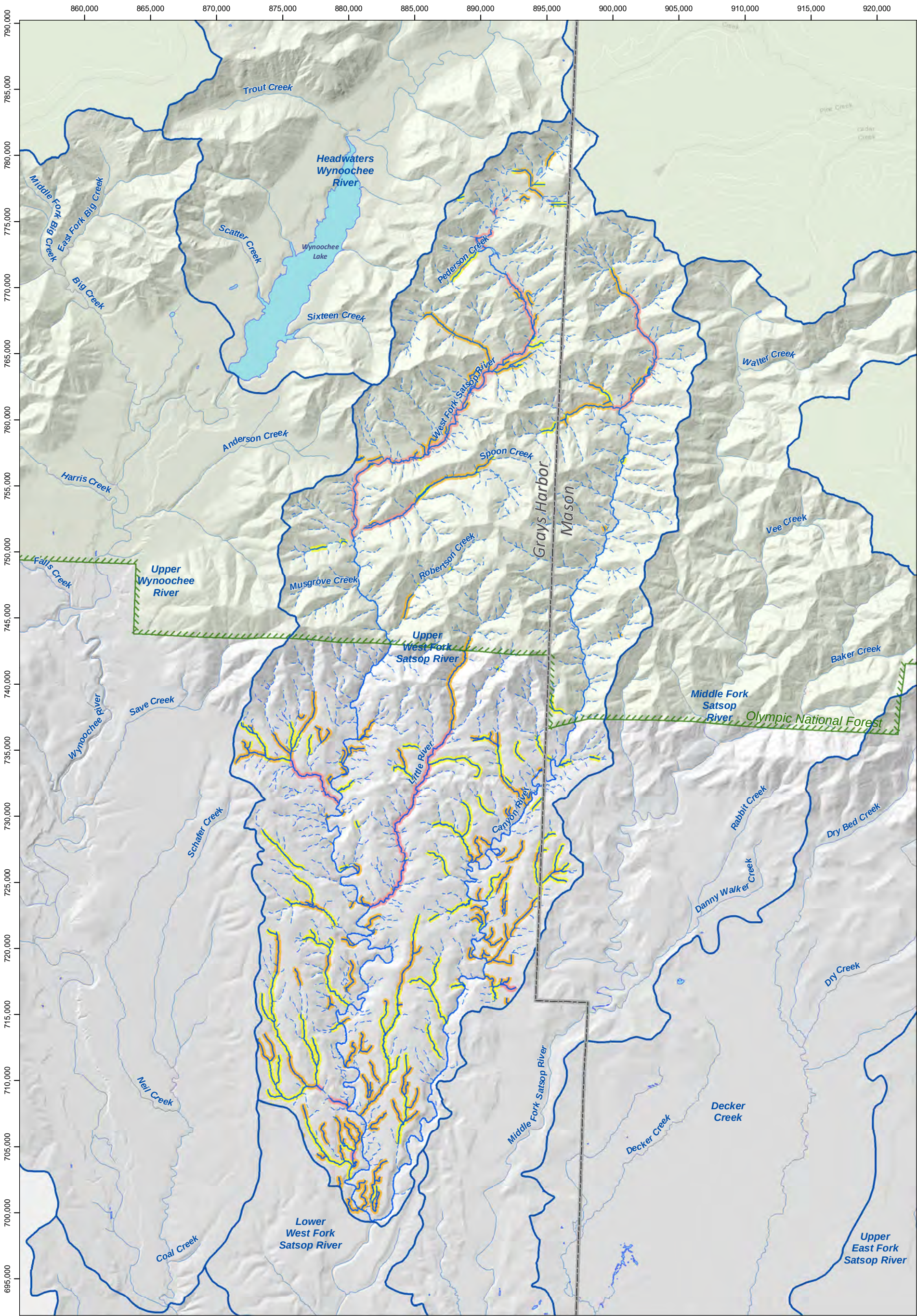
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable
- Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 4 of 12
Upper West Fork Satsop River

- Streams (Unassessed if not Highlighted)

Stream Reaches (<8% slope)

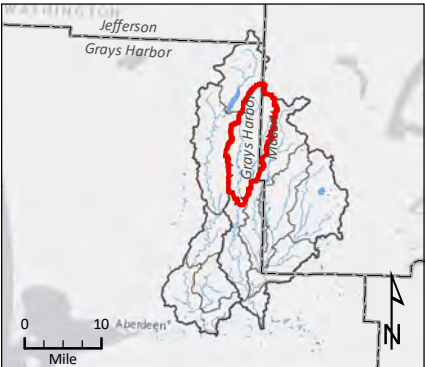
Stream Reaches (>8% slope)
- In-Stream Structures

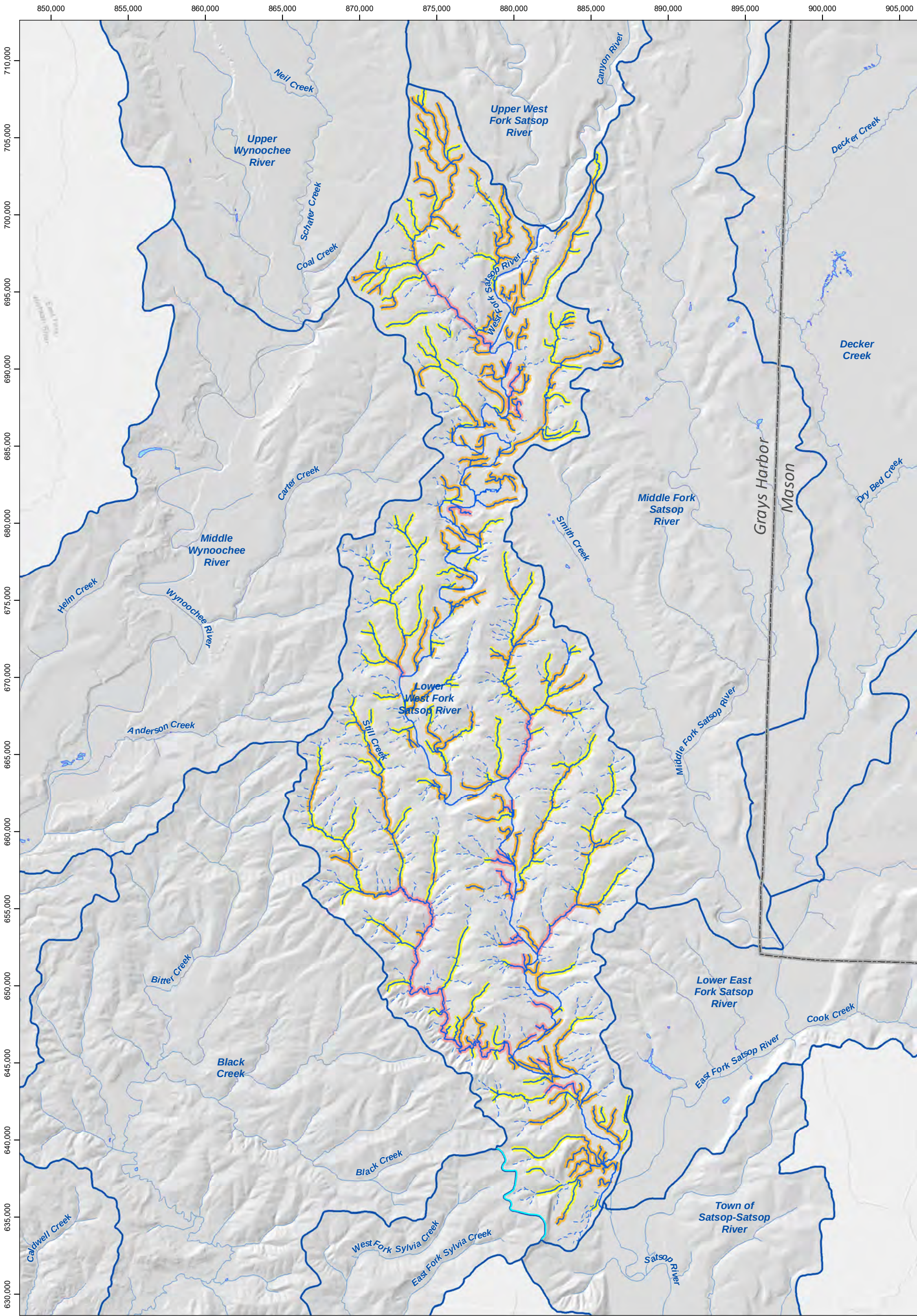
Hand-Built, Likely Suitable

Hand-Built, Possibly Suitable

Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.





Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches

Map 5 of 12

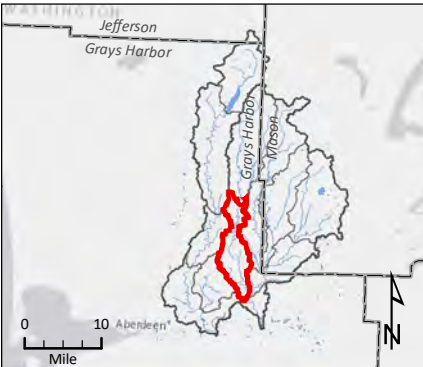
Lower West Fork Satsop River

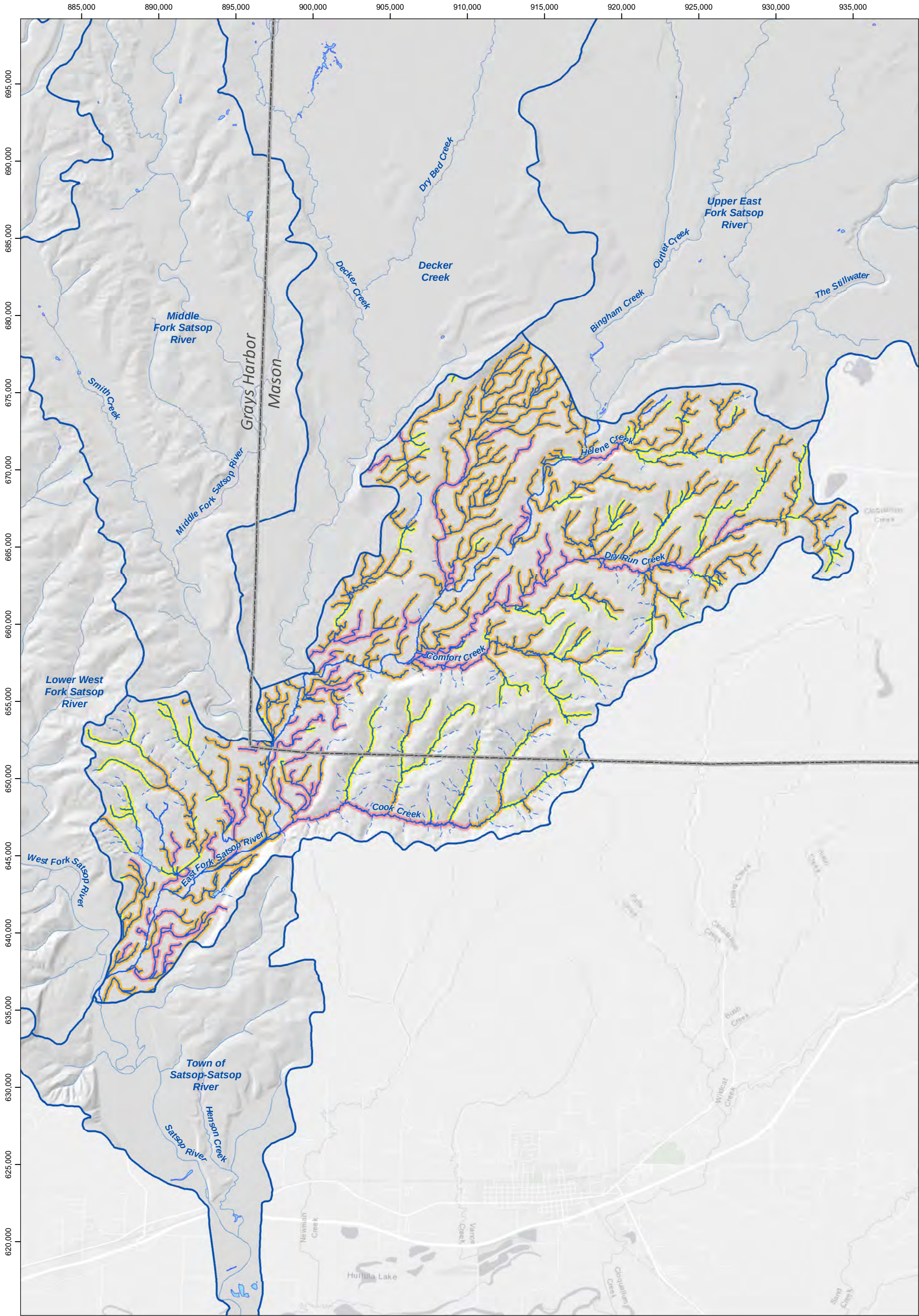
- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 6 of 12
Lower East Fork Satsop River

Streams (Unassessed if not Highlighted)

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

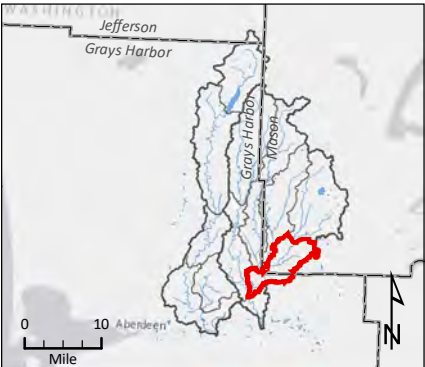
In-Stream Structures

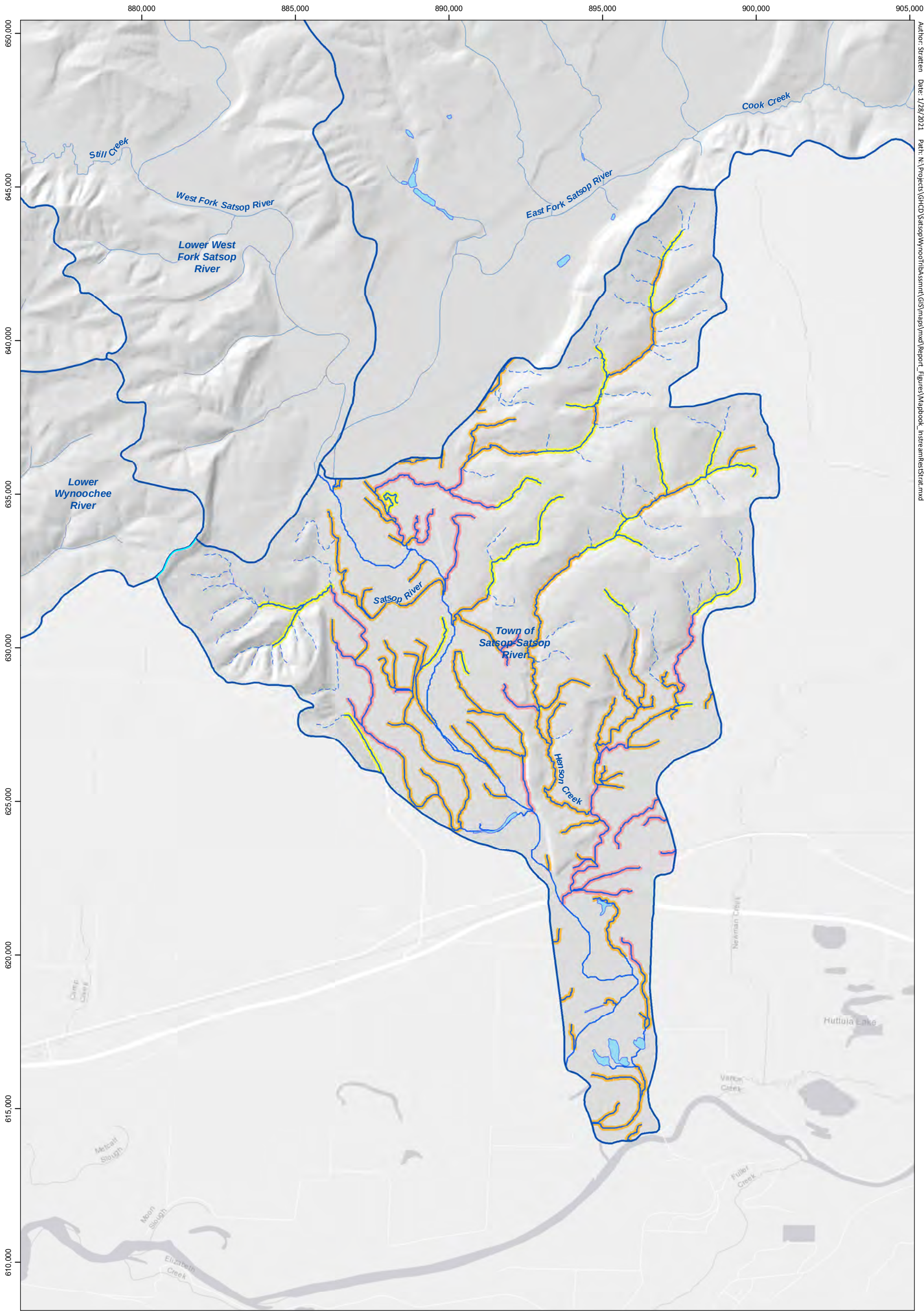
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable
- Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\Bassm\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 7 of 12
Town of Satsop-Satsop River

Streams (Unassessed if not Highlighted)

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

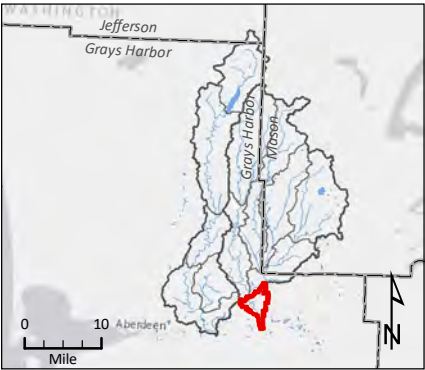
In-Stream Structures

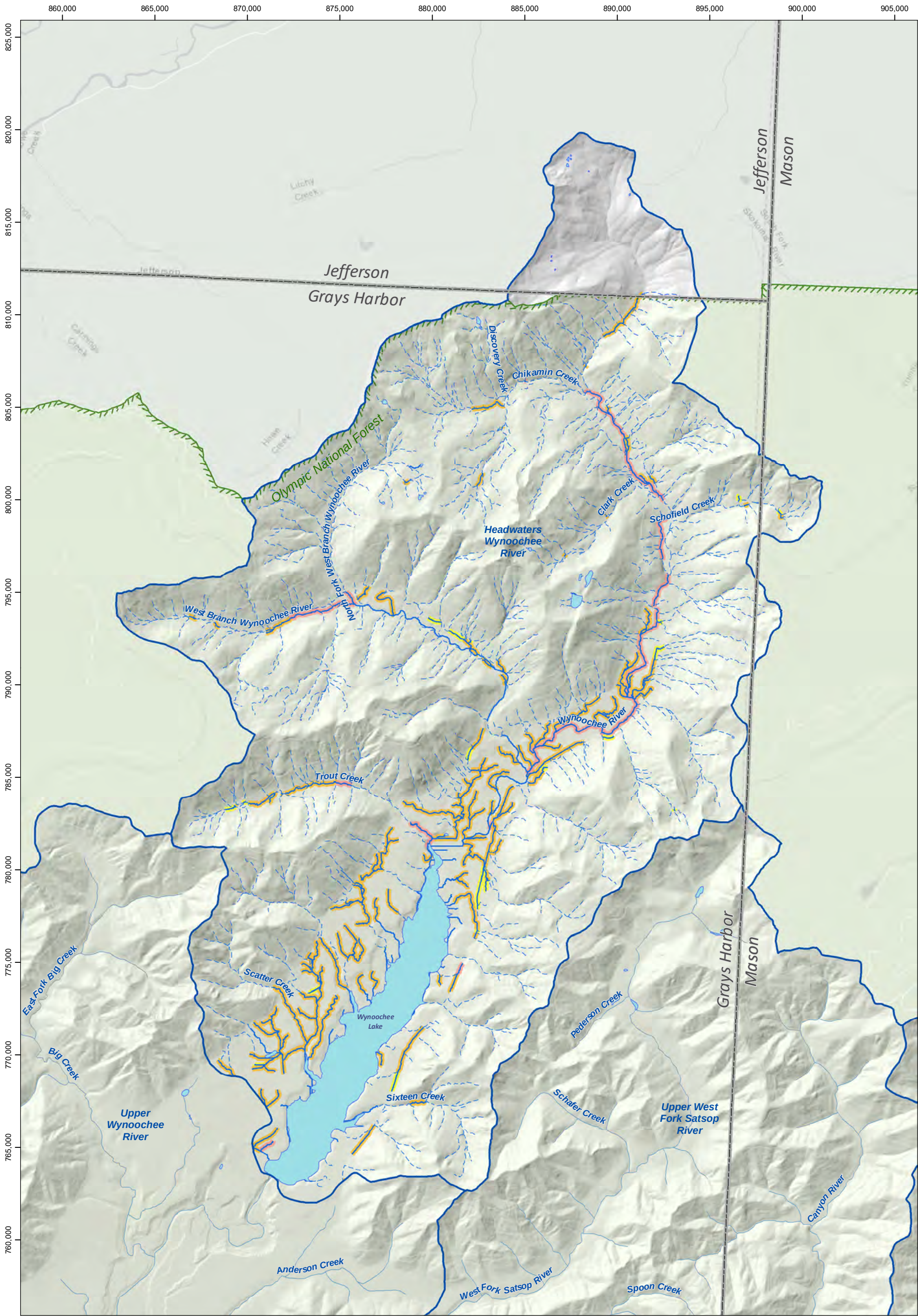
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable
- Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





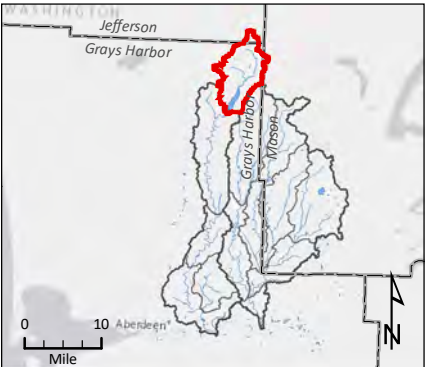
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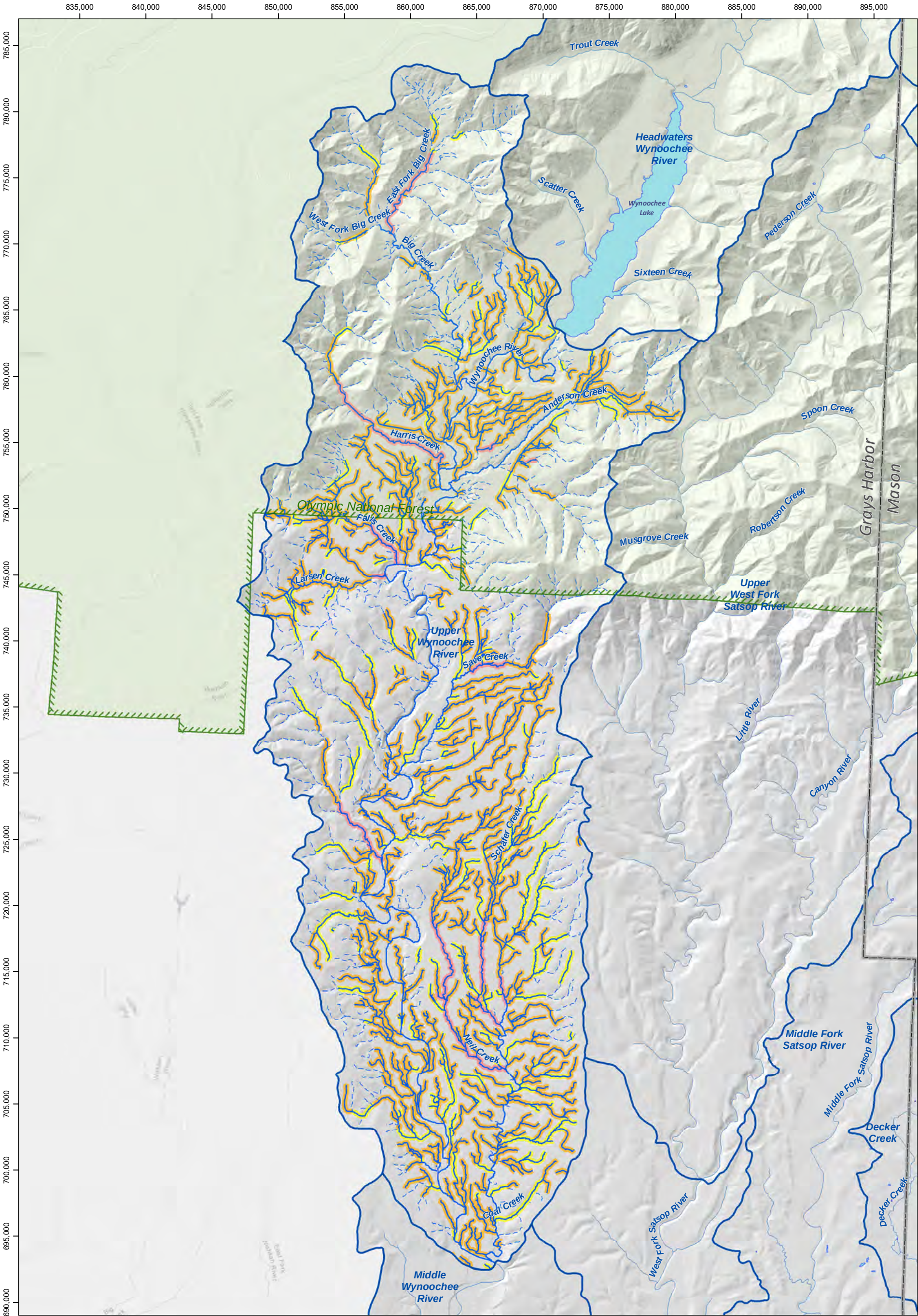
Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 8 of 12
Headwaters Wynoochee River

- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.





