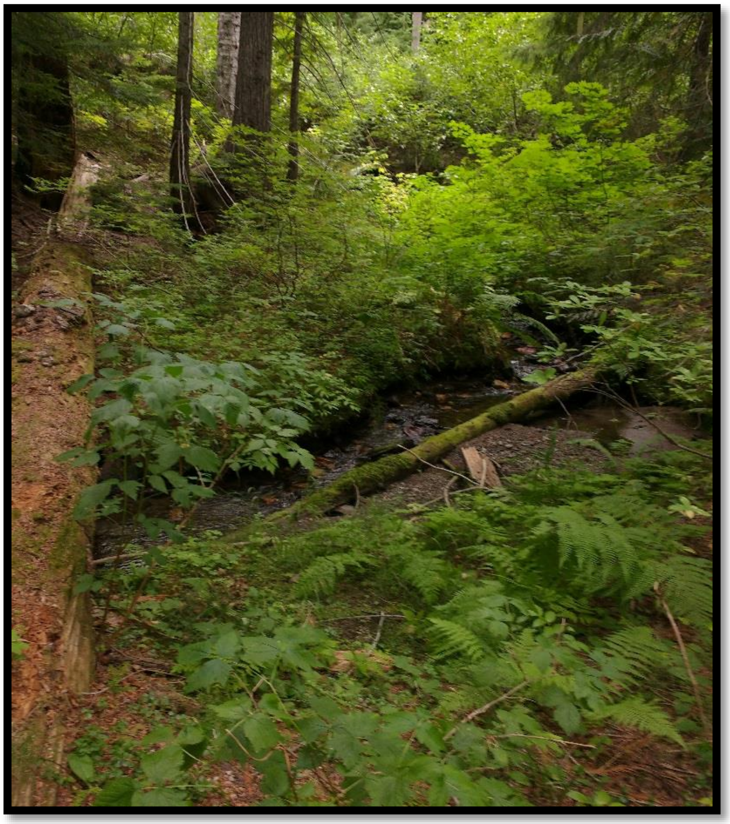
Chelan Pilot Restoration Project
Upper Wenatchee
Landscape Evaluation



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Okanogan-Restoration Forest Restoration Team

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** Note: All the data and auxillary information used for this analysis could not fit into the Appendices. This data can be found on the USFS T: Drive.*

1. INTRODUCTION

1.1 Chelan Pilot Project Introduction

The eastern Cascades of Washington State is an incredibly diverse and complex ecoregion that supports abundant fish and wildlife, a wide range of forest communities, and provides an array of critical ecosystem services including water, wood products, forage for grazing, and a wide variety of recreational opportunities. Ranging from the crest of the Cascades down to the shrub steppe of the Columbia Basin, the variability in the forests and rangelands of the east Cascades are driven by the interplay of topography, precipitation, soils, and disturbances such as fire, insects, flooding, and wind (Hessburg et al. 1999, Stine et al. 2014).

Throughout the 20th century, forests across western North America have had a history of wildfire suppression, grazing pressure, intensive timber harvesting, and road building associated with these activities. This has caused widespread degradation of forest, rangeland, watershed condition and stream habitat, and has increased the risks of uncharacteristically severe wildfire (Hessburg et al. 2000a, Bunting et al. 2002, Lehmkuhl et al. 2013, Hessburg et al. 2015). The resulting shifts in tree species composition and increases in forest density have resulted in decreased resilience to drought and fire for many of the region's forests, and this occurs at a time when climate change is projected to increase drought stress and wildfire risks (Hessburg et al. 2000a, Haugo et al. 2014, Jones et al. 2000, Littell et al. 2010). Twentieth century forest management also led to the building of extensive forest road networks which have dramatically altered watershed hydrology, increased sediment delivery into streams, reduced floodplain functioning, and fragmented aquatic habitats (Bisson et al. 2003, Jones et al. 2000, Rieman et al. 2010). These stressors of aquatic habitats have and will continue to be further exacerbated by the increases in stream temperatures and decreases in snowpack as a result of climate change (Mote, 2003; Mantua et al. 2009; Isaak et al. 2010, 2012).

Across western North America and within the eastern Cascades, the challenges currently facing forested ecosystems from past management and future climate change, have prompted a wide scale shift in land management to focus on "ecological restoration" (Rieman et al. 2010, Gaines et al. 2012, Hessburg et al. 2015). Ecological restoration is defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). In order to develop a restoration project that effectively works across forest ownership and management allocations, the North Central Washington Forest Health Collaborative (NCWFHC) is working together with the USFS to provide recommendations for restoration work on the Wenatchee River Ranger District on the Okanogan-Wenatchee National Forest.

This need for restoration was highlighted clearly in the last few years, after Eastern Washington experienced some of its worst fire seasons on record. This has created a sense of urgency among land managers to restore resiliency to these valuable landscapes. The Chelan Pilot project is an attempt to break new ground in collaboration between USFS and external partners, and treat landscapes at a larger scale than has been done in the past, to address these threats (NCWFHC 2016).

1.2 Site Description

The Chelan Pilot Project Area consists of four 6th field sub-watersheds (12 Code HUC) comprising nearly 75,000 acres (Figure 1). These are: Lake Wenatchee, Beaver Creek- Wenatchee River, Big

Meadow Creek, and Lower Chiwawa River. These sub-watersheds contain a variety of aquatic and terrestrial resource and conservation values, including- but not limited to- habitat for federally listed Upper Columbia spring Chinook (*Oncorhynchus tshawytscha*; UCSRB 2007), Upper Columbia Steelhead (*Oncorhynchus mykiss*; UCSRB 2007), Columbia River bull trout (*Salvelinus confluentus*; USFWS 2015), gray wolf (Canus lupus; USFWS 1967), grizzly bear (Ursus arctos; USFWS 1997, 2011), northern spotted owl (*Strix occidentalis caurina*; USFWS 2011) and numerous rare late successional vascular and non-vascular plant species.

Prior to the 20th century (pre-settlement/anthropogenic influence) fires played a more natural role within these landscapes. This intrinsic process created a natural, diverse, resilient landscape, with varying structural stages of vegetative communities, and a heterogeneous mix of species composition. Historical fire disturbances could be characterized as mixed burn severity. Mixed Severity is described by Stephen Arno as “a mixture of frequent nonlethal fires and infrequent stand replacement fires”—it is a “variable fire regime”. (Arno et al. 2000). Mixed severity fire effects are present when the tree mortality of the area of interest is within the range of 20-70% (Agee 1993).

Since the turn of the last century, fire exclusion and suppression has resulted in considerable interruptions in natural processes, and has helped shape the landscape into its current condition. Previous assessments have shown that eastern Washington landscapes, such as those in the Chelan Pilot project area, are now more susceptible to uncharacteristic high severity, stand replacement crown fires as a result of this suppression. (Hessburg et al. 1999, 2007). In the Chelan Pilot project area, there has been very little wildfire in recent years; since 1994, wildfire disturbances have occurred on only 5,114 acres (<7%) of the total area.

Past timber harvest activities, however, have occurred across at least one third of the overall landscape. These harvests have included clear-cutting, commercial thinning and selective tree removal. Post-harvest treatments typically included prescribed burning to address harvest activity fuels (logging slash) and tree planting within the regeneration harvest areas. These actions occurred along with the construction of an extensive road network. Currently, there are over 400 miles of roads across the whole project area.

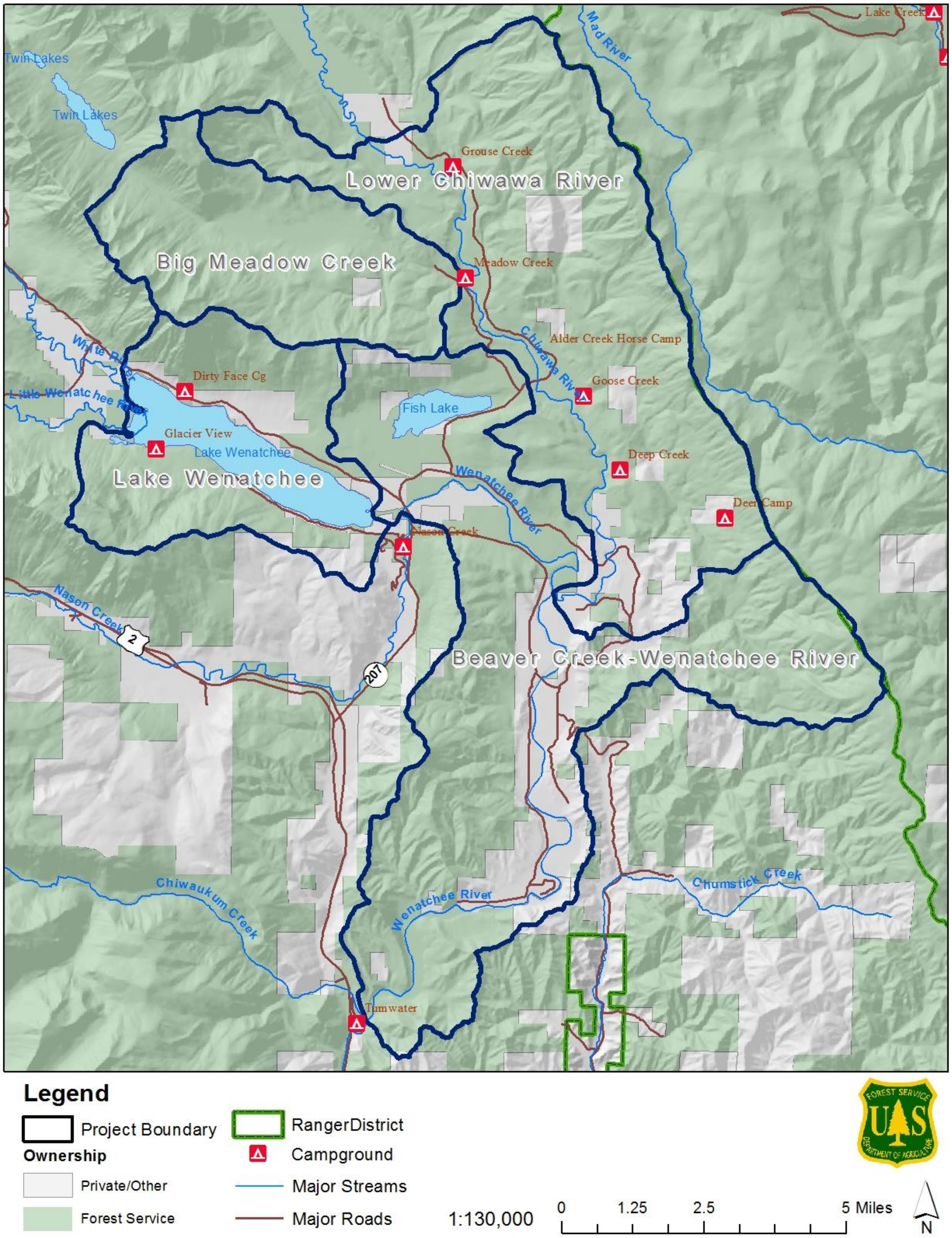


Figure 1. Chelan Pilot Project HUC12 sub-watersheds and land ownership

1.4 Purpose of this Document

The purpose of this document is to clearly evaluate the ecological conditions of the Chelan Pilot (Upper Wenatchee) landscape and describe objectives that will result in more functional ecological conditions. This report documents the results and interpretation of the landscape analysis resulting from the application of the Okanogan Wenatchee National Forest Restoration Strategy (USFS 2012). This document describes the current conditions and compares them to reference conditions, a comparison that is then used to define broad-scale desired conditions. It is intended to inform a more detailed planning effort carried out under the National Environmental Policy Act (NEPA) process.

This document diagnoses landscape scale issues of pattern and composition for multiple attributes. It establishes a framework of ecologically meaningful objectives that, when accomplished in site-specific situations, result in greater resilience of certain attributes to disturbance. This approach of quantifying the landscape through landscape metrics and comparing with historical reference conditions is useful as it provides for a common set of indicators that can be used across disciplines. The idea is that multiple questions can be analyzed using the same data sets, and with the same logic. Also this concept of 'degree of departure' from reference conditions provides an easy way to monitor and evaluate restoration efforts in the future (Reynolds and Hessburg 2014).

Previous watershed assessments were completed in the late 1990s as part of the requirements of the Northwest Forest Pan (ROD, 1994). That documented had mandated periodic assessments of the watersheds in order to describe existing conditions and compare with reference conditions. Therefore this document is an attempt to update this effort using the latest science.

2. LANDSCAPE EVALUATION METHODS

2.1 Forest Restoration Strategy

The Forest Restoration Strategy for the Okanogan-Wenatchee National Forest (USFS 2012) outlines a set of procedures to assess the terrestrial landscape for departures from the natural range of variability. It also introduces an aquatic component to diagnose issues related to hydrology and aquatic biology. For the Aquatic side, the 'natural condition' can be assumed to be a landscape with no roads, barriers to fish, or other stream impairments. This Aquatic component has been more fully detailed in an aquatic update of the restoration strategy (USFS 2015).

It is recognized that both components, Terrestrial and Aquatic, are necessary since they are so interrelated. Forests and streams are tightly linked through a range of critical ecological processes and functions (Naiman and Turner 2000). These include: the transfer of materials and energy that influence habitat structure (large wood and sediment), food webs and trophic dynamics (nutrients and organic carbon supply), and water quality and temperature (riparian shade) (Rieman et al. 2010). Forests can also strongly influence stream hydrology through impacts on snowpack dynamics, runoff, evapotranspiration, soil moisture, floodplain functioning, and groundwater infiltration among other processes (Luce et al. 2012, Lundquist et al. 2013).

2.2 Terrestrial Evaluation Methods

Forest patterns and processes are intricately tied together. Patterns give rise to processes across the landscape which in turn influence future patterns (Hessburg et al. 2015). Therefore an understanding of landscape patterns provides crucial information about underlying processes. There are numerous metrics that exist to quantify landscape pattern, and these can be used to directly compare current landscapes with historical landscapes.

The steps involved in a terrestrial evaluation are: 1) Aerial photo-interpretation of the entire watershed at a 1:12,000 scale; 2) Derivation of forest attributes related to forest structure and function; 3) Quantification of these attributes using landscape metrics; 4) Comparison of these metrics with those generated from historical imagery; and 5) Assessment of the degree of departure from historic conditions. The degree of departure highlights the need for restoration and provides an accounting tool to monitor and evaluate restoration treatments (USFS 2012).

An additional step also is done to estimate future conditions under a warmer/drier climate scenario. The range of conditions found in the historical imagery is referred to as the 'Historic Range of Variability' (HRV), while the range of conditions found in a hypothetical future scenario is referred to as the 'Future Range of Variability' (FRV). Reference conditions are based on the Ecological Sub-Region (ESR) that the watershed occurs in; essentially these are just geographic areas with similar temperature and precipitation regimes (see also Appendix F). The Future Range of Variability is just based on the ESR with the next warmer and drier condition from what the watershed is currently in. This is based on studies which suggest a warmer, drier future due to climate change (Gartner et al. 2008; Keene et al. 2009). There have been other studies suggesting different climate scenarios, particularly for Eastern Washington, so the FRV should be treated with caution.

Departures are identified as values occurring outside of the 80th percentile of historical values (HRV). The same thing is done with the Future Range of Variability. The 'Desired Condition' therefore rests in the overlap between the two. By comparing current conditions to both the historic and future reference conditions, managers are better able to assess options that mimic patterns and processes under which species have evolved, but also consider what resilient landscapes may look like in the future (Hessburg et al. 2013, 2015).

The photo-interpretation effort pulls out basic stand features that can be identified from the aerial photography- species, size classes, canopy cover, and layering. From these basic attributes, other attributes can be derived based on established rule-sets from the literature. In this way Cover Type, Potential Vegetation, Structure Class, and Late Successional Forest Habitat, among others, can be derived. The data can also be used to model habitat suitability for a wide variety of key wildlife species- using published descriptions of such habitat- and it can be used to estimate vulnerability to disturbances such as fire and insect/disease. A full set of original and derived attributes is listed in Table 1.

The modelling for the forest disturbance modules has been published in the works of Hessburg et al. 1999 and Ottmar et al. 1999. Insect and Disease ratings are established by giving each patch a vulnerability factor according to several criteria- site quality, host abundance, canopy structure, patch density, host age, patch vigor, and host patch connectivity. These ratings are all derived from the original photo-interpreted attributes and then grouped together for an overall rating. Fire modeling is done through the BEHAVE and CONSUME algorithms, where each set of patch attributes is assigned a fuel model number, and that model number forms the basis for the modelling.

Table 1. Terrestrial landscape evaluation photo-interpretation derived attributes

Vegetation*	**Wildfire Vulnerability**
Physiognomic type	Crown Fire Potential
Cover Type	Rate of Spread
Structure Class	Flame length
Med-Large Tree Presence	Fire Line Intensity
Late Successional - Old Forest	Fuel Loading
Remnant Large Tree	Fuel Consumption
	Smoke PM10
Wildlife Habitat	Smoke PM5
Northern Spotted Owl	
American Marten	**Insect Vulnerability**[+]
White-headed Woodpecker	Douglas-fir Beetle
Northern Goshawk	W. Spruce Budworm

*Note: See Appendix B for summary and description of vegetation and forest structural attributes.
+Insect Vulnerability was also calculated for a variety of other pathogens. These were not compared with reference conditions, but the data still exists

2.3 Aquatic Evaluation Methods

As with terrestrial ecosystems, aquatic patterns and processes are intricately linked. Stream channel geo-morphology and aquatic habitat patterning is a function of stream processes as well as upland watershed processes. The patterns influence processes and vice versa. By analyzing disruptions in patterns, disruptions in processes can be inferred.

For many forested environments in the Pacific Northwest, road networks are a major focus in an aquatic evaluation since they disrupt the natural timing and rate of water and sediment delivery to stream channels. In short, roads cause water to leave watersheds sooner and faster, which may lead to several negative ecological effects. The severity of these effects are influenced by road density, proximity to streams, surface condition, and slope. The analysis outlined below is intended to highlight where watershed road management may be used to reduce adverse impacts on aquatic habitat and water quality.

The aquatic evaluation includes several steps: 1) Calculation of biological condition indicator metrics per catchment based on focal fish distribution, potential habitat, and stream geomorphology; 2) Cataloging the inferred mechanisms of habitat impairment using smaller catchments for the unit of analysis; 3) Calculation of hydrological condition indicator metrics per catchment based on roads and riparian areas; 4) Use of a simple hydro-geomorphic model to estimate the percent increase in drainage area caused by roads; 5) Verification of hydrological condition on the ground, taking particular note of road network condition, erosion features, and fish passage barriers; 6) Providing a ranking based on these factors to prioritize and inform treatment options (USFS, 2015b).

The hydro-geomorphic model uses road, stream, and elevation data to determine potential areas of impact. The model provides four metrics to highlight areas of potential impact: 1) road density expressed as the ratio of road length to catchment area; 2) riparian road density expressed as the ratio of the total length of roads within a 300m buffer of streams and the total area of the riparian buffer area; 3) riparian road to stream length ratio expressed as the ratio of the total length of roads in the riparian buffer to the total length of streams; and 4) crossings per stream mile expressed as the ratio of stream crossings to the total stream length for each catchment. The values for these metrics where were binned into severity groupings. This scoring highlights areas with higher potential for impact due to higher instances of roads and particularly roads in the riparian area. The Aquatics Evaluation Metrics table (Appendix A) provides more information on the specific metrics used.

2.4 Data Collection

The upper two sub-watersheds of the project area (Lower Chiwawa and Big Meadow) were analyzed during the calendar year 2016, whereas the lower two (Lake Wenatchee and Beaver Creek) were analyzed in 2017. In both cases the photo-interpretation was performed with high resolution (25cm) stereo imagery acquired in 2014, and the delineations were done with the Summit software interfaced with ArcGIS. A rigorous Quality Assurance and Quality Control (QAQC) process was then implemented to insure consistency in the photo-interpretation. The upper two watersheds were field checked in the summer of 2016, while the lower two were done in the summer of 2017. The accuracy was assessed for the two project areas separately.

Overall agreeance of the interpretation with field data was deemed acceptable, with only 8% of the patches being completely miss-classified in the lower two watersheds. Agreeance for individual photo-interpreted attributes, however, was variable with some attributes scoring as low as 50% agreeance. Canopy cover was the attribute most often at variance with the ground, but that is an attribute that is notoriously difficult to estimate in the field. Otherwise there were some species calls that were off particularly on young, regeneration stands, and some confusion between medium and large trees in older multi-storied stands (USFS, 2017).

For the Aquatic analysis, data was collected at each road/stream crossing and along the roads themselves to highlight areas of concern. This data helped to verify the broad-scale applicability of the hydro-geomorphic assessment methods and to highlight/verify potential restoration projects. Catchments scoring high according to multiple ecological indicators, also showed high levels of riling, rutting, undersized culverts, and fish passage culverts.