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Satsop and Wynoochee Tributary Restoration Strategy

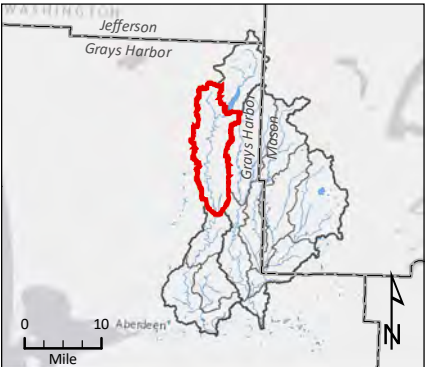
In-Stream Restoration Approaches
Map 9 of 12
Upper Wynoochee River

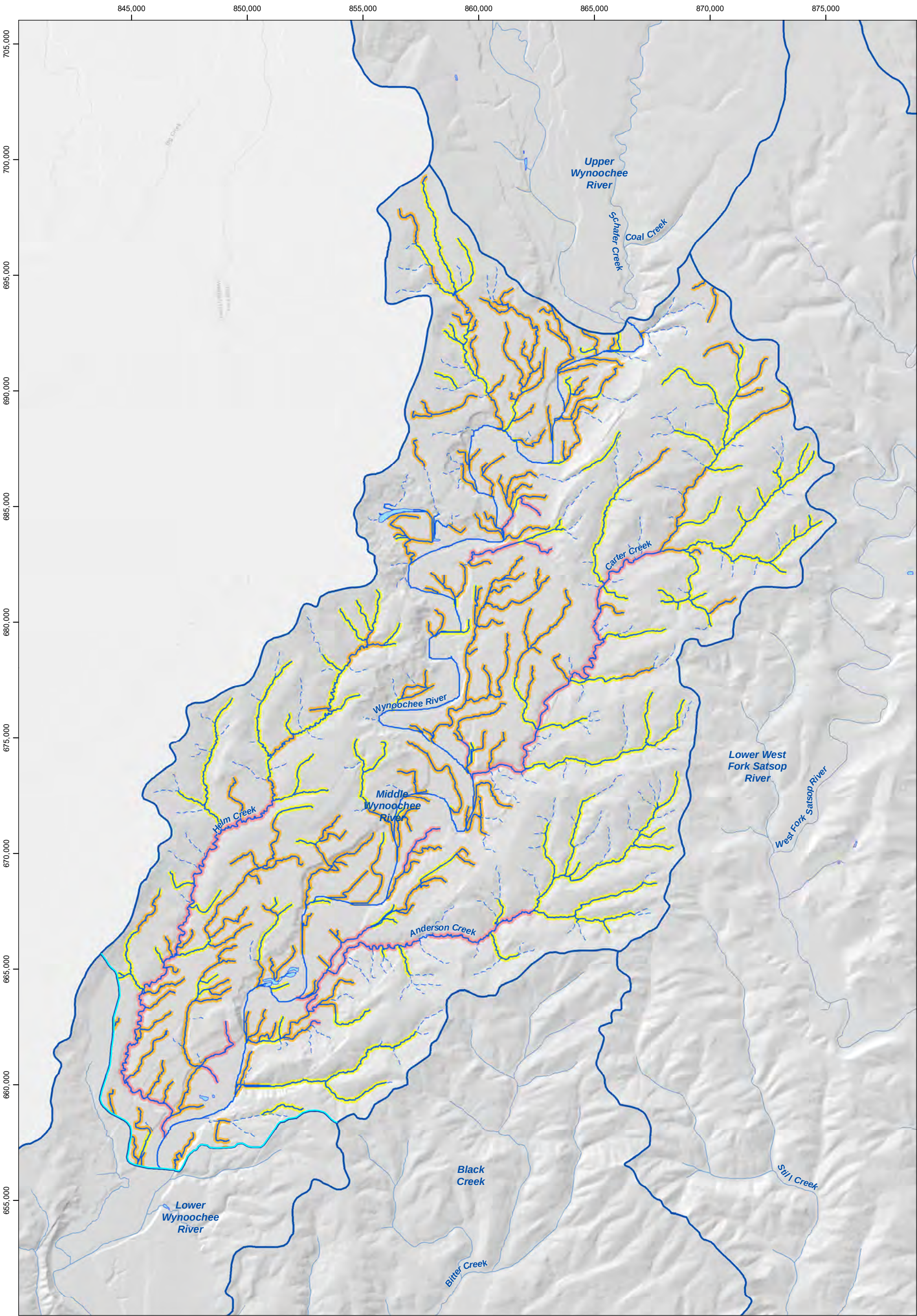
- Streams (Unassessed if not Highlighted)

 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures

 - Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.





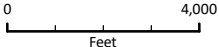
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Satsop and Wynoochee Tributary Restoration Strategy

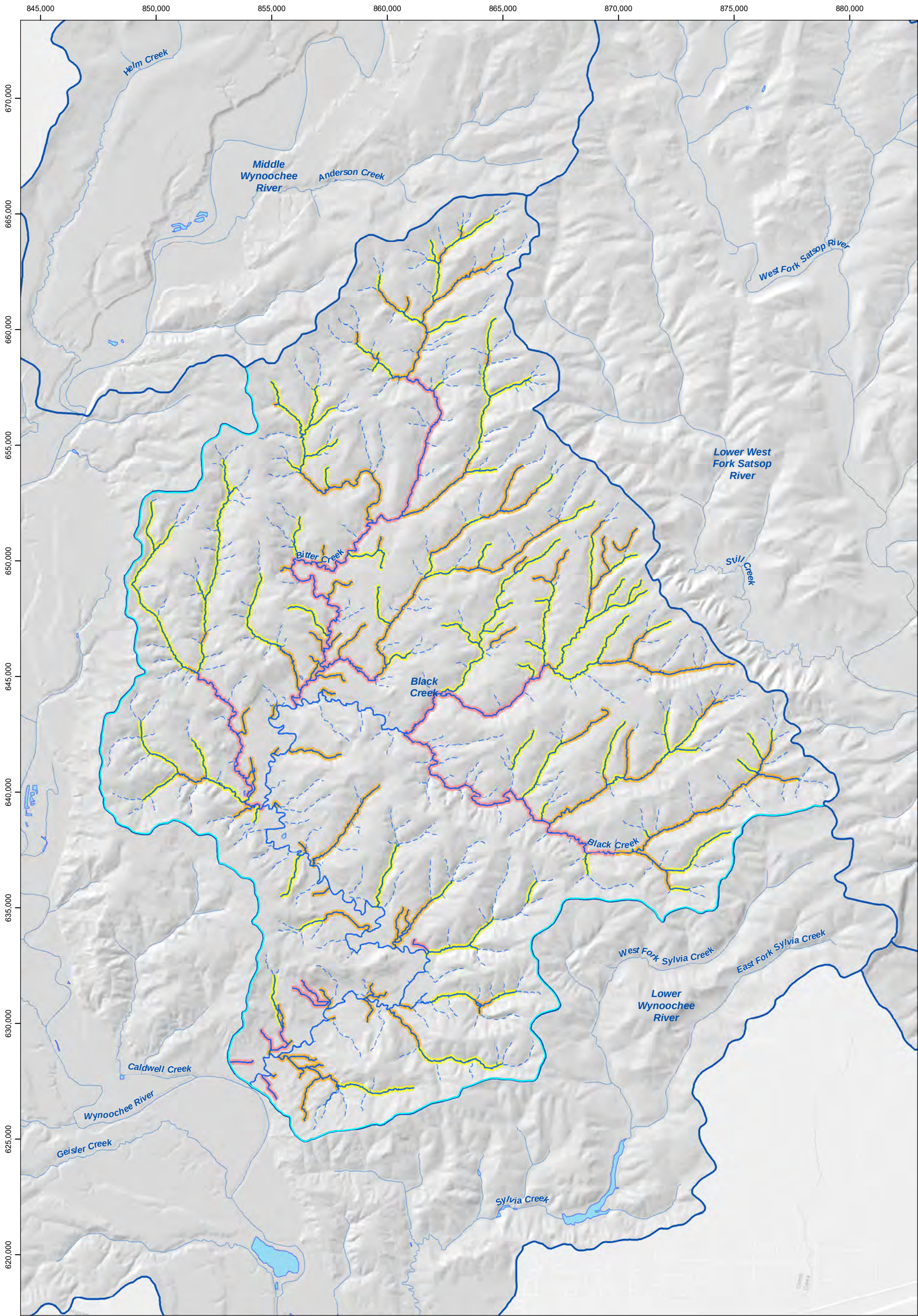
In-Stream Restoration Approaches
Map 10 of 12
Middle Wynoochee River

- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW



Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_InstreamRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 11 of 12
Black Creek

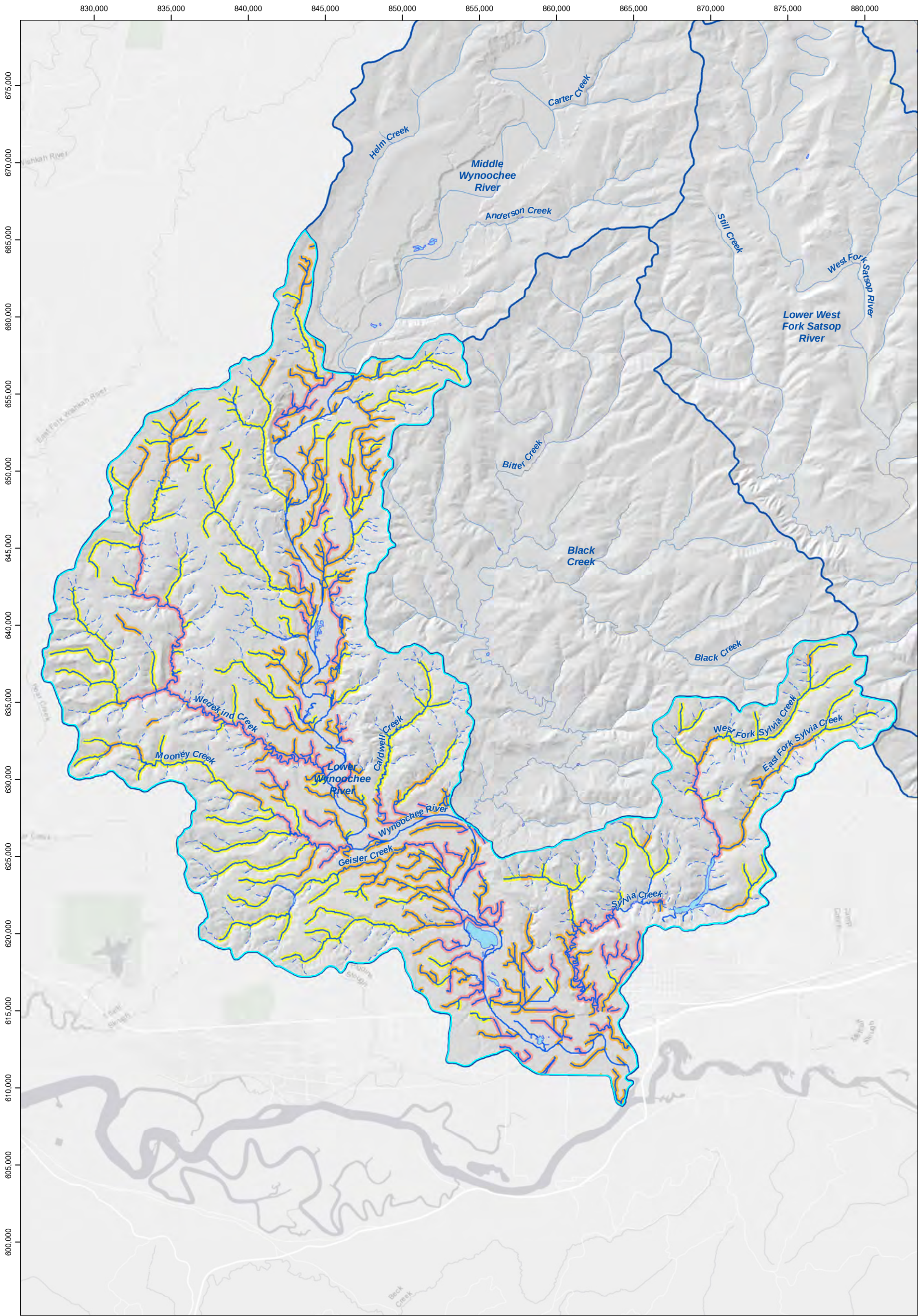
- Streams (Unassessed if not Highlighted)

 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures

 - Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable

Note: See Table 5 for interpretation of hand-built suitability.

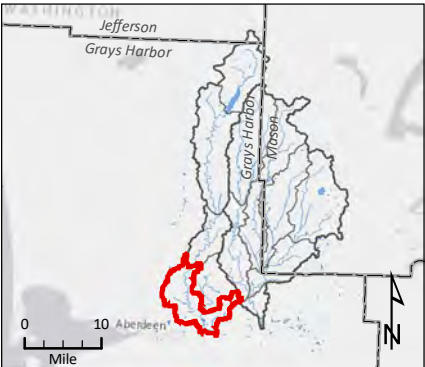




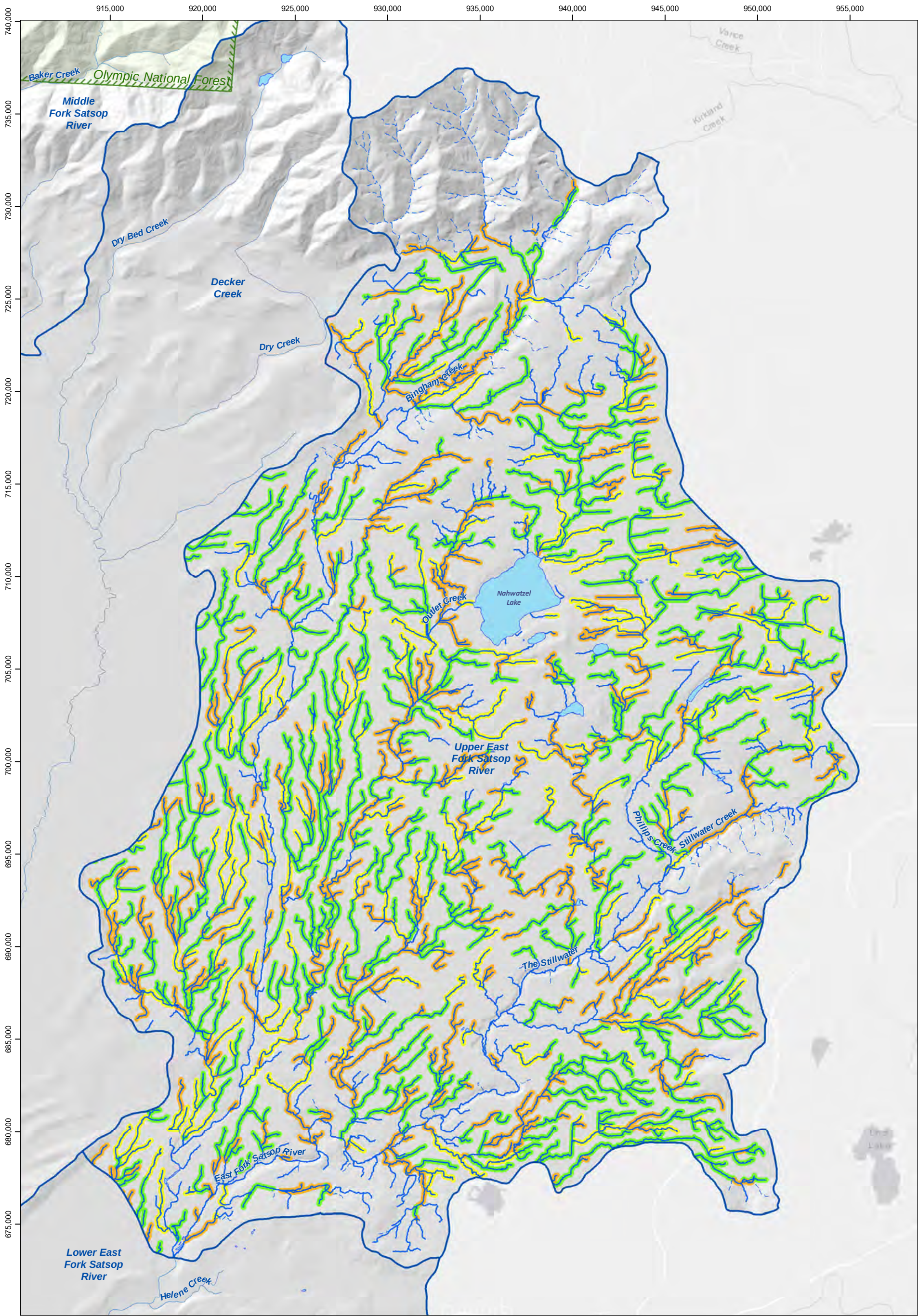
Satsop and Wynoochee Tributary Restoration Strategy

In-Stream Restoration Approaches
Map 12 of 12
Lower Wynoochee River

- Streams (Unassessed if not Highlighted)
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- In-Stream Structures
- Hand-Built, Likely Suitable
 - Hand-Built, Possibly Suitable
 - Machine-Built, Suitable
- Note: See Table 5 for interpretation of hand-built suitability.



APPENDIX D. MAPBOOK OF GEOMORPHIC MODIFICATION RESTORATION APPROACHES



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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 1 of 12
Upper East Fork Satsop River

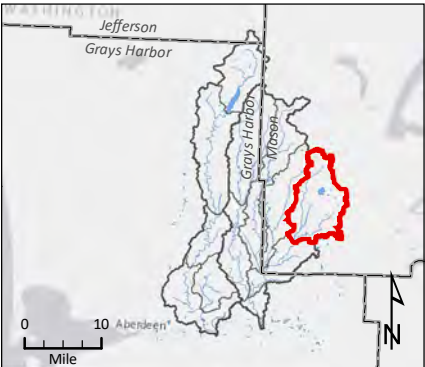
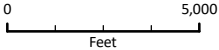
- Streams

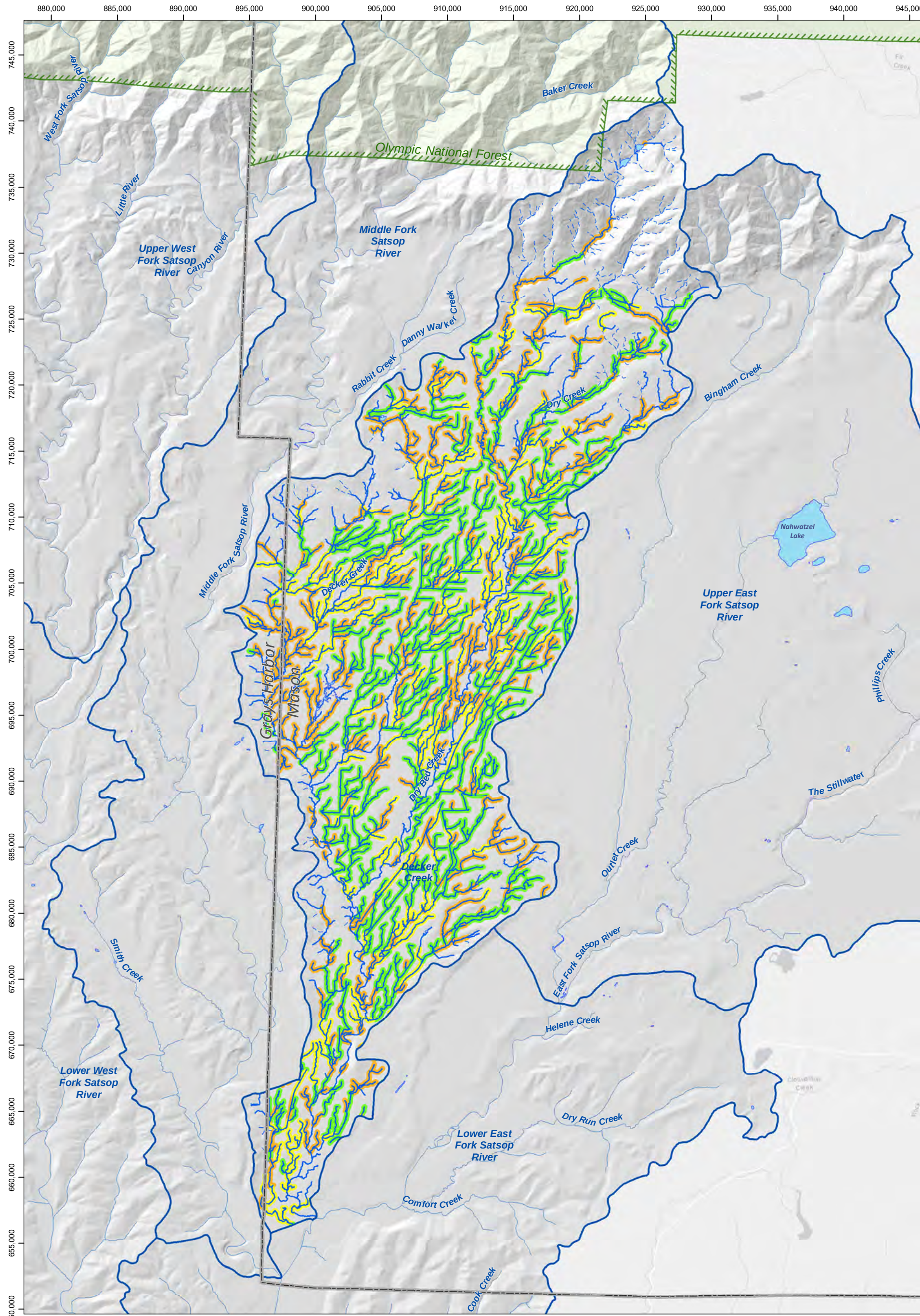
 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Author: Stratten Date: 1/27/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\mapa\mxd\Report_Figures\Mapbook_GeomorphRestStrat.mxd

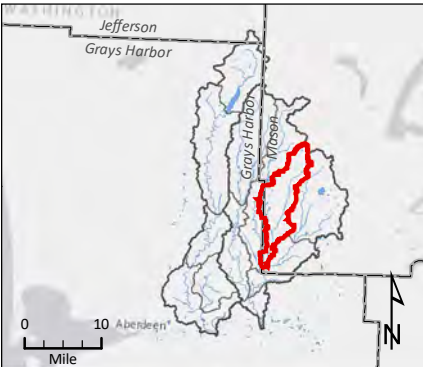
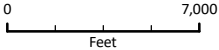
Satsop and Wynoochee Tributary Restoration Strategy

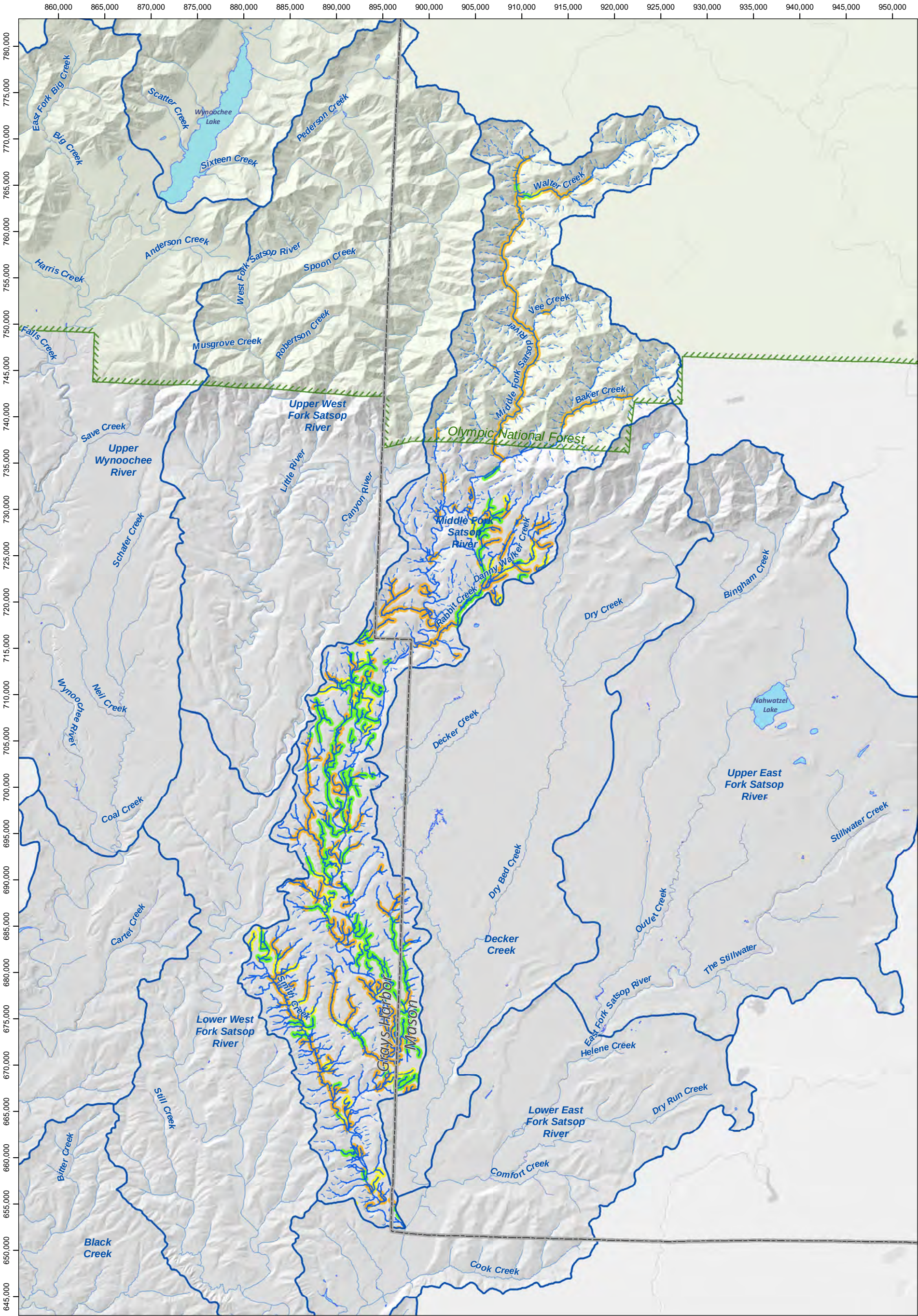
Geomorphic Modification Restoration Approaches
Map 2 of 12
Decker Creek



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW

- Streams
- Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification
- Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation





Author: Stratten Date: 1/27/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_GeomorphRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 3 of 12
Middle Fork Satsop River

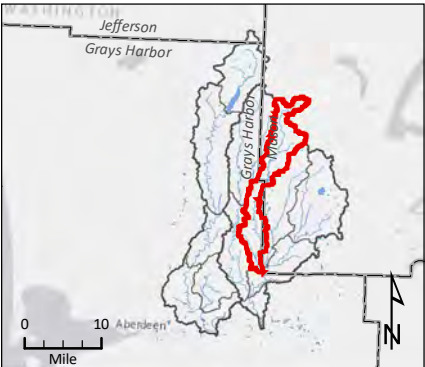
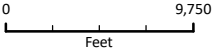
- Streams

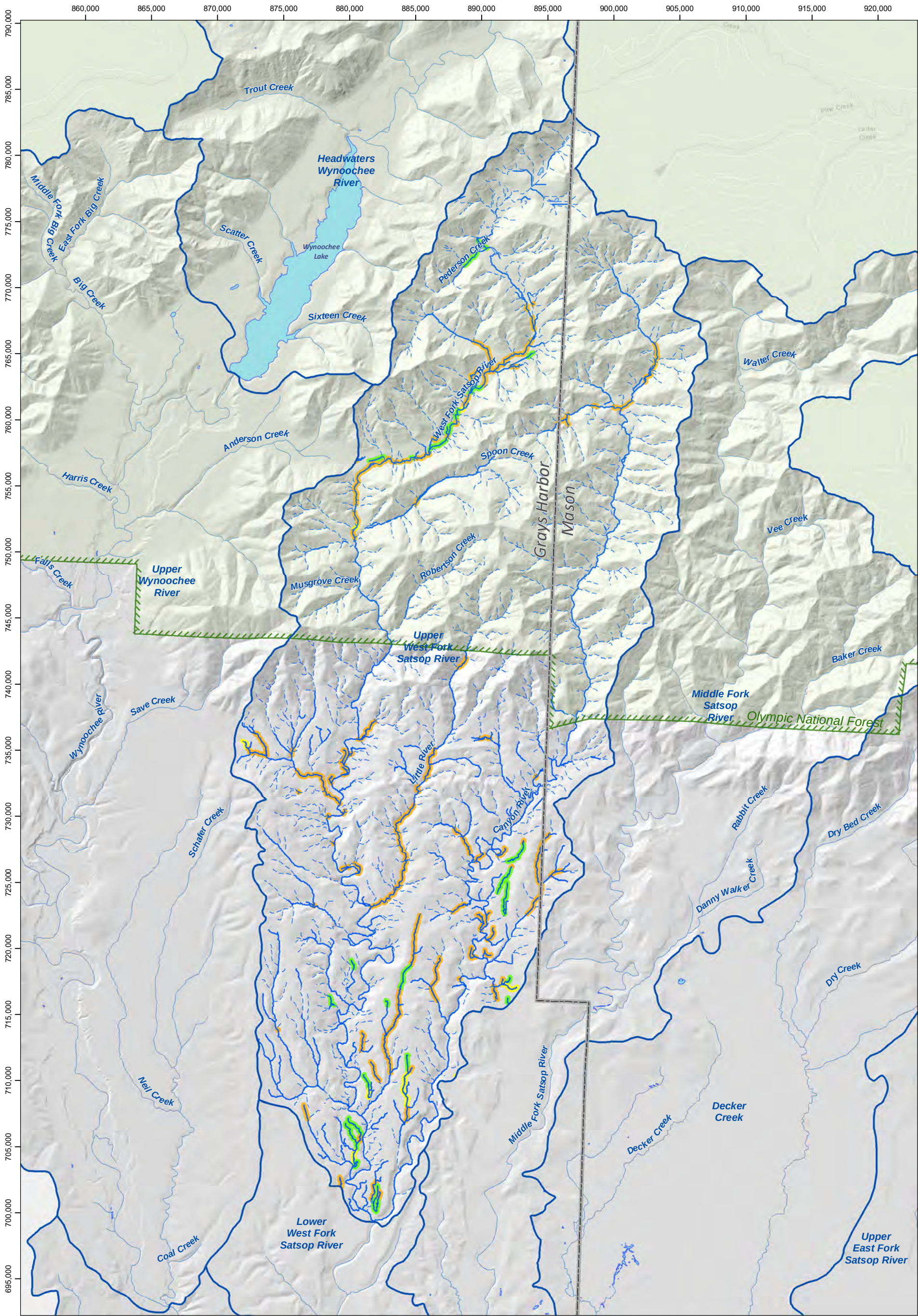
 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 4 of 12
Upper West Fork Satsop River