3. LANDSCAPE EVALUATION SUMMARIES

3.1 Terrestrial Evaluation Summary

The Upper Wenatchee project area crosses large environmental gradients, extending from the lower elevation dry ponderosa pine forests to high elevation sub-alpine fir and white bark pine dominated forests. Table 2 shows the general characteristics and trends in the project area. In general, the area is heavily forested with dry forest ponderosa pine and Douglas-fir. These stands have reached a late successional stage, though not old-growth. They are dense stands with high canopy cover, multiple layers, and a medium to large overstory tree size. These conditions create good habitat for many species, but they also create conditions ripe for fire and insect and disease outbreaks. These dry, dense, young stands are also spatially arranged across the landscape such that they pose a huge risk for the spread of fire and insects across the landscape.

Table 2: General characteristics and trends for the Upper Wenatchee Project Area

ATTRIBUTE	GENERAL CHARACTERISTICS/TRENDS
Physiognomic Type	Mostly forest with some woodland and nonforest (of which water makes up a big part)
Cover Type	Dominated by Douglas-fir and ponderosa pine. These proportions overall are not different from reference conditions, though Douglas-fir cover is on the high end.
Structure Class/Late Successional Old Forest/Medium-Large Trees	Dominated by late successional but still young forest conditions. The percent of land in these 'young forest multi-story' stage is higher than in reference conditions. There are also quite a few old growth stands and stands with medium/large trees, particularly in the lower two watersheds
Structure/Cover/PVG	There is a great deal more dry forest Douglas fir stands in young-forest multi-story structures, than in reference conditions. Overall forest patches are smaller, but occur in greater density on the landscape. There are also many unique combinations forest cover/structure combinations that are overabundant, as they do not exist in reference conditions
Habitat	There is a great deal of suitable habitat for the Northern Spotted Owl on these landscapes, and smaller, though still notable amounts of habitat for White-headed Woodpecker, American Marten, and Northern Goshawk. The amount of Spotted Owl habitat is on the high end or even departed from reference conditions, and the same is true for White-headed Woodpecker
Fire	The fire metrics mostly fall within reference conditions, although the arrangement of fuels across the landscape is departed. The density of high risk fire areas is spread out evenly throughout the landscape in small but dense patches.
Insect/Disease	A large portion of the landscape is under high risk of disease outbreak for Douglas-fir beetle and Western Spruce budworm. This high percentage of the landscape is well above reference conditions especially in the lower two watersheds.

Table 3 gives the break-down for each sub-watershed by cover type, structure class, habitat, and insect and disease risk. The four sub-watershed are all dominated by Douglas-fir and ponderosa pine, but in the upper reaches, they also contain a fair amount of Lodgepole Pine, Sub Alpine Fir, and even some Western Hemlock, Grand Fir and Pacific Silver Fir. The actual level of Grand-Fir presence is not adequately captured in the cover type, however, as Grand Fir is often a co-dominant species with Douglas-fir, so many of the Douglas-fir stands also contain a large component of Grand Fir. Down in the valley there is also a fair amount of urban and agriculture lands, as well as shrubland and herbland. In Lake Wenatchee, the Lake itself represents some 23% of the total area (non-forest).

In terms of structure, the majority of the area falls into the young forest multi-story (YFMS) structural class and this represents a significant departure from both historical and future reference conditions. These young, multi-storied forest patches also represent late successional forest, and they contain a fair amount of medium and large trees- attributes which also represent a departure from reference conditions. Furthermore, many of these larger trees qualify as 'Remnant Large' trees- as they are contained in structure classes other than old forest. That being said, there is still a fair amount of old forest multi-story- particularly in the Lake Wenatchee sub-watershed.

These young, multi-storied conditions place the area at high risk for fire and insect/disease outbreaks. The area classified as having a high risk of Crown Fire is over 30% for each watershed, with similar percentages for each of the other fire metrics in the 'high' category. These metrics are all on the high end of the historical range of variability, although not necessarily departed. For insect and disease, Beaver Creek in particular comes out highly vulnerable, with 62% of the area at high risk for Douglas-fir Beetle, and 84% for Western Spruce Budworm.

Figures 2 to 7 show the distribution of forest types and their derived characteristics across the landscape. Here the relationship between the different elements can be seen visually: the dominant matrix of young-forest multistory Douglas fir, is also largely the area that is suitable Spotted Owl Habitat, and yet the area at most risk for Crown Fire and Douglas-fir beetle outbreak.

Table 3: Biophysical composition of the Upper Wenatchee project area. Values show percent of land in each attribute category, and highlighted areas show percentages that are departed from the historic and future range of variability

ATTRIBUTE	BEAVER CREEK	LAKE WENATCHEE	BIG MEADOW	LOWER CHIWAWA
DERIVED				
Physiognomic Type	75% Forest 15% Woodland 6% NonForest 4% Herbland 0% Shrubland	61% Forest 10% Woodland 23% NonForest 1% Herbland 5% Shrubland	79% Forest 6% Woodland 5% NonForest 5% Herbland 5% Shrubland	83% Forest 11% Woodland 3% NonForest 2% Herbland 2% Shrubland
Cover Type	48% PSME 36% PIPO 6% Other 4% Herb	39% PSME 17% PIPO 23% Other 7% ABLA2	41% PSME 26% PIPO 15% ABLA2 10% Shrub	62% PSME 23% PIPO 5% PIAL 4% ABLA2
Structure Class	59% yfms 12% seoc 7% si 6% ofms 6% other	37% yfms 23% other 16% ofms 7% seoc 7% ur	31% yfms 26% ur 11% secc 10% shrub 10% seoc	55% yfms 12% ur 12% si 12% seoc 4% shrub
Late Successional Old Forest	44% ls 6% ofms	23% ls 16% ofms	36% ls 0% ofms	53% ls 2% ofms
Med-Large Tree	45% medium 6% large 28% med/large	25% medium 4% large 31% med/large	52% medium 0% large 0% med/large	64% medium 1% large 2% med/large
Remnant Large Tree	28% remnant large	18% remnant large	0% remnant large	0% remnant large
MODELLED				
Habitat (Yes)	14% Woodpecker 9% Goshawk 2% Marten	5% Woodpecker 11% Goshawk 7% Marten	0% Woodpecker 44% Goshawk 6% Marten	5% Woodpecker 55% Goshawk 2% Marten

	39% Spotted Owl	30% Spotted Owl	35% Spotted Owl	49% Spotted Owl
Fire Risk (High)	34% Crown Fire Potential 45% Rate of Spread 25% Flame Length 27% Fire Line Intensity	31% Crown Fire Potential 28% Rate of Spread 25% Flame Length 26% Fire Line Intensity	49% Crown Fire Potential 29% Rate of Spread 16% Flame Length 17% Fire Line Intensity	50% Crown Fire Potential 33% Rate of Spread 15% Flame Length 16% Fire Line Intensity
Insect/Disease (High)	62% Douglas-fir Beetle 84% W. Spruce Budworm	39% Douglas-fir Beetle 66% W. Spruce Budworm	17% Douglas-fir Beetle 69% W. Spruce Budworm	18% Douglas-fir Beetle 67% W. Spruce Budworm

- Cover: PIPO= Ponderosa Pine; PSME= Douglas-fir; ABLA2= Subalpine Fir; PIAL= Whitebark Pine;
- Structure: si= stand initiation; seoc= stem exclusion open canopy; secc= stem exclusion closed canopy; ur= understory re-initiation; yfms= young forest multi-story; ofms= old forest multi-story; ofss= old forest single story; ls= late successional

Text- Departure from HRV and FRV (Increase)   Text- Departure from HRV and FRV (Decrease)

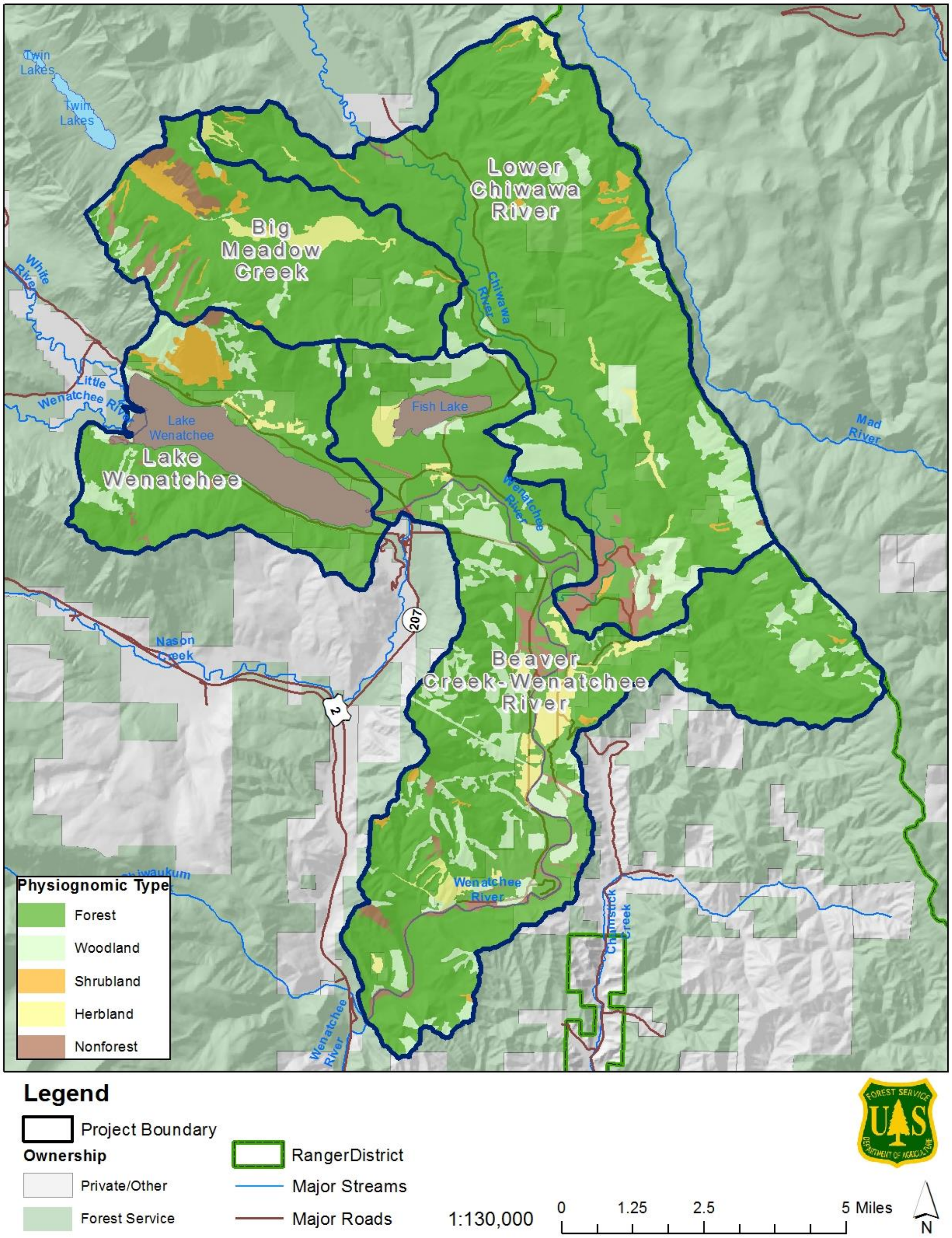


Figure 2. Physiognomic Type distribution for the Upper Wenatchee project area

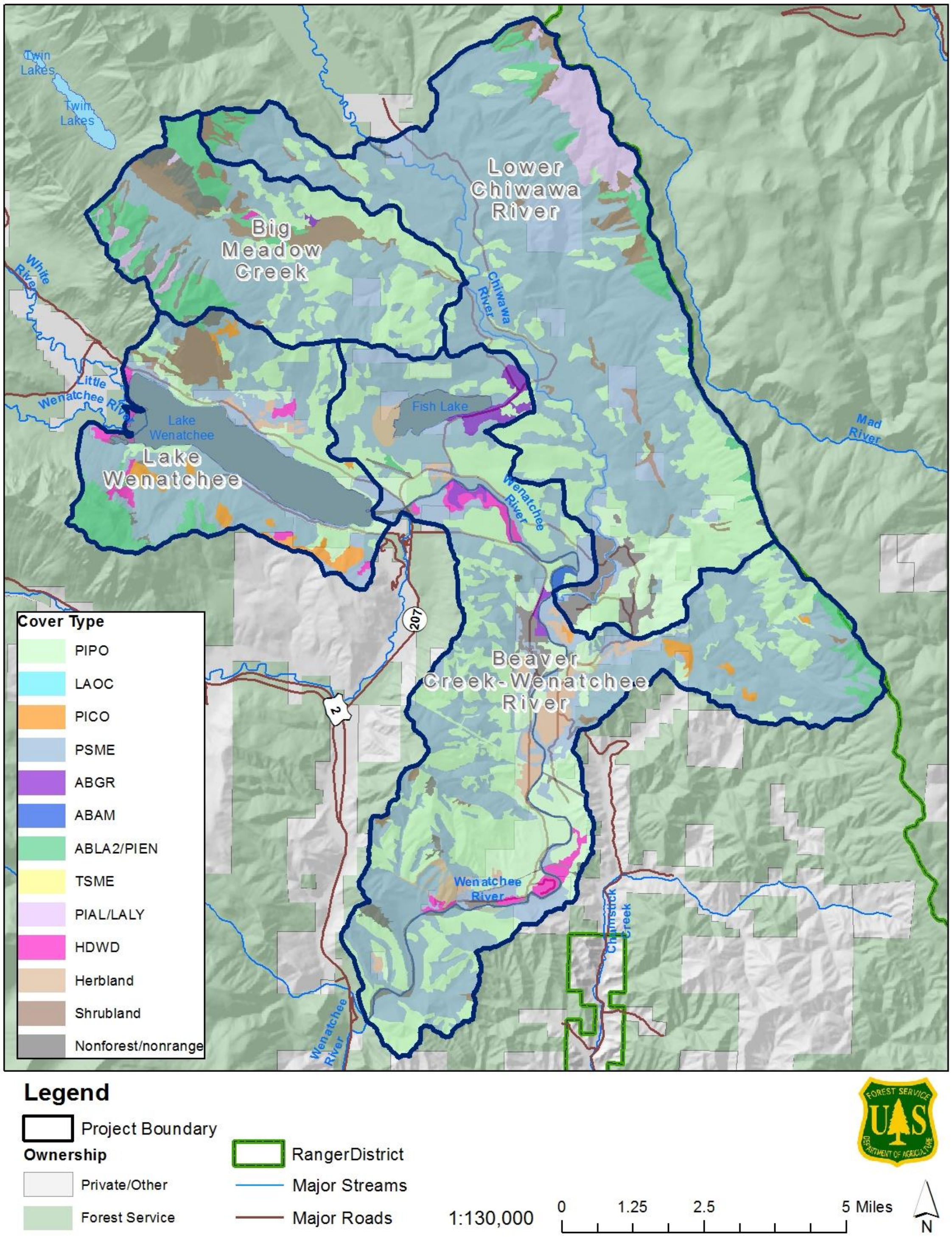


Figure 3. Derived Cover Types for the Upper Wenatchee project area

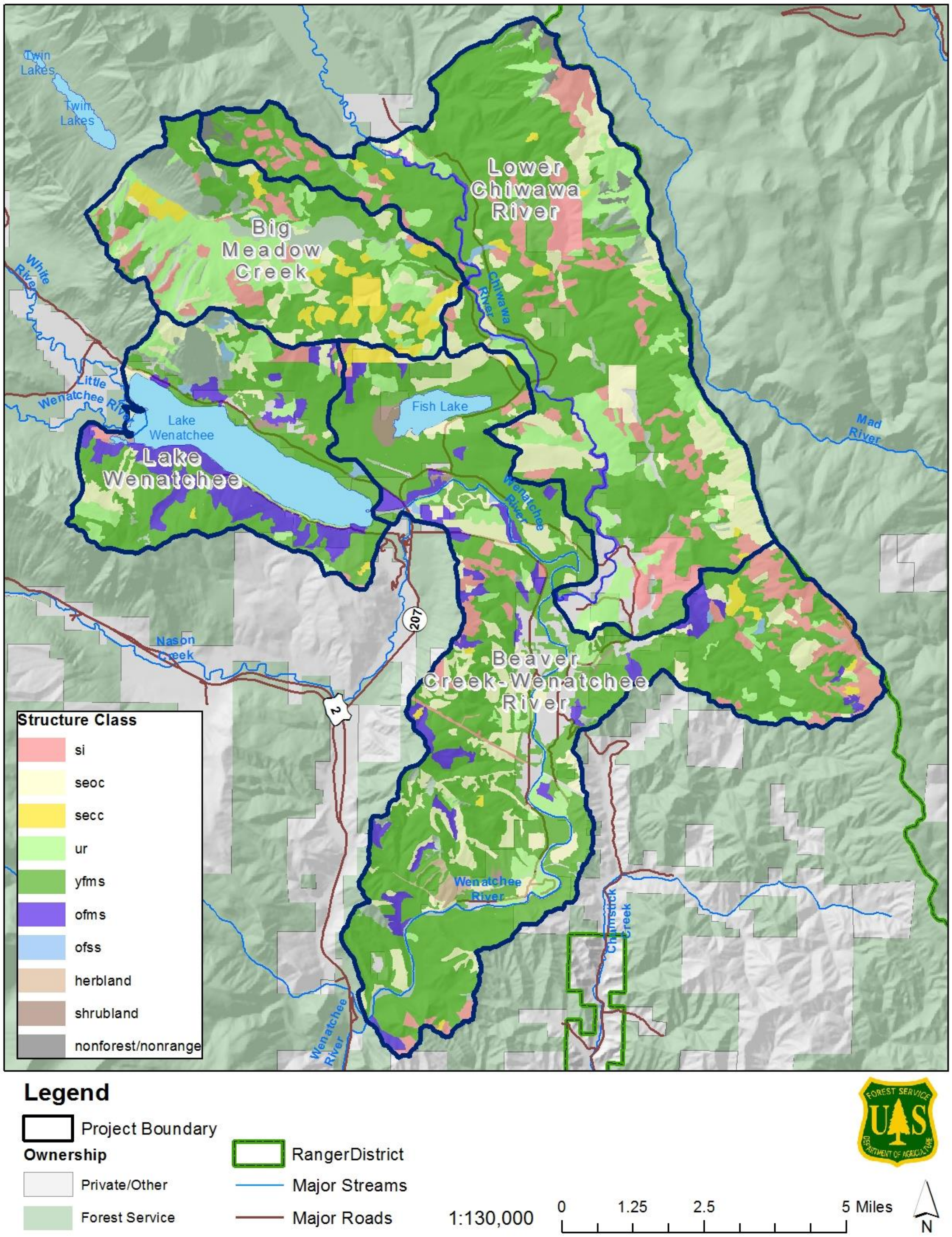


Figure 4. Derived Structure Classes for the Upper Wenatchee project area

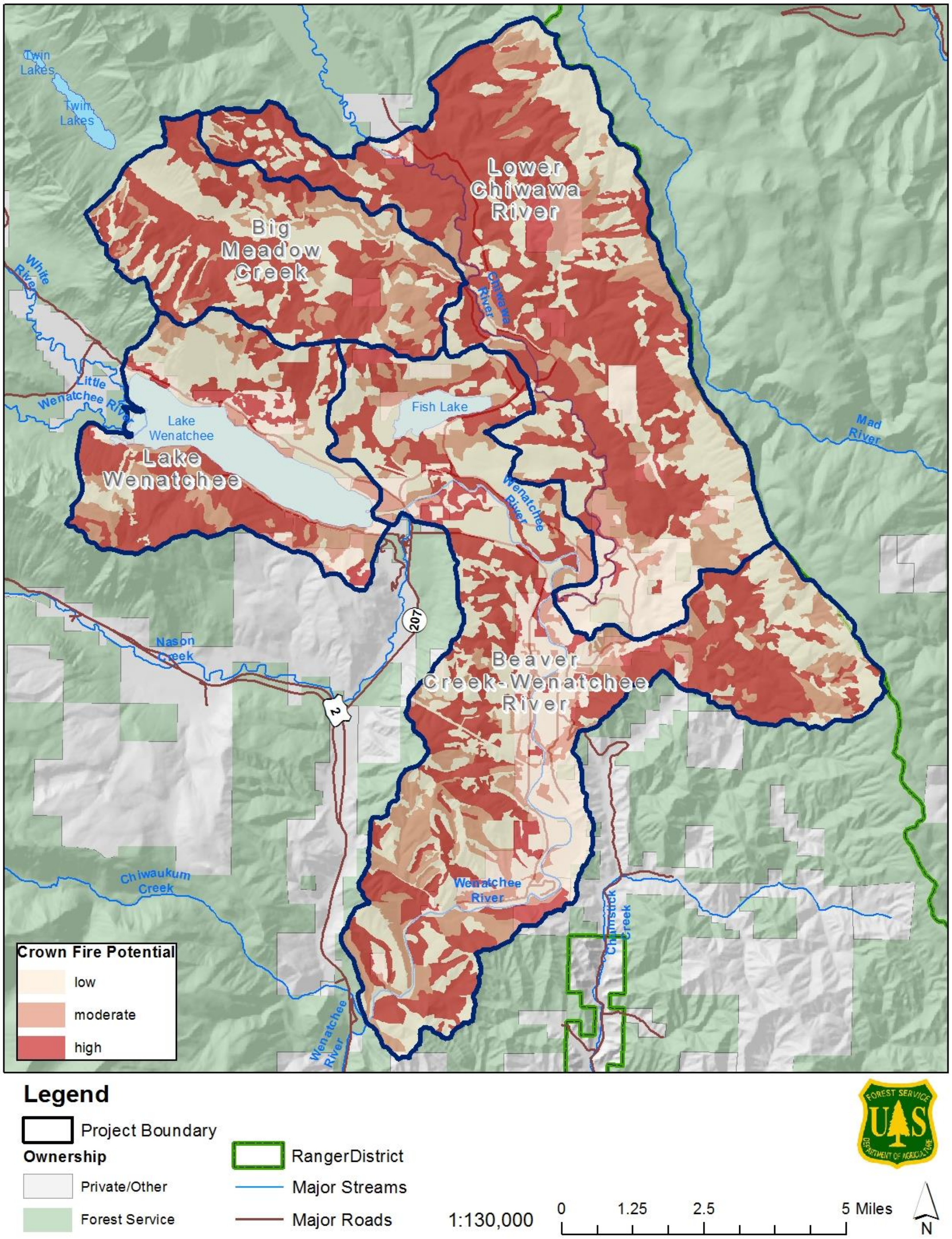


Figure 5. Crown fire potential vulnerability for the Upper Wenatchee project area