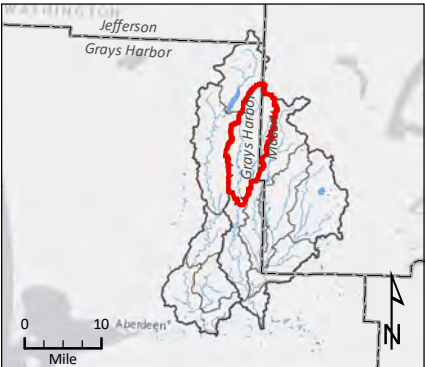
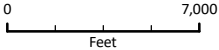
- Streams

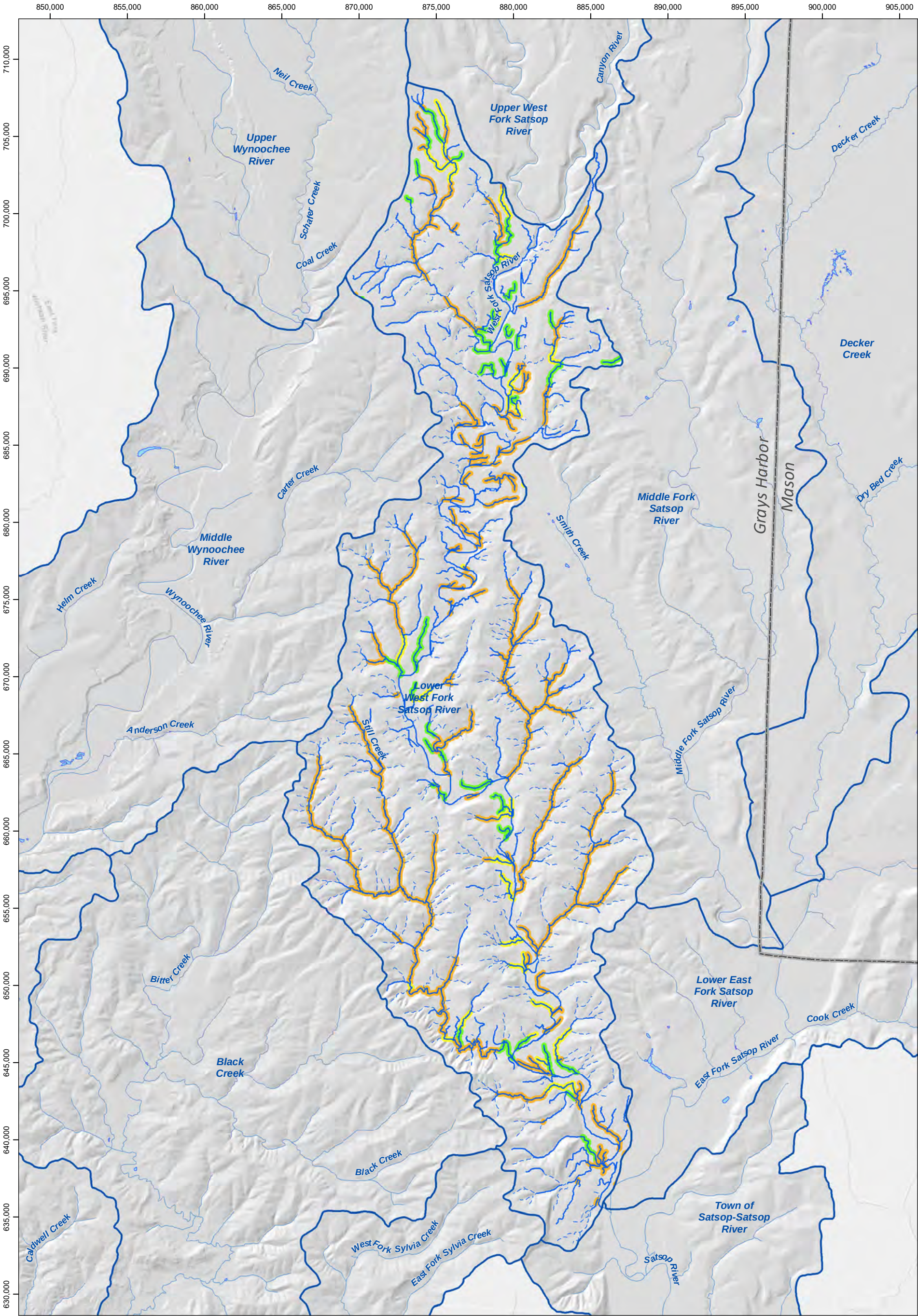
 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 5 of 12
Lower West Fork Satsop River



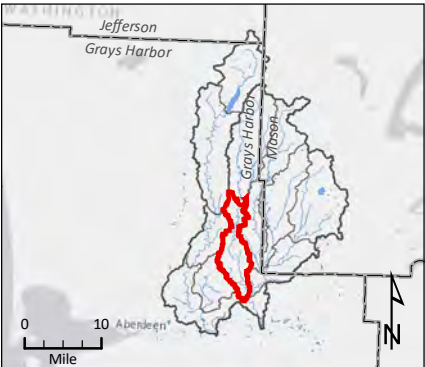
Lambert conformal conic projection
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Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW

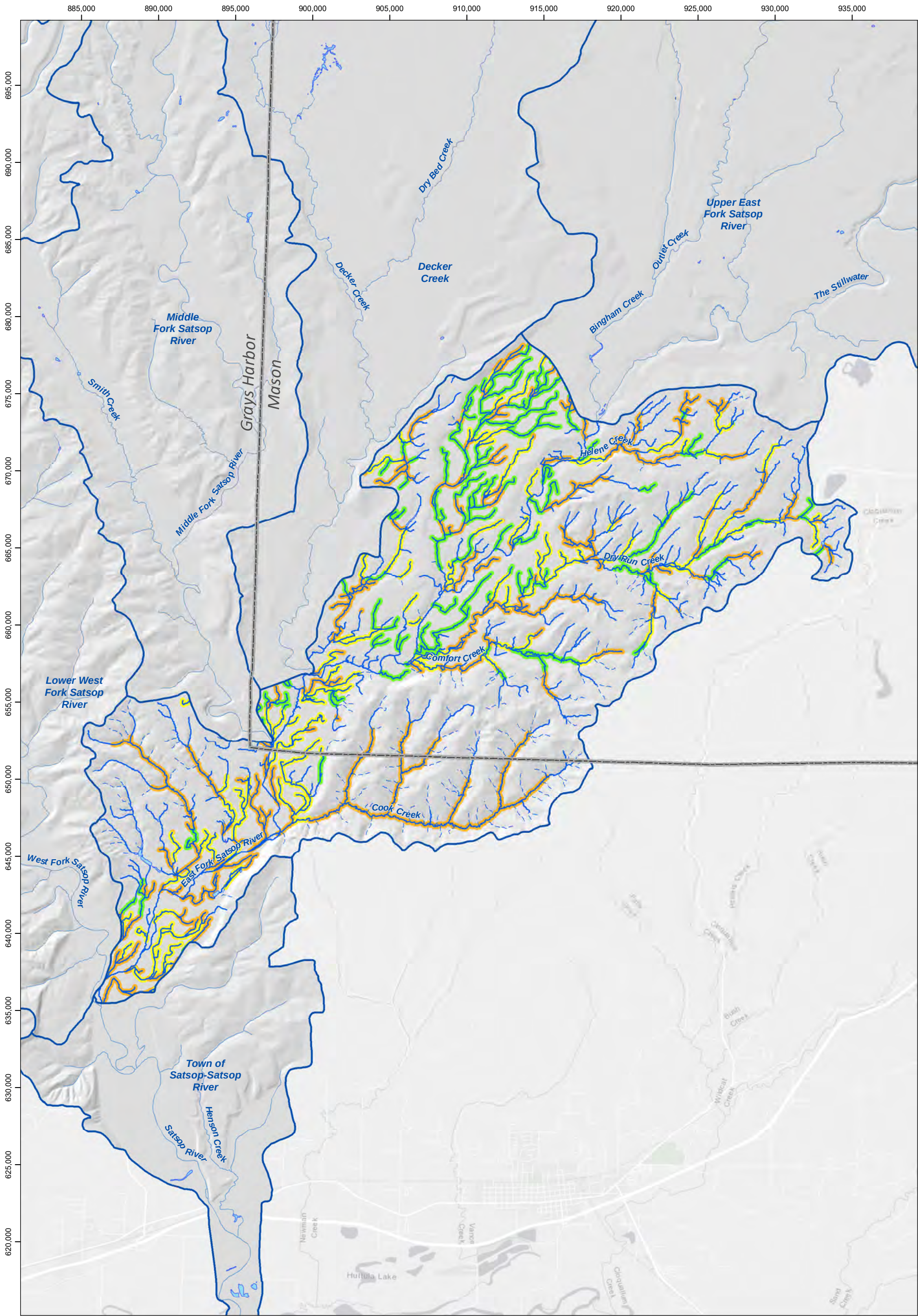
Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

Geomorphic Modification

- Strategic Excavation
- Humanscape Modification or Strategic Excavation
- Valley Reset, Humanscape Modification, or Strategic Excavation





Author: Stratten Date: 1/27/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_GeomorphicRestStrat.mxd

Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 6 of 12
Lower East Fork Satsop River

Streams

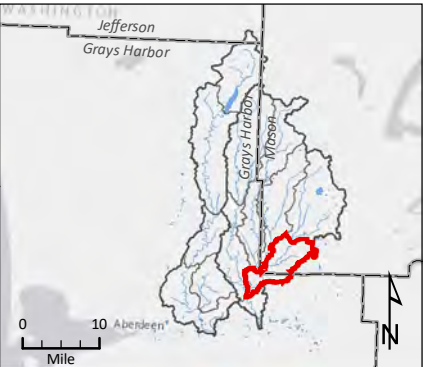
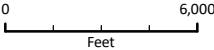
- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

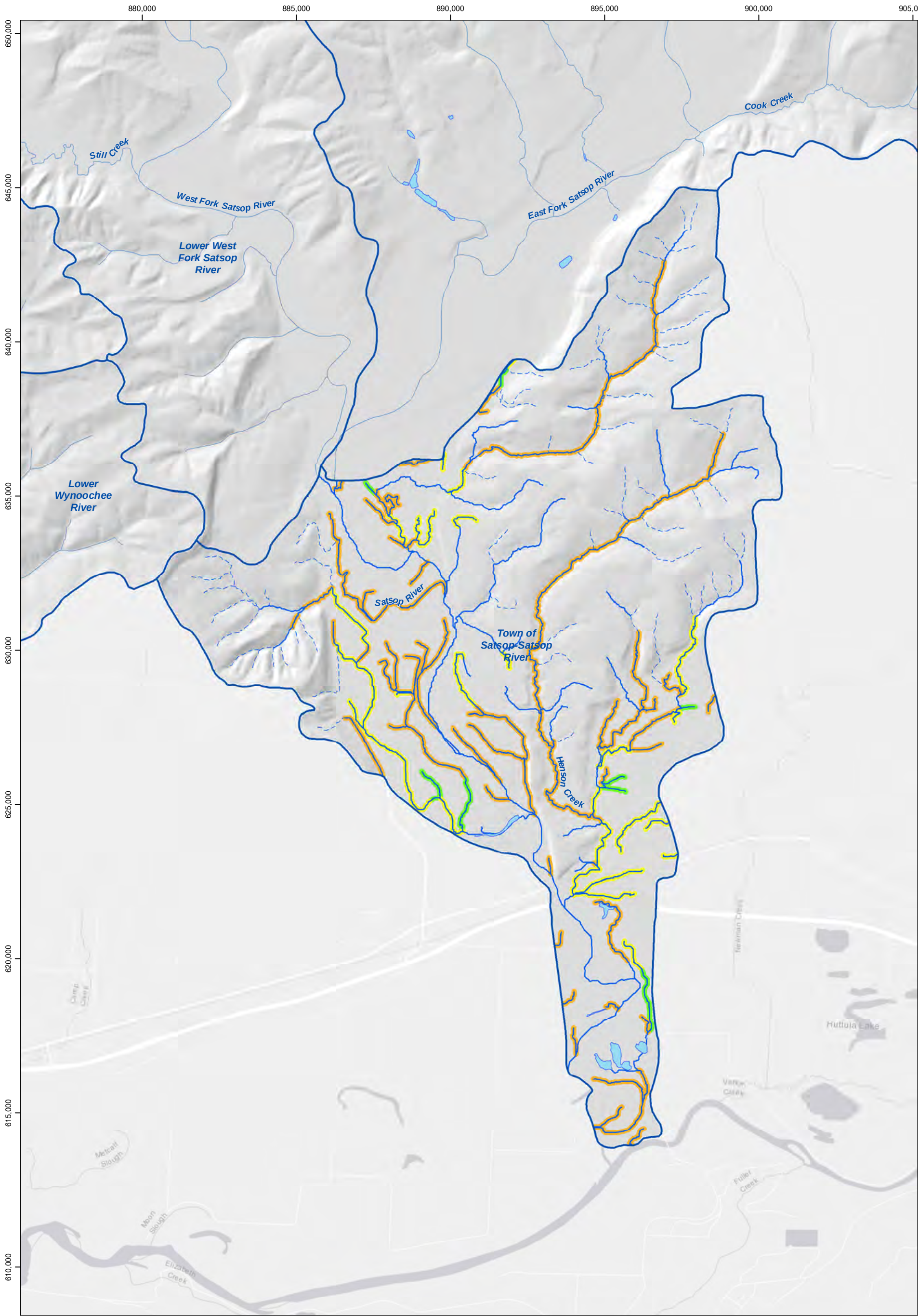
Geomorphic Modification

- Strategic Excavation
- Humanscape Modification or Strategic Excavation
- Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 7 of 12
Town of Satsop-Satsop River

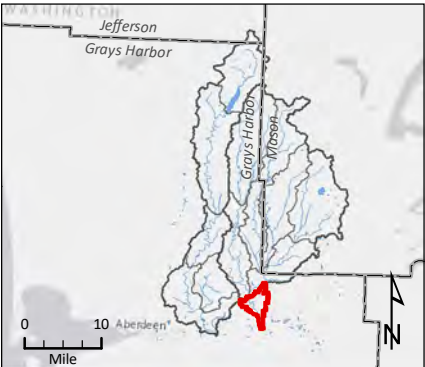
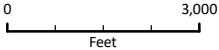
- Streams

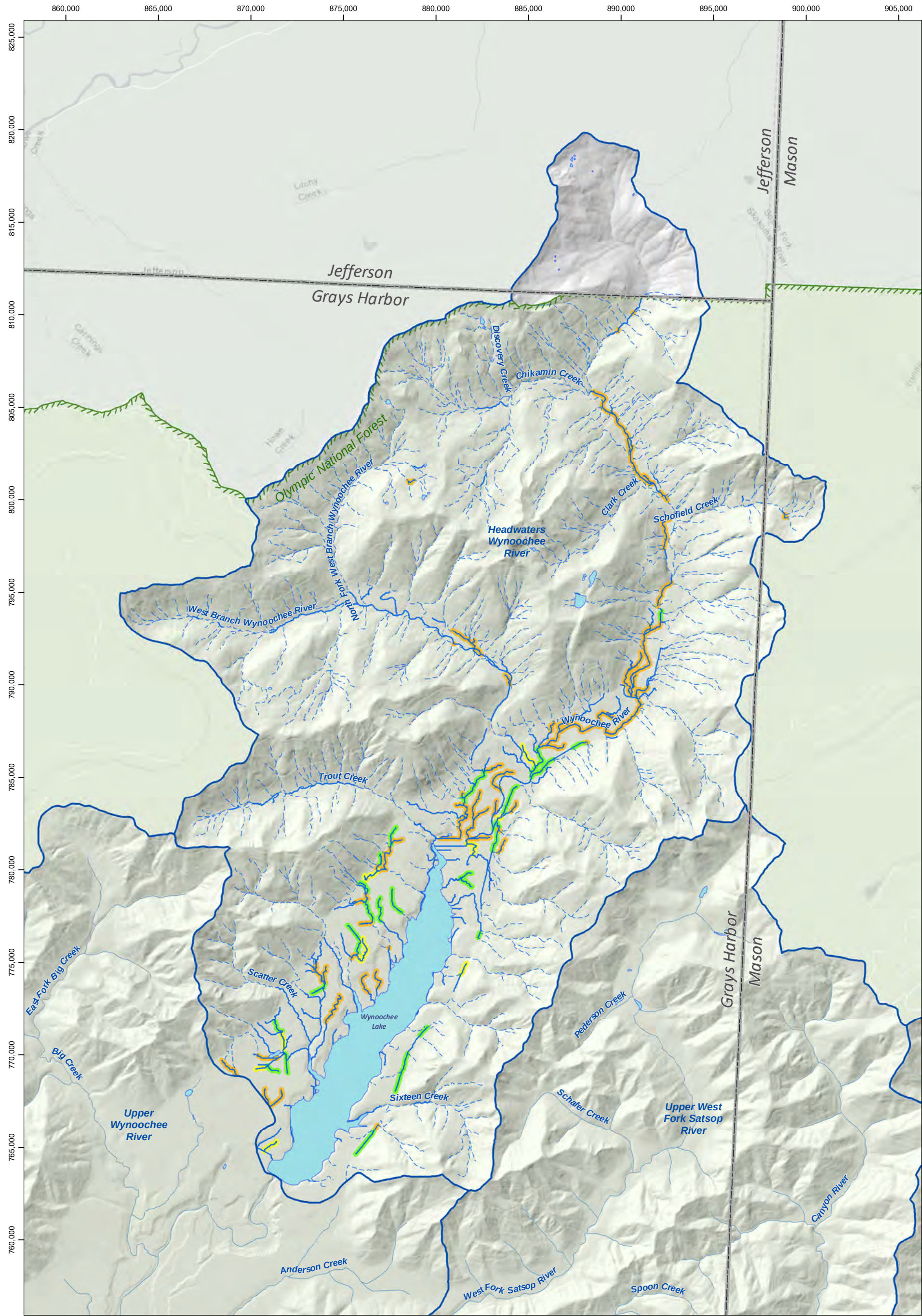
 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 8 of 12
Headwaters Wynoochee River

Streams

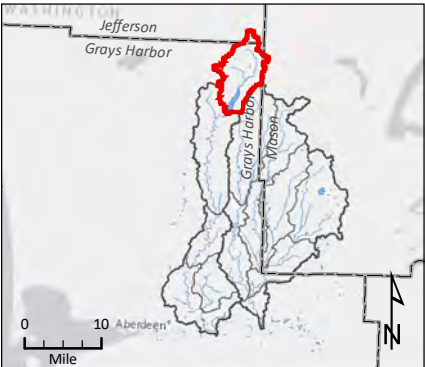
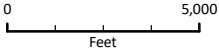
- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

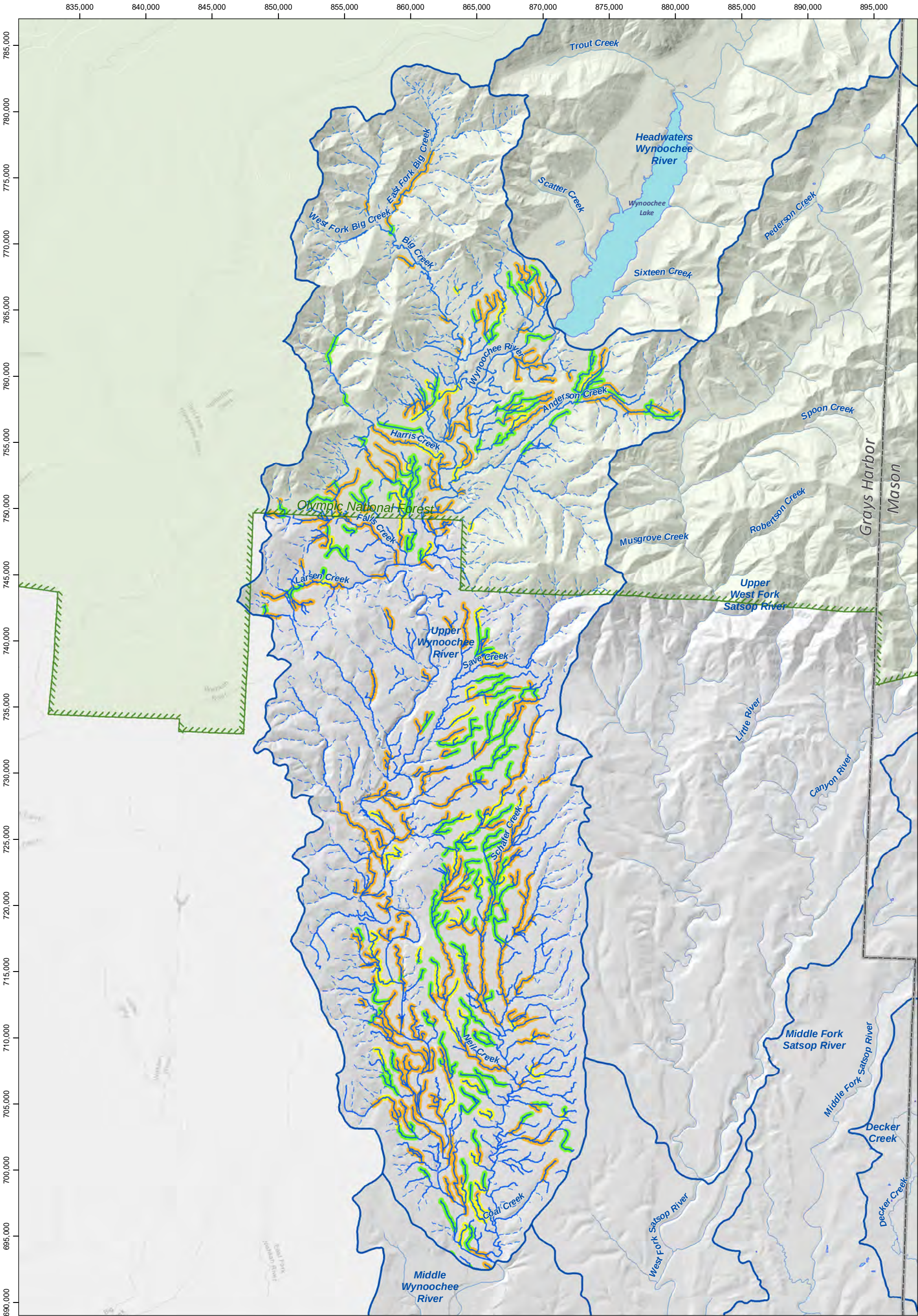
Geomorphic Modification

- Strategic Excavation
- Humanscape Modification or Strategic Excavation
- Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 9 of 12
Upper Wynoochee River

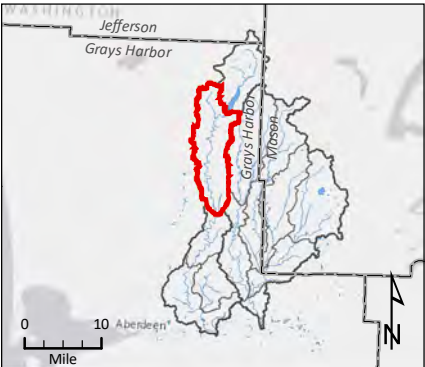
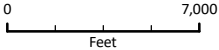
- Streams

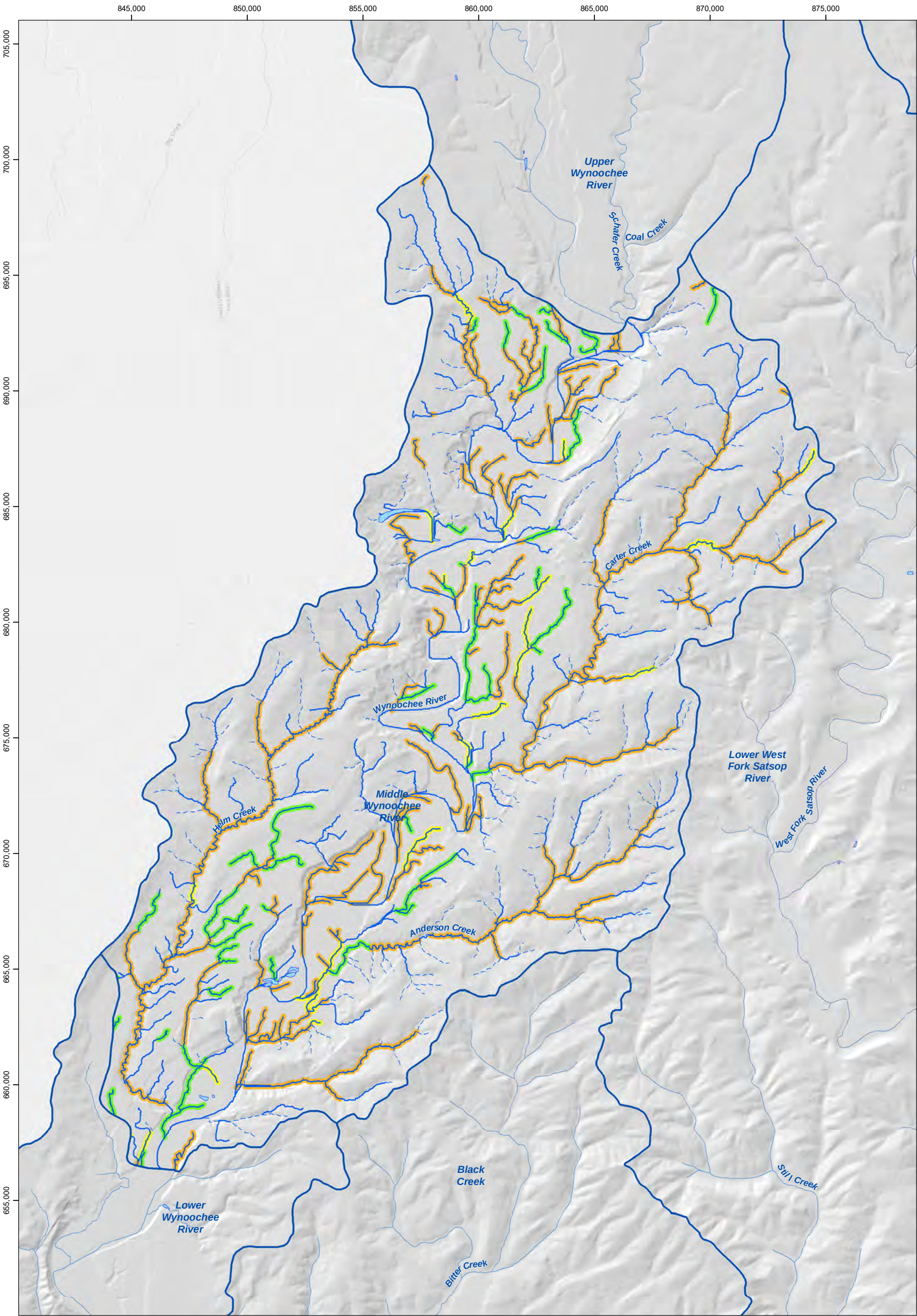
 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
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 - Strategic Excavation
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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 10 of 12
Middle Wynoochee River