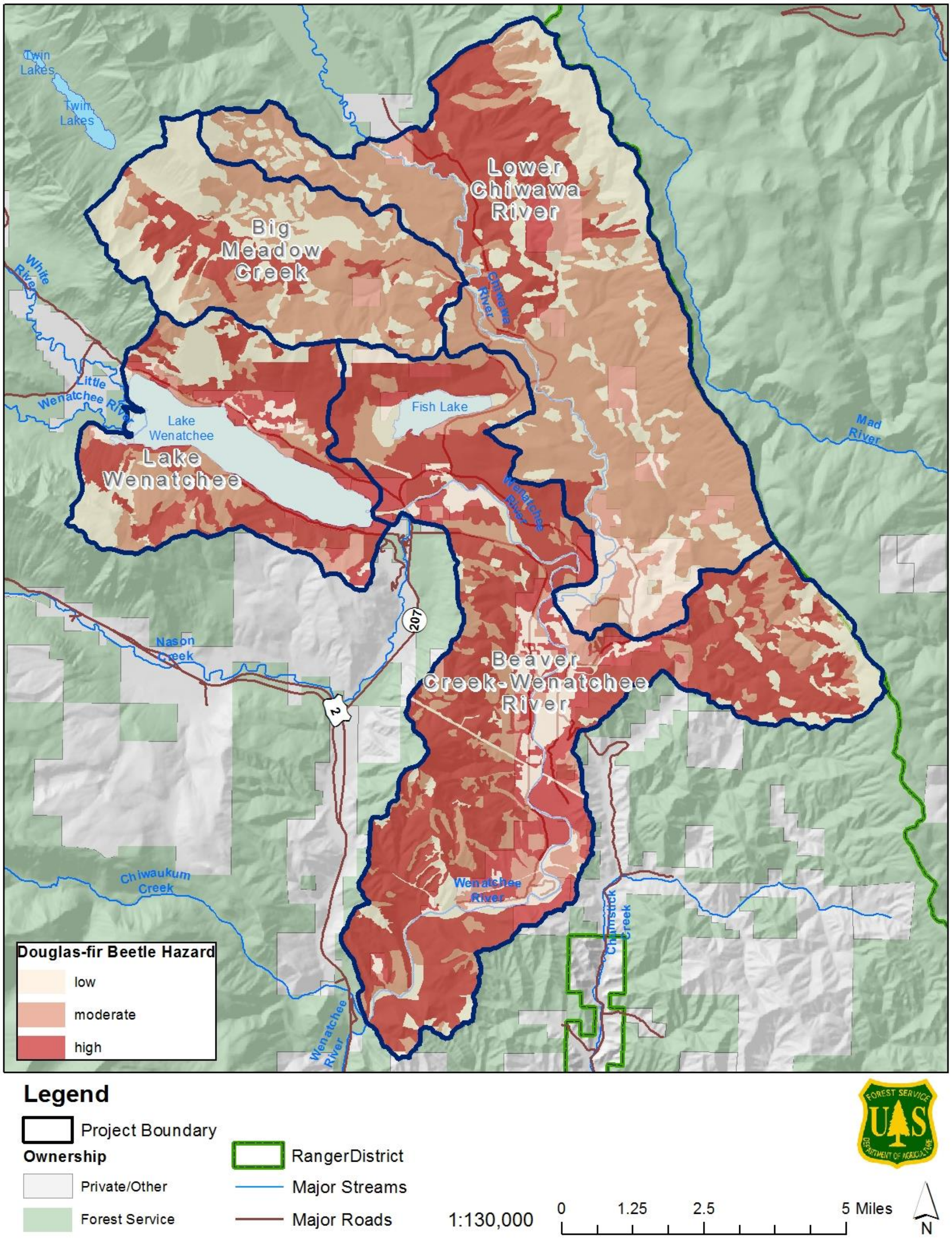


Figure 6. Douglas-fir beetle vulnerability for the Upper Wenatchee project area

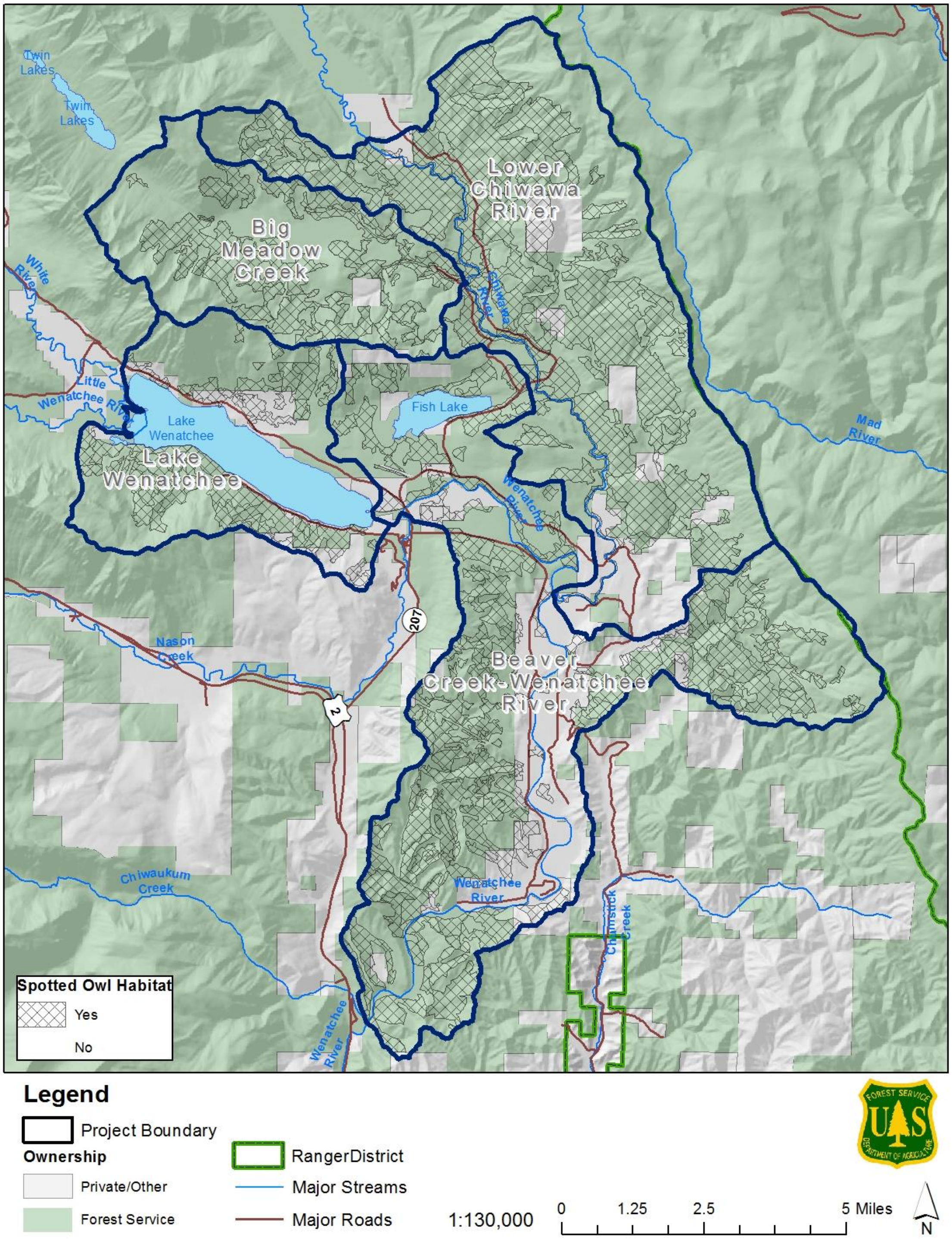


Figure 7. Spotted Owl habitat suitability for the Upper Wenatchee project area

Central to the landscape evaluation process is comparing not just how the abundance of the vegetation, wildlife habitat, wildfire and insect measures may have departed from HRV/FRV, but also how the spatial patterns may have departed. "Spatial pattern" refers to the size, shape, and configuration of patches as defined by vegetation, wildlife habitat, wildfire and insect measures. These spatial patterns are a critical drivers of ecosystem processes and functioning (Hessburg et al. 2015). For example, simply evaluating the amount of Northern Spotted Owl habitat within a sub-watershed does not capture whether that habitat is fragmented across many small patches or aggregated together in few large patches. Similarly, the distribution of vegetation patch sizes has a significant influence on the spread of fire across a landscape (Hessburg et al. 2015).

Within each of the sub-watersheds, there are several different spatial metrics that can be used to compare each vegetation, wildlife habitat, wildfire, and insect/disease measure to HRV and FRV reference conditions (Table 4). Table 5 shows some of the most significant departures according to spatial arrangement of patches, across the four sub-watersheds.

Table 4. Spatial metrics used in terrestrial landscape evaluations

Class Metrics	**Basic Interpretation**
Percent Land	Percentage of the landscape occupied by a given class type. Ecologically important in describing landscape composition
Mean Patch Size	Average patch size for a class type across a sub-watershed. Represents the typical patch size. An important component of habitat quality.
Patch Density	Number of patches on the sub-watershed by patch type (class). Indicates how fragmented is a given class type.
Mean Nearest Neighbor	Average distance between any given patch and the closest patch of the same class. Represents the isolation of individual patches.
Largest Patch Index	Quantifies the percentage of total landscape area represented by the largest patch.
Landscape Metrics	
Contagion	How easy it is to move within a patch type, aggregated across all patch types present on the landscape. A measure of the connectivity within each class type.
Interspersion - Juxtaposition	How intermixed patches are across the sub-watershed. Reflects the ability to move from one patch type to all other patch types.
Patch Richness	The number of different patch types on the landscape.
Shannon Diversity Index	A measure of diversity across the landscape. Sensitive to rare patch types
Hill's Diversity Index N1	Represents the number of 'abundant' species.

Table 5: Primary departures for the four watersheds of the Upper Wenatchee project area. These are areas departed according to both HRV and FRV. Highlighted cells show percent land departures*

ATTRIBUTE	Beaver Creek	Lake Wenatchee	Big Meadow	Lower Chiwawa
Physiognomic Type			More herbland	
Landscape Metrics	N/A	N/A	N/A	N/A
Class Metrics	Increased Patch Density (woodland)	Increased Mean Patch Size (shrubland, nonforest)	Increased Patch Density (shrubland, woodland) Increased Mean Patch Size (herbland) Decreased Mean Patch Size (woodland)	N/A
Cover Type		More Hardwood	More Shrubland	More Douglas-fir, Whitebark Pine
Landscape Metrics	Increased Patch Richness	N/A	N/A	N/A
Class Metrics	Decreased Mean Patch Size (PIPO) Increased Mean Patch Size (TSHE)	Increased Patch Density (PIPO, PSME, HDWD) Increased Mean Patch Size (HDWD, Shrub, Other)	Increased Patch Density (PIPO, PSME, PIAL, Shrub) Increased Mean Patch Size (HDWD)	Increased Patch Density (PIPO, Shrub) Increased Mean Patch Size (PIAL)
Structure Class	More Young Forest Multi-Story	More Young Forest Multistory		More Young Forest Multistory
Landscape Metrics	N/A	N/A	Decreased Contagion	N/A
Class Metrics	Increased Patch Density (SEOC, OFMS) Decreased Mean Patch Size (UR)	Increased Patch Density (OFMS) Decreased Mean Patch Size (UR)	Increased Patch Density (SI, SEOC, SECC, UR) Decreased Mean Patch Size (SEOC)	Increased Patch Density (SI)
Late Successional and Old Forest (LSOF)	More Late Successional Forest	More Non Forest Less Other Forest		More Late Successional Forest
Landscape Metrics	N/A	Decreased Contagion Increased Diversity Indices	N/A	N/A
Class Metrics	Increased Patch Density (LS, OFMS)	Increased Patch Density (LS, OFMS)	Increased Patch Density (LS)	
Habitat (yes)	More Spotted Owl Habitat	N/A	More Goshawk Habitat	More Goshawk Habitat; More Spotted Owl Habitat

Landscape Metrics	Decreased Contagion (NSO_HAB) Increased Diversity Indices (NSO_HAB)		Decreased Contagion (GH_HAB, NSO_HAB) Increased Diversity Indices (GH_HAB)	Decreased Contagion (GS_HAB, NSO_HAB) Increased Diversity Indices (GH_HAB, NSO_HAB)
Class Metrics	Increased Patch Density (WH_HAB, GH_HAB, AM_HAB, NSO_HAB)	Increased Patch Density (WH_HAB, GH_HAB, NSO_HAB)	Increased Patch Density (GH_HAB, NSO_HAB)	Increased Mean Patch Size (NSO_HAB)
Fire (high)			Less Fire Line Intensity	Less Fire Line Intensity
Landscape Metrics	Decreased Contagion (RCF, RATE) Increased Diversity Indices (RATE)	Decreased Contagion (FLAME, INT, Fuel, CONS) Increased Diversity Indices (FLAME, INT, Fuel, CONS)	Decreased Contagion (Fuel)	Increased Contagion (INT) Decreased Diversity Indices (INT)
Class Metrics	Increased Patch Density (RCF, RATE, FLAME, INT, Fuel, CONS, PM5) Decreased Mean Patch Size (RATE)	Increased Patch Density (Fuel, CONS, PM5)	Increased Patch Density (RCF, FLAME, INT, Fuel, CONS, PM5) Decreased Mean Patch Size (FLAME, INT, CONS, PM5)	Increased Patch Density (RATE, FLAME, INT) Decreased Mean Patch Size (FLAME, INT)
Insect/Disease (high)	More Douglas-fir Beetle risk More Western Spruce Budworm risk	More Douglas-fir Beetle risk		
Landscape Metrics	N/A	Decreased Contagion (DFB) Increased Diversity Indices (DFB)	Decreased Contagion (DFB)	N/A
Class Metrics	Increased Patch Density (DFB)	Increased Patch Density (DFB)	N/A	N/A

** Not all departures are listed here, for more see the full dataset*

- Cover: PIPO= Ponderosa Pine; PSME= Douglas-fir; TSHE= Western Hemlock; HDWD= Hardwoods; PIAL= Whitebark Pine
- Structure/LSOF: SI= stand initiation; SEOC= stem exclusion open canopy; SECC= stem exclusion closed canopy; UR= understory re-initiation; YFMS= young forest multi-story; OFMS= old forest multi-story; OFSS= old forest single story; LS= late successional
- Habitat: WH_HAB= White-headed Woodpecker Habitat; GH_HAB= Goshawk Habitat; AM_HAB= American Marten Habitat; NSO_HAB= Northern Spotted Owl Habitat
- Fire: RCF= Running Crown Fire Potential; RATE= Rate of Spread; FLAME= Flame Length; INT= Fire Line Intensity; Fuel= Fuel Loading; CONS= Fuel Consumption; PM5= Smoke Production Particulate Matter 5 microns
- Insect/Disease: DFB= Douglas-fir Beetle; WSB= Western Spruce Budworm

Over most attributes, there is an increase in patch density and a corresponding decrease in mean patch size. This relationship holds so long as the percent of the landscape has not changed, and it reflects a fragmentation of the landscape. This is further illustrated in the landscape metrics, which show increases in patch richness and diversity (both Shannon's and Hill's indices) and decreases in contagion. The patch types most affected by this fragmentation are the younger forest structures (stand initiation, stem exclusion open canopy, stem exclusion closed canopy, and understory re-initiation) that have regrown after past management activities. The cover types for these patches is often ponderosa pine, as it planted this way in plantations or grew up naturally as an early seral species. Sometimes Douglas-fir has been the dominant cover type to regenerate, while other times the patch has not reforested at all and has come back as shrubland or hardwoods.

The area surrounding these patches of past treatments is generally young forest multistory, and this has greatly increased on the landscape with respect to historic conditions. Visually it appears as if this young forest multistory is the dominant matrix from which patches have been removed (Figure 4). This area has been largely untouched in recent years, but it is still a relic of past logging and disturbance, such that it has not reached old-growth status yet. Nonetheless it has reached a late successional stage and has become good habitat for many wildlife species, particularly the Northern Spotted Owl. At the same time, this area is also the most vulnerable to fire and insect and disease. It is largely composed of Douglas-fir and is thus a host for Douglas-fir beetle and Western Spruce budworm. The dense, multilayered conditions create ideal conditions for the spread of pathogens as well as the spread of fire.

The derived attributes of structure, habitat, and disturbance classes also reflect this fragmentation, with high patch densities, decreased contagion, and increased patch diversity. For habitat, this is obviously a problem as the fragmented habitat types restrict species movement and dispersal. For disturbances- fire and insect/disease- the fragmentation might be seen as a good thing, but it also just distributes the high risk areas throughout the landscape, so instead of having a single large contiguous portion of the landscape under high risk, there is large portion of the landscape dispersed throughout. Also much of the remainder still is at moderate risk.

Overall, the Upper Wenatchee Landscape is a product of its history. The legacy of logging in the early to mid-part of the 20th century, followed by a sudden drop in logging pressure and fire suppression, has led to major changes on the landscape. Legacy old growth forests have been largely removed by past logging, while new forests growing up since have been shielded from fire disturbance. This has led to the creation of dense, multi-layered, young stands. These patches provide potentially good habitat for a variety of species, particularly Northern Spotted Owl, however they are also very much at risk to fire and insect and disease. These disturbances have been held back for so long that they have not been able to become an integral part of the stand's development, as was the case in the past. In addition, settlement, recreation, and other human use has led to the creation of a much broader suite of cover/structure types than would have existed traditionally, and this has likely been exacerbated by past forest management activities. Thus numerous patch types exist in a scattered pattern throughout the landscape leading to a very fragmented landscape. The patches are arranged in such a way that they maximize richness and diversity of patches, while minimizing the contagion or connectivity of the landscape.

3.2 Aquatic Evaluation Summary

Aquatic Biota Assessment:

The Chelan Pilot project area supports multiple threatened or endangered fish species including steelhead (*Oncorhynchus mykiss)*, bull trout (*Salvelinus confluentus)*, and spring Chinook (*Oncorhynchus tshawytscha)*. Over the whole four sub-watersheds, up to 48.1 miles of stream have one or more of these focal species (Table 6, Figure 8).

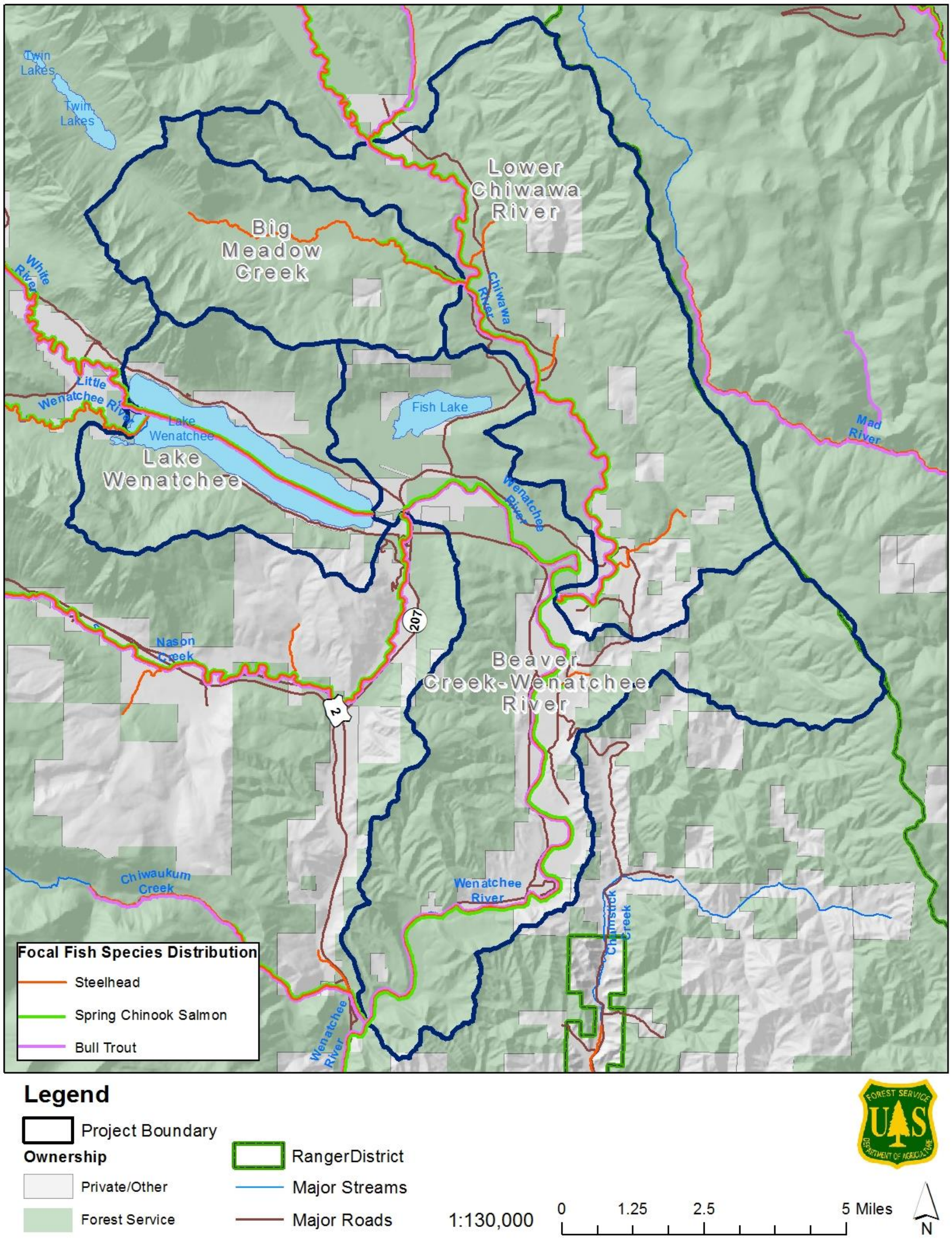


Figure 8. Current distribution for focal fish species in the Upper Wenatchee project area

Table 6. Miles of current habitat for focal species in the Upper Wenatchee project area

	Fish Species		
Sub-Watershed	**Bull Trout**	**Spring Chinook Salmon**	**Steelhead**
Beaver Creek-Wenatchee River	17.8	18.2	18.8
Big Meadow Creek	0.4	2.1	6.4
Lake Wenatchee	5.0	5.0	5.0
Lower Chiwawa River	14.1	14.1	17.9
Grand Total	**37.3**	**39.4**	**48.1**

Habitat connectivity for Chinook salmon, bull trout and steelhead is good in the Chiwawa River and Wenatchee River but limited in most of the tributaries. The main-stem rivers are key migration corridors for all three species, and key areas for juvenile steelhead rearing (USFS 1997). Tributaries to these main channels, however, may also include good potential habitat that is not currently being used.

Intrinsic Potential Habitat can be evaluated using complex models involving stream gradients, geology, geomorphology, and topography considerations (UCSRB, 2007). However the primary driver of these models appears to be gradient. Stream gradients can be extracted easily using GIS, and then classified by gradient thresholds to map areas potentially capable of supporting fish populations. The gradient thresholds for each species has been determined as follows: <4% for spring Chinook, <7% for steelhead, and <10% for bull trout. Some studies have suggested higher gradient thresholds for intrinsic potential, which would increase the potential range of these species, but on the other hand other models suggest more restrictive ranges (UCSRB, 2007; WDFW, 2009).

Based on the break points listed above, there are some 109 miles of potential habitat in the Upper Wenatchee area that are not currently supporting fish populations, and much of this may be due to barriers to fish passage. According to the WDFW fish barrier inventory, 23 of the 70 catchments in the four sub-watersheds have potential road related barriers to aquatic organism passage. These barriers may block up to 42 miles of potential habitat for the focus fish species, primarily due to culverts that impede fish passage (Table 7, Figure 9). The creeks with potential blocked habitat are listed in Table 8.

Table 7. Miles of potential habitat for focal species in the Upper Wenatchee project area

Potential Habitat	Sum of Miles
Blocked Potential	
0 -4% (Spring Chinook)	15.21
0 -7% (Steelhead)	28.86
0 - 10% (Bulltrout)	41.96
Unblocked Potential	
0 -4% (Spring Chinook)	32.43
0 -7% (Steelhead)	50.70
0 - 10% (Bulltrout)	67.27

Table 8: Principle creeks potentially affected by fish passage barriers

Creek Name	Sum of Miles
Blocked Potential	**41.96**
Alder Creek	2.87
Big Meadow Creek	1.61
Brush Creek	2.35
Clear Creek	0.45
Deep Creek	1.97
Elder Creek	0.42
Fall Creek	0.06
Gate Creek	1.62
Goose Creek	1.01
Grouse Creek	0.70
South Fork Beaver Creek	2.43
Twin Creek	0.54
(blank)	25.91

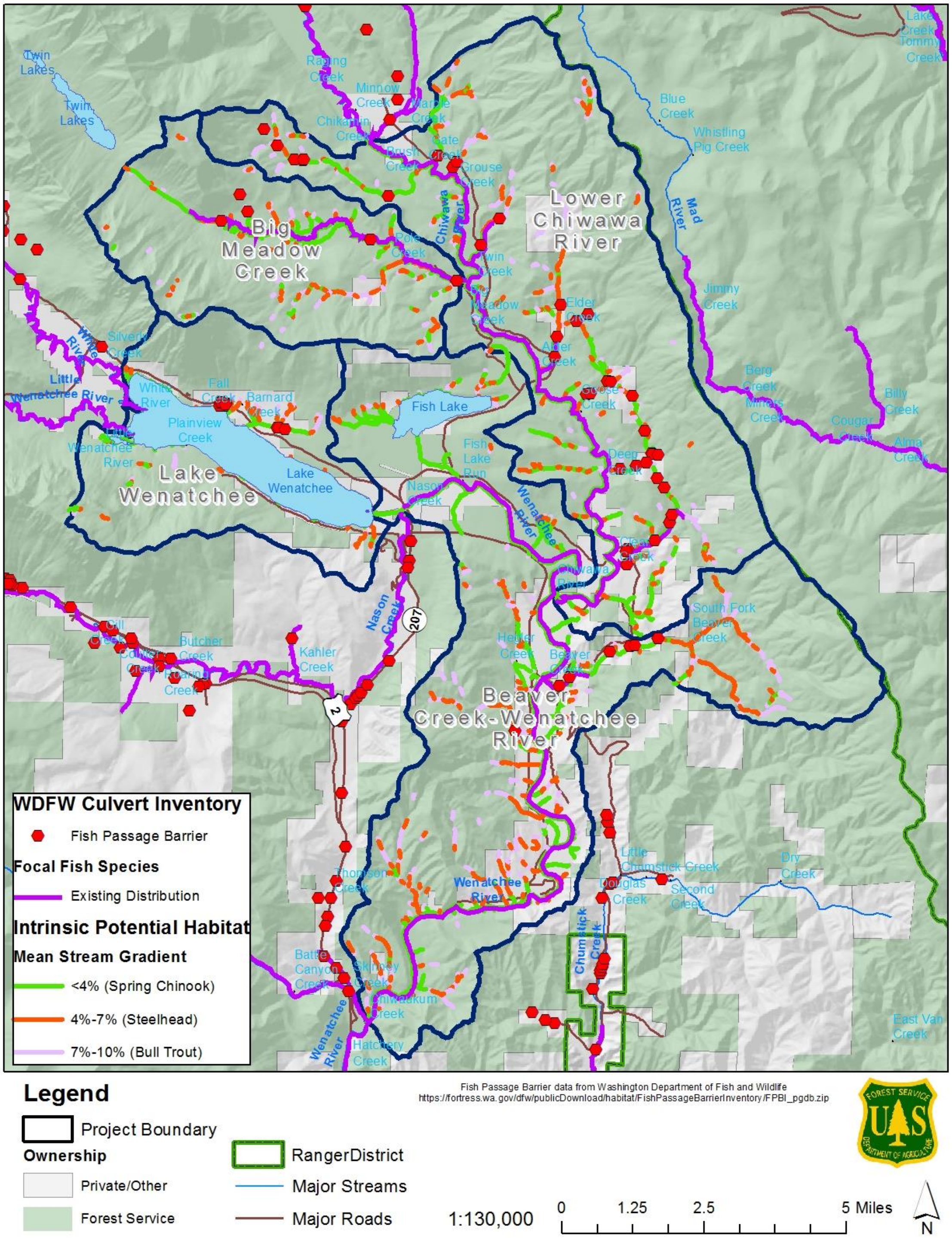


Figure 9. Fish intrinsic potential habitat based on stream gradient and probable blockage locations

Stream surveys in the Lower Chiwawa and Big Meadow watersheds reveal certain geo-morphological characteristics that may also impact how fish are using these water systems (Figures 11 and 12). The main stem of the Chiwawa, as well as Meadow Creek, Alder Creek, and Clear Creek have moderate to high bankfull width to depth ratios (BFWD) and low to moderate entrenchment ratios. No Forest Service stream surveys exist for the lower two watersheds (Lake Wenatchee and Beaver Creek), but a detailed reach assessment of the main stem Wenatchee River was recently conducted by Yakima Nation Fisheries (YNF, 2012). This data shows a similar situation for the Wenatchee, with a shallow but incised stream channel that is often not able to access its floodplain. The assessment notes that some of this is due to geological constraints: parts of the channel are confined by glacial terraces and thus are not able to meander and create for complex habitat. In these reaches, stream energy is higher, geomorphic processes of channel migration, avulsion, braiding, and sediment deposition are limited, and this leads to less potential fish habitat (Figure 10).

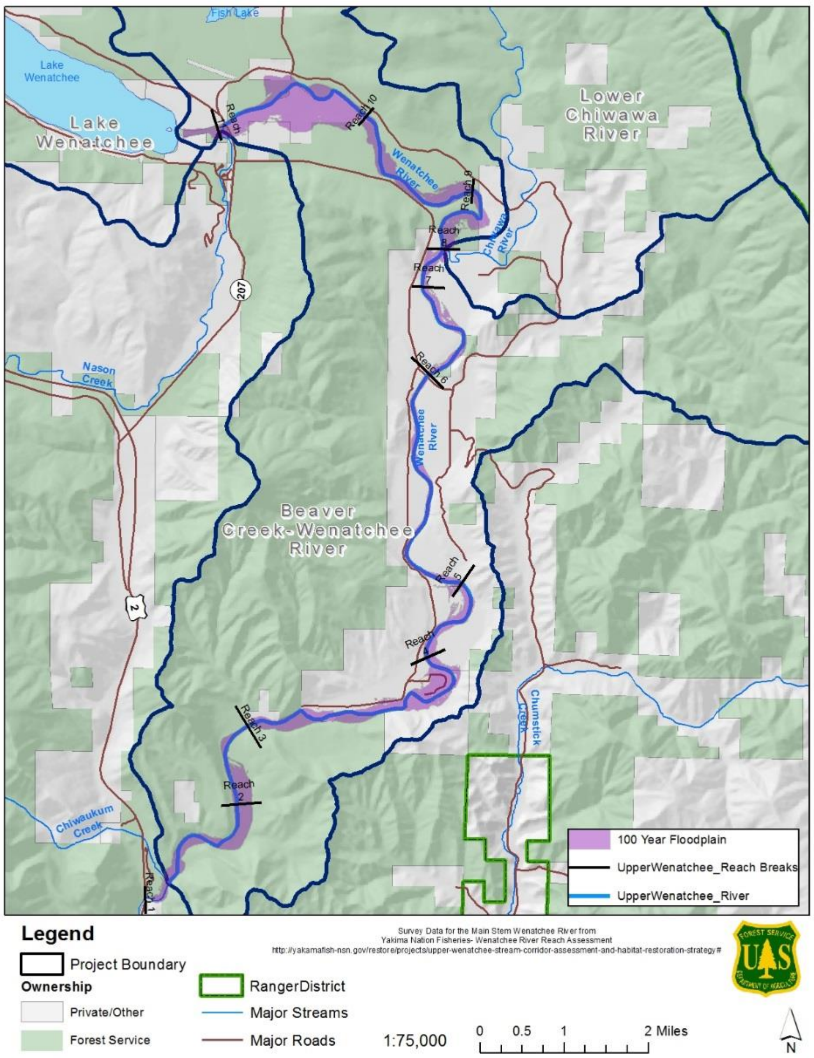


Figure 10: Reach assessment areas for the Upper Wenatchee River

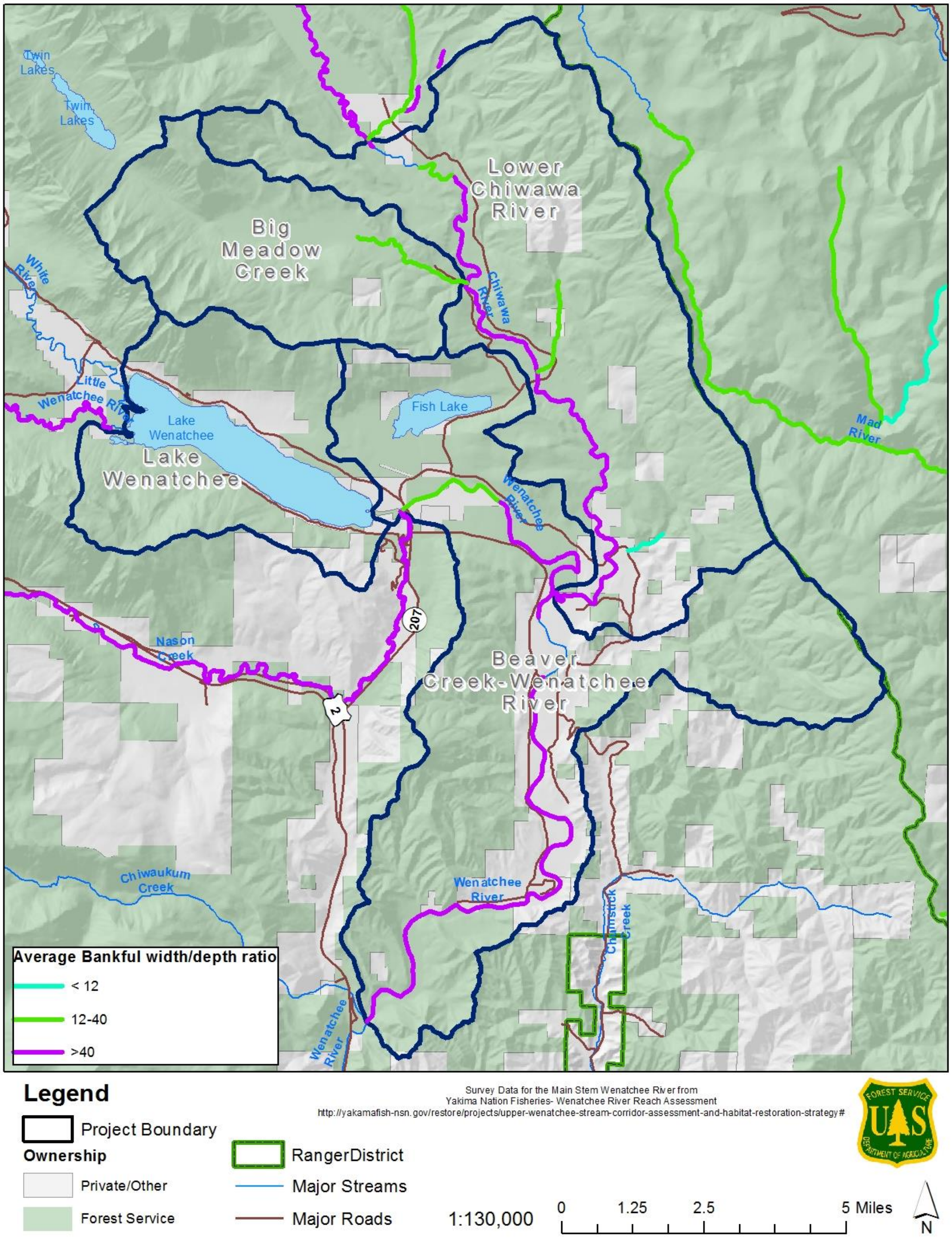


Figure 11: Bankfull Width to Depth Ratio values for surveyed streams in the Upper Wenatchee project area

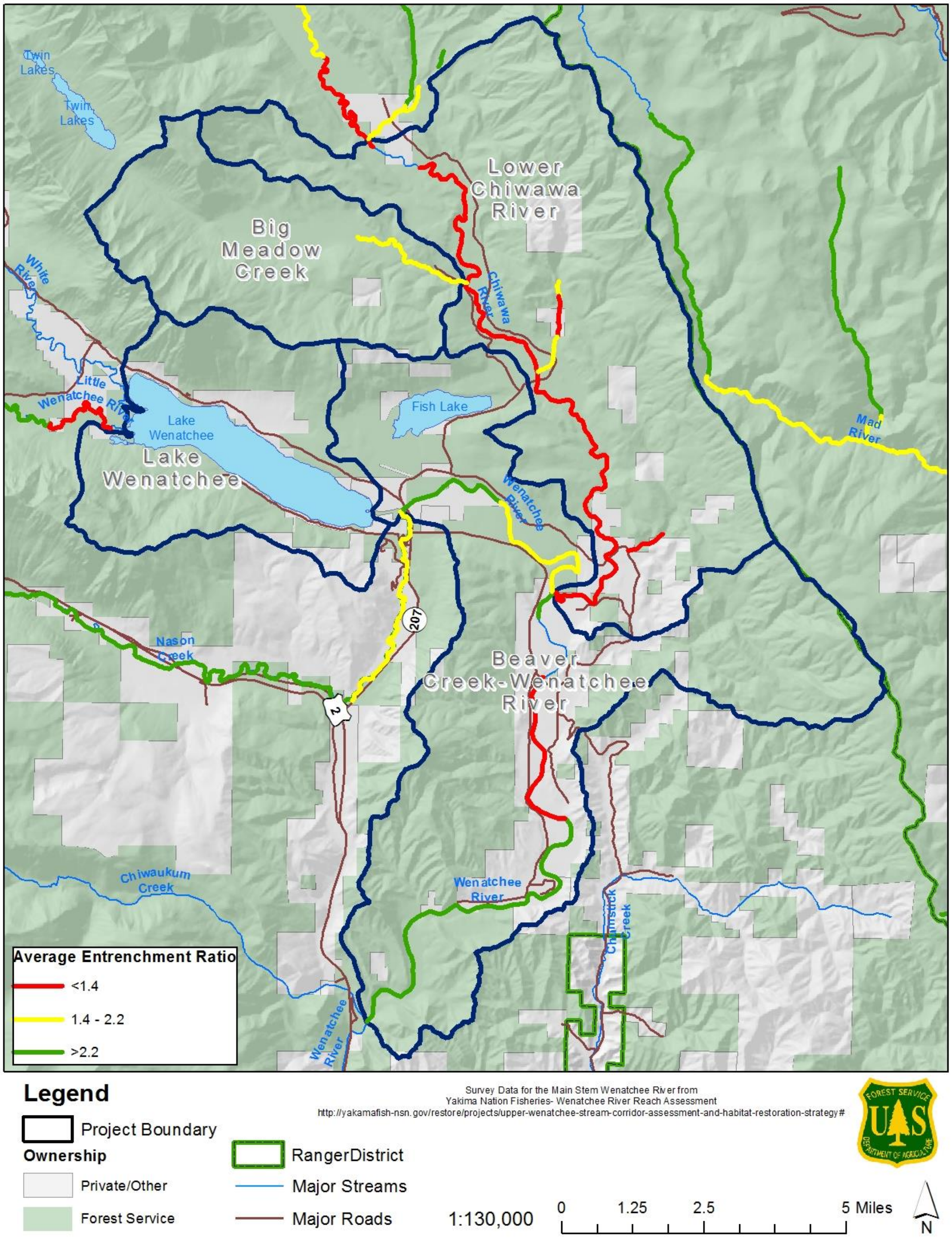


Figure 12: Entrenchment Ratio values for surveyed streams in the Upper Wenatchee project area

According to the Rosgen Stream Classification system (Rosgen, 1996), the Lower Chiwawa and Wenatchee main stem is a Type F stream. These streams are by nature deeply incised in valleys of low relief with highly weathered rock, for example in glacial outwash. They have a naturally occurring high channel width to depth ratio and low entrenchment ratio. Therefore the conditions observed on these stream channels are not necessarily evidence of departure. Nonetheless, both rivers have a long history of land-use which may have contributed to existing channel conditions, and has definitely altered habitat availability. Both the Wenatchee and the Lower Chiwawa have seen road development and riparian vegetation removal associated with urban development on private land, as well as the annual log drives that were known to have occurred in the early 1900’s. Furthermore the channel conditions on some of the side drainages do show departures from classic Rosgen stream types. Meadow Creek, Alder Creek, and Clear Creek all show signs of entrenchment, and these are in Type B or C streams where this level of entrenchment would not be expected, and is likely a reflection of impacts from past ground disturbance activities. In Meadow and Brush Creek drainages, timber harvest was known to be initiated in the late 1950’s or early 1960’s and continued into the late 1980’s, harvesting approximately 35% of the total acreage in these watersheds (USFS 1997). Some roads and harvest units were located in the riparian zone, triggering stream channel instability.