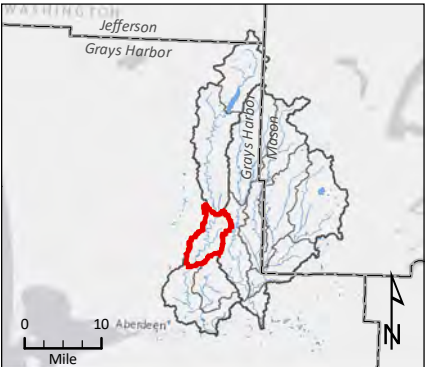
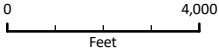
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NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW

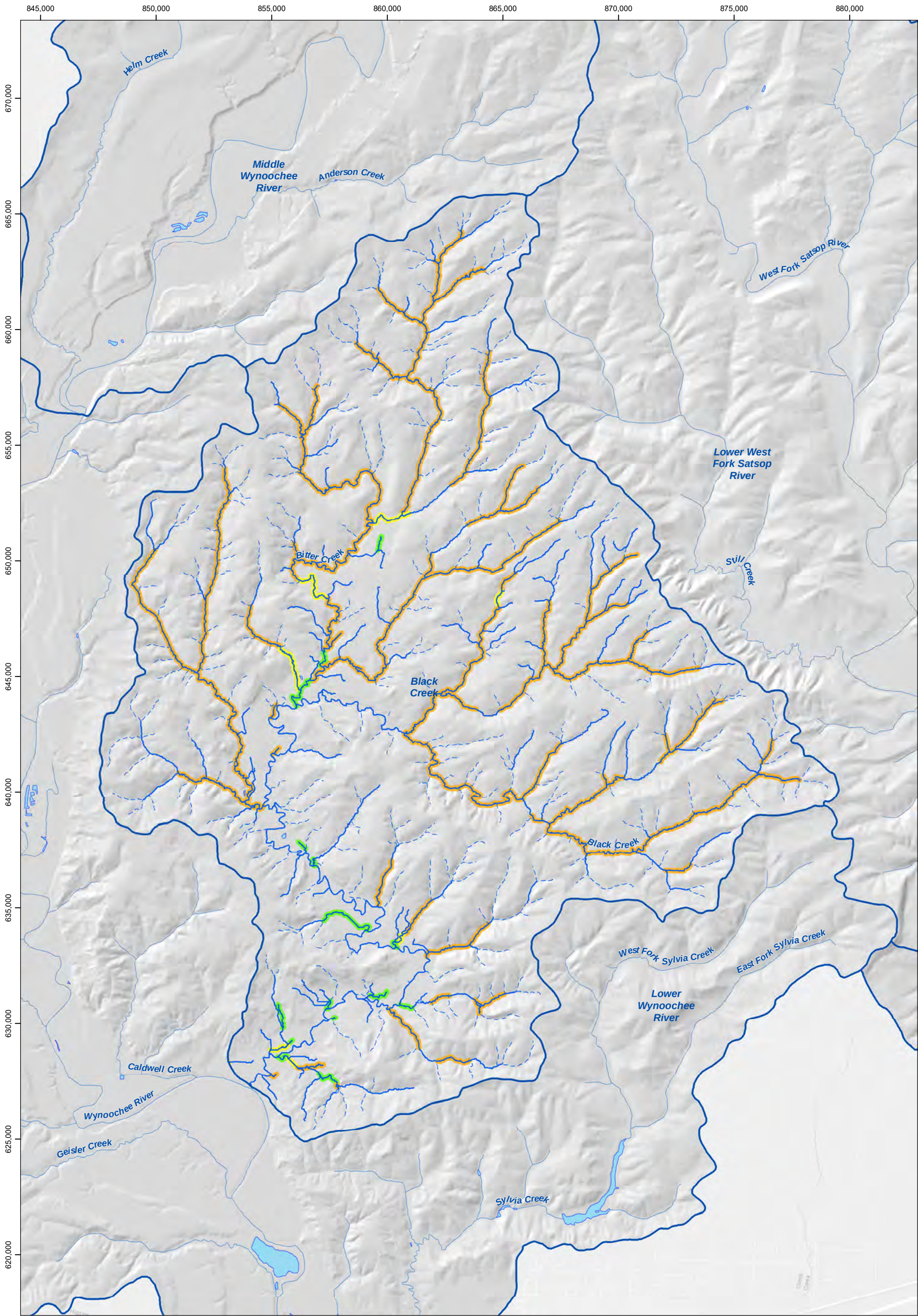
Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

Geomorphic Modification

- Strategic Excavation
- Humanscape Modification or Strategic Excavation
- Valley Reset, Humanscape Modification, or Strategic Excavation





Author: Stratten Date: 1/27/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_GeomorphicRestat.mxd

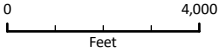
Satsop and Wynoochee Tributary Restoration Strategy

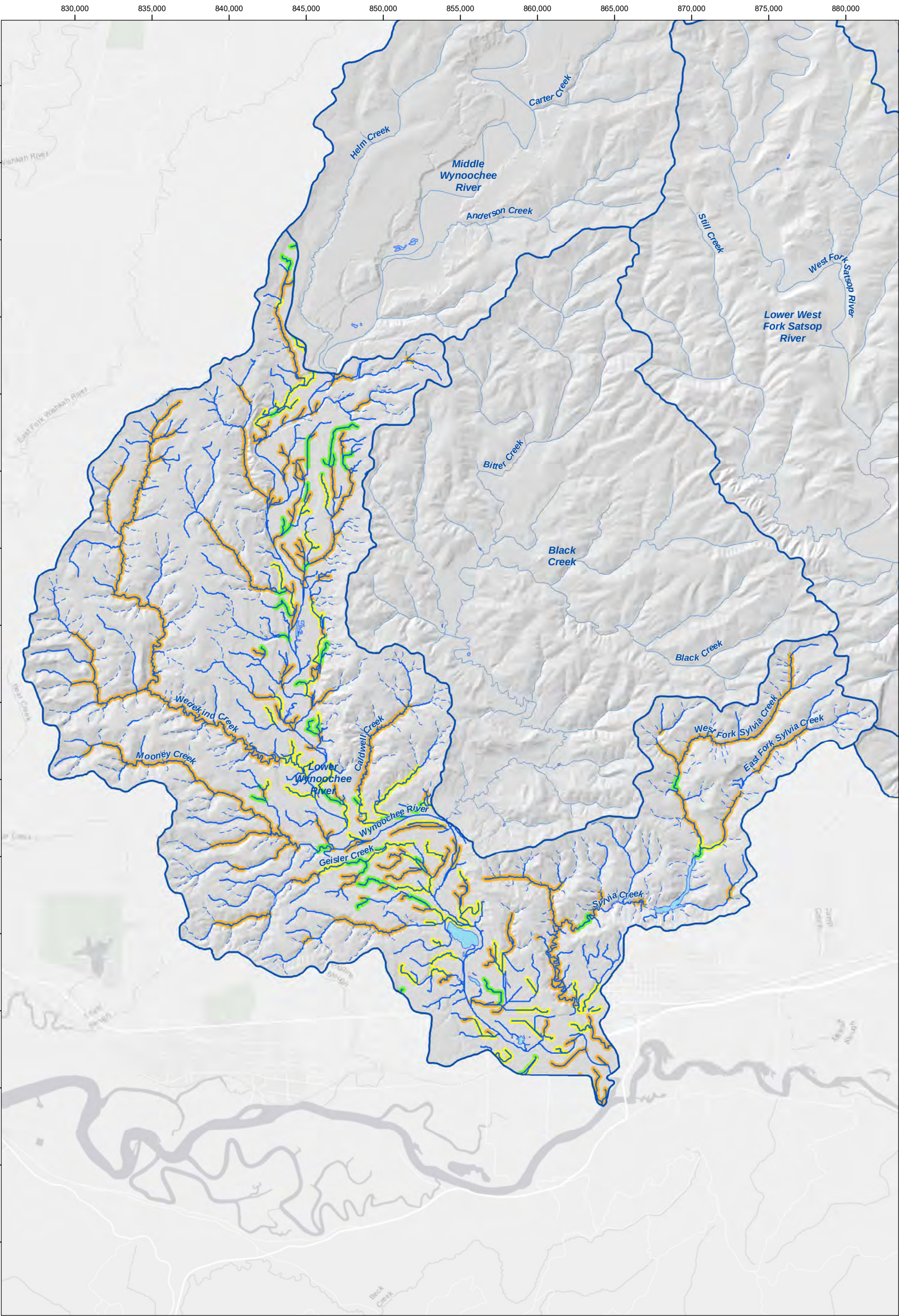
Geomorphic Modification Restoration Approaches
Map 11 of 12
Black Creek

- Streams

 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation





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Satsop and Wynoochee Tributary Restoration Strategy

Geomorphic Modification Restoration Approaches
Map 12 of 12
Lower Wynoochee River

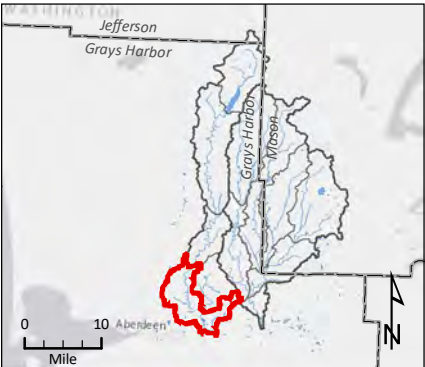
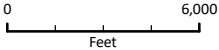
- Streams

 - Stream Reaches (<8% slope)
 - Stream Reaches (>8% slope)
- Geomorphic Modification

 - Strategic Excavation
 - Humanscape Modification or Strategic Excavation
 - Valley Reset, Humanscape Modification, or Strategic Excavation



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW



APPENDIX E. PILOT PROJECT BASIS OF DESIGN MEMORANDUM

To: Anthony Waldrop, GHCD

From: Susan Dickerson-Lange, PhD, PG; Evan D’Oro, PE; Eleanor Bartolomeo, PE; and Torrey Luiting, PWS;
Natural Systems Design

Date: 6/17/2021

Re: Schafer Creek Alluvial Water Storage Project: Basis of Design

Introduction

The design team at Natural Systems Design (NSD) has worked collaboratively with Grays Harbor Conservation District (GHCD) to develop a restoration design for the Schafer Creek Alluvial Water Storage Project. The Schafer Creek project area (hereafter, “Project Area”) extends from approximately River Mile (RM) 6.0 to 6.3 (with RM 0 located at the confluence of Schafer Creek with the Wynoochee River). The purpose of this memorandum is to summarize the rationale for the identification of Schafer Creek as a pilot project location and the basis of design for the design drawing plan set (“Plan Set”) for the project. This basis of design memorandum and Plan Set are intended to support permitting and implementation of the pilot project, as well as to provide an example application of the Satsop and Wynoochee River Tributary Restoration Plan (“Restoration Plan”). The goal of the Restoration Plan and of this project is to restore natural water and sediment storage functions that have been diminished via channel incision and simplification, along with analysis to support identification of restoration approaches as a reach scale, such as estimated bankfull water depth and the proximity of infrastructure.

The primary objective of this project is to **increase the overall in-situ water storage within the Project Area**. The project is a component of a broader effort to restore tributaries in the Satsop and Wynoochee River watersheds in order to increase water and sediment storage, with potential benefits to water quantity and quality. The Project Area was identified as having relatively high potential for restorable water storage via implementation of a new GIS-based spatial modeling tool, the development of which was directed and funded by GHCD.

The motivation for and scientific basis of the alluvial water storage restoration approach is described in detail in the tributary restoration plan document (NSD 2020 (DRAFT)). The scientific basis for restoring water storage functions is also well documented in the peer-reviewed scientific literature for degraded meadow environments, but research on restoring water storage within alluvial aquifer systems is limited. Thus, this project serves not only to directly benefit watershed function through increased water storage, but also provides an opportunity to monitor the effects of in-stream restoration on water storage so that the approach may be refined and more widely and more effectively implemented.

Project Area and Setting

Schafer Creek is a left bank tributary to the Wynoochee River near RM 29 and drains roughly 13 square miles from a basin-high elevation of 2,000-ft (above sea level) to its confluence with the Wynoochee River at an elevation of approximately 210 ft (USGS StreamStats 2019). The basin is primarily forested and steeply sloped and receives approximately 121 inches of precipitation per year. The project area is in the upper watershed with a drainage area of approximately 0.7 square miles. The basin’s lithology is

composed primarily of Pleistocene glacial sediments. Alluvial sands, gravels and silts are present in the channel through the Project Area, but consolidated glacial sediments (i.e., local bedrock) is present in some locations.

Nearly the entire basin has been influenced by logging and associated road building. Logging operations clearing large tracts of nearby hillsides as recently as 2013 were observed using Google Earth imagery. Active logging roads are evident paralleling the creek at the top of the slope throughout the Project Area, but steep, ravine topography has prevented roads from crossing the creek. Since the 1993 timber harvest practices are regulated by the Washington Forest Practices Act, and a densely vegetated, mature riparian corridor surrounds the project area.

The project reach flows entirely within Green Diamond property and is surrounded by other parcels actively managed for timber harvest. The nearest logging road crossing is approximately 800 feet downstream at RM 5.8, a 5.0-foot diameter culvert which is listed as 100% Passable by WDFW (WDFW 2004). There are multiple head cuts in the project reach, the largest, just upstream of the culvert has a drop of approximately 4.5 feet and is temporarily stabilized by natural buried large wood. Smaller head cuts were observed at RM 5.9 and in the project area at RM 6.2.

USGS operated gauge 12036400 on lower Schafer Creek from 1986 until 1996 (USGS 2021). This gauge covers a much larger drainage than the project site, including the Neil Creek tributary.

Using the Restoration Plan to Screen Pilot Project Sites

Geospatial Analysis

The geospatial information developed as part of the Restoration Plan (NSD, 2020) was used as primary screening criteria for identifying potential pilot project sites. The design team leveraged the spatially explicit results from the restoration plan analysis, which are mapped to a polyline feature class within GIS, to conduct the following data query:

- ▶ County: Grays Harbor
- ▶ Landowner: Green Diamond Resource Co.
- ▶ Fish bearing: Yes
- ▶ Modeled alluvial water storage potential: > 2 ac-ft/mi
- ▶ Appropriate for hand-built structures: Yes
- ▶ Stream order: < 5
- ▶ Slope: < 5%

The data query components were developed in consultation with GHCD with the overarching goal to identify a subset of reaches to assess as possibly pilot project locations. The project needed to be in Grays Harbor County due to the project sponsor, GHCD. Green Diamond was the preferred landowner since part of the pilot project is to promote ecological restoration and build collaborative relationships on lands managed for timber harvest, and there is a concurrent pilot project with Weyerhaeuser Co. in the Satsop River watershed (on Still Creek). A fish bearing stream was selected because many of the future projects coming out of the Restoration Strategy will be on fish bearing streams, and we wanted the pilot project to identify and address any potential aquatic species issues. An alluvial water storage capacity greater than 2 acre-feet/mi. placed the pilot reach the top 10% of assessed streams for acre feet/mi. Hand-built structures were a condition of the project funding. Limiting the stream order and slope helped to screen

out very small or very steep reaches, which would not be appropriate for this type of treatment, as well as larger reaches, which would prevent construction of the wood structures by hand.

The data query yielded a subset of reaches to assess visually by looking at the resulting reach locations in comparison to other datasets and further winnow into top sites to visit for field assessment. Secondary screening criteria included ease of site access, water quality, and local geomorphic setting, particularly the degree of incision. As a pilot project, we wanted the pilot project to be in an easily accessible site to facilitate construction and make it easy to monitor the project, as well as bringing funders, partners, and other practitioners to visit the site. We also preferred a site with water quality impairments, such as sediment, water quantity or dissolved oxygen issues since the Department of Ecology is interested in addressing water quality impairments and it would be informative to monitor the effect of the project on these conditions. Lastly, we used high resolution topographic data and aerial photographs to examine reach-scale characteristics such as valley width and length, topographic cross sections, riparian vegetation, and proximity to infrastructure. Observations from this step were discussed to focus the list of possible project locations to those with the highest potential to meet the project goals.

The design team along with representatives from GHCD, Mason CD, and Green Diamond visited several locations during initial field reconnaissance in November 2020. Schafer Creek was selected over 5 other locations due to its wide valley morphology, proximity to access roads, absence of invasive species (which would have added considerable cost to the project implementation), channel morphology, lack of large instream wood, and field observations that even relatively small instream wood was effective at holding grade, implying significant potential for this approach.

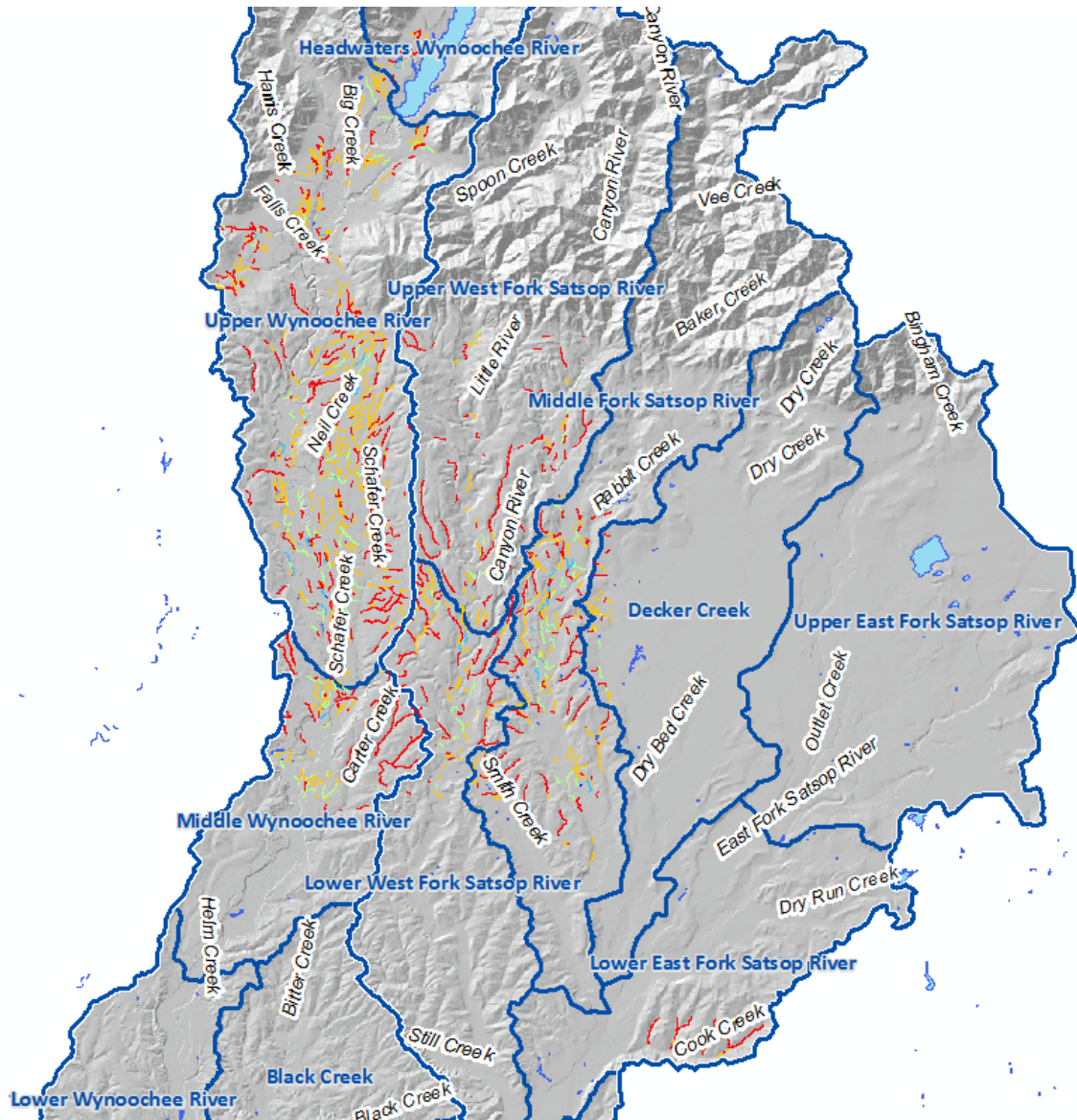


Figure 1. Results of the site identification query with stream segments mapped only where they meet all of the query criteria. Colors represent relative alluvial water storage potential with highest relative potential blues and greens and lowest in orange and reds.

Field Reconnaissance

After Schaffer Creek was identified as the top candidate, field reconnaissance was conducted on November 11, 2020, to confirm suitability and on January 11, 2021, and March 16, 2021, to assess current channel, riparian, and floodplain conditions and begin design. We used these field observations to identify locations for structure installation as well as to identify feasible construction methods and access routes.

Relevant field observations include:

- ▶ Much of the project area is incised as evidenced by the channel geometry, which included multiple head cuts and high, steep channel banks, indicating that large quantities of alluvium (sand, gravel, and cobble) have been flushed from the channel.
- ▶ Historical large wood is present in the channel. Observed wood appeared to be stable and holding grade in some locations and being actively undercut in others (Figure 2 & 3).
- ▶ There is a hydraulic drop at station 19+00 (approximately RM 6.2).
- ▶ The channel is approximately 5 to 10 ft wide by 2 to 5 feet deep with smaller side channels in broader areas of the valley.
- ▶ An inset floodplain is present in some locations, with higher terraces in the floodplain, which might be relict floodplains, abandoned by incision.
- ▶ Riparian vegetation is moderately dense, and consists of coniferous and deciduous trees, and shrubs (Figure 4). Invasive species were conspicuously absent from the project area.
- ▶ Channel sediments consist dominantly of sand and gravels with clay deposits visible in several locations (Figure 5).
- ▶ Floodplain sediments consist primarily of sand and silty sand with some gravel. Monitoring well installation by direct push methods during March 2021 suggest the presence of a gravel or cobble layer around 7-8 feet below ground surface.

Based on field observations, the reach from station 1700 to 2750 was selected for treatment. (Station 0 is at the confluence with the next small tributary.)

Monitoring

A control sub-reach was identified to leave untreated upstream of the treatment reach for monitoring purposes. Monitoring will focus on characterizing the geomorphic and hydrologic effects of the project implementation, particularly with regard to increasing storage of sediment and groundwater. The approach is described in NSD's Monitoring Memo (NSD 2021).

Expected Water Storage Benefits

Within the treatment reach, the related baseflow contribution from the drainage of the groundwater reservoir is estimated to be 0.04 cubic feet per second (cfs) for approximately 60 days following the onset of baseflow as a result of 0.25 mile of treatment actions. These values do not account for the potential increased water usage by riparian vegetation. Although the volume and flux of water storage will vary from year to year depending on the timing and magnitude of spring flows as well as variations in riparian forest water use, this additional storage capacity is expected to provide a continuing hydrologic benefit. Conceptually, the aggraded stream channel will lower groundwater drainage rates and effectively re-saturate a wedge of the groundwater aquifer. The newly stored volume of water may not discharge locally due to the reduced lateral gradient (e.g., Nash *et al.*, (2018)). Nonetheless, this restored volume is expected to flow down-valley and ultimately discharge, setting up an annual cycle of filling and discharging the stored water.



Figure 2. Example of historical wood holding grade in the channel; Photograph taken facing upstream near RM 6.3 in January 2021.



Figure 3. Example undercut historical wood. Photograph taken facing upstream near RM 6.2 in January 2021.



Figure 4. Typical floodplain vegetation. Photograph taken in November 2020.



Figure 5. Example of clay beds in channel substrate. Photograph taken in November 2020.

Design Approach

The design approach aims to increase hydraulic roughness within the stream channel by increasing the amount and effect of stable instream wood in order to capture and retain incoming alluvium and re-aggrade the incised stream channel. Stable large wood will be reintroduced to the channel in the form of channel-spanning engineered logjam structures (hereafter, “structures”). The structures are designed to mimic minimally porous natural wood obstructions. These wood structures will reduce the average open-channel and subsurface hydraulic gradient, dissipate basal shear stress, and reduce flow velocities within the treated reaches, which will in turn trigger sediment deposition and bed aggradation. Re-aggradation of the channel bed will raise in-channel and subsurface water elevations and improve lateral hydrologic connectivity as well as maintain elevated water levels for a longer duration than under incised conditions. A reduction in the subsurface hydraulic gradients will increase the volume of subsurface water storage and decrease lateral groundwater drainage rates. Together, these processes are expected to increase riparian water availability, improve water quality (temperature and excessive sediment loading), and increase the amount of groundwater storage available to supplement instream baseflow (Loheide and Gorelick, 2006; Tague *et al.*, 2008; Hunt *et al.*, 2018).

Stream Characteristics

Schafer Creek is relatively steep through the project area (approximately 3.5% slope) and largely confined to a single, sinuous channel, with minimal instream hydraulic resistance (wood), but with a relatively rough, shrubby overbank. Valley width ranges from 200 to 500 feet, but floodplain inundation during flows up to the 100-year recurrence interval flood (i.e., 1% chance of occurring in any given year) is contained within an inset corridor 20 to 60 feet wide. The elevation of the channel bed relative to the floodplain ranges from less than 1 foot to more than 4 feet. Both the narrow, inset floodplain and the depth of the channel bed in some reaches presents additional evidence of incision.

Figure 6 shows the Schafer Creek profile through the project area. The primary treatment reach is between stations 1700 and 2750. Note the small grade break at station 1900.

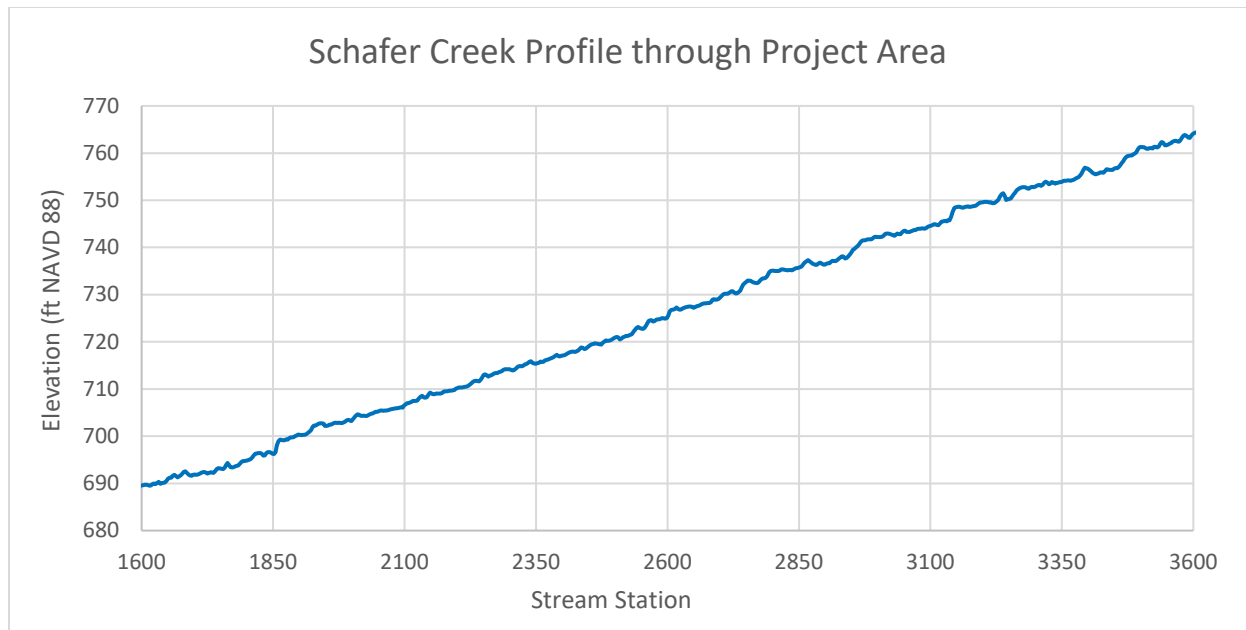


Figure 6. Longitudinal profile of the Project Area, based on the lidar DEM. The treatment reach is station 1700 to 2750.