The Upper Wenatchee reach assessment documents current geomorphic and habitat conditions for each reach of the Wenatchee. These were given qualitative rankings in terms of their functionality with respect to habitat quality, channel dynamics and riparian condition (Table 9). The majority of the reaches scored as ‘at risk’ or ‘unacceptable’ for these characteristics. In particular reaches 4 through 7 were found to be mostly unacceptable due to the heavy impact of human activities including residential development, roadways, and floodplain alteration. (YNF, 2012).

Table 9: Summary of geomorphic and habitat conditions by reach of the Upper Wenatchee River

General Characteristics	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11
Habitat Assessment	Physical Barriers	Main Channel Barriers	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate	adequate
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	adequate	adequate	adequate	at risk	adequate	adequate	adequate	at risk	at risk	adequate	adequate
	LWD	Pieces per mile at bankfull	adequate	unacceptable	at risk	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable	unacceptable
	Pools	Pool frequency and quality	adequate	at risk	at risk	at risk	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk
	Off-Channel Habitat	Connectivity with main channel	adequate	adequate	at risk	unacceptable	unacceptable	at risk	unacceptable	at risk	at risk	at risk	at risk
Channel	Dynamics	Floodplain connectivity	adequate	adequate	at risk	unacceptable	unacceptable	unacceptable	unacceptable	at risk	at risk	at risk	adequate
		Bank stability/Channel migration	adequate	adequate	unacceptable	unacceptable	unacceptable	at risk	adequate	adequate	adequate	unacceptable	adequate
		Vertical channel stability	adequate	adequate	at risk	unacceptable	at risk	at risk	at risk	at risk	unacceptable	at risk	at risk
Riparian Vegetation	Condition	Structure	adequate	adequate	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk	at risk
		Disturbance (human)	adequate	adequate	unacceptable	at risk	unacceptable	unacceptable	at risk	at risk	at risk	at risk	at risk
		Canopy Cover	adequate	adequate	at risk	at risk	unacceptable	at risk	at risk	at risk	adequate	at risk	at risk

Previous habitat surveys also indicate that Lower Chiwawa, Meadow Creek, Alder Creek, Clear Creek, and portions of Brush Creek do not meet Forest Plan Standards for large woody material (LWM) (Figure 13). In the case of the Lower Chiwawa fourth order stream, this may be the result of a combination of anthropogenic influences and the geomorphic setting of the channel. Lower order streams, however, are also deficient in LWM to some degree. In Meadow, Alder, Clear and Brush creeks, quantities of LWM in the meadow reach are likely constrained due to lack of geomorphic transport and meadow topography. Deficiencies in the lower stream reaches are likely a result of anthropogenic influences such as past timber harvest and associated roads.

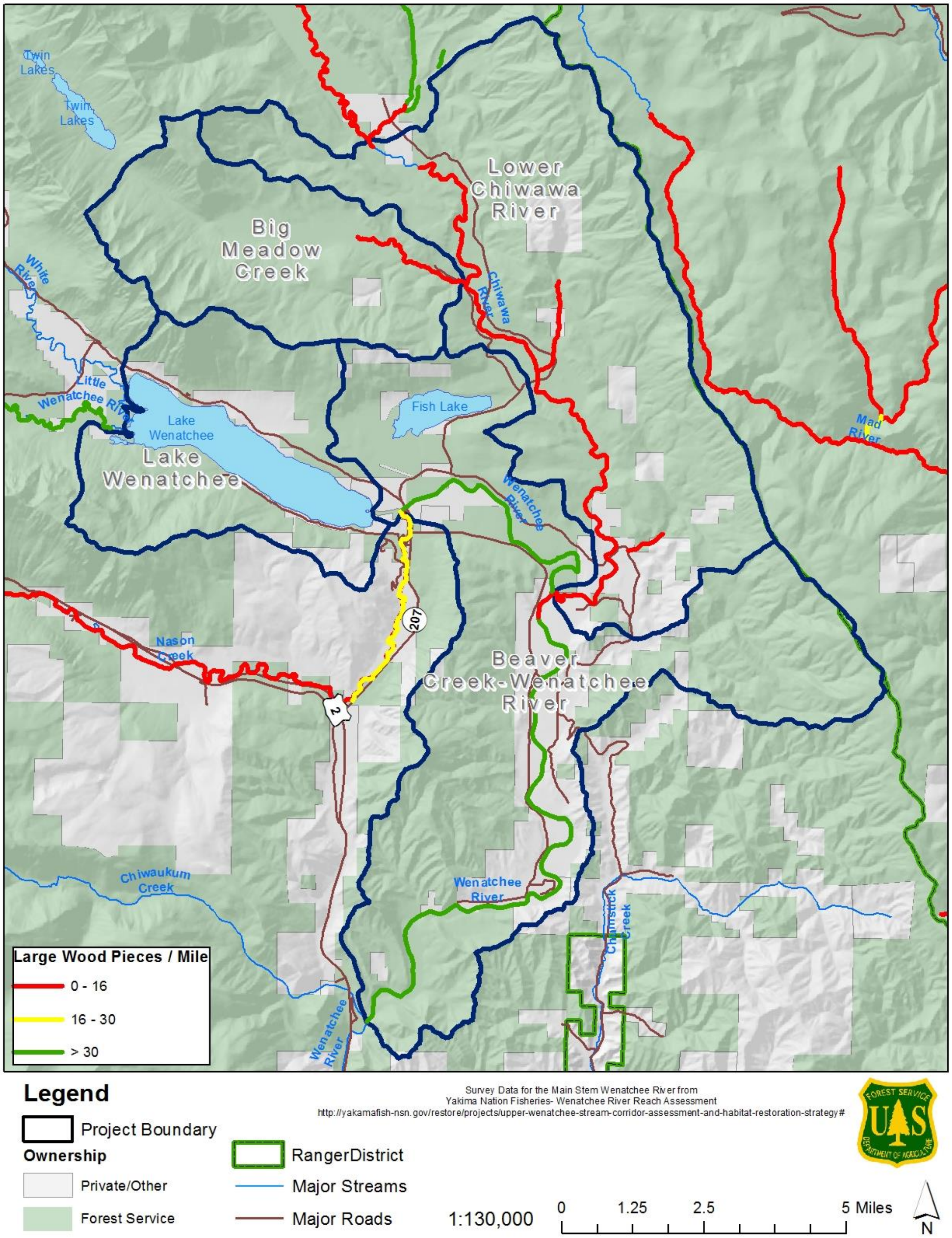


Figure 13. Large Woody Material for surveyed streams in the Upper Wenatchee project area

Stream temperature is another factor that has a bearing on fish habitat. Figure 14 shows the average annual stream temperature for the years 1993 to 2011, as modeled by the NorWest Stream Temperature project (Isaak et al., 2016). Temperature is mostly a function of elevation, with the warmest water being the Wenatchee main stem itself with mean annual temperatures at around 17 to 18 degree Celsius.

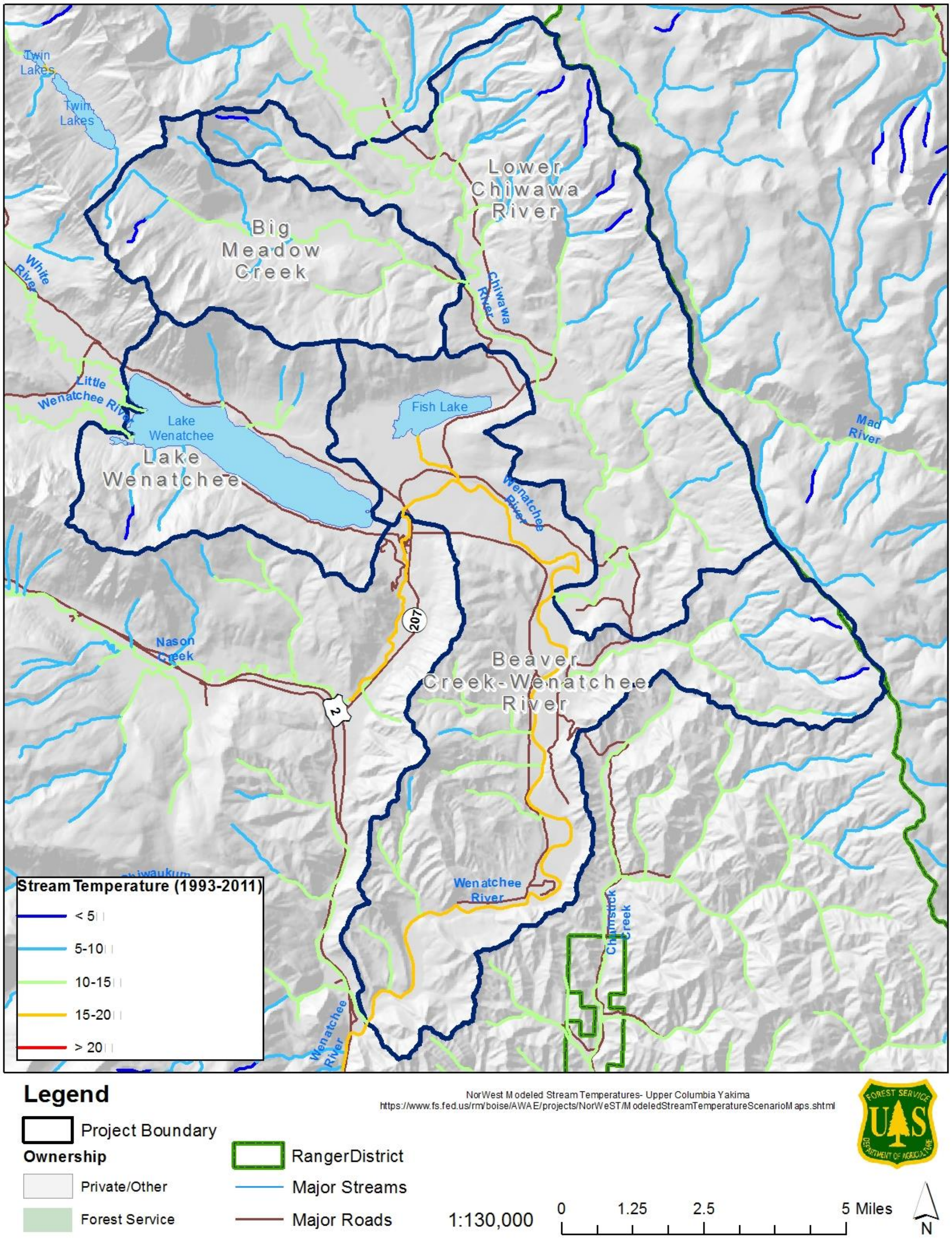


Figure 14. Mean Annual Stream Temperatures for the Upper Wenatchee project area (as modelled by NorWest)

For fish, mean annual temperature is not as critical however as maximum temperature. The Forest Service standard for Class AA waters is 16^{o} C: temperatures should not exceed 16 degrees due to human activity. Sometimes natural conditions can cause the temperature to rise above this level, but this 16 threshold is still the target. Site specific temperature monitoring has occurred within the project area at various locations and levels of intensity since 1994. Monitoring has documented temperature exceedances in the project area at several times over these years, especially during the summer months. Stream temperature in the Chiwawa at one point reached 20^{o} C in August of 2005. A temperature longitudinal profile established annual (1998-2003) temperature exceedances in the lower Chiwawa River (at least up to river mile 6.0, Goose Creek), but none for the rest of the project area (USFS, 2015a). Possible explanations for the Chiwawa site exceedances include: change in fluvial geomorphological indexes in the lower reaches (higher width/depth ratios), geomorphic land type differences from upper reaches, and a relative reduction in the quantity of cold water inputs from tributaries when compared to upper reaches and possible influences from floodplain development. Management activities that reduce riparian vegetation and stream shade (roads, timber harvest, grazing) can have an effect on stream temperature.

Road-Stream Assessment:
The hydro-geomorphic model was run on all four watersheds to assess the potential impact of roads to aquatic environments. A total of 70 catchments were delineated in all four watersheds, and hydrological indicator metrics were summarized by catchment. The results indicate a landscape that is heavily impacted by roads and erosion.

Road density is the first indicator of watershed health, and overall road densities in the project area come out as high, with greater than 2.4 miles/sq. mile in 52 out of the 70 total catchments. Moreover, road densities within a 300 foot riparian buffer are greater than 2.4 miles/sq. mile in 42 of the catchments (Figure 15). Seven of the catchments have more than three crossings per stream mile, while 30 catchments have between one and three crossings per stream mile (Figure 16). Only three catchments have a road within riparian length to stream length ratio greater than one (another indicator of relative road system influence on the stream network), but 37 of the catchments have ratios greater than 0.3, which is considered a medium level of influence (Appendix E). A final indicator is the drainage increase due to the road network. In 39 of the catchments, potential flow accumulation and delivery to the stream network ratios from roads in the riparian buffer is greater than 0.3, which is considered high.

Combined, these indicators highlight numerous catchments where the road system is affecting stream habitat within the two sub-watersheds. In total 74% of the catchments have high road densities; 60% have high road densities within riparian areas; 10% of the catchments have high numbers of stream crossings per stream mile; 59% have potential increases in the drainage network due to roads of greater than 30%; and 4% have high riparian road length to stream length ratios (Figure 17).

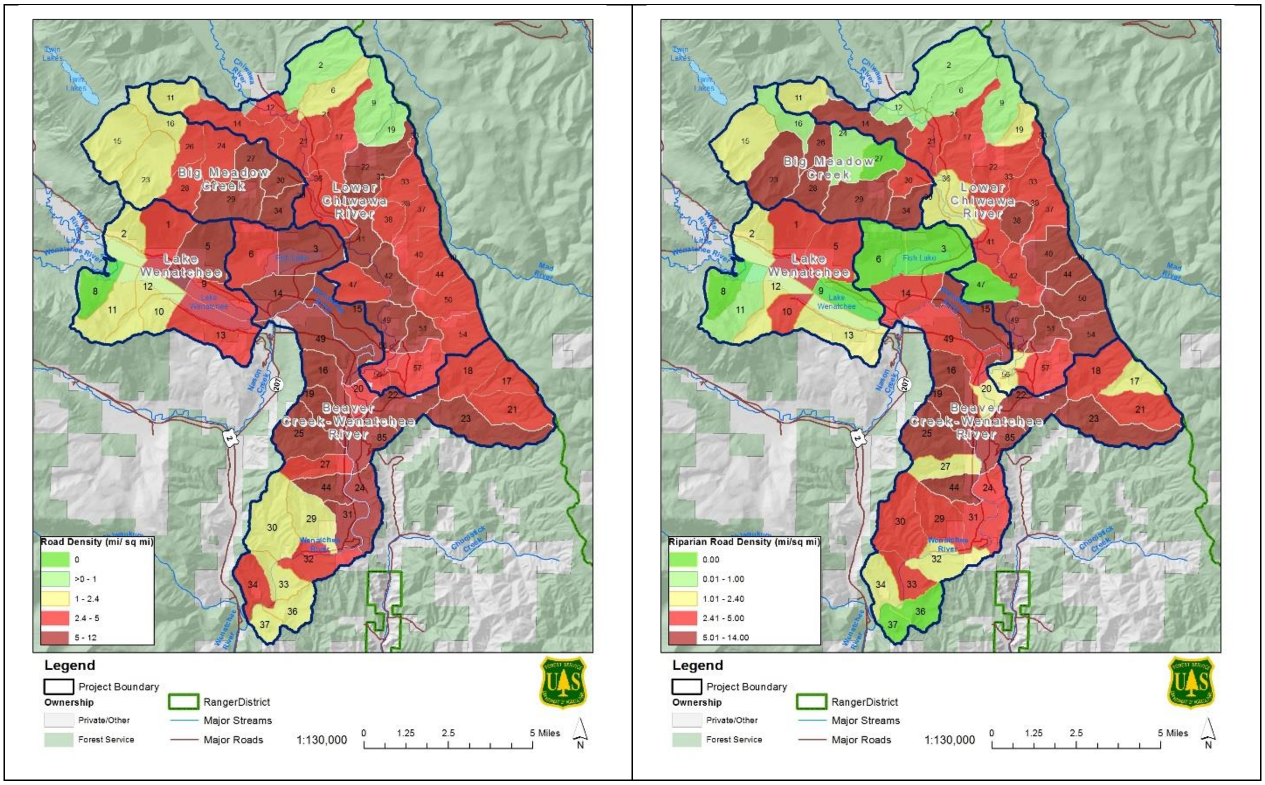


Figure 15. Road densities and riparian road densities in the project area

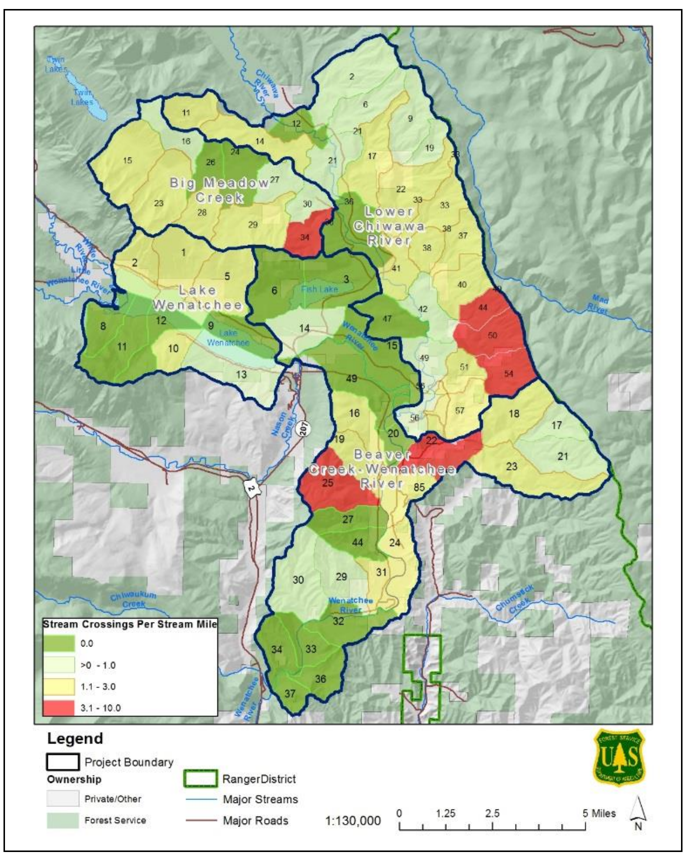


Figure 16. Number of stream crossings in the project area

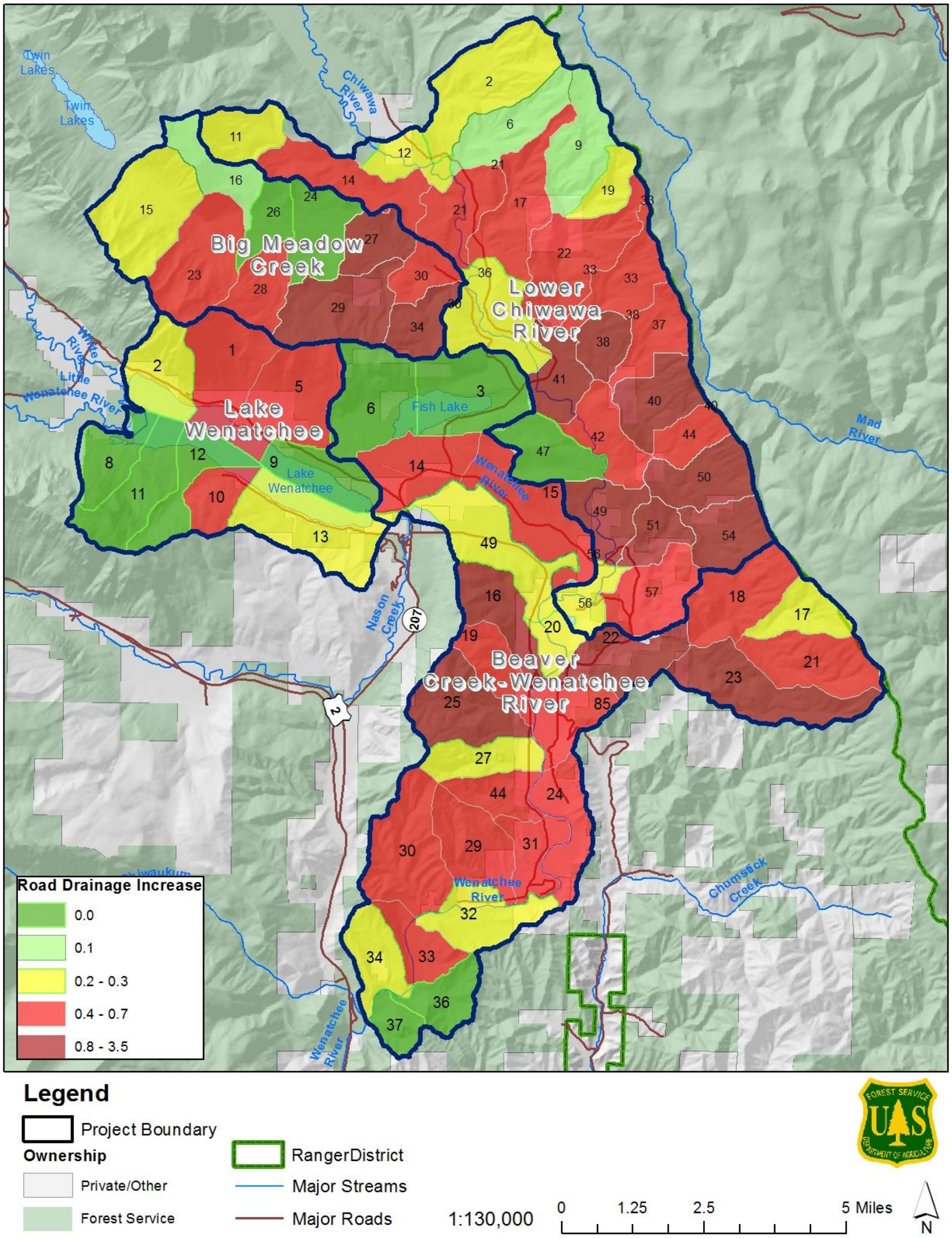


Figure 17. Modeled drainage increase in the project area due to the road network

Field Data:

The field data on road/stream interactions confirms these results. Extensive field data was only collected for the lower two watersheds, but this can provide some validation for the model as a whole. All the roads used in the model were confirmed to exist in the field (278 miles), of which 199 miles were open and drivable. The model found a total of 192 stream crossings, whereas in the field only 103 were actually found. However, many of those that were missed were located on Private lands and could not be accessed. Rills and hydrological road damage were also documented in the field (Figure 18). These data when overlaid on the results of the Hydro-geomorphic model show that the catchments that scored highest according to the model are indeed those with the most problems. These catchments had high numbers of road-stream crossings contributing sediment to the waterways, high levels of severe rutting/riling, and other examples of overland flow, sheet erosion, or cutslope/hillslope failure.

The field data also indicated that many of the culverts are too narrow to encompass the bank-full stream width. The degree to which different culverts are undersized can be estimated by taking the culvert width (in feet), dividing by the bankfull width (feet), and then multiplying by 100. This gives the percent ‘undersizedness’; values over 100 indicate an undersized culvert (Figure 19).

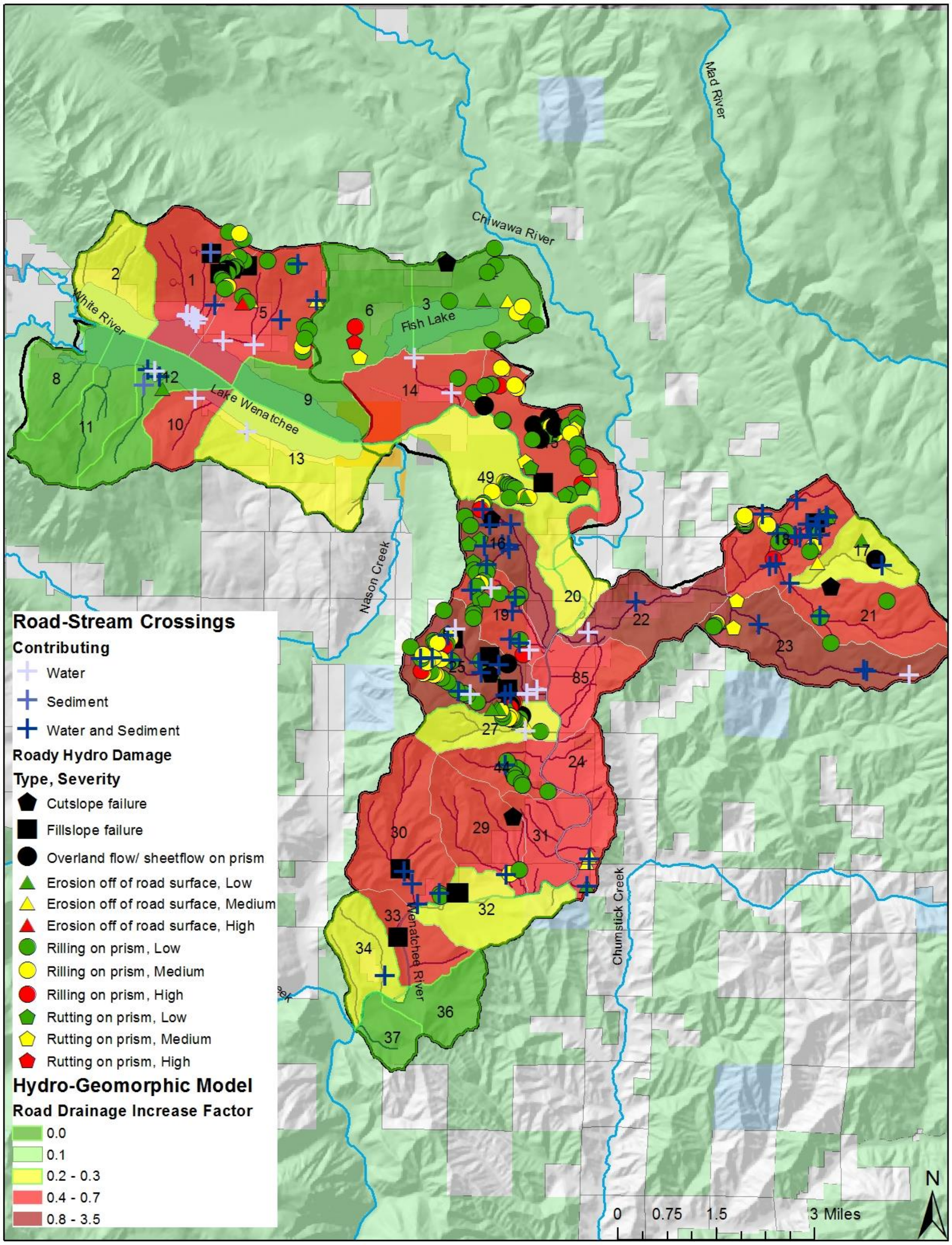


Figure 18: Field data for the Lake Wenatchee and Beaver Creek sub-watersheds, overlaid on results of Hydro-geomorphic model

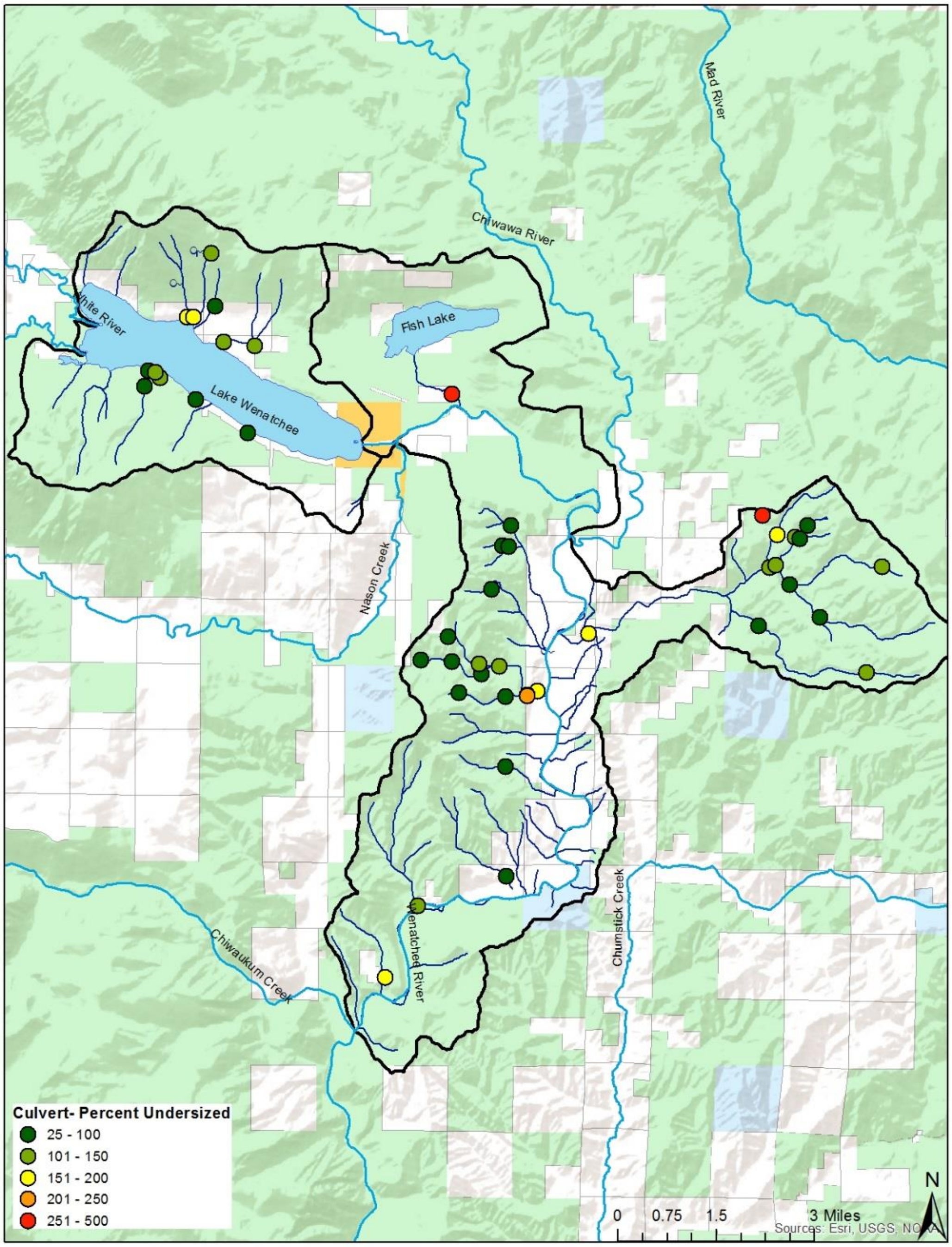


Figure 19: Possible Undersized Culverts in the Lake Wenatchee- Beaver Creek sub-watersheds

The hydro-geomorphic model presented above provides a worst-case scenario estimation of the hydrologic conditions of the catchments contained in the Upper Wenatchee Creek project area. For simplicity it treats all roads and streams the same regardless stream type or road condition. It is thus not meant to provide a strict answer to how roads are influencing streams, but rather to provide a first approximation of where the most significant problems are likely to occur, and thus where to focus restoration efforts.

4. RESTORATION OPPORTUNITY

The results of this analysis point to several ways in which the current Upper Wenatchee landscape is departed from reference conditions, leading to a less resilient environment. The metrics provided in this report point to quantifiable departures that can be addressed and then also monitored in the future as a means to track ecosystem health improvement. The current diagnosis thus presents several opportunities for restoration, both in terms of the aquatic environment and the terrestrial environment.

4.2 Terrestrial Opportunity Summary

Terrestrial restoration opportunities exist throughout much of the project area. Restoration activities would focus on correcting key ecological departures described in this document, while at the same time integrating in protective measures for aquatic resources, unique ecologic features (springs, seeps, meadows, huckleberry), and endangered wildlife/plant/fish species.

The main departure across the landscape is the amount and configuration of the young-forest multistory (YFMS), and this in turn throws off several other conditions from their natural range of variability. Landscape restoration could focus on management within YFMS stand structures, using both mechanical treatments and prescribed burning. In so doing, these treatments would improve multiple departures (wildlife, fuels, and cover/structure) on the same piece of ground.

Management within YFMS stand structures would focus on creating old forest single story (OFSS), old forest multi story (OFMS), or stand exclusion open canopy (SEOC), from existing YFMS stands. Large diameter early seral tree species would be featured in the residual stands as smaller late seral species (ladder fuels) are removed. This would reduce potential crown fire and insect vulnerabilities (Douglas-fir beetle and spruce budworm) while increasing tree vigor and accelerating the attainment of large trees. Additionally, a strategic shift of some YFMS structures to stand initiation (SI) and understory re-initiation (UR) would address departures related to patch density and patch size to improve those landscape metrics. The treatments could connect existing SI and UR stands to increase their patch sizes, while reducing the continuity and increasing the density of YFMS stands. These actions would provide reduced potential of crown fire, and offer stand replacement risk reduction to blocks of key wildlife habitat and private lands.

Another opportunity involves overstory removal within ponderosa pine plantations (SEOC and UR) that were planted with off-site seed stock or planted on moist forest types. The extent of these treatments is low, however conditions exist where planted ponderosa pine trees are un-healthy due to incorrect seed stock and planting in a moist forest type. The understory trees within the moist forest stands would be cultured as the primary cohort. Depending on the site potential and juxtaposition, the stands could move to either multi-story or single stories stands.

Finally there is the possibility of thinning within the young Douglas-fir and ponderosa pine plantations to accelerate diameter growth and attain larger tree size classes sooner. Existing stand structures within these, primarily even-aged, plantations include SEOC, stem exclusion closed canopy (SECC), UR and SI. By creating more open stand conditions, resilience from disturbances would be improved, wildfires would burn at lower intensities and insect populations would remain at endemic population levels. The trajectory for these stands would be adjusted to more quickly to attain the large (>25”dbh) tree size class and old-forest structures.

Different strategies can be used when deciding on specific locations for treatments. Hessburg et al. 2015 recommends using topography as a guide to connect patches in order to mimic natural disturbance patterns. Also making use of the inherent potential of a site can be helpful. Data layers representing the Evapotranspiration and Moisture Deficit in Eastern Washington can be used to determine which trajectory is best for a given forest patch (Churchill et al., 2013). Areas with high moisture deficit cannot support multi-storied conditions as well as areas where moisture is not limited (Figure 21). In these areas the risk of crown-fire can be too great, and so a shift to stem exclusion open canopy or old forest single story may be more appropriate.

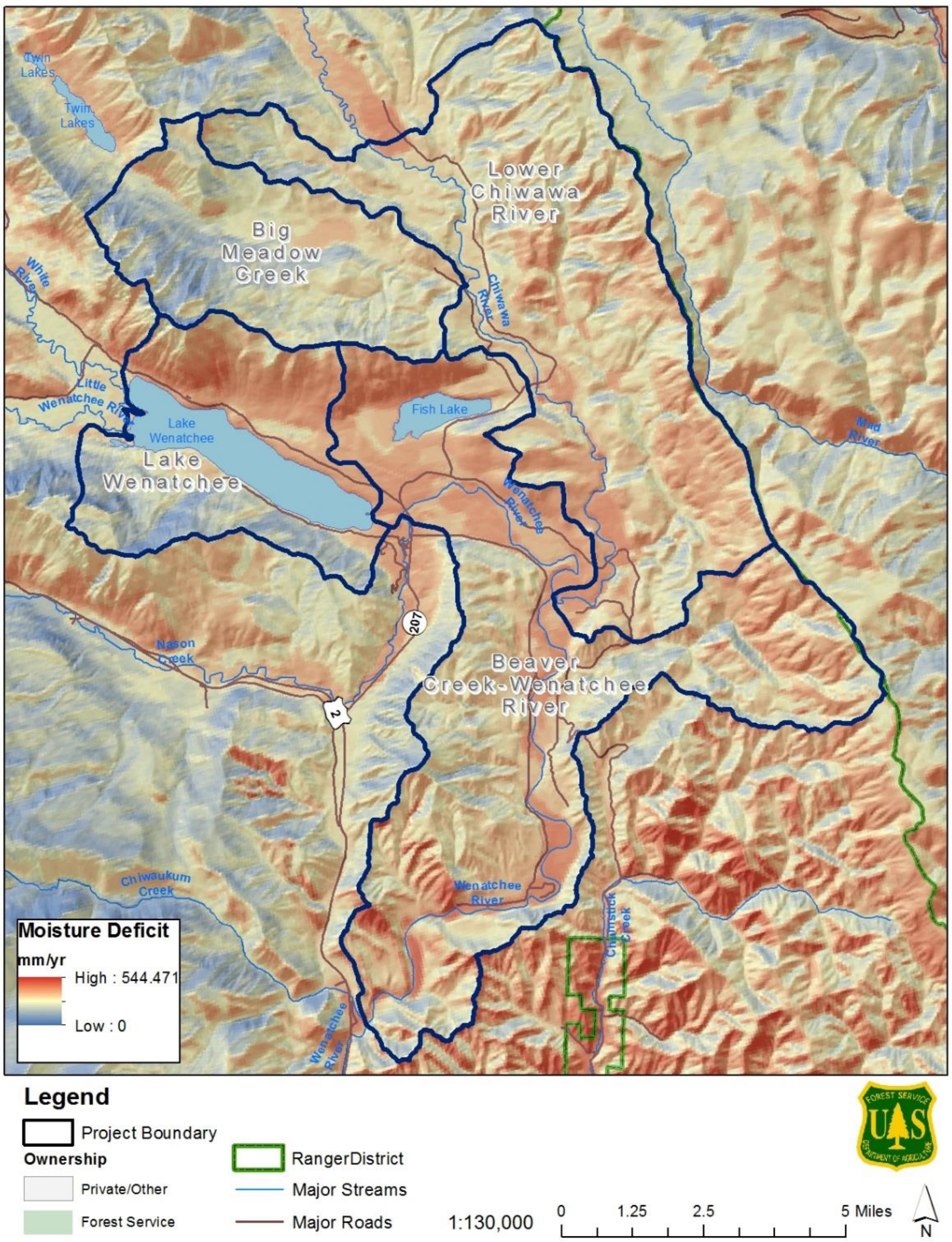


Figure 20: Modeled moisture deficit for the Upper Wenatchee project area

Strategic placement of treatments to connect habitat patches, using topography as a guide, can be used to create larger forest patch sizes across a suite of younger forest structures. Within these patches, thinning can be used to improve tree vigor and accelerate growth rates, while at the same time retaining larger large trees and promoting clumps and gaps. Fire should also be re-introduced to get back to a more natural fire regime, and improve resilience to disturbance agents (Hessburg et al., 2015).

Finally, target conditions can be set by using the overlap between the Historic and Future range of variability. This overlap provides a best guess at a 'desired condition'. Tables 8 through 11, provide the patch sizes and densities of cover and structure classes for all four watersheds. These tables indicate just those classes for which the amount or arrangement is departed with respect to the reference. The goal then is to move the current values to somewhere within the range of overlap between historic and future conditions. Obviously it is not possible to fully achieve this for every class, but this is the goal. In many classes the patch sizes and densities are orders of magnitude different from the reference conditions; addressing these departures first will bring other departures back within the range of variability and improve the overall health and resilience of the stand.