Structure Type and Siting

Based on field and desk assessment and project budget, approximately 1,050 feet of stream were identified for treatment, as shown on Sheet 3 of the Plan Set (Appendix B). Structures were designed to take advantage of locally available woody materials and use primarily locally available large wood, such as logs that cross but are perched above the stream, and pre-commercial thinning wood sourced in collaboration with Green Diamond. The design includes three repeatable structure types each suitable for a different geomorphic and riparian setting, as shown on Sheets 4 – 6 of the Plan Set (Appendix B).

- ▶ Type A structures are based primarily around multiple large logs stacked in and across the stream channel with the voids filled with racking a slash. These structures can accommodate grade breaks or significant changes in channel width and slope and rely primarily on standing riparian trees for entanglement and stability, although hand-driven posts can also be used.
- ▶ Type B structures are primarily post supported consist of interwoven bundles of racking and slash. They are best for areas of uniform channel slope but are flexible in planform can easily be extended laterally or lengthwise to cover a broader valley or accommodate a sharp bend. They are a good choice for when large wood is not locally available or there are no suitable riparian trees for entanglement.
- ▶ Type C structures are much smaller and consist of one or two channel spanning logs surrounded by racking. They are primarily post supported. These are ideal for when only a small amount of wood is available nearby or for filling gaps between smaller structures when ideal structure sites are slightly farther apart than in optimal for water storage.

The primary design considerations for the layout and structural performance include:

Minimize longitudinal structure spacing

Structures were spaced along the channel to maintain continuous longitudinal influence on surface-flow hydraulic gradient. Structure types A and B are spaced with a maximum of 75-feet longitudinally between the upstream end of the structure and the upstream end of the next structure (of any type) so that the backwater created by the upstream structure will impose a tailwater on the downstream structure. Type C structures are spaced with a maximum of 25-feet longitudinally between the upstream end of the structure and the upstream end of the next structure (of any type). This tailwater will not only reduce the overall hydraulic gradient through the treatment reach but will reduce drop scour imposed on the downstream end of the impoundment induced by each structure.

Minimize structure porosity

The structures are intended to block as much of the main channel's conveyance area as possible in order to trigger sediment deposition and lateral flow dispersion as a result of a drastic reduction in basal shear stress and flow velocity during high flow events. The Project Area is mapped as potential coho habitat (WDFW SalmonScape 2021), so the structures are designed to be as similar as possible to natural wood accumulations. The design was vetted with the WDFW Area Habitat Biologist to identify and address fish passage concerns. The main elements incorporated into the design to minimize porosity are:

- ▶ Large quantities of slash, racking and woody debris (2" - 8" diameter pieces of various lengths and species) (All structure types);
- ▶ Logs oriented normal to flow where possible (structure types A and C); and
- ▶ Additional wood at varying orientations, where available, to increase instream complexity (all structure types).

Maximize structure stability and longevity based on risk-level and proposed construction methods

Given the "low" risk to infrastructure and private property at this site, structures were designed to be stable at the 25-year recurrence interval flow event (Table 1) with a target factor of safety of 1.0 for vertical and lateral load resistance. The primary structural failure mechanisms and structural components include:

- ▶ Scour – As a result of an increased hydraulic gradient across the channel obstruction, drop scour can undermine the channel bed and entrain wood in flow as well as displace batter piles.
 - Using drop scour equations developed by Veronese (1937) and D'Agostino and Ferro (2004), we predict a maximum scour depth (not residual) of 2-ft beneath the downstream channel bed elevation.
 - Hand installed structures are designed to depth of 2 to 3-feet beneath channel bed, and it is assumed that only 50% of the predicted scour will act on the piling because of the incorporation of a "scour mattress" consisting of debris bundles that surround and encompass the foundation of the structure.
- ▶ End-running – As flow encounters the structures, a degree of lateral erosion and local scour will occur as a result of channel blockage and flow acceleration zones. End-running can cause the channel to erode a new channel around a mid-channel structure, but the risk is minimized here by:

- Dense longitudinal structure spacing, which will reduce the overall hydraulic gradient as well as capture/retain any sediment released as a result of erosion around upstream structures.
- Extend the structures longitudinally onto the floodplain to increase roughness and dissipate energy of over bank flows.
- ▶ Buoyancy, translation, and wood-breakage – The mid-channel structures were designed to resist hydraulic drag, hydrostatic loads, and buoyancy. Debris impact was neglected in this design because of the lack of large trees and the small size of the stream corridor, which limits wood transport. The primary structural elements include:
 - Hand-driven timber batter-posts – The number of posts specified varies per structure type, 4" diameter posts to be driven to a minimum of 2 feet beneath the channel bed and 3+ feet in the floodplain (the maximum feasible by hand construction techniques).

Hydraulic Analysis

A basic Mannings n and normal depth based hydraulic analysis was conducted for a typical cross section to characterize general hydraulic conditions within the channel to inform structure design. Peak flow events used in hydraulic analysis were estimated using regional regression equations queried through the USGS Streamstats application. Peak discharge estimates are summarized below in Table 1. Due to a lack of local streamflow monitoring, peak flow measurements and observations, the analysis was not calibrated, but used to estimate general hydraulic conditions such as depth, velocity, and inundation extents for the estimated flows.

Table 1. Peak Flow Estimates (USGS StreamStats 2020)

Peak flow recurrence interval	Discharge (cfs)	Max Flow Depth (ft)	Typical Flow Velocity (ft/s)	Typical top width (ft)
2-year	116	2.4	5.2	30
10-year	171	2.6	5.8	35
25-year	194	2.7	6.1	35
100-year	235	2.8	6.5	35

Construction Methods & Access

Construction will be accomplished primarily by hand using ground-crews. Previously cleared staging areas at the top of the hill are available for staging imported or on-site generated material and are shown in the Plan Set (Appendix B). Areas disturbed during access and staging should be stabilized with a native seed-mix or plantings as specified by GHCD.

Access routes to the channel were identified in the field to minimize clearing of riparian vegetation and disturbance of steep slopes. Small machinery may be used to transport material from the upslope staging area to the edge of the floodplain, where existing cleared access routes allow. All transportation within the stream corridor will be by foot or pack animal traffic only. Access areas will be flagged prior to construction and approved by the engineer or GHCD. All fire restrictions and standard safety protocol will be adhered to and practiced during construction.

Risk Considerations

The nearest public infrastructure to the project site is the Wynoochee Valley Road bridge crossing near RM 5.7 (Figure 7). The bridge was installed in 2018 as a fish passage improvement project (WDFW 2018). It fully spans the creek (no in-channel piers) with apparent sufficient clearance and overbank capacity to pass the type of small wood proposed for this project. Consequently, the project is not considered a risk to the bridge structure.

Wood could potentially rack against the Green Diamond logging road and culvert 800 feet downstream of the project reach in the event of a structure failure during a large flow event. However, flow depths and velocities in the project reach are low enough that the larger wood is unlikely to be transported that far before bottoming out in the channel or being entangled in dense riparian shrubs, and the 5-foot culvert diameter is large enough to pass much of the smaller racking and slash material used in the project.



Figure 7. Wynoochee Valley Road Bridge (image credit WDFW 2018).

List of Appendices

Appendix A: Relative Elevation Map of Project Area displaying alluvial water storage potential

Appendix B: Design Plan Set

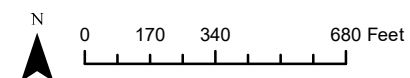
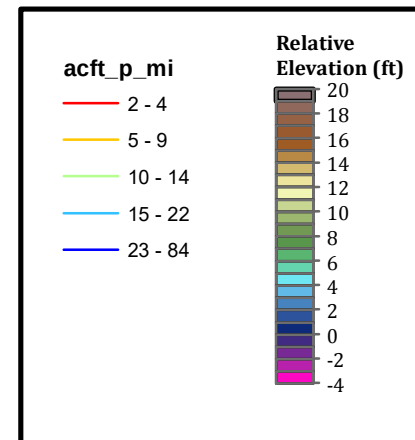
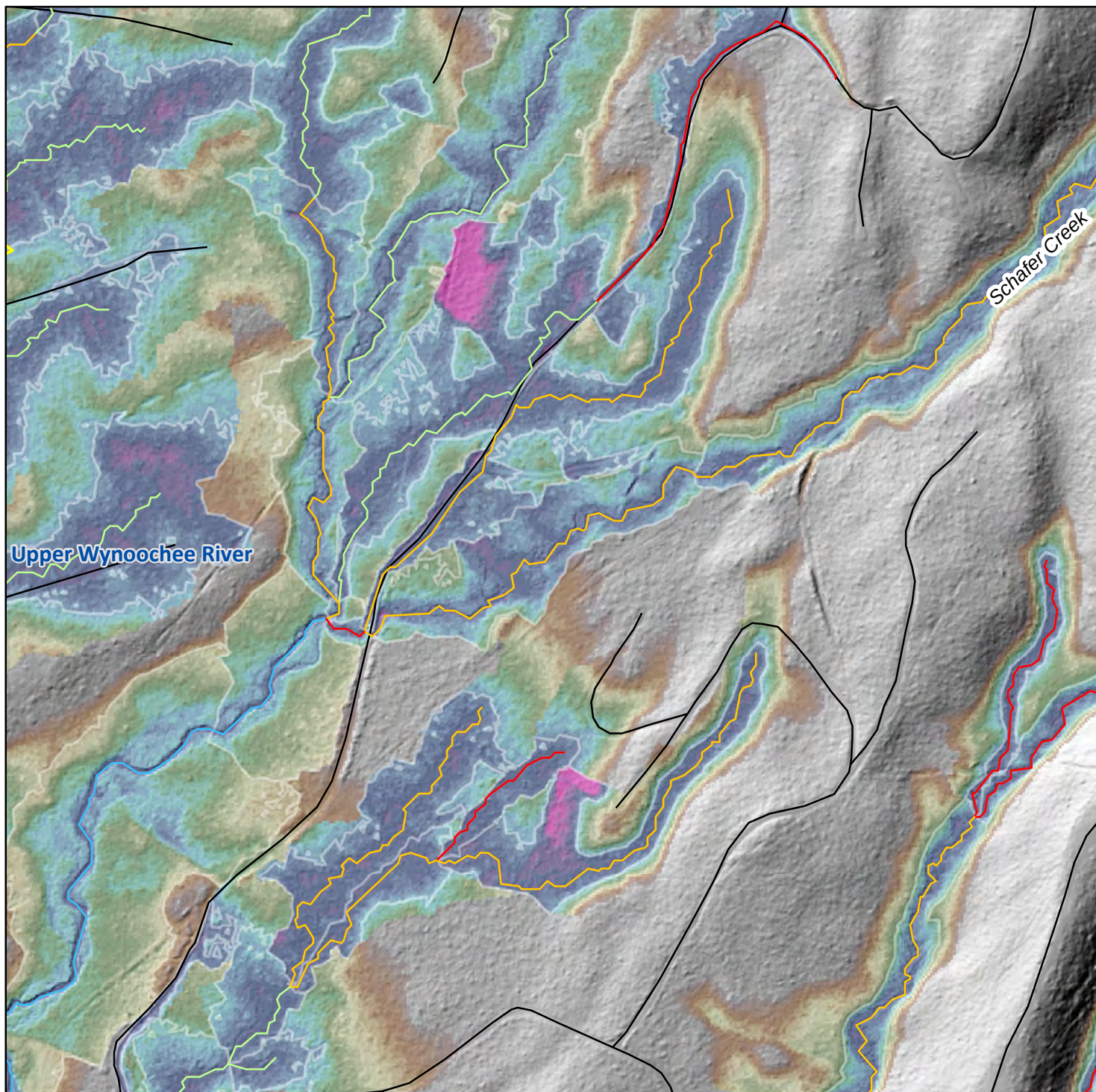
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APPENDIX A

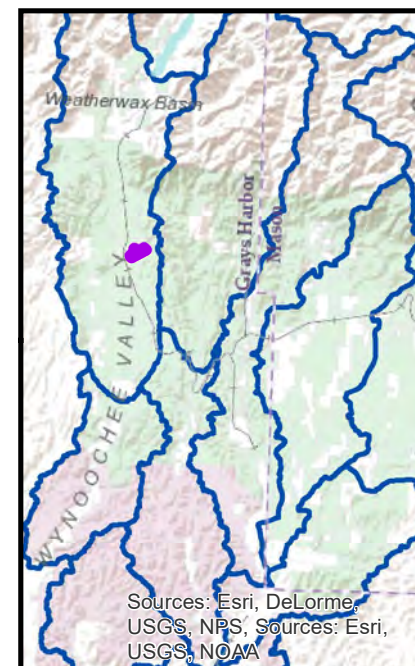
RELATIVE ELEVATION MAP

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GHCD AWS
Pilot Project

Headwaters Schafer
Creek



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APPENDIX B

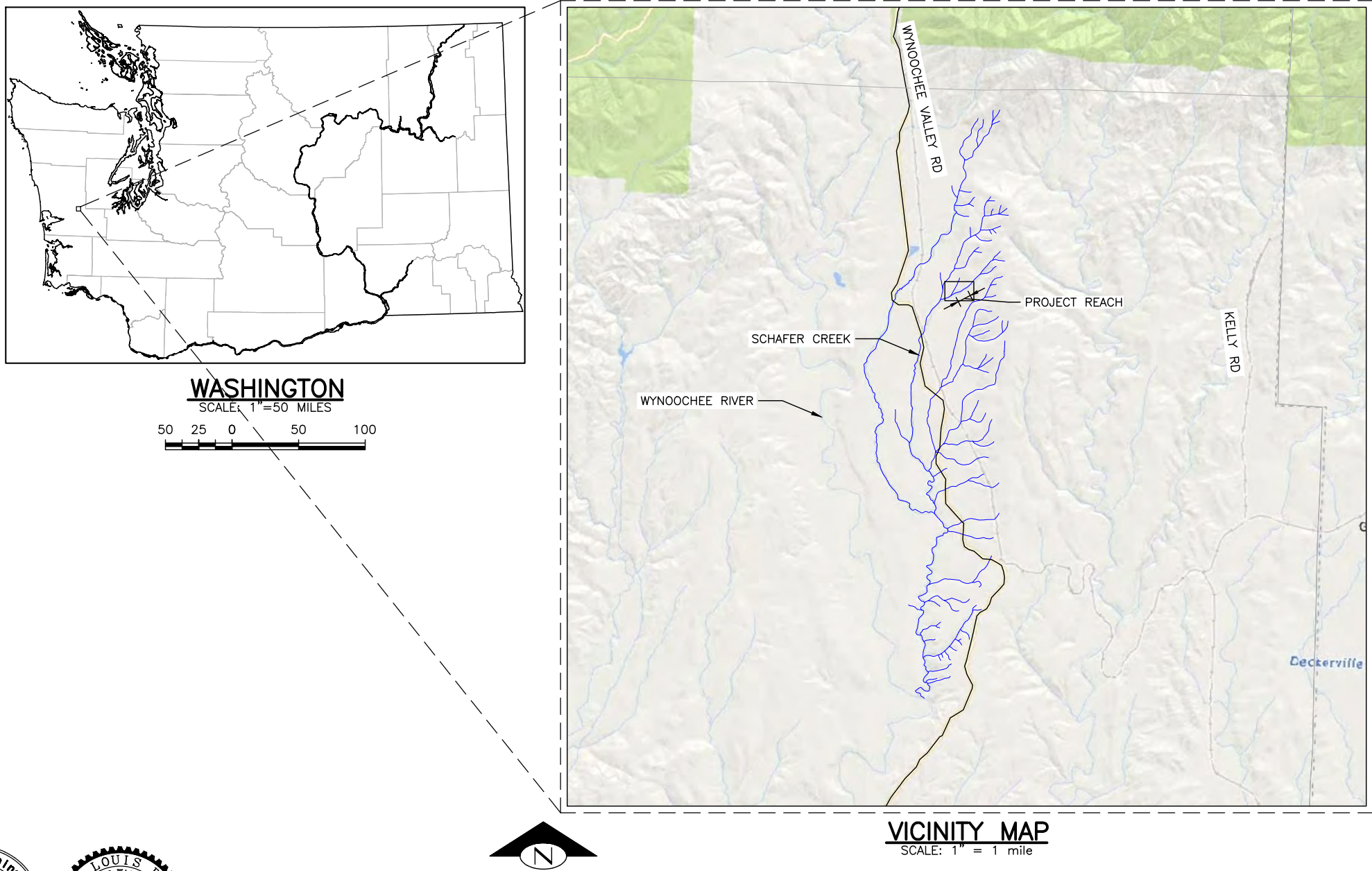
DRAFT DESIGN DRAWING PLAN SET

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SCHAFER CREEK

ALLUVIAL WATER STORAGE PILOT PROJECT

GRAYS HARBOR CONSERVATION DISTRICT

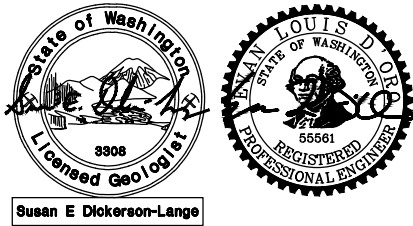


SHEET LIST TABLE	
Sheet Number	Sheet Title
1	COVER SHEET
2	QUANTITIES AND NOTES
3	OVERVIEW AND ACCESS
4	TYPE A STRUCTURE DETAILS
5	TYPE B STRUCTURE DETAILS
6	TYPE C AND GENERAL STRUCTURE DETAILS

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330 PIONEER AVE W
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(360) 249-8532



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IF THIS BAR DOES NOT
MEASURE 1" THEN
DRAWING IS NOT PLOTTED
TO ORIGINAL SCALE.



NAME OR INITIALS AND DATE		GEOGRAPHIC INFORMATION	
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CHECKED	ELD, SDL	DATE	JUNE 2021

SCHAFER CREEK AWS PILOT
PROJECT

COVER SHEET

1
SHEET 1 OF 6

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Jun 16, 2021 DRAFT FINAL

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MATERIAL QUANTITIES					
LOG TYPE	DESCRIPTION	QUANTITY PER STRUCTURE TYPE (STRUCTURE COUNT)			TOTAL
		A (3)	B (14)	C (7)	
P	POST, 6' L x 4" DIA	15-40	280	20-55	315-375
A	LOG, 5-7' L x 10-12" DBH	3		7-21	10-24
B	LOG, 8-10' L x 10-12" DBH	6			6
C	LOG, 18-22' L x 10-12" DBH	18			18
RB	RACKING BUNDLE	20-30	335-465	15-35	370-530
R/S	LOOSE RACKING AND SLASH	55 CY	170 CY	15 CY	240 CY

GENERAL NOTES

1. CONSTRUCTION SHALL FOLLOW ALL PERMIT TERMS AND CONDITIONS. ANTICIPATED PERMITS INCLUDE: WDFW HPA AND SHPO CULTURAL RESOURCES CONSULTATION.
2. TEMPORARY EROSION AND SEDIMENT CONTROL BMPS SHALL BE EMPLOYED TO PREVENT TURBIDITY FROM ENTERING SCHAFER CREEK.
3. CONSTRUCTION WILL TAKE PLACE ON LAND OWNED BY GREEN DIAMOND CORPORATION.
4. PLAN CONTOURS ARE FROM LIDAR (2019) AND ARE SHOWN AT 5 FOOT INTERVALS. 2019 NAIP AERIAL IMAGERY.

LEGEND

- STREAM CENTERLINE
- OHWM
- ORDINARY HIGH WATER MARK
- EXISTING LOGGING ROAD
- ACCESS ROUTE
- TEMPORARY ACCESS ROUTE
- STAGING AREA
- TYPE A ELJ STRUCTURE
- TYPE B ELJ STRUCTURE
- TYPE C ELJ STRUCTURE



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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.



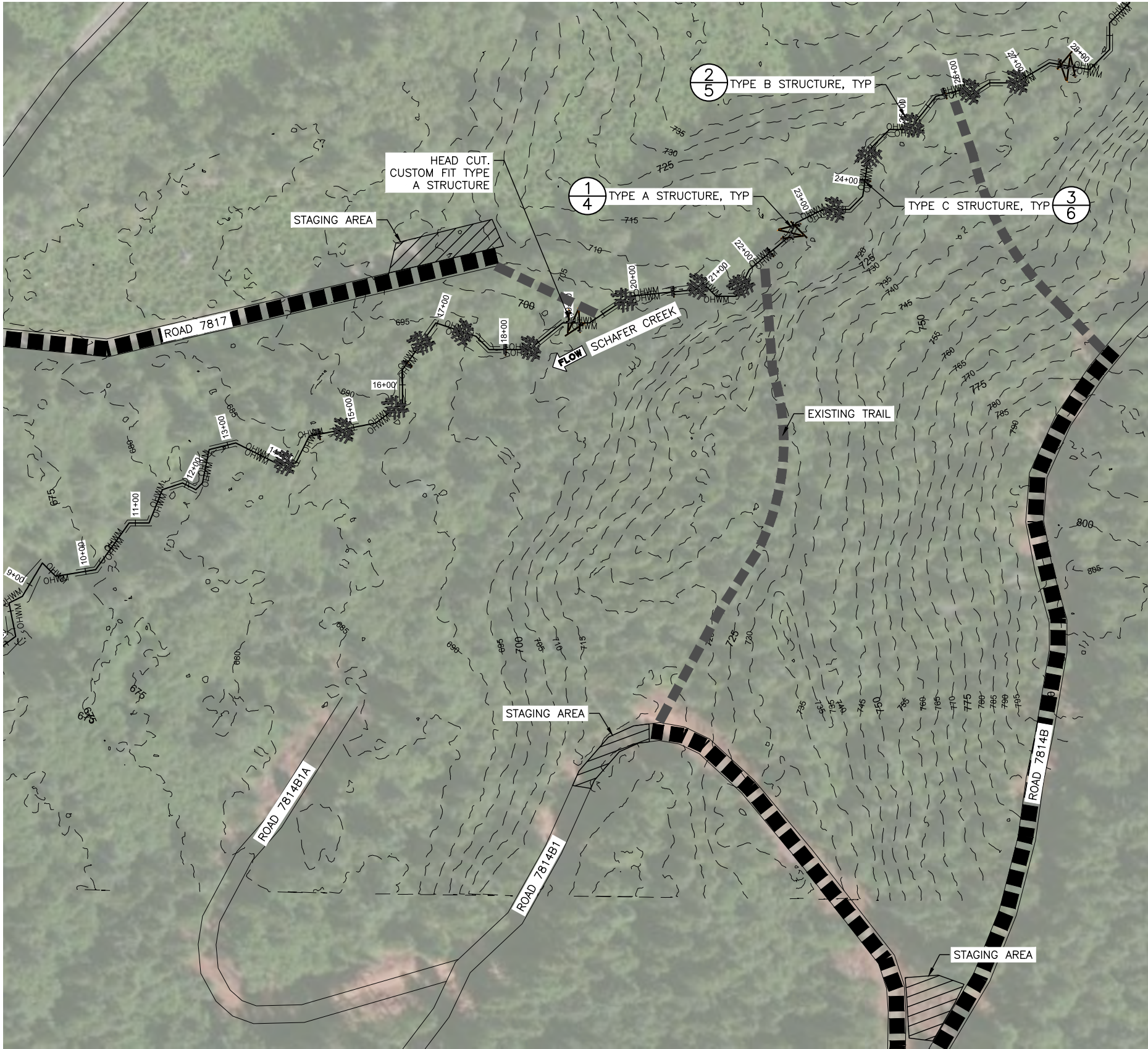
NAME OR INITIALS AND DATE
DESIGNED ELD
CHECKED ELD, SDL
DRAWN ESB
CHECKED ELD, SDL

GEOGRAPHIC INFORMATION
LATITUDE 47.291315
LONGITUDE 123.606753
TN/SC/RG T21N/20/7W
DATE JUNE 2021

SCHAFER CREEK AWS PILOT PROJECT

QUANTITIES AND NOTES
SHEET 2 OF 6

2
SHEET 2 OF 6



NOTES

- 1. TYPE A AND B STRUCTURES MAY BE USED INTERCHANGABLY DEPENDING ON MATERIAL AVAILABILITY AND ANCHORING POTENTIAL. TWO TYPE C STRUCTURES MAY BE SUBSTITUTED FOR ONE TYPE B STRUCTURE, WITH APPROVAL OF THE ENGINEER.
- 2. TYPE A AND B STRUCTURES SHALL BE SPACED WITH A MAXIMUM OF 75' FROM THE FRONT OF THE STRUCTURE TO THE FRONT OF THE NEXT STRUCTURE (OF ANY TYPE) UPSTREAM. TYPE C STRUCTURES SHALL BE SPACED WITH A MAXIMUM OF 25' FROM THE FRONT OF THE STRUCTURE TO THE FRONT OF THE NEXT STRUCTURE (OF ANY TYPE) UPSTREAM.
- 3. A HEAD CUT OR NATURAL PROFILE BREAK IS PRESENT AT APPROXIMATELY STA 19+00. THE TYPE A STRUCTURE IN THIS LOCATION SHALL BE CUSTOM FIELD FIT BY THE ENGINEER TO THE TOPOGRAPHY. MATERIALS WILL BE PLACED TO MINIMIZE THE POTENTIAL FOR FURTHER EROSION. STRUCTURE TYPE SUBSTITUTION IS NOT APPROPRIATE AT THIS LOCATION.
- 4. TEMPORARY ACCESS ROUTES SHALL BE FOR FOOT OR EQUESTRIAN TRAFFIC ONLY.

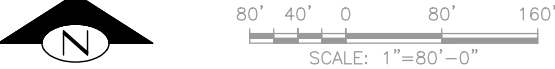
TREATMENT LOCATIONS

STA	STRUCTURE TYPE	NOTES
13+75	B	
14+50	C	
14+75	B	
15+50	B	
16+25	C	
16+50	B	
17+25	B	
18+00	C	
18+25	B	
19+00	A	CUSTOM FIELD FIT
19+75	B	
20+50	C	
20+75	B	
21+50	B	
22+25	C	
22+50	A	
23+25	B	
24+00	C	
24+25	B	
25+00	B	
25+75	C	
26+00	B	
26+75	B	
27+50	A	

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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

Grays Harbor Conservation District

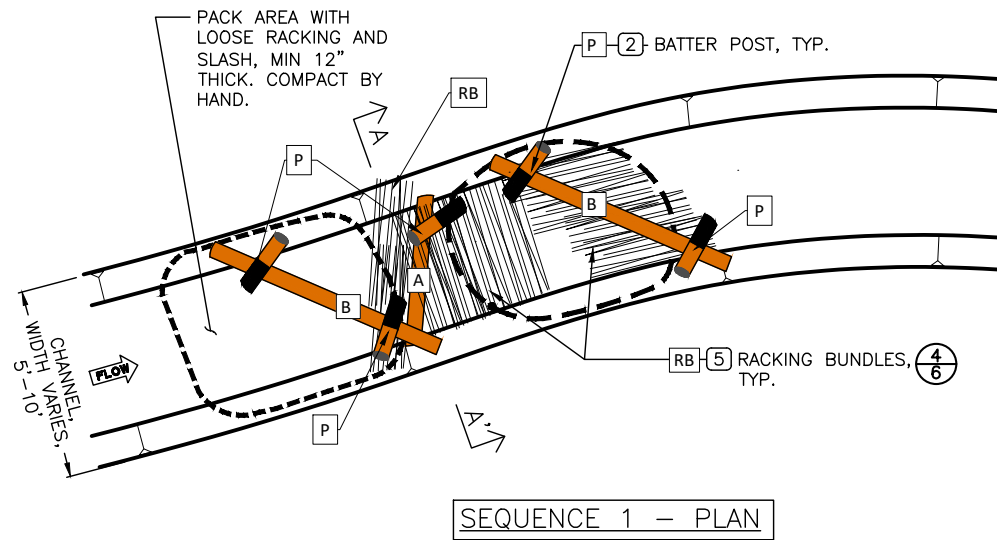


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CHECKED	ELD, SDL	LONGITUDE	123.606753
DRAWN	ESB	TN/SC/RG	T21N/20/W
CHECKED	ELD, SDL	DATE	JUNE 2021

SCHAFFER CREEK AWS PILOT PROJECT

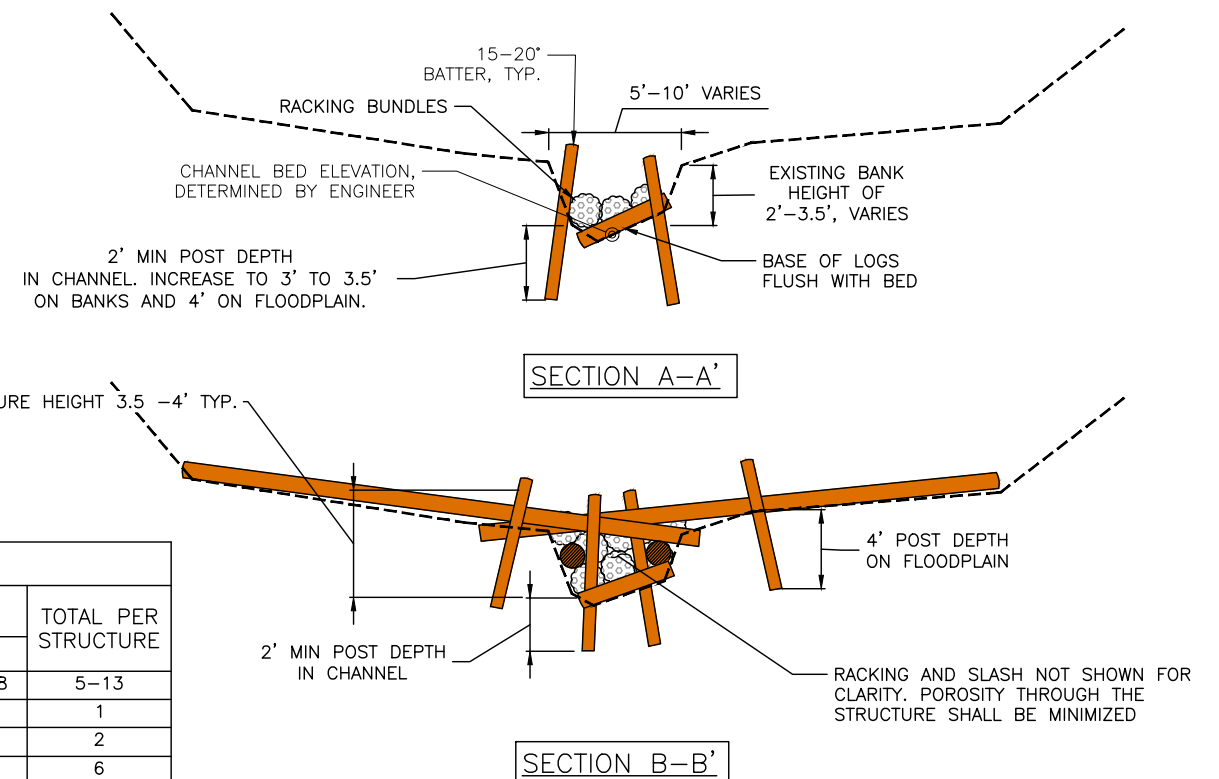
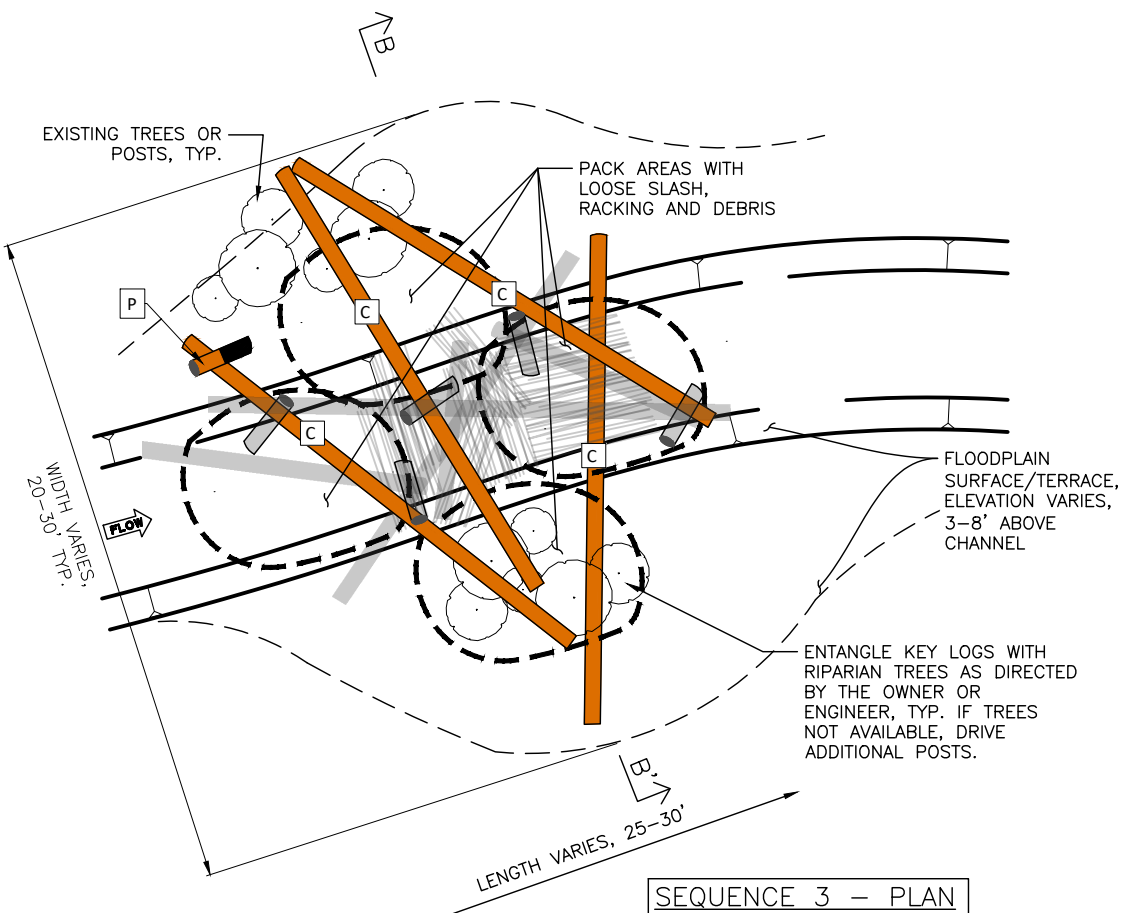
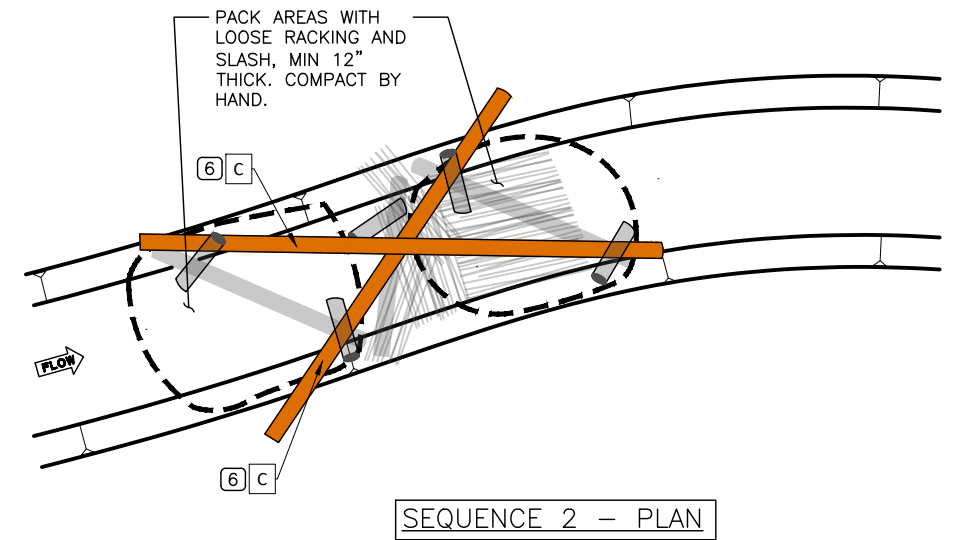
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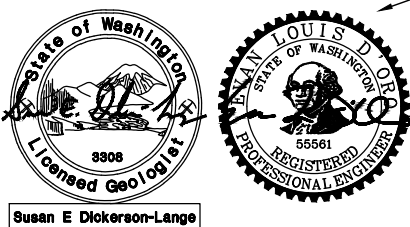
STRUCTURE TYPE A NOTES

1. ACTUAL LAYERING WILL VARY TO SUIT FIELD CONDITIONS. THE ENGINEER OR OWNER SHALL DIRECT THE LAYERING. SEQUENCE 1 AND 2 ARE CRITICAL.
2. POSTS SHALL BE DRIVEN IN PLACE (NO EXCAVATION). POSTS SHALL BATTER 15-20 DEG FROM VERTICAL AND "TRAP" SURROUNDING LOGS. ENTANGLEMENT WITH RIPARIAN TREES IS PREFERRED TO BATTER POST INSTALLATION. THE OWNER OR ENGINEER SHALL SPECIFY HOW TO ENTANGLE LOGS WITH RIPARIAN TREES. ADDITIONAL LOGS AND POSTS OR ENTANGLEMENT MAY BE DIRECTED BY THE ENGINEER OR OWNER FOR STRUCTURE STABILITY.
3. LOG LENGTHS WILL VARY AND BE CUT IN PLACE TO FIT STRUCTURE DIMENSIONS PER OWNER OR ENGINEER. CUT ENDS SHALL BE INCORPORATED INTO STRUCTURE OR USED AS DIRECTED BY OWNER OR ENGINEER.
4. CUT SEQUENCE 1 LOGS TO PLACE SNUG TO CHANNEL TOES AND PRESS FIRMLY INTO THE CHANNEL BED.
5. RACKING BUNDLES SHALL SURROUND POSTS TO PROTECT FROM SCOUR. VOIDS SHALL BE PACKED WITH LOOSE RACKING AND SLASH. SEQUENCE 1 RACKING BUNDLES MAY BE WRAPPED IN COIR FABRIC TO FURTHER REDUCE PERMEABILITY (OPTIONAL).
6. WHEN NEARBY WOOD IS RE-SITUATED WITHIN THE CHANNEL, EFFORT SHALL BE MADE TO RETAIN THE ROOTWAD IF PRESENT.
7. HARVEST OR SALVAGE OF ON-SITE WOODY DEBRIS WILL BE DIRECTED BY THE OWNER. ANY VEGETATION CLEARED DURING ACCESS SHALL BE INCORPORATED INTO THE STRUCTURE.



TYPE A STRUCTURE QUANTITIES					
LOG TYPE	DESCRIPTION	QUANTITY PER SEQUENCE			TOTAL PER STRUCTURE
		1	2	3	
P	POST, 6' L X 4" DIA	5		0-8	5-13
A	LOG, 5-7' L x 10-12" DBH	1			1
B	LOG, 8-10' L x 10-12" DBH	2			2
C	LOG, 18-22' L x 10-12" DBH		2	4	6
RB	RACKING BUNDLE	6-8	1-2		7-10
R/S	LOOSE RACKING AND SLASH	6 CY	6 CY	6 CY	18 CY

TYPE A - ENTANGLED LOG STRUCTURE
NTS



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IF THIS BAR DOES NOT
MEASURE 1" THEN
DRAWING IS NOT PLOTTED
TO ORIGINAL SCALE.

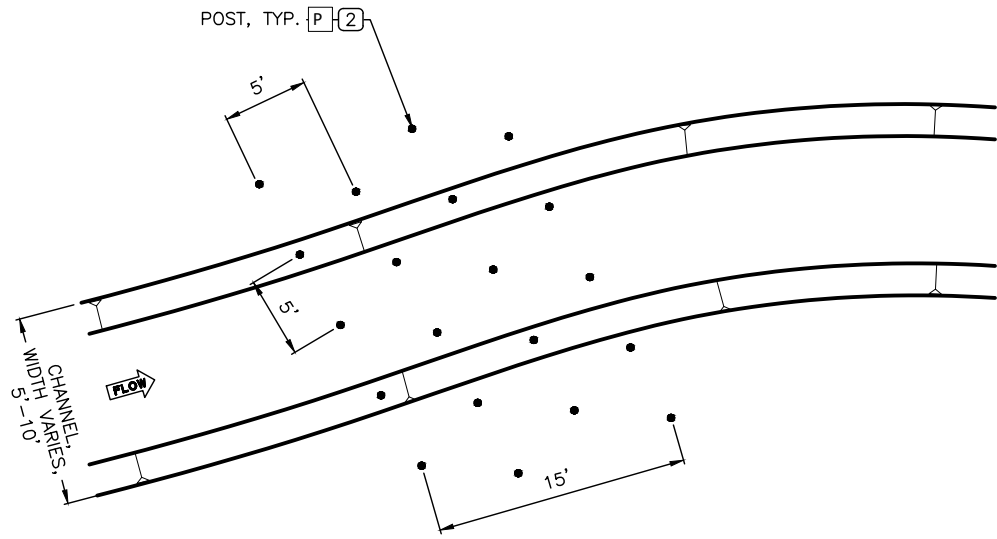


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CHECKED	ELD, SDL	DATE	JUNE 2021

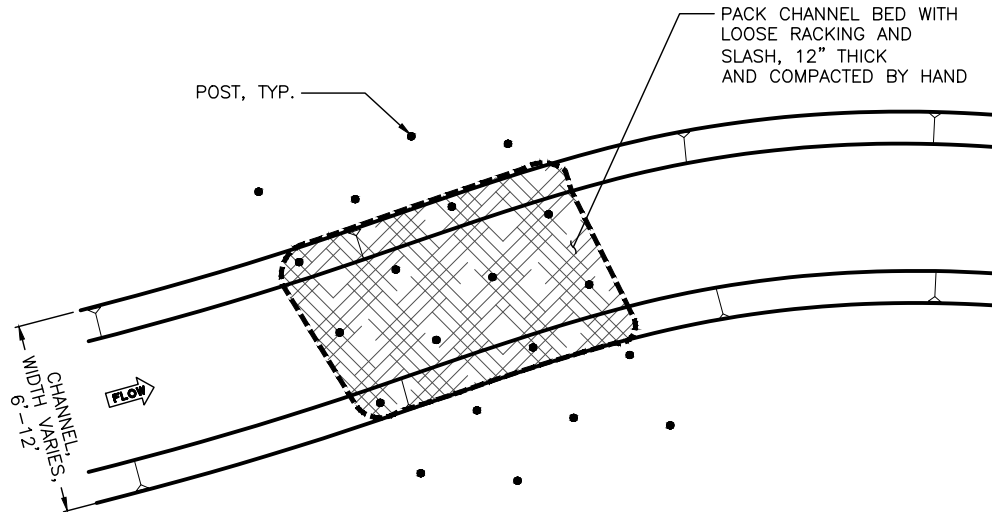
SCHAFFER CREEK AWS PILOT
PROJECT

TYPE A STRUCTURE DETAILS

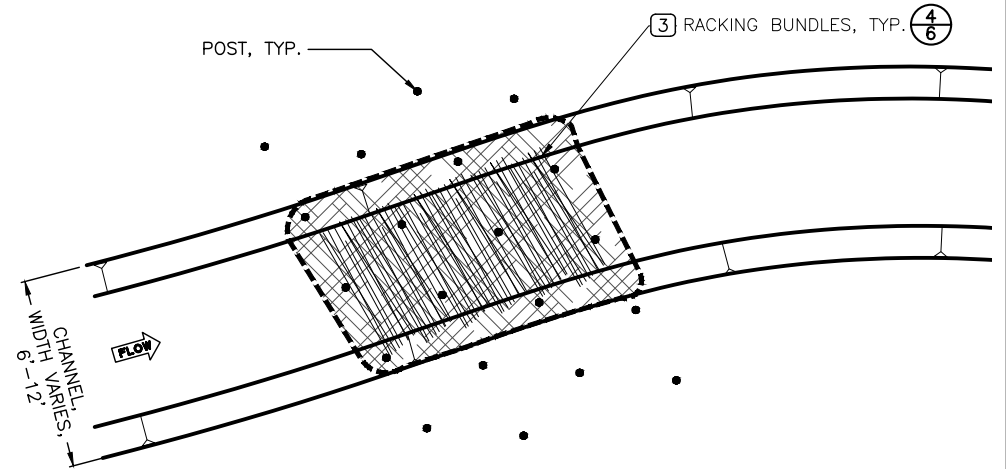
4
SHEET 4 OF 6



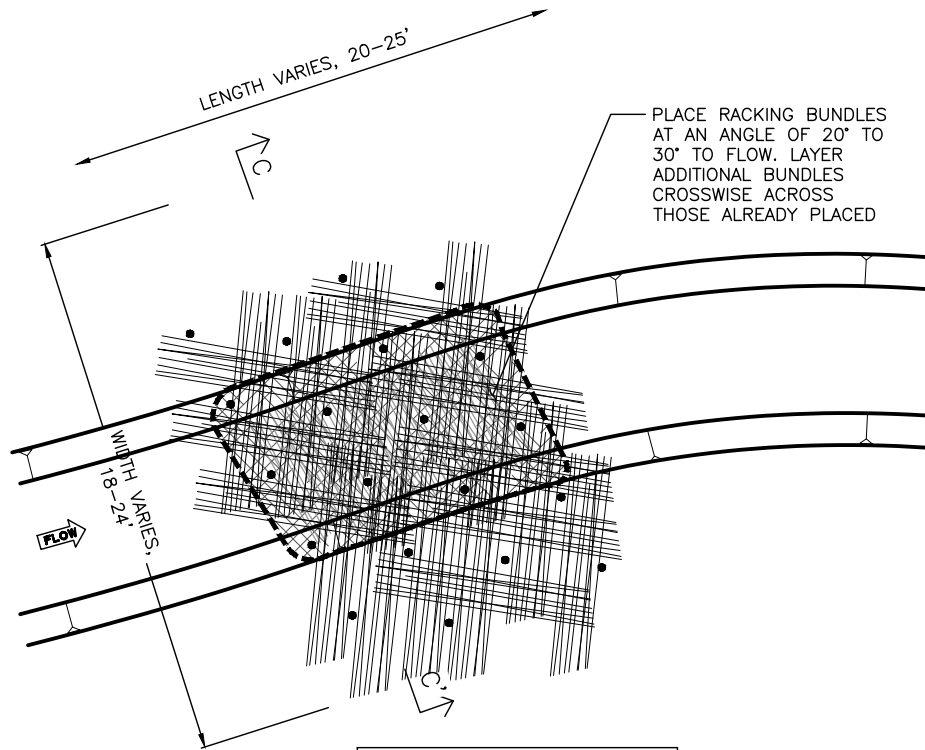
SEQUENCE 1 - PLAN



SEQUENCE 2 - PLAN



SEQUENCE 3 - PLAN



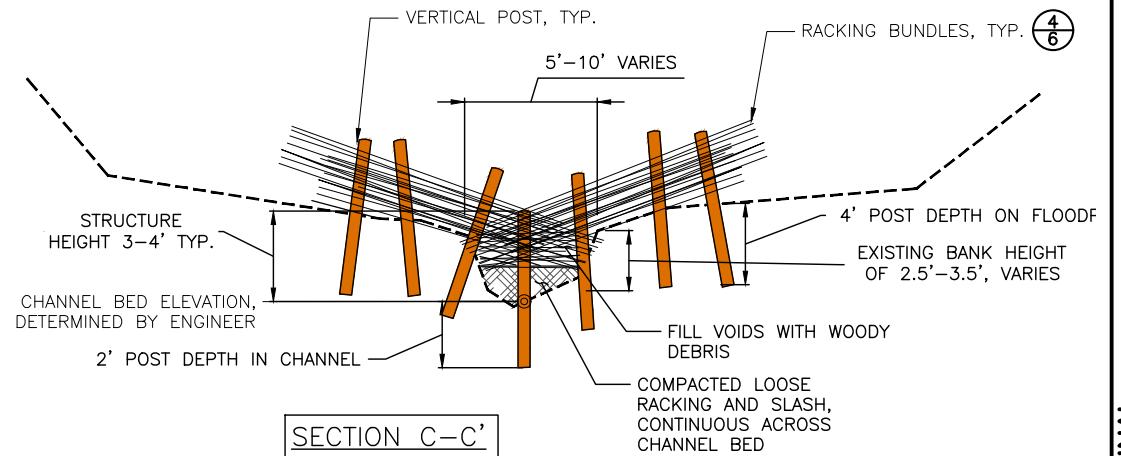
SEQUENCE 4 - PLAN

STRUCTURE TYPE B NOTES

1. ACTUAL LAYERING WILL VARY TO SUIT FIELD CONDITIONS. THE ENGINEER OR OWNER SHALL DIRECT THE LAYERING. SEQUENCE 1 AND 2 ARE CRITICAL.
2. POSTS WITHIN THE FLOODPLAIN MAY BE OMITTED IF SUITABLE RIPARIAN TREES EXIST TO PROVIDE EQUAL RESISTANCE AND ENTANGLEMENT. POSTS SHALL BE DRIVEN AT VARYING ANGLES TO LOCK IN MATERIALS, TO THE EXTENT POSSIBLE.
3. RACKING BUNDLES SHALL SURROUND POSTS TO PROTECT FROM SCOUR. VOIDS SHALL BE PACKED WITH LOOSE RACKING AND SLASH. SEQUENCE 3 RACKING BUNDLES MAY BE WRAPPED IN COIR FABRIC TO FURTHER REDUCE PERMEABILITY (OPTIONAL). RACKING BUNDLE LENGTHS WILL VARY AND MAY BE ADJUSTED TO FIT THE MEANS OF TRANSPORT PER OWNER OR ENGINEER.
4. ADDITIONAL RACKING, POSTS, OR ENTANGLEMENT MAY BE DIRECTED BY THE ENGINEER OR OWNER FOR STRUCTURE STABILITY.
5. HARVEST OR SALVAGE OF ON-SITE WOODY DEBRIS WILL BE DIRECTED BY THE OWNER. ANY VEGETATION CLEARED DURING ACCESS MAY BE INCORPORATED INTO THE STRUCTURE.

TYPE B STRUCTURE QUANTITIES

LOG TYPE	DESCRIPTION	QUANTITY PER SEQUENCE				TOTAL PER STRUCTURE
		1	2	3	4	
P	POST, 6' L x 4" DIA	20				20 (2)
RB	RACKING BUNDLE			6-8	18-25	24-33
R/S	LOOSE RACKING AND SLASH		8 CY	2 CY	2 CY	12 CY



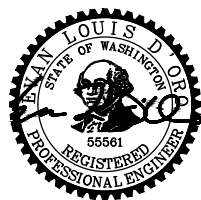
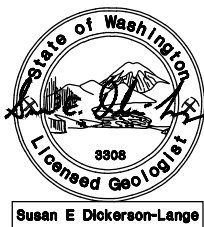
SECTION C-C'

TYPE B - POST AND SLASH STRUCTURE

NTS

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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.



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CHECKED ELD, SDL
DRAWN ESB
CHECKED ELD, SDL

GEOGRAPHIC INFORMATION
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LONGITUDE 123.606753
TN/SC/RG T21N/20/7W
DATE JUNE 2021

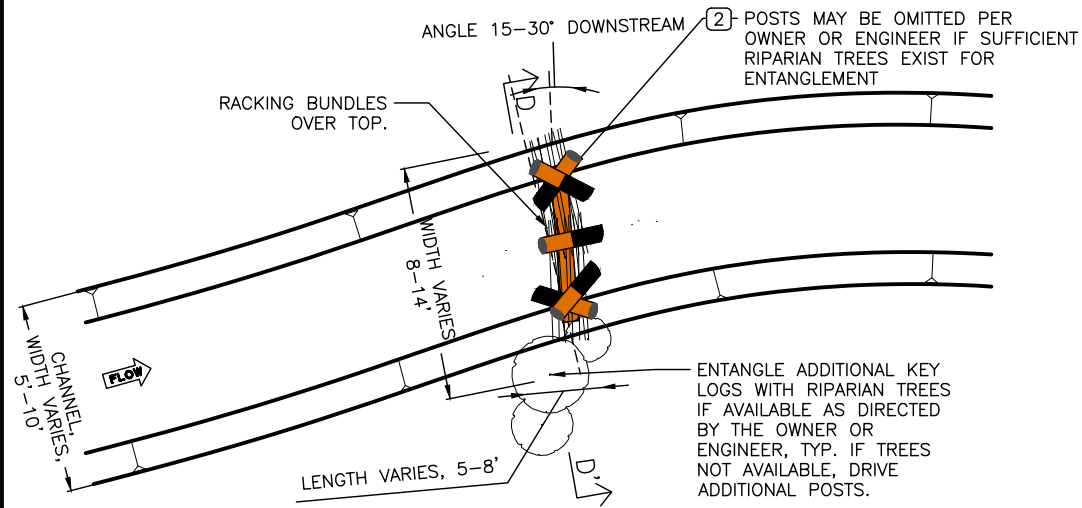
SCHAFFER CREEK AWS PILOT PROJECT

TYPE B STRUCTURE DETAILS

5
SHEET 5 OF 6

Jun 16, 2021 DRAFT FINAL

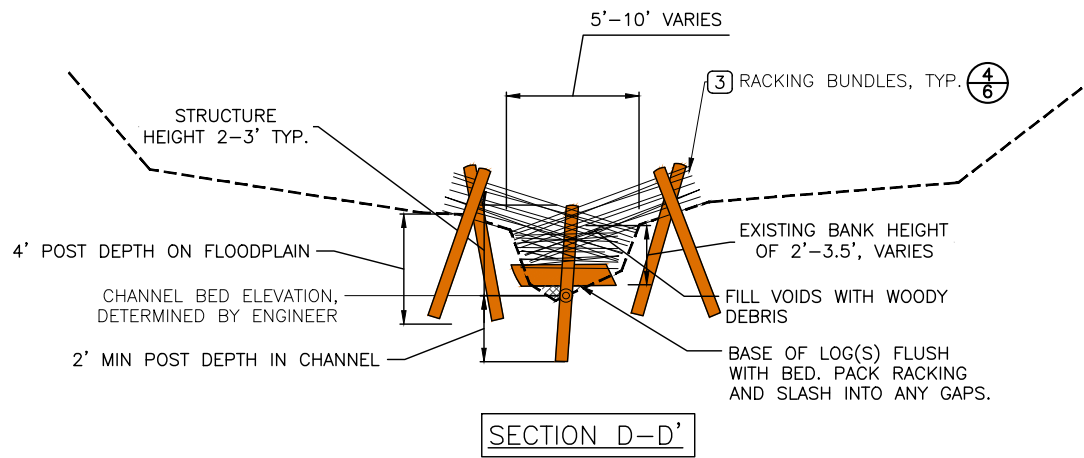
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TYPE C - POST-ASSISTED LOG

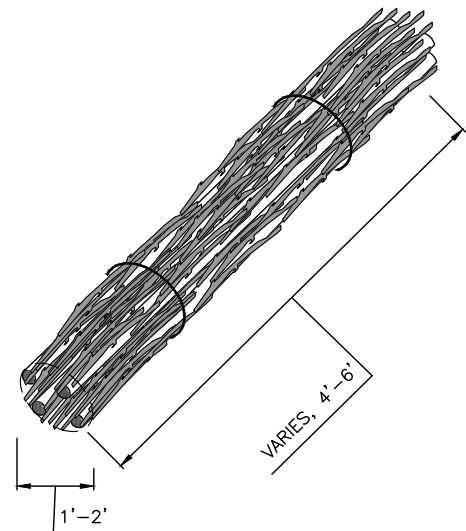
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NTS



- STRUCTURE TYPE C NOTES**
1. ACTUAL LAYERING WILL VARY TO SUIT FIELD CONDITIONS. THE ENGINEER OR OWNER SHALL DIRECT THE LAYERING.
 2. POSTS WITHIN THE FLOODPLAIN MAY BE OMITTED IF SUITABLE RIPARIAN TREES EXIST TO PROVIDE EQUAL RESISTANCE AND ENTANGLEMENT. POSTS SHALL BE DRIVEN AT VARYING ANGLES TO LOCK MATERIALS INTO PLACE.
 3. RACKING BUNDLES SHALL SURROUND POSTS TO PROTECT FROM SCOUR. VOIDS SHALL BE PACKED WITH LOOSE RACKING AND SLASH. RACKING BUNDLES MAY BE WRAPPED WITH COIR FABRIC TO REDUCE PERMEABILITY (OPTIONAL). RACKING BUNDLE LENGTHS WILL VARY AND MAY BE ADJUSTED TO FIT THE MEANS OF TRANSPORT PER OWNER OR ENGINEER.
 4. LOG LENGTHS WILL VARY AND BE CUT IN PLACE TO FIT STRUCTURE DIMENSIONS PER OWNER OR ENGINEER. CUT ENDS SHALL BE INCORPORATED INTO STRUCTURE OR USED AS DIRECTED BY OWNER OR ENGINEER.
 5. ADDITIONAL LOGS AND POSTS OR ENTANGLEMENT MAY BE DIRECTED BY THE ENGINEER OR OWNER FOR STRUCTURE STABILITY.
 6. HARVEST OR SALVAGE OF ON-SITE WOODY DEBRIS WILL BE DIRECTED BY THE OWNER. ANY VEGETATION CLEARED DURING ACCESS SHALL BE INCORPORATED INTO THE STRUCTURE.