Lower Chiwawa

Table 10. Summary of existing vegetation conditions and ranges for the 80th percentile reference conditions in the Lower Chiwawa sub-watershed

Vegetation Metrics	Existing	Reference Overlap (overlap ESR 4 & 5)	HRV (esr-4)	FRV (esr-5)
COVER				
Percent of Landscape (%)				
Ponderosa Pine	22.9	* 9.8 – 11.7	0 – 9.8	11.7 – 54.9
Douglas-fir	61.9	6.3-49.8	5.3-52.9	6.3-49.8
Whitebark Pine	4.6	0 – 2.6	0 – 4.3	0 – 2.6
Herbland	0.0	0.1 – 1.5	0.1 – 3.8	0 – 1.5
Mean Patch size (Ha)				
Ponderosa Pine	155.2	220.1 – 874.8	0 – 874.8	220.1 – 3128.6
Douglas-fir	2221.1	124.0 – 1442.7	124.0 – 2322.0	117.0 – 1442.7
Subalpine Fir	81.9	117.6 – 747.4	117.6 – 747.4	0 – 2627.9
Whitebark Pine	387.2	0 – 33.7	0 – 104.8	0 – 33.7
Herbland	0.0	13.7 – 130.7	13.7 – 130.7	0 – 148.9
Patch Density (# per 10 ha)				
Ponderosa Pine	90.0	*12.4	0 – 12.4	12.4 – 61.8
Subalpine Fir	31.6	9.9 – 27.2	9.9 – 69.2	0 – 27.2
Herbland	0.0	2.5 – 14.8	2.5 – 29.7	0 – 14.8
Shrubland	55.9	0 – 12.4	0 – 54.4	0 – 12.4
STRUCTURE				
Percent of Landscape (%)				
YFMS	54.9	0.9-31.6	0.6-31.6	0.9-36.8
SECC	0.6	3.4-16.8	3.4-32.9	0.0-16.8
UR	12.4	16.5-37.3	4.4-37.3	16.5-42.4

Mean Patch Size (Ha)				
SECC	19.1	62.4-241.5	62.4-528.5	0-241.5
UR	107.6	173.1-590.7	66.4-590.7	173.1-1404.6
YFMS	626.0	58-438.6	58-438.6	36.3-848.8
OFMS	238.2	0.0-78.5	0-802.0	0-78.5
Patch Density (# per 10k Ha)				
SI	128.8	4.9-59.3	4.9-59.3	0.0-79.0

Big Meadow

Table 11. Summary of existing vegetation conditions and ranges for the 80th percentile reference conditions in the Big Meadow sub-watershed

Vegetation Metrics	Existing	Reference Overlap (overlap ESR 4 & 5)	HRV (ESR-4)	FRV (ESR-5)
COVER				
Percent of Landscape (%)				
Ponderosa pine	25.9	*9.8 – 11.7	0-9.8	11.7-54.9
Hardwoods	0.2	0 - 0	0 - 0	0 – 0.53
Herbland	0.0	0.1 – 1.5	0.1 – 3.8	0 – 1.5
Shrubland	10.2	0 – 1.3	0 – 7.4	0 – 1.3
Mean Patch size (Ha)				
Ponderosa Pine	154.4	220.1 – 874.8	0 – 874.8	220.1 – 3128.6
Whitepark Pine	38.9	0 – 33.7	0 – 104.8	0 – 33.7
Hardwoods	15.6	0 - 0	0 - 0	0 – 12.4
Herbland	0.0	13.7 – 130.7	13.7 – 130.7	0 – 148.9
Shrubland	93.8	0 – 44.7	0 – 145.5	0 – 44.7
Patch Density (# per 10k Ha)				
Ponderosa Pine	102.4	*12.4	0 – 12.4	12.4 – 61.8
Douglas-fir	60.2	9.9 – 54.4	7.4 – 56.8	9.9 – 54.4
Subalpine Fir	66.2	9.9 – 27.2	9.9 – 69.2	0 – 27.2
Whitebark Pine	36.1	0 – 14.8	0 – 22.2	0 – 14.8
Hardwoods	6.0	0 – 0	0 – 0	0 – 7.4
Herbland	0.0	2.5 – 14.8	2.5 – 29.7	0 – 14.8
Shrubland	66.2	0 – 12.4	0 – 54.4	0 – 12.4
STRUCTURE				
Percent of Landscape (%)				
YFMS	31.1	0.9-31.6	0.6-31.6	0.9-36.8
Mean Patch size (Ha)				
SEOC	30.1	63.3-175.4	63.3-175.4	50.9-557.9
UR	137.1	173.1-590.7	66.4-590.7	173.1-1404.6
Patch Density (# per 10k Ha)				
SI	102.4	4.9-59.3	4.9-59.3	0-79
SEOC	198.7	34.6-93.9	27.1-113.7	34.6-93.9
SECC	90.4	14.8-64.2	14.8-64.2	0-69
UR	114.4	24.7-71.6	22.2-84.0	24.7-71.6

Beaver Creek

Table 12. Summary of existing vegetation conditions and ranges for the 80th percentile reference conditions in the Beaver Creek sub-watershed

Vegetation Metrics	Existing	Reference Overlap (overlap ESR 5 & 11)	HRV (ESR-5)	FRV (ESR-11)
COVER				
Percent of Landscape (%)				
Hardwoods	1.5	0 – 0.5	0 – 0.5	0 – 2.8
Herbland	4.3	0.3 – 1.5	0 – 1.5	0.3 – 40.5
Western Hemlock	0.1	0 – 0	0 – 0.1	0 - 0
Mean Patch size (Ha)				
Ponderosa Pine	176.4	320.3 – 2808.4	220.1 – 3128.6	320.3 – 2808.4
Western Hemlock	24.9	0 – 0	0 – 8.8	0 – 0
Pacific Silver Fir	56.0	0 – 0	0 – 317.1	0 - 0
Hardwoods	60.2	0 – 12.4	0 – 12.4	0 – 83.6
Patch Density (# per 10k Ha)				
Ponderosa Pine	126.2	12.4 – 61.8	12.4 – 61.8	7.4 – 66.7
Grand FIr	6.4	0 – 4.9	0 – 24.7	0 – 4.9
Douglas-fir	81.3	9.9 – 54.4	9.9 – 54.4	0 – 84.0
Hardwoods	15.0	0 – 7.4	0 – 7.4	0 – 19.8
Herbland	27.8	7.4 – 14.8	0 – 14.8	7.4 – 108.7
Shrubland	15.0	0 – 12.4	0 – 12.4	0 – 81.5
Western Hemlock	2.1	0 - 0	0 – 2.5	0 - 0
STRUCTURE				
Percent of Landscape (%)				
YFMS	58.7	0.9 – 36.8	0.9 – 36.8	0.8 – 38.6
OFMS	6.2	0 – 2.4	0 – 2.4	0 – 11.5
UR	4.3	16.5 – 42.4	16.5 – 42.4	1.9 – 50.4
Mean Patch size (Ha)				
SEOC	48.3	50.9 – 416.0	50.9 – 557.9	35.3 – 416.0
UR	39.7	173.1 – 945.6	173.1 – 1404.6	56.7 – 945.6
Patch Density (# per 10 Ha)				
YFMS	68.4	9.9 – 56.8	9.9 – 56.8	2.5 – 81.6
SEOC	151.8	34.6 – 93.9	34.6 – 93.9	27.2 – 128.5
UR	66.3	24.7 – 49.4	24.7 – 71.7	4.9 – 49.4
OFMS	59.8	7.4 – 19.7	0 – 19.7	7.4 – 108.7

Lake Wenatchee

Table 13. Summary of existing vegetation conditions and ranges for the 80th percentile reference conditions in the Lake Wenatchee sub-watershed

Vegetation Metrics	Existing	Reference Overlap (overlap ESR 4 & 5)	HRV (ESR-4)	FRV (ESR-5)
COVER				
Percent of Landscape (%)				
Ponderosa Pine	16.8	* 9.8 – 11.7	0 – 9.8	11.7 – 54.9
Hardwoods	2.8	0 - 0	0 – 0	0 – 0.5
Shrubland	5.0	0 – 1.3	0 – 7.4	0 – 1.3
Mean Patch size (Ha)				
Ponderosa Pine	153.9	220.1 – 874.8	0 – 874.8	220.1 – 3128.6
Hardwoods	38.3	0 – 0	0 - 0	0 – 12.4
Shrubland	550.4	0 – 44.7	0 – 145.5	0 – 44.7
Patch Density (# per 10k Ha)				
Ponderosa Pine	66.7	*12.4	0 – 12.4	12.4 – 61.8
Lodgepole Pine	38.9	0 – 14.8	0 – 14.8	0 – 42.0
Douglas-fir	61.1	9.9 – 54.4	7.4 – 56.8	9.9 – 54.4
Subalpine Fir	27.8	9.9 – 27.2	9.9 – 69.2	0 – 27.2
Hardwoods	44.4	0 – 0	0 – 0	0 – 7.4
Herbland	22.2	2.5 – 14.8	2.5 – 29.7	0 – 14.8
STRUCTURE				
Percent of Landscape (%)				
OFMS	15.8	0 – 2.4	0 – 17.3	0 – 2.4
SECC	0.3	3.4 – 16.8	3.4 – 32.9	0 – 16.8
YFMS	37.3	0.9 – 31.6	0.6 – 31.6	0.9 – 36.8
Mean Patch size (Ha)				
OFMS	157.3	0 – 78.5	0 – 802.0	0 – 78.5
SECC	14.0	62.4 – 241.5	62.4 – 528.5	0 – 241.5
SEOC	52.5	63.3 – 175.4	63.3 – 175.4	50.9 – 557.9
UR	63.2	173.1 – 590.7	66.4 – 590.7	173.1 – 1404.6
YFMS	454.7	58.1 – 438.6	58.1 – 438.6	36.2 – 848.8
Patch Density (# per 10k Ha)				
OFMS	61.1	0 – 19.8	0 – 37.1	0 – 19.8
OFSS	22.2	0 – 19.8	0 – 29.7	0 – 19.8
SECC	11.1	14.8 – 64.2	14.8 – 64.2	0 – 69.2

4.1 Aquatic Opportunity

There are also many opportunities to improve the aquatic health of these four sub-watersheds. This overview has attempted to show that stream and habitat characteristics are generally a direct function of processes going on higher in the watershed. In particular, the impact of roads high in the watershed has a direct effect on stream functionality. The energy from road runoff and erosion can create both deposition and scouring environments on the stream channel with many negative cascading consequences. Therefore it is understood that while focusing on site specific actions may be necessary in the short term, in the long-term dealing with the ultimate cause of these impacts is critical.

Road related impacts, including moderate and high riparian road densities, can be addressed by implementing road specific restoration methods. Methods include decommissioning, relocating all or portions of the road, hydrologically closing roads, and upgrading existing roads. Site-specific investigations can determine the appropriate mitigations to address the identified road issues. Where specific road related restoration opportunities do not exist within larger floodplain and wetland complexes, emphasis should be placed on protection and maintenance of the floodplain or wetland through management consistent with Aquatic Conservation Strategy.

Other actions can also be taken to preserve or create fish habitat and restore stream functionality. Fish distribution can be improved by addressing culvert barriers, either through complete removal or by installing culverts designed to pass fish. Stream channels can be improved with site specific actions. The Yakima Nation Fisheries assessment of the Wenatchee River identified the following opportunities for aquatic restoration (YNF, 2012): 1)Protecting existing functional stream habitat; 2) restoring riparian areas by replanting and eliminating invasive species; 3)reconnecting habitat via infrastructure modification- particularly removal of levees and channel structures that inhibit channel functioning; 4) placement of structural habitat elements including log-jams for the creation of habitat; and 5) creation of off-channel habitat, including construction of side channels or backwaters.

Where funding is limited, restoration work can focus on the catchments that are most departed from the natural range of variability. These are the ones that score the highest according to all the different metrics (for example see Figure 21).

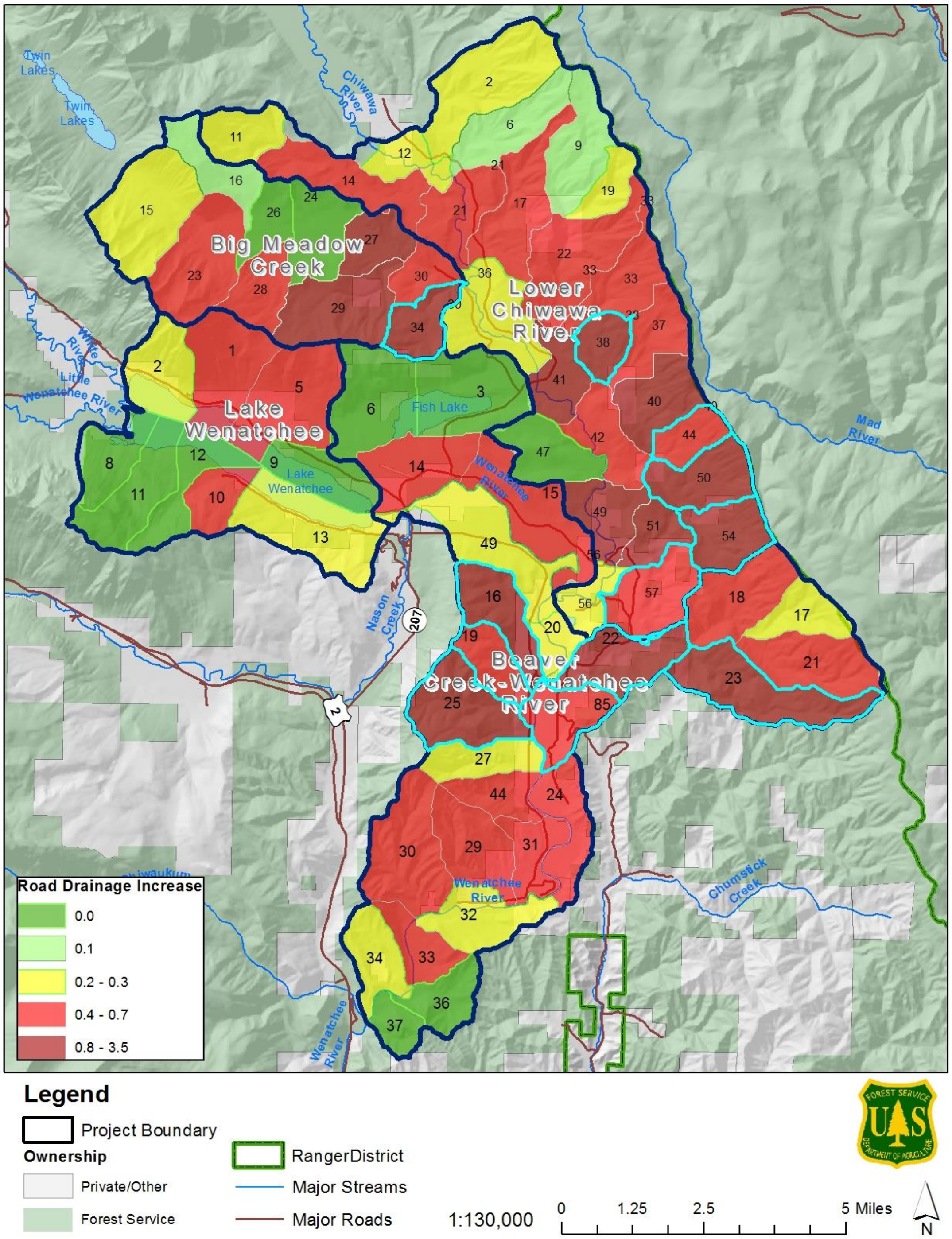


Figure 21. Highlighted catchments of consistent high impact potential that may make good priority candidates for restoration. These are catchments that score high according to all the indicator metrics

LITERATURE CITED

Agee, J.K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, D.C.

Arno, Stephen F.; Parsons, David J.; Keane, Robert E.; Mixed-severity fire regimes in the northern Rocky Mountains: consequences of fire exclusion and options for the future. 2000.

Bisson, P.A., B.E. Rieman, C. Luce, P.F. Hessburg, D.C. Lee, J.L. Kershner, G.H. Reeves, and R.E. Gresswell. 2003. Fire and aquatic ecosystems of the western USA: current knowledge and key questions. Forest Ecology and Management 178: 213-229.

Bunting, S.C.; Kingery, J.L.; Hemstrom, M.A.; Schroeder, M.A.; Gravenmier, R.A.; Hann, W.J. 2002. Altered rangeland ecosystems on the interior Columbia Basin. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-553.

Churchill, D.J., A.J. Larson, M.C. Dahlgreen, J.F. Franklin, P.F. Hessburg, and J.A. Lutz 2003. Restoring forest resilience: From reference spatial patterns to silvicultural prescriptions and monitoring. Forest Ecology and Management 291: 442-457.

Gaines, W.L., D.W. Peterson, C.A. Thomas, and R.J. Harrod. 2012. Adaptations to climate change: Colville and Okanogan-Wenatchee National Forests. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-862.

Gartner, S., K.M. Reynolds, P.F. Hessburg, S. Hummel, and S. Twery. 2008. Decision support for evaluating landscape departure and prioritizing forest management activities in a changing environment. Forest Ecology and Management 256: 1666-1676.

Haugo, R., C. Zanger, T. DeMeo, C. Ringo, A. Shlisky, K. Blankenship, M. Simpson, K. Mellen-McLean, J. Kertis, and S. Stern. 2014. A new approach to evaluate forest structure restoration needs across Oregon and Washington. Forest Ecology and Management 335: 37-50.

Hessburg, P.F., B.G. Smith, S.D. Kreiter, C.A. Miller, R.B. Salter, C.H. McNicoll, and W.J. Hann. 1999. Historical and current forest and range landscapes in the interior Columbia River Basin and portions of the Klamath and Great Basins. Part 1: Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-458.

Hessburg, P.F., B.G. Smith, R.B. Salter, R.D. Ottmar, and E. Alvarado. 2000a. Recent changes (1930s-1990s) in spatial patterns of interior northwest forests, USA. Forest Ecology and Management 136: 53-83.

Hessburg, P., Salter, R.B., Richmond, M.B. and Smith, B.G., 2000b. Ecological subregions of the interior Columbia Basin, USA. *Applied Vegetation Science*, *3*(2), pp.163-180.

Hessburg, P. F., K. M. Reynolds, R. B. Salter, J. D. Dickinson, W. L. Gaines, and R. J. Harrod. 2013. Landscape evaluation for restoration planning on the Okanogan-Wenatchee National Forest, USA. Sustainability **5**:805-840.

Hessburg, P. F., D. J. Churchill, A. J. Larson, R. D. Haugo, C. Miller, T. A. Spies, M. North, N. A. Povak, R. T. Belote, P. H. Singleton, W. L. Gaines, R. E. Keane, G. H. Aplet, S. L. Stephens, P. Morgan, P. A. Bisson, B. E. Reiman, R. B. Salter, and G. H. Reeves. 2015. Restoring fire-prone Inland Pacific landscapes: seven core principles. Landscape Ecology.

Isaak, D.J., C. Luce, B.E. Rieman. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. Ecological Applications 20: 1350-1371.

Isaak, D.J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwestern US from 1980-2009 and implications for salmonid fishes. Climatic Change 113: 499-524.

Isaak, D.J.; Wenger, S.J.; Peterson, E.E.; Ver Hoef, J.M.; Hostetler, S.W.; Luce, C.H.; Dunham, J.B.; Kershner, J.L.; Roper, B.B.; Nagel, D.E.; Chandler, G.L.; Wollrab, S.P.; Parkes, S.L.; Horan, D.L. 2016. NorWeST modeled summer stream temperature scenarios for the western U.S. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0033.

Jones, J.A., F.J. Swanson, B.C. Wemple, and K.U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14: 76-85.

Lehmkuhl, J.F.; Lyons, A.L.; Bracken, E.; Leingang, J.; Gaines, W.L.; Dodson, E.K.; Singleton, P.H. 2013. Forage composition, productivity, and utilization in the eastern Washington Cascade Range. Northwest Science 87(3): 207-231.

Littell, J. S., E. E. Oneil, D. McKenzie, J. A. Hicke, J. A. Lutz, R. A. Norheim, and M. M. Elsner. 2010. Forest ecosystems, distributions, and climatic change in Washington State, USA. Climate Change 102:129-158.

Luce, C.H., Stabb, B., Kramer, M., Wenger, S., Isaak, D., McConnell, C., Sensitivity of Summer Stream Temperatures to Climate Variability in Pacific Northwest Forests. 2012.

Lundquist, J. D., S. E. Dickerson-Lange, J. A. Lutz, and N. C. Cristea. 2013. Lower forest density enhances snow retention in regions with warmer winters: a global framework developed from plot-scale observations and modeling. Water Resources Research 49:6356-6370.

Mantua, N., I. Tohver, and A. Hamlet. 2009. Impacts of climate change on key aspects of freshwater salmon habitat in Washington State. In: Elsner, M.M.; Littel, J.; Binder, L.W., eds. The Washington Climate Change Impacts Assessment. Seattle, WA: Center for Science in the Earth System, Joint Institute for the Study of Atmosphere and Oceans, University of Washington: 217-254.

Mote, P. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters 30: 1601-1604.

Naiman, R.J., and M.G. Turner. 2000. A future perspective on North America's freshwater ecosystems. Ecological Applications 10: 958-970.

National Marine Fisheries Service (NMFS). 1996. Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale. August, 1996.

North Central Washington Forest Health Collaborative (NCWFHC). 2016. Fire-Resilient Communities and Landscapes in Chelan County: Draft Pilot Proposal. January, 2016.

Ottmar, R.D., Alvarado, E., Hessburg, P.F., Smith, B.G., Kreiter, S.G., Miller, C.A., Salter, R.B., 1999. Historical and current forest and range landscapes in the Interior Columbia River Basin and portion of the Klamath and Great Basins. Part II. Linking vegetation patterns and potential smoke production and fire behavior. Gen. Tech. Rep. PNW-GTR-XXX. Portland, OR., USDA Forest Service, Pacific Northwest Research Station.

Reynolds, K.M. and Hessburg, P.F., 2014. An overview of the ecosystem management decision-support system. In *Making transparent environmental management decisions* (pp. 3-22). Springer Berlin Heidelberg.