TYPE C STRUCTURE QUANTITIES		
LOG TYPE	DESCRIPTION	TOTAL
P	POST, 6' L x 4" DIA	3-8 2
A	LOG - 5-7' L x 10-12 DBH	1-3
RB	RACKING BUNDLE	2-5
R/S	LOOSE RACKING AND SLASH	2 CY



- NOTES**
1. SECURE BUNDLES ON BOTH ENDS WITH 3 WRAPS WITH 0.5" DIAMETER MANILA ROPE SECURED WITH A SQUARE KNOT WITH 6" TAILS.
 2. BUNDLES SHALL CONSIST OF YOUNG TREES AND BRANCHES HAVING VARYING DIAMETERS OF 0.5-3 INCHES AND A LENGTH OF 3-6 FEET, APPROXIMATELY 6 TO 10 PIECES PER BUNDLE.
 3. BUNDLES SHALL CONTAIN LEAVES, TWIGS, DUFF, AND LOCAL DEBRIS TO FILL VOIDS AS FEASIBLE AND CREATE A LOW-PERMEABILITY BUNDLE.
 4. BUNDLES MAY BE INDIVIDUALLY WRAPPED IN COIR FABRIC TO DECREASE PERMEABILITY, AT OWNER'S DISCRETION.

RACKING BUNDLE

4/4-6

NTS



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IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT PLOTTED TO ORIGINAL SCALE.

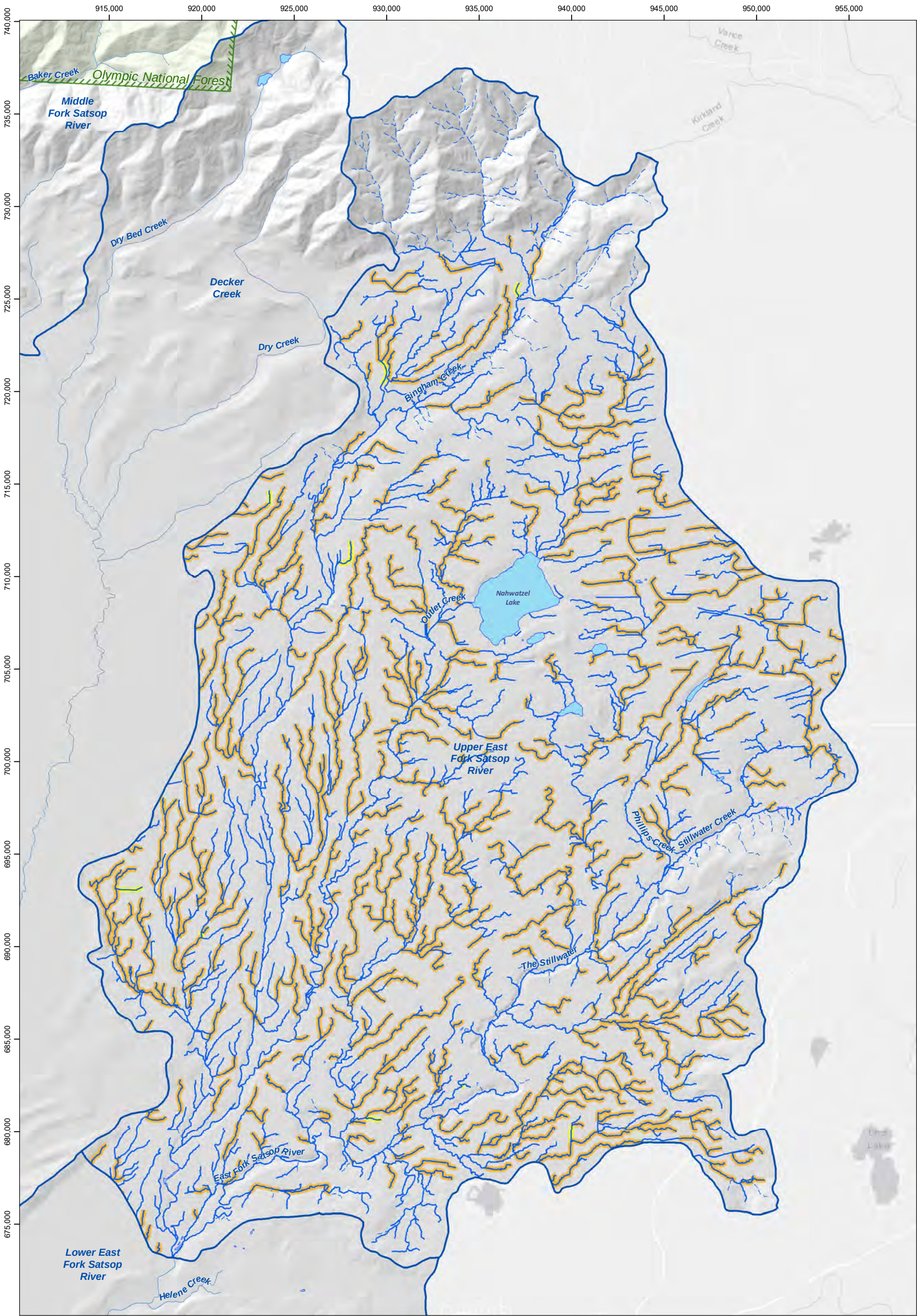


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CHECKED	ELD, SDL	LONGITUDE	123.606753
DRAWN	ESB	TN/SC/RG	T21N/20/7W
CHECKED	ELD, SDL	DATE	JUNE 2021

SCHAFER CREEK AWS PILOT PROJECT

TYPE C AND GENERAL STRUCTURE DETAILS

APPENDIX F. MAPBOOK OF HAND-BUILT REACHES WITH TOP 50% RESTORABLE ALLUVIAL WATER POTENTIAL



Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemnt\GIS\maps\mxd\Report_Figures\Mapbook_FilteredResults.mxd

Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 1 of 12
Upper East Fork Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

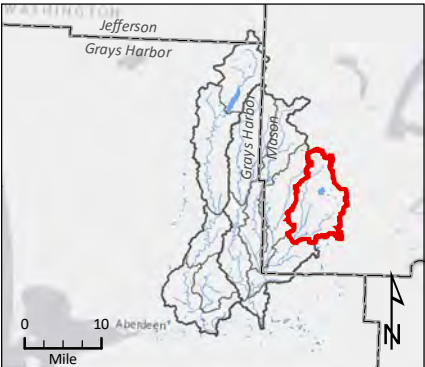
In-Stream Structures

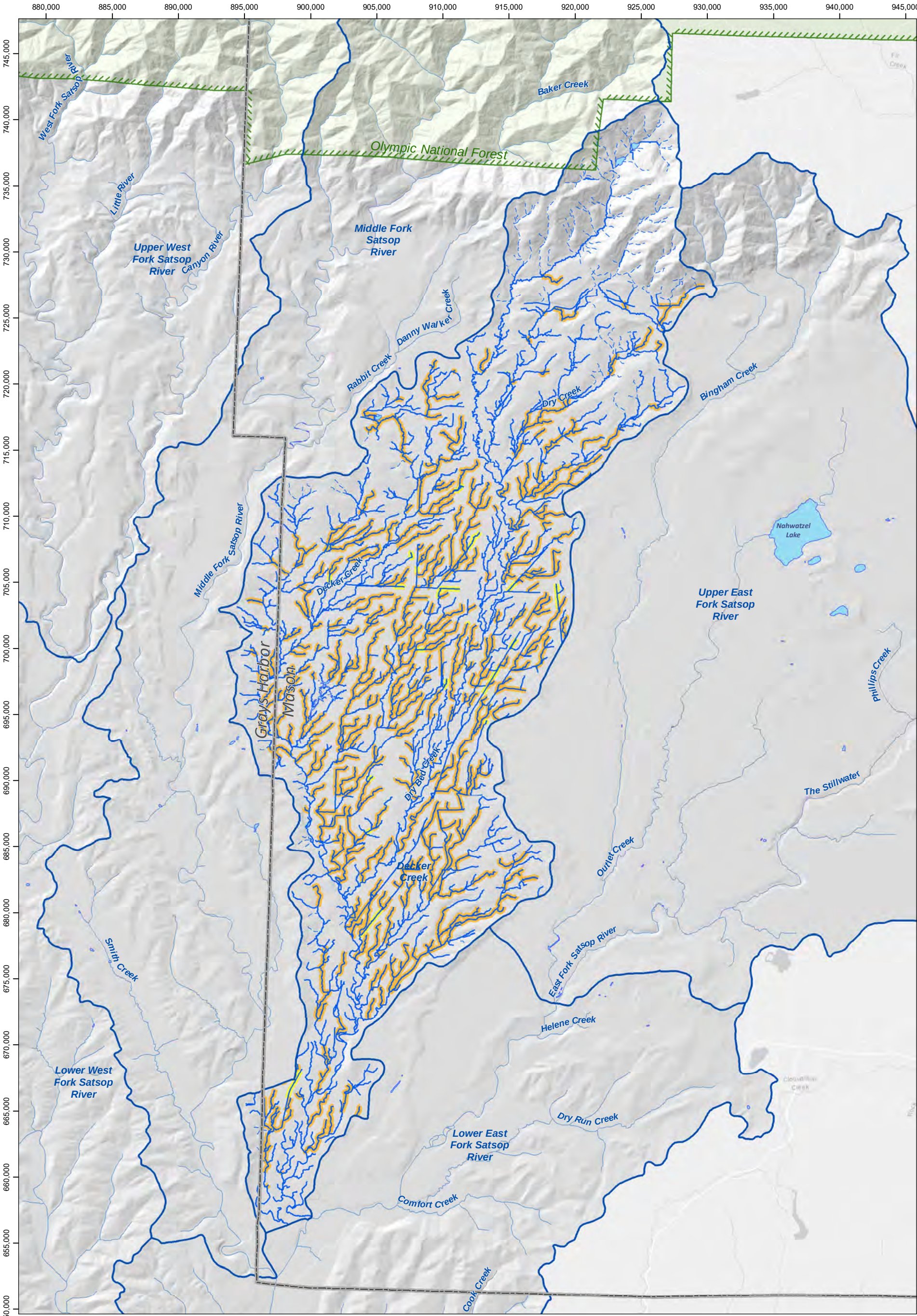
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





Author: Stratten Date: 1/28/2021 Path: N:\Projects\GHCD\Satsop\Wynoochee\basemaps\GIS\maps\mxd\Report_Figures\Mapbook_FilteredResults.mxd

Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 2 of 12
Decker Creek

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

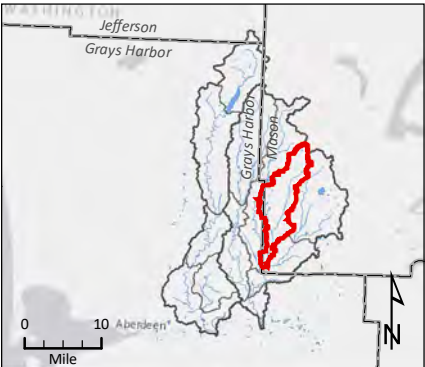
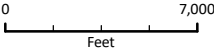
In-Stream Structures

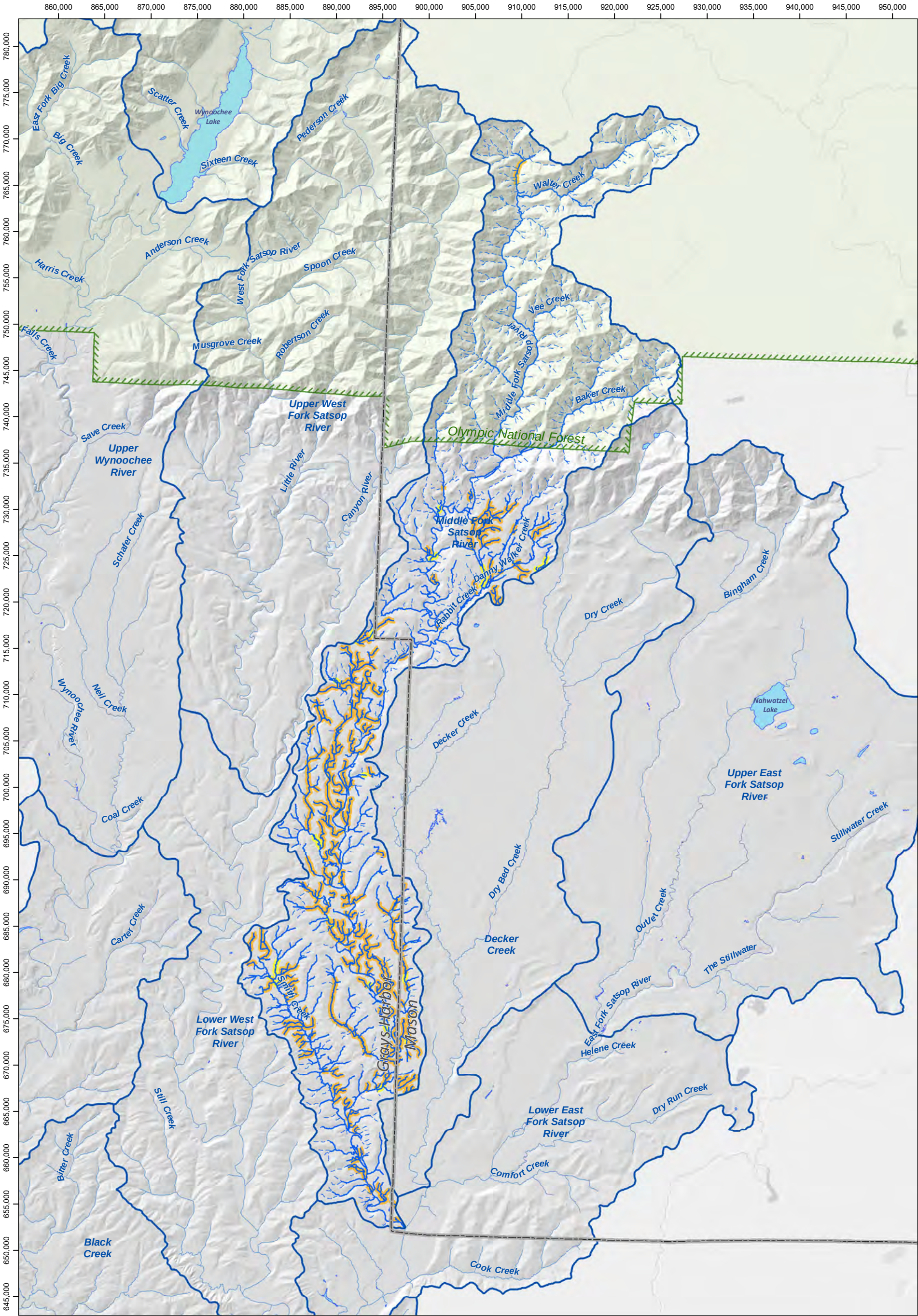
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Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 3 of 12
Middle Fork Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

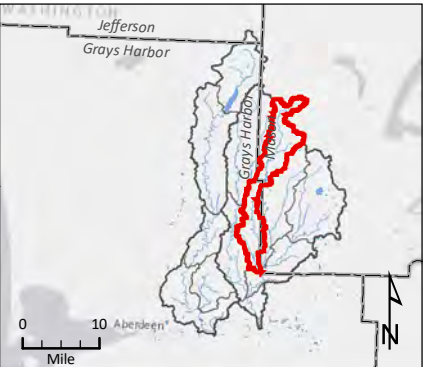
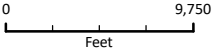
In-Stream Structures

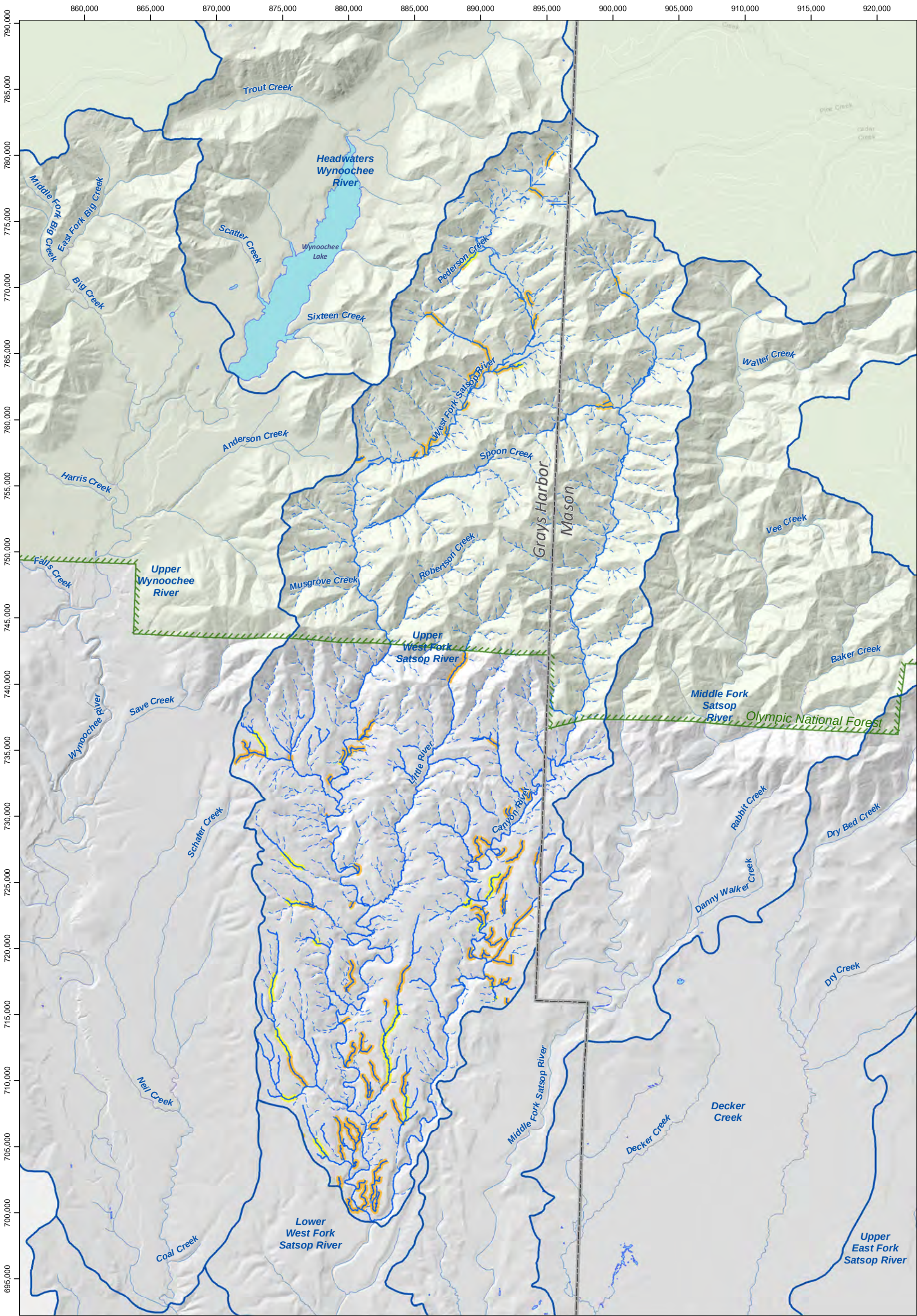
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 4 of 12
Upper West Fork Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

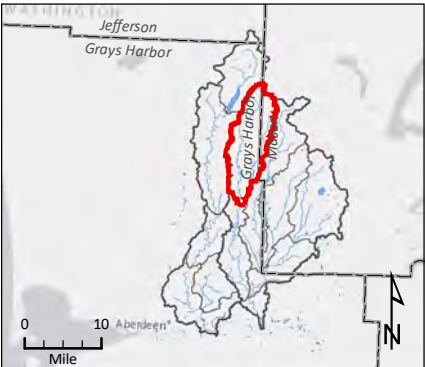
In-Stream Structures

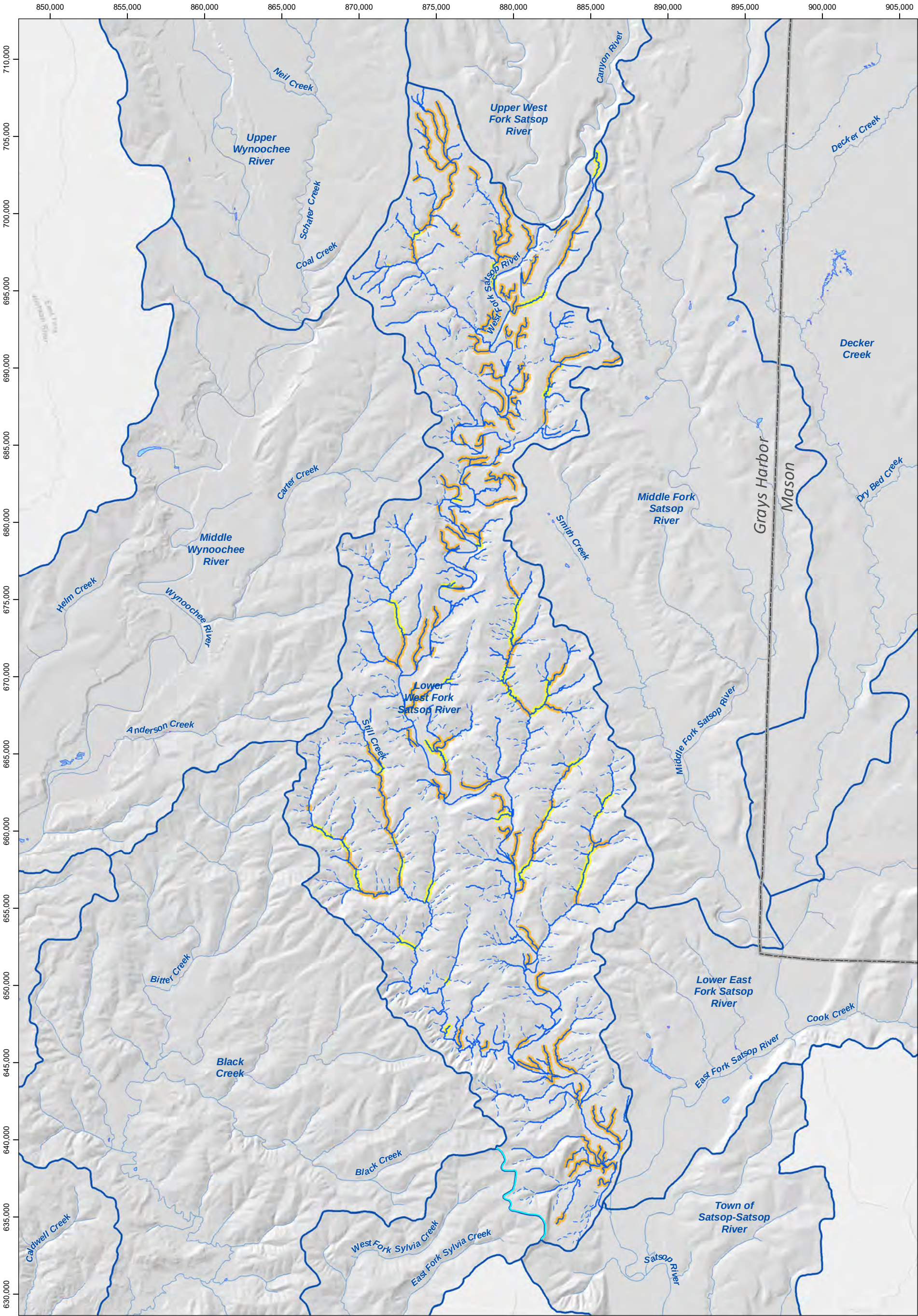
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 5 of 12
Lower West Fork Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

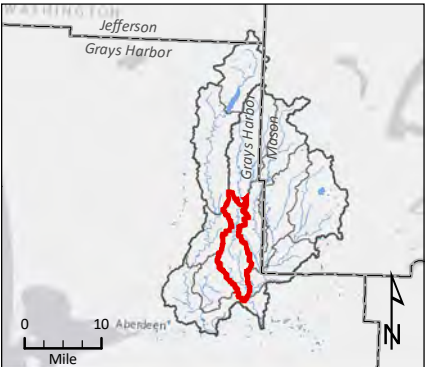
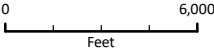
In-Stream Structures

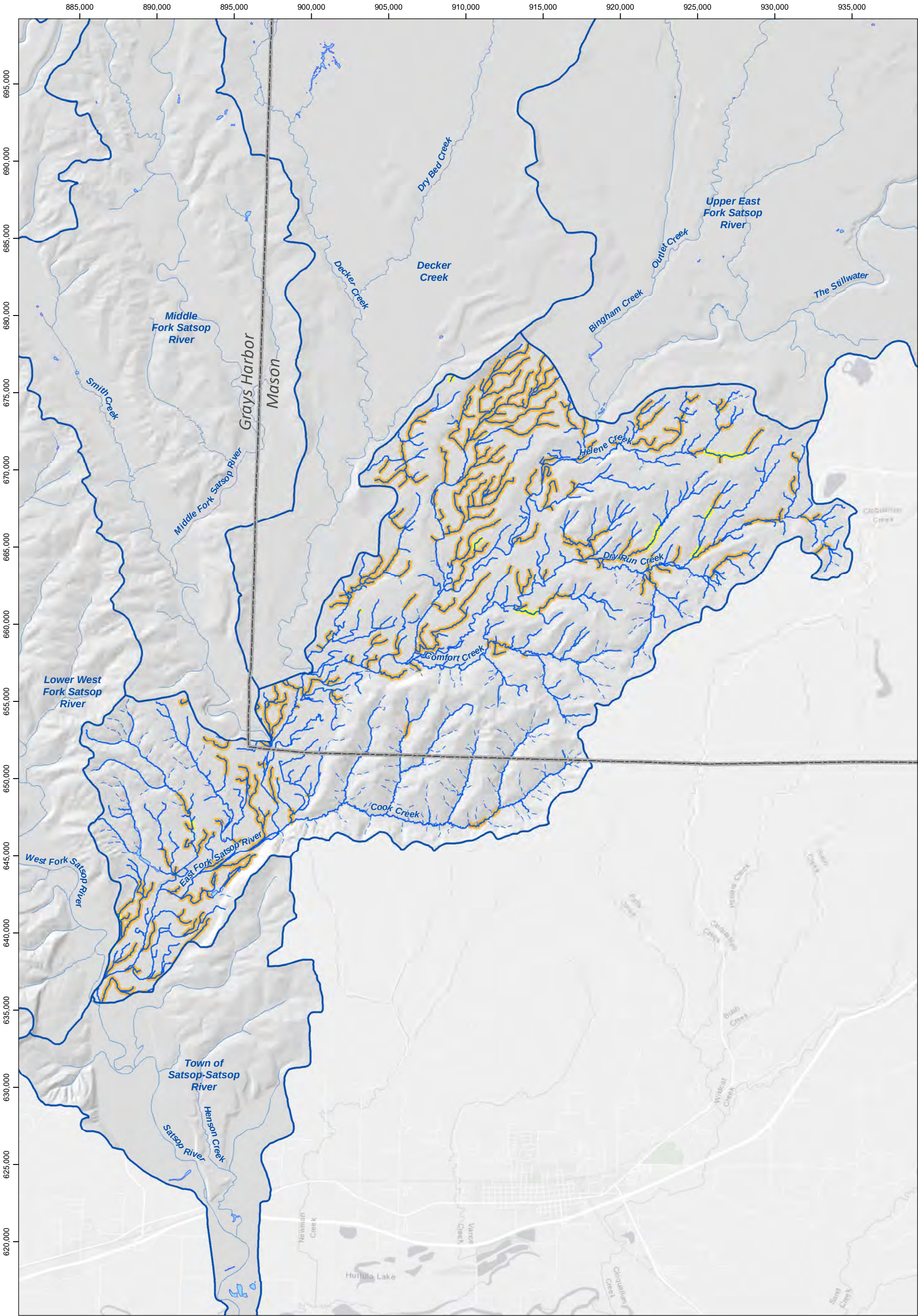
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 6 of 12
Lower East Fork Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

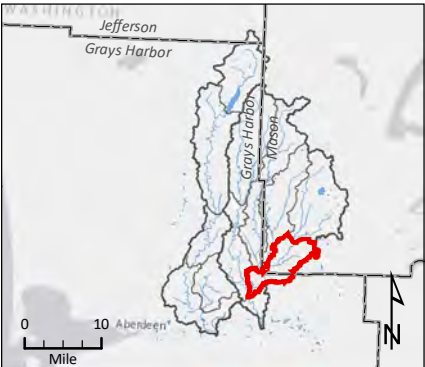
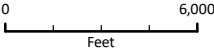
In-Stream Structures

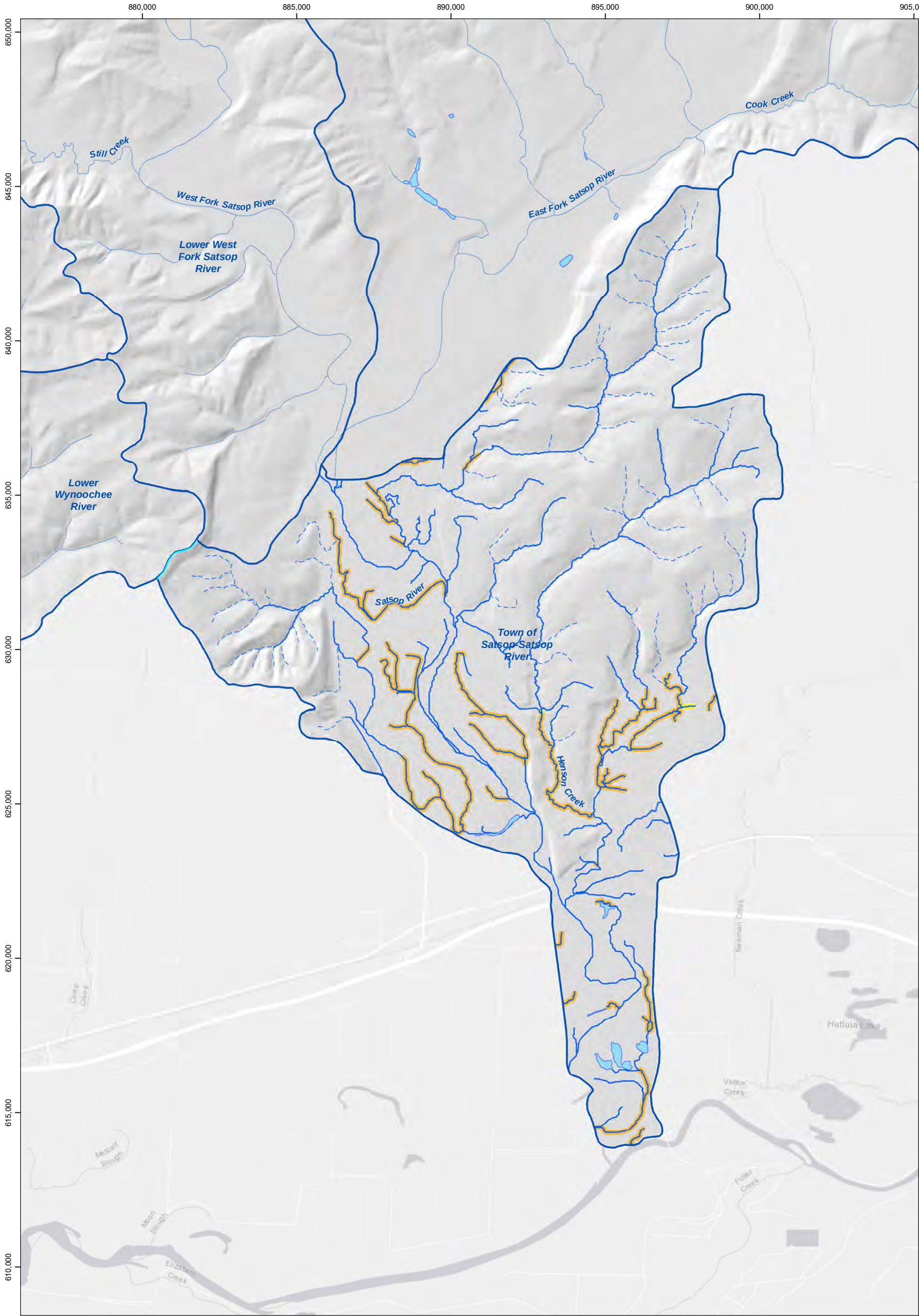
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 7 of 12
Town of Satsop-Satsop River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

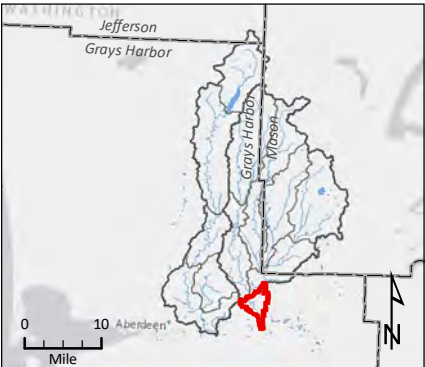
In-Stream Structures

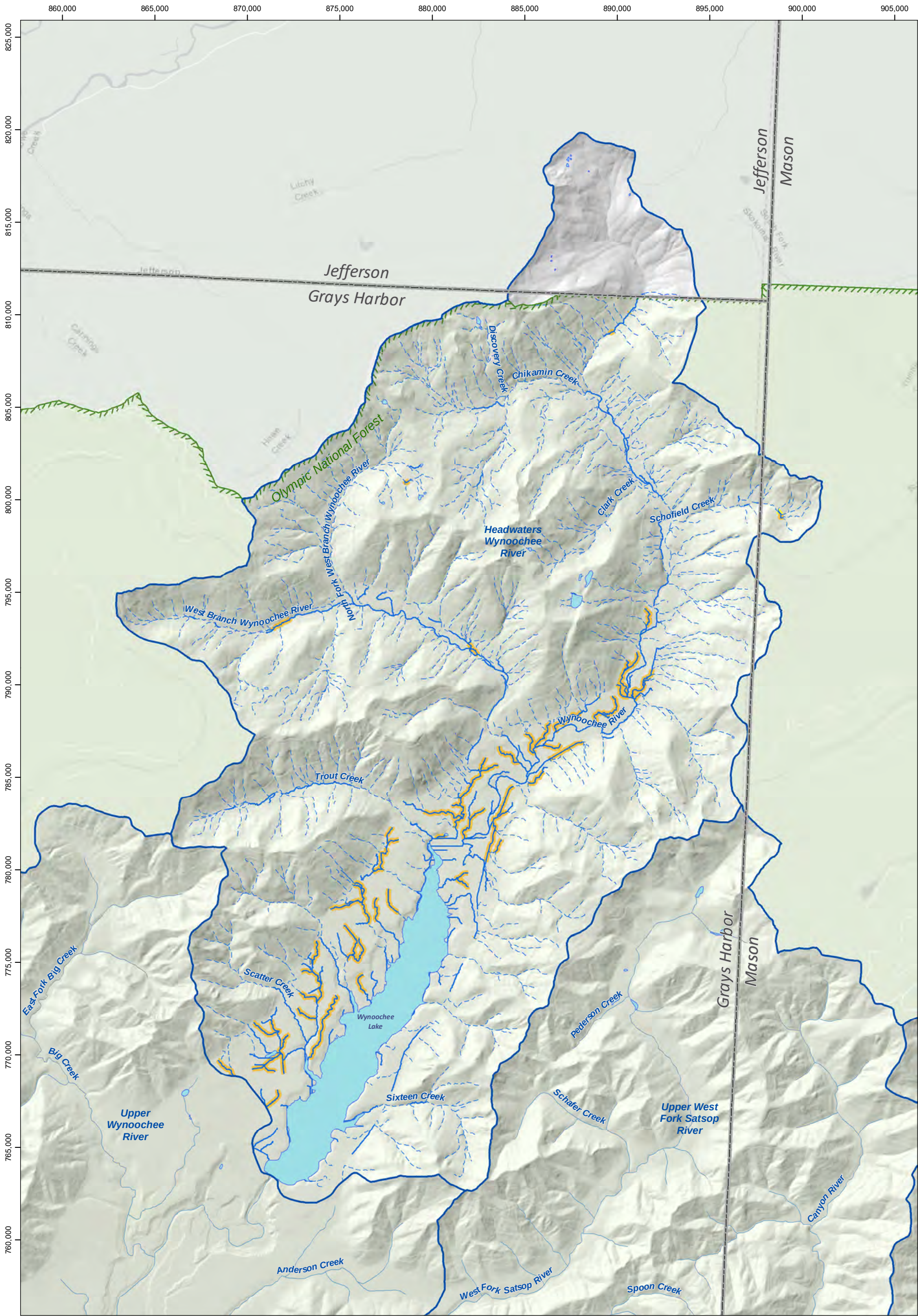
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 8 of 12
Headwaters Wynoochee River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

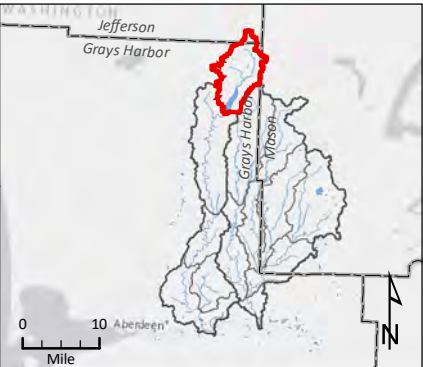
In-Stream Structures

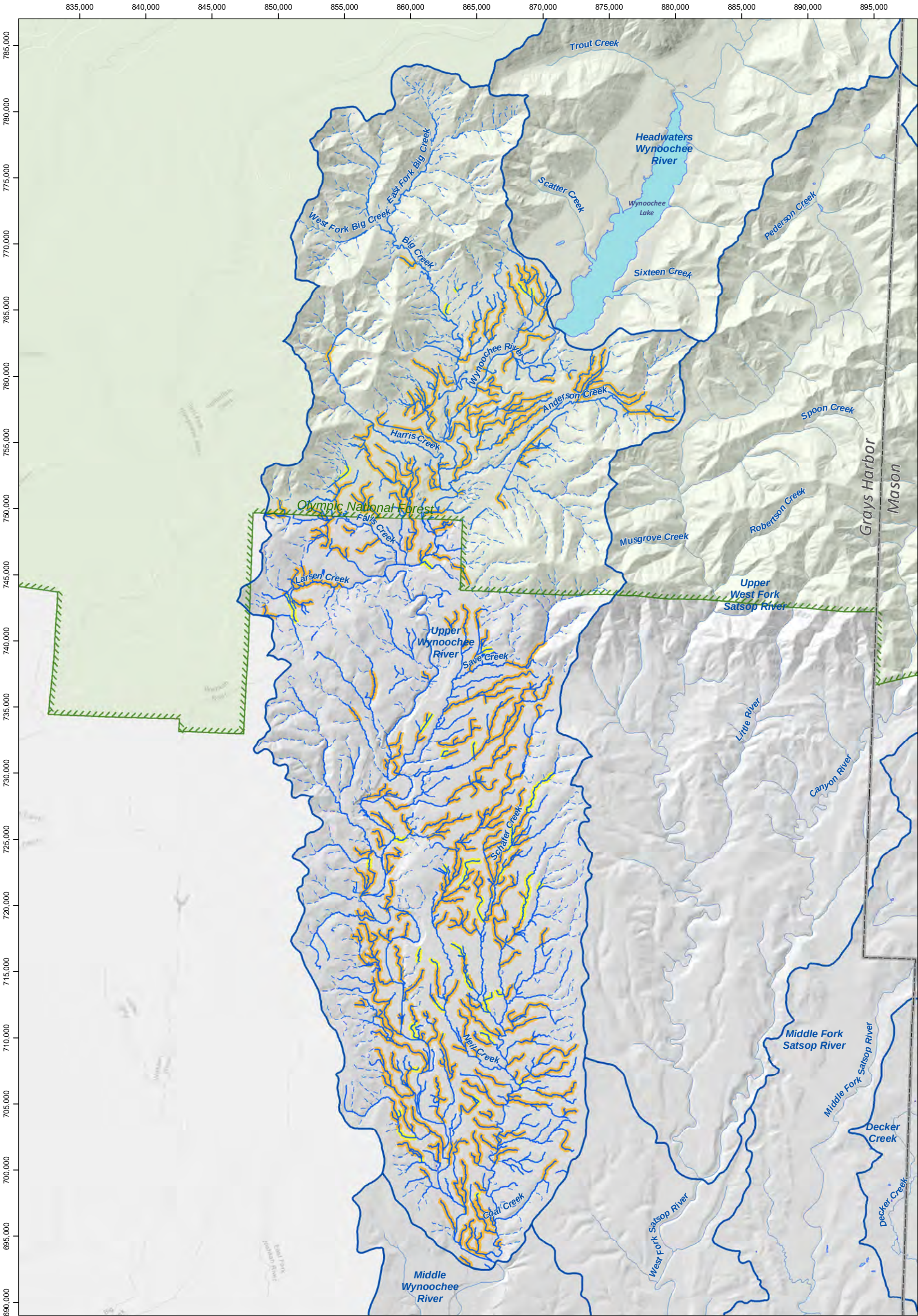
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 9 of 12
Upper Wynoochee River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

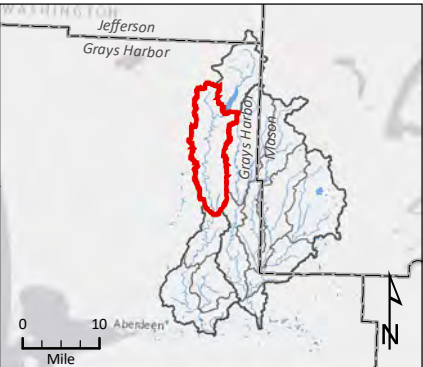
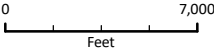
In-Stream Structures

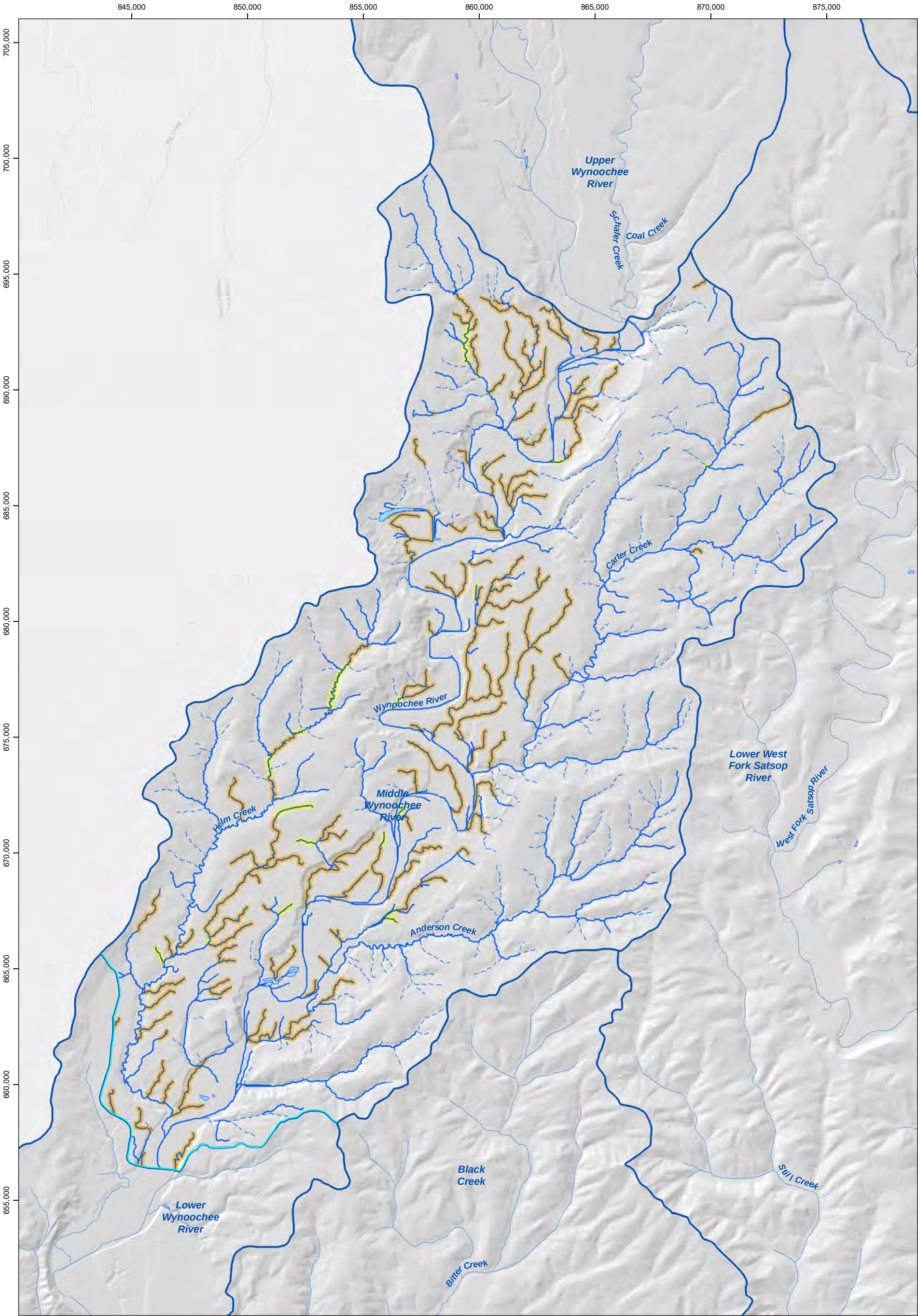
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 10 of 12
Middle Wynoochee River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

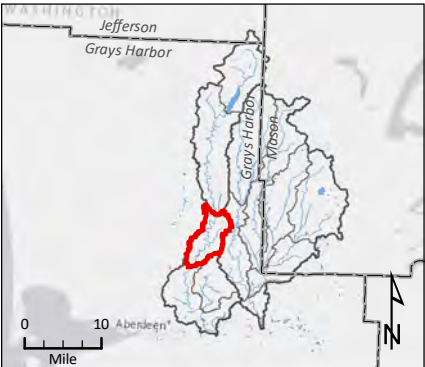
In-Stream Structures

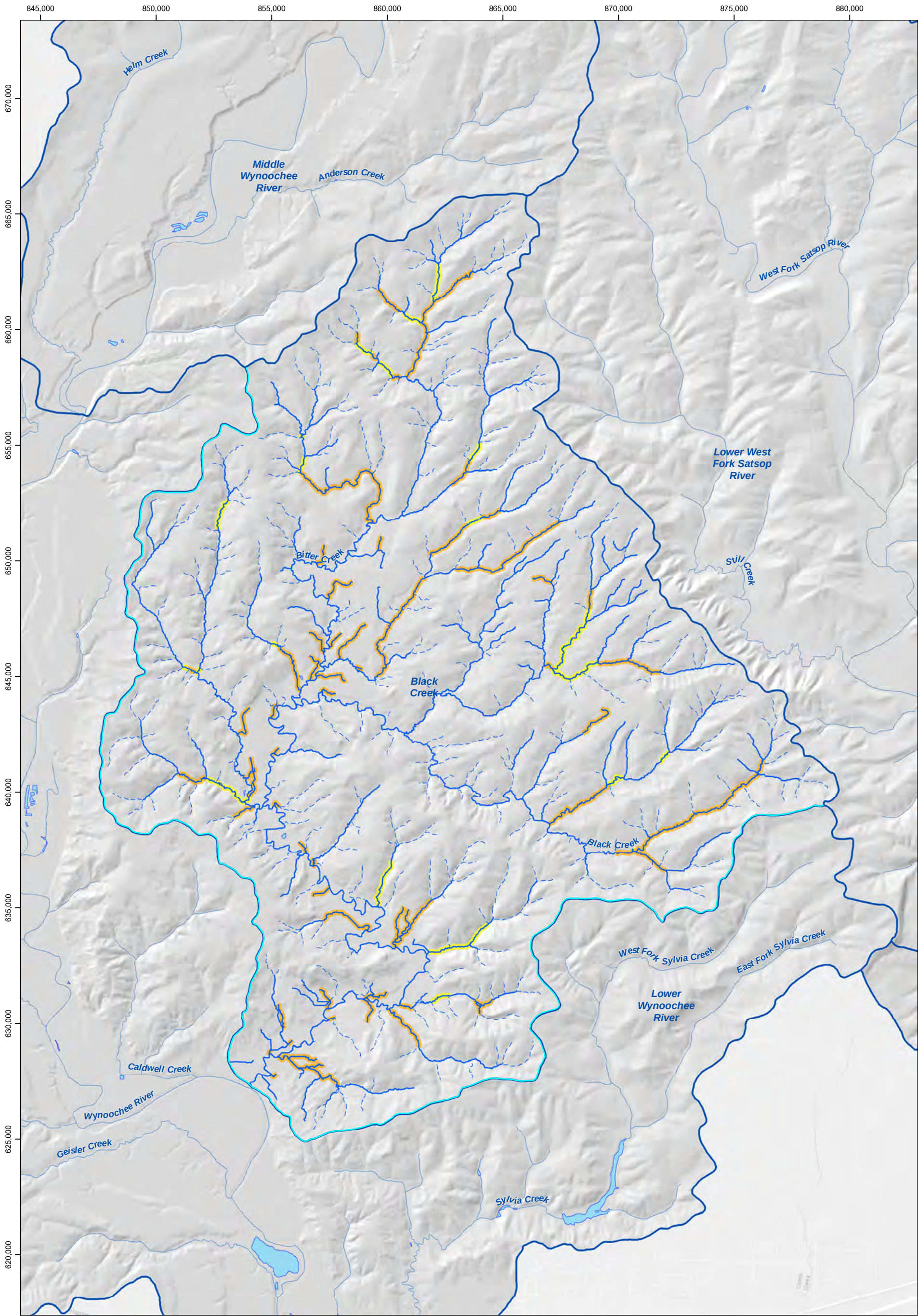
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 11 of 12
Black Creek

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

In-Stream Structures

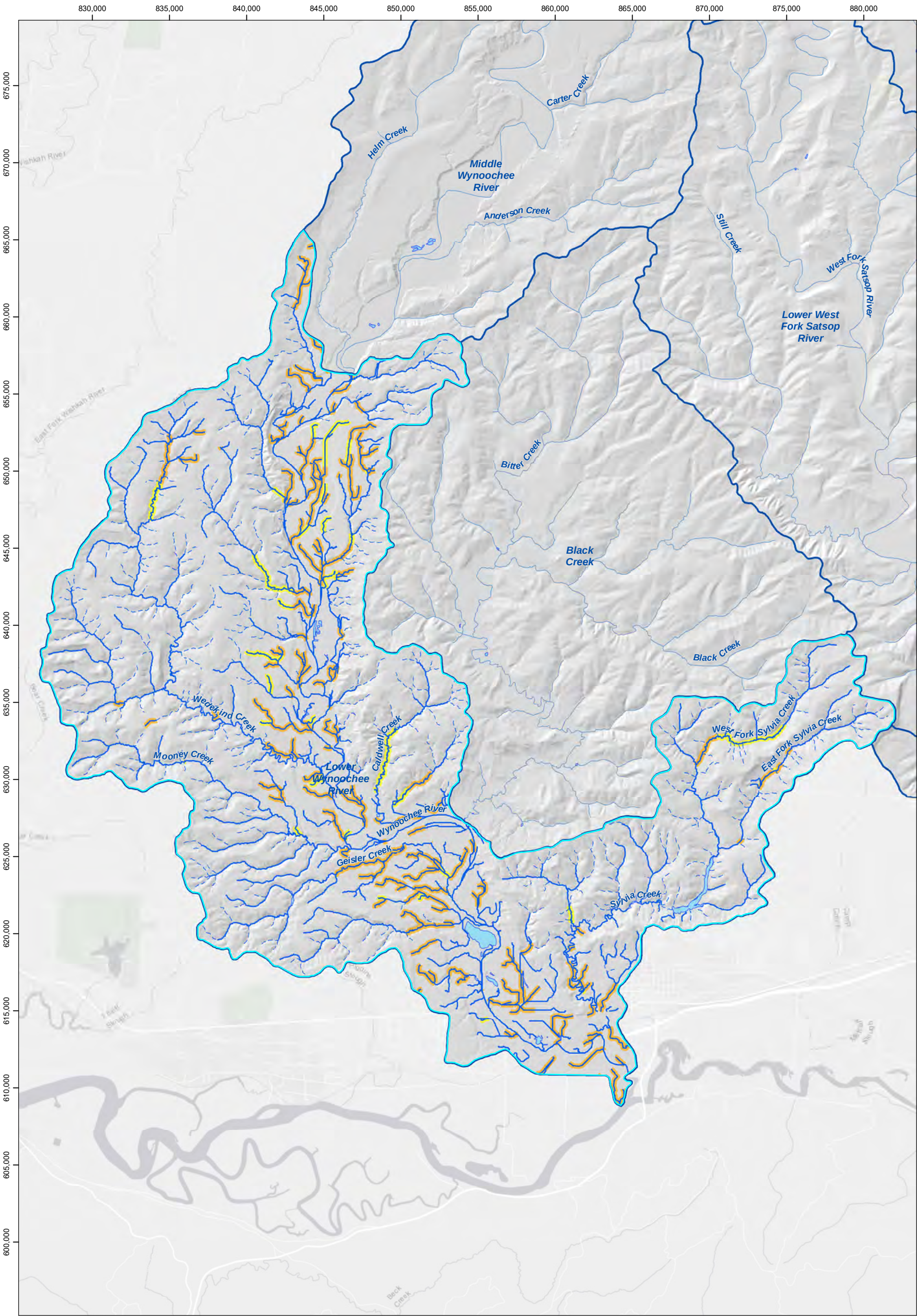
- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinault, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW





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Satsop and Wynoochee Tributary Restoration Strategy

Top 50% Restorable Alluvial Water Potential (by HUC12)
with Potential for Hand-Built In-Stream Restoration
Map 12 of 12
Lower Wynoochee River

Streams

- Stream Reaches (<8% slope)
- Stream Reaches (>8% slope)

In-Stream Structures

- Hand-Built, Likely Suitable
- Hand-Built, Possibly Suitable

Note: See Table 5 for interpretation of hand-built suitability.



Lambert conformal conic projection
NAD 1983 State Plane Coordinate System (WA South Zone).
Topographic data source: Lidar (Quinalt, 2012; Grays Harbor, 2012; Chehalis, 2017; SW Washington Foothills 2017; Olympics, 2017; Olympics South OPSW