Rieman, B.E., P.F. Hessburg, C. Luce, and M.R. Dare. 2010. Wildfire and management of forest and native fishes: conflict or opportunity for convergent solutions? BioScience 60: 460-468.

Record of Decision (ROD). 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. USDA Forest Service and USDI BLM. April 1994.

Rosgen, D. 1996. Applied River Morphology, Second Edition. Wildland Hydrology, Pagosa Springs, Co.

SER. 2004. The SER international primer on ecological restoration, version 2. Society for Ecological Restoration Science and Policy Working Group.

Stine, P., P. Hessburg, T. Spies, M. Kramer, C.J. Fettig, A. Hansen, J. Lehmkuhl, K. O'Hara, K. Polivka, P. Singleton, S. Charnley, A. Merschel, and R. White. 2014. The ecology and management of moist mixed-conifer forests in eastern Oregon and Washington: a synthesis of the relevant biophysical science and implications for future land management. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-897.

USDA Forest Service (USFS). 1997. Chiwawa River Watershed Assessment. Wenatchee National Forest, Lake Wenatchee Ranger District.

USDA Forest Service (USFS). 2012. The Okanogan-Wenatchee National Forest Restoration Strategy: adaptive ecosystem management to restore landscape resiliency. USDA Forest Service, Pacific Northwest Region. Portland, OR.

USDA Forest Service (USFS). 2015a. Temperature Monitoring Report- Wenatchee River and Entiat Ranger Districts. Wenatchee, WA.

USDA Forest Service (USFS). 2015b. Okanogan-Wenatchee National Forest: Procedures for Watershed and Aquatic Resource Assessment, Analysis, and Proposal Development for Whole Watershed Scale Projects. Draft.

USDA Forest Service (USFS). 2017. Quality Assurance/Quality Control Assessment for the Lake Wenatchee/Beaver Creek Watersheds.

US Fish and Wildlife Service (USFWS). 1998. A Framework to Assist in Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Bull Trout Subpopulation Watershed Scale. February, 1998.

US Fish and Wildlife Service (USFWS). 2015. Mid-Columbia recovery unit implementation plan for bull trout recovery plan. U.S Fish and Wildlife Service, Portland, OR.

Upper Columbia Salmon Recovery Board (UCSRB). 2007. Upper Columbia Spring Chinook Salmon And Steelhead Recovery Plan. www.ucsrb.com/plan.asp.

Upper Columbia Salmon Recovery Board (UCSRB). 2014. Integrated Recovery Plan: Habitat Report. http://www.ucsrb.org/mdocuments-library/reports/

Washington Department of Fish and Wildlife (WDFW). 2009. Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual. WDFW. Olympia, WA.

Washington Department of Fish and Wildlife (WDFW). 2017. Washington Fish Passage and Diversion Screen Inventory. http://wdfw.wa.gov/conservation/habitat/fish_passage/data_maps.html

White, P.S., and J. Harrod. 1997. Disturbance and diversity in a landscape context. In: Bissonette, J.A. ed. Wildlife and Landscape Ecology. Springer-Verlag, New York, NY: 128-159.

Yakima Nation Fisheries (YNF). 2012. Upper Wenatchee River Stream Corridor Assessment and Habitat Restoration Strategy. Toppenish, WA. http://yakamafish-nsn.gov/restore/projects/upper-wenatchee-stream-corridor-assessment-and-habitat-restoration-strategy#

APPENDIX A. Aquatic Evaluation Procedure
We utilized the sub-watershed assessment procedure described in the 2015 *Okanogan-Wenatchee National Forest: Procedures for Watershed and Aquatic Resource Assessment, Analysis and Proposal Development for Whole Watershed Scale Projects (DRAFT)* protocol. The supporting science for use of this methodology is referenced therein.

The sub-watershed assessment is a process performed at the sub-watershed scale (HUC 6) and incorporates an analysis of metrics that assess disruption of physical watershed functional processes and subsequent impacts on water quality, aquatic habitat and fish populations.

Sub-watersheds (6th field hydrologic unit codes, HUC6) are relatively large areas of land ranging from 10,000 to 40,000 acres. This assessment is conducted at both the sub-watershed and catchment (500-1500 acres) scales to more effectively account for the spatial variability of the direct effects that roads have on watershed function and aquatic ecosystems.

We compare a suite of metrics used as indicators of biological and water quality conditions. These metrics are intended to identify where in a sub-watershed the indicator variables show that the risks to aquatic resources may be the greatest. The results of this analysis are intended to display where in the watershed road management may be best used to reduce impacts to aquatic habitats and water quality.

The evaluation process included the following steps:

Step 1. Conduct a biological condition functional impairment assessment. Identify and assess indicator metrics. Identify listed fish species of concern, species distribution of listed fish species, critical habitat and potential habitat for listed fish species. Identify natural and anthropogenic limits to species distribution and occupied habitat. (USFS, 2015b). A visual output for Focal Fish Species Distribution for this project can be seen in Figure 2.

Use available habitat surveys to display location and extent of habitat indicator metrics including bankfull width depth ratios (BFWD), channel entrenchment, and channel large woody material (LWM) quantities.

Step 2. Delineate the sub-watershed into catchments
Land management activities that have caused impairment are not always distributed evenly across a given HUC6. Therefore, it's necessary to divide a HUC6 into smaller catchments in order to focus the analysis on areas within the HUC6 that have the highest degree of impairment (Figure 3).

Step 3. Calculate indicator variables for each catchment. Assess inferred mechanism extents and locations.

Calculate overall road density by catchment and the riparian road density (density of roads within a 300 foot buffer of streams) by catchment. Road densities greater than 1 mi/mi^2 are characterized as being functioning at risk, while densities greater than 2.4 mi/mi^2 are characterized as being non-functioning (NMFS 1996, USFWS 1998).

Determine the number of road crossings/stream mile per catchment. Road/stream crossings are an indicator of direct interaction between roads and the stream network. Road/stream crossings have the potential to disrupt stream flow and natural sediment transport processes and impede aquatic organism passage. More than three crossings per stream mile in a catchment indicates a high degree of interaction between roads and the stream network.

Calculate the potential road drainage increase to the stream network (ratio of riparian road drainage lengths to stream length). During runoff generating precipitation and melt off events, water that drains off of a road that is within 300 ft. of the stream network, has a high potential of creating artificial channels and other conduits that provide efficient flow and sediment delivery to streams. The more that drainage networks increase as a result of roads, the more efficient a watershed will drain itself. Ratios greater than 0.3 are considered to have a high impact on the stream network.

Calculate the ratio of riparian roads to stream channel length. The ratio of riparian roads to stream channel length is a measure of the magnitude of potential direct impacts of roads to the stream network for any given catchment. (USFS, 2015b)

Step 4. Initial Field Review
Field evaluation is needed to ensure that observations in the office portion of the restoration analysis are consistent with resource conditions on-the-ground. Information and observations during the initial field review can be used to update biologic conditions and indicator metrics for iteration of analysis as warranted.

Step 5. Identify catchments to focus a more in-depth review in order to identify proposed actions. Focus on those catchments with inferred mechanisms that indicate departure, have the ability to propagate down the network, and can lead to biologic function impairment. Consistent with the purpose and need, other facets of Forest Plan direction and in response to pertinent phases of public comment, the IDT will refine appropriate elements of the watershed and aquatic restoration proposals.

Table A1. Aquatic Evaluation Metrics

Metric and Catchment Ranking Criteria	**Mechanism**	**Indicator**	**Rationale**	**Data/GIS Tool Source**
Miles of current focal fish species known distribution		X	Displays the location of fish distribution and its physical relationship to road related impacts that effect aquatic habitat (i.e. receiving effects produced from upper watershed sectors).	HUC 6 Layer LLID Stream Layer Oka-Wen Fish Distribution Layer
Location of designated critical habitat		X	Overlays designated critical habitat and compares undesired proximity and magnitude of the inferred mechanism outputs to it (i.e. receiving effects from upstream.	HUC 6 Layer LLID Stream Layer Critical Habitat Layers for; Bull trout, Upper and Middle Columbia

Miles of potential habitat for focal fish species		X	Predicts potential habitat (stream gradients less than or equal to 10% for Bull Trout and Steelhead and 4% for Spring Chinook) and compares undesired proximity and magnitude of the inferred mechanism outputs to it.	HUC 6 Layer NHD Stream Layer Oka-Wen Fish Distribution Layer Oka-Wen Habitat Barrier Layer Oka-Wen Stream Gradient Layer
Field measured width/depth ratio to predicted (from Rosgen 1996)		X	Displays field derived measurement of width/depth ratio and compares undesired proximity and magnitude of the inferred mechanism outputs to them.	HUC 6 Layer NHD Stream Layer NRIS AqS Width to Depth Ratio Layer
Field measured entrenchment ratio to predicted (from Rosgen 1996)		X	Displays field derived measurement of entrenchment ratio and compares undesired proximity and magnitude of the inferred mechanism outputs to them.	HUC 6 Layer NHD Stream Layer NRIS AqS Entrenchment Ratio Layer
Catchment Road Density Low = <1 mi/mi^2 Med = 1 to 2.4 mi/mi^2 High = > 2.4 mi/mi^2	X		Displays overall road density by catchment as a general indicator of road/stream interaction.	HUC 6 Layer Catchment Layer Road Layer
Riparian Road Density Low = <1 mi/mi^2 Med = 1 to 2.4 mi/mi^2 High = > 2.4 mi/mi^2	X		Displays road density of roads within a 300 foot buffer of streams. General indicator of riparian interaction and impacts of road system.	HUC 6 Layer Catchment Layer Road Layer NHD Layer
No. of road crossings per stream mile Low = 0-1 Med = 1-3 High = >3	X		Displays the ratio of road length to stream length in mapped floodplains. Number of stream crossings per stream mile. An indicator of direct road interaction with the stream network and indicator of potential increases in drainage efficiency and sediment delivery.	HUC 6 Layer Catchment Layer Road Layer NHD Stream Layer Road-Stream Crossing Layer
Road Drainage Increase (Ratio of potential Riparian Road Drainage Lengths to Stream Length) Low = <.1 Med = .1-.3 High .3	X		Displays the predicted degree of road caused artificial increase in drainage networks leading to an undesired increase in efficiency of watershed drainage patterns.	HUC 6 layer Catchment layer Road Layer NHD Stream Layer Road-Drain Model DEM Layer
Ratio of Riparian roads within 300 ft. of stream channel to Stream Length Low = .3 Med = .3 - 1 High = >1	X		Displays the ratio of road length to stream length in 300 ft. riparian buffer.	HUC 6 Layer Catchment Layer Road Layer Floodplain Layer

APPENDIX B. Classification of Forest Vegetation

A host of vegetation classification schemes has been developed. The classification used for the ICBEMP (Hessburg et al. 1999) is the most relevant for our use, as it is the basis for historical range of variability and future range of variability estimates. This classification scheme, developed to facilitate ecosystem management, is part of the interim direction ("Eastside Screens") for forests East of the Cascade Mountains (and outside of the range of the Northwest Forest Plan) in Oregon and Washington (USFS 1998). It has been the basis of much subsequent research and analysis (Hessburg et al. 1999a, 2000).

The ICBEMP classification uses combinations of composition, potential vegetation, and forest structure to categorize landscapes. In this classification system, forest cover types are determined from overstory and understory species composition and crown cover. Forest cover is classified according to Society of American Foresters (SAF) cover type definitions (as applied by Hessburg et al. 1999a). Potential Vegetation Type (PVT) is the vegetation that would develop in a similar environment in the absence of disturbance.

Forest PVT is classified at the series level (Lillybridge et al. 1995) determined from overstory and understory species composition, as well as elevation, slope, and aspect. PVT allows evaluation of both cover type and structure class in the site context. Stratifying a landscape into process-based structure classes allows subsequent analysis of landscape patterns and ecological processes. The seven structural/process classes used by Hessburg et al. 2000a and in this Strategy are shown below.

Young Forest Multi-Strata (YFMS): Two or more cohorts are present through establishment after periodic disturbances. Large and/or old early seral trees are often at reduced density from fire or logging.

Old Forest Multi-Strata (OFMS): Two or more cohorts and strata are present including large, old trees.

Old Forest Single-Strata (OFSS): Single-stratum stands of large, old trees. Relatively few young trees are present in the understory.

Stand Initiation (SI): Growing space is reoccupied following a stand replacing disturbance.

Stem Exclusion Closed Canopy (SECC): New individuals are excluded through light or below-ground competition.

Stem Exclusion Open Canopy (SEOC): Below-ground competition limits establishment of new individuals.

Understory Reinitiation (UR): Initiation of a new cohort as the older cohort occupies less than full growing space

APPENDIX C: Terrestrial Evaluation Principles

The terrestrial landscape evaluations and prescriptions follow the OWFRS (USDA Forest Service 2012, Hessburg et al. 2013) landscape evaluation process. This process is based upon the concept that a stand by stand approach to forest restoration without establishing a landscape context for the location, amount, and type of restoration treatments, will not lead to resilient forested landscapes. The OWFRS process provides a framework to directly apply the seven principles of landscape restoration outlined by Hessburg et al. (2015):

Principle 1: Important ecological processes[1] operate across spatial scales – from tree neighborhoods to regional landscapes. *Implication: Planning and management must incorporate and link the tree neighborhood, patch, drainage/hillslope, local landscapes, and regional landscapes.*

Principle 2: Topography provides a natural template for vegetation and disturbance patterns across the landscape hierarchy scales. *Implication: Use topography to guide restoration treatments*

Principle 3: Disturbance and succession drive ecosystem dynamics. *Implication: Focus on restoring the ecosystems' inherent fire/disturbance regimes and vegetation successional patterns; other ecological processes will follow.*

Principle 4: Predictable distributions of forest-patch sizes naturally emerge from interactions climate-disturbance-topography-vegetation. *Implication: focus on restoring the natural distribution of forest patch sizes across landscapes.*

Principle 5: Patches are "landscapes within landscapes: *Implication: focus on restoring characteristic tree clump and gap patterns within stands/patches*.

Principle 6: Widely distributed large, old trees, provide a critical ecological backbone for forested landscapes. *Implication: focus on retaining and promoting large/old trees and post-disturbance large snags and down logs*.

Principle 7: Traditional patterns of land ownership and management disrupt inherent landscape and ecosystem patterns. *Implication: develop restoration projects that effectively work across forest ownership and management allocations*.

[1] Fish and wildlife dispersal, hydrology, and the frequency, severity, and extent of disturbances such as fire, insects, disease, wind, and floods.

APPENDIX D: Ecological Sub-Regions

The determination of Historic and Future Ranges of Variability is based on the ecological sub-region. These were delineated as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Hessburg et al., 1999, Hessburg et al., 2000). These were groupings of land units with similar geology, landform, and climate. Within each of these ESRs, a subset of sub-watersheds was photo-interpreted using historical imagery dating from the 1930s to the 1960s. A total of 337 sub-watersheds was sampled this way over 53 total ESRs, or an average of 6 per ESR.

The range of conditions found in those sampled watersheds represented the historic range of variability (HRV). Thus for example in ESR 4, Ponderosa Pine was found to represent anywhere from 0 to 9.8% of the sub-watershed, its mean patch size varied from 0 to 874.8ha, and its patch density varied from 0 to 12.4 patches per 10,000ha. The determination of FRV is then just those same values but for the ESR that is the next warmer/drier one. Normally this corresponds to the adjacent ESR that is lower in elevation.

The Upper Wenatchee Project Area straddles 3 ecological sub-regions. Lake Wenatchee, Big Meadow Creek, and Lower Chiwawa are located in ESR 4, defined as 'Wet-Warm-Moist Forest/Cold Forest with low solar radiative flux', whereas Beaver Creek-Wenatchee River is in ESR 5, defined as 'Moist-Warm- Moist Forest/Cold Forest with moderate solar radiative flux' (Hessburg et al., 2000). Lower Chiwawa does straddle ESR 4 and 5, but it was determined to mostly carry the characteristics of ESR 4. Beaver Creek straddles ESR 5 and 13, but again the determination was made to stick with ESR 5 as it is the dominant condition in that watershed.

For Future conditions an ESR was chosen that represented the most likely ESR under a warmer/dryer hypothetical future climate. For the first three watersheds, this warmer/dryer scenario was ESR 5, whereas for Beaver Creek-Wenatchee River it was ESR 11- 'Dry/Moist-Warm-Moist Forest/Dry Forest, with moderate solar radiative flux'.

ESR	Sampled Basins (8th code HUC)	Sampled Sub-watersheds*	Photo Years
4	Wenatchee, Naches, Upper Yakima	16	1949 (WEN), 1942-1959 (UYK), 1938-1949 (NAC)
5	Upper Deschutes, Methow, Wenatchee, Naches	6	1943-1959 (UDS), 1954-1956 (MET), 1949 (WEN), 1938-1949 (NAC)
11	San Poil, Naches, Palouse, Upper Yakima, Lower Yakima, Wenatchee	13	1936-1944 (SPO), 1938-1949 (NAC), 1932-1951 (PLS), 1942-1959 (UYK), 1949 (LYK), 1949 (WEN)

* Number of sub-watersheds where the majority is in that ESR

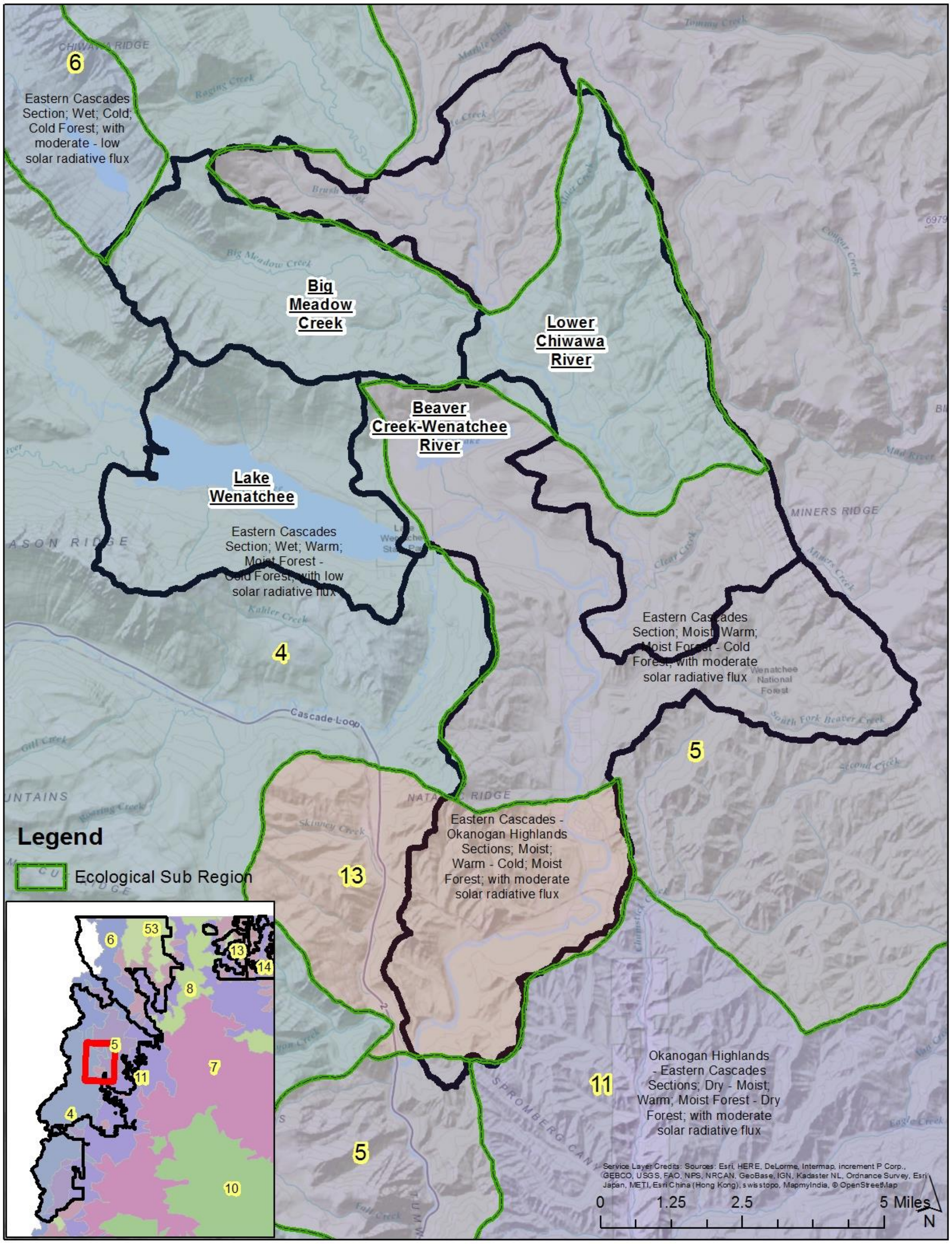
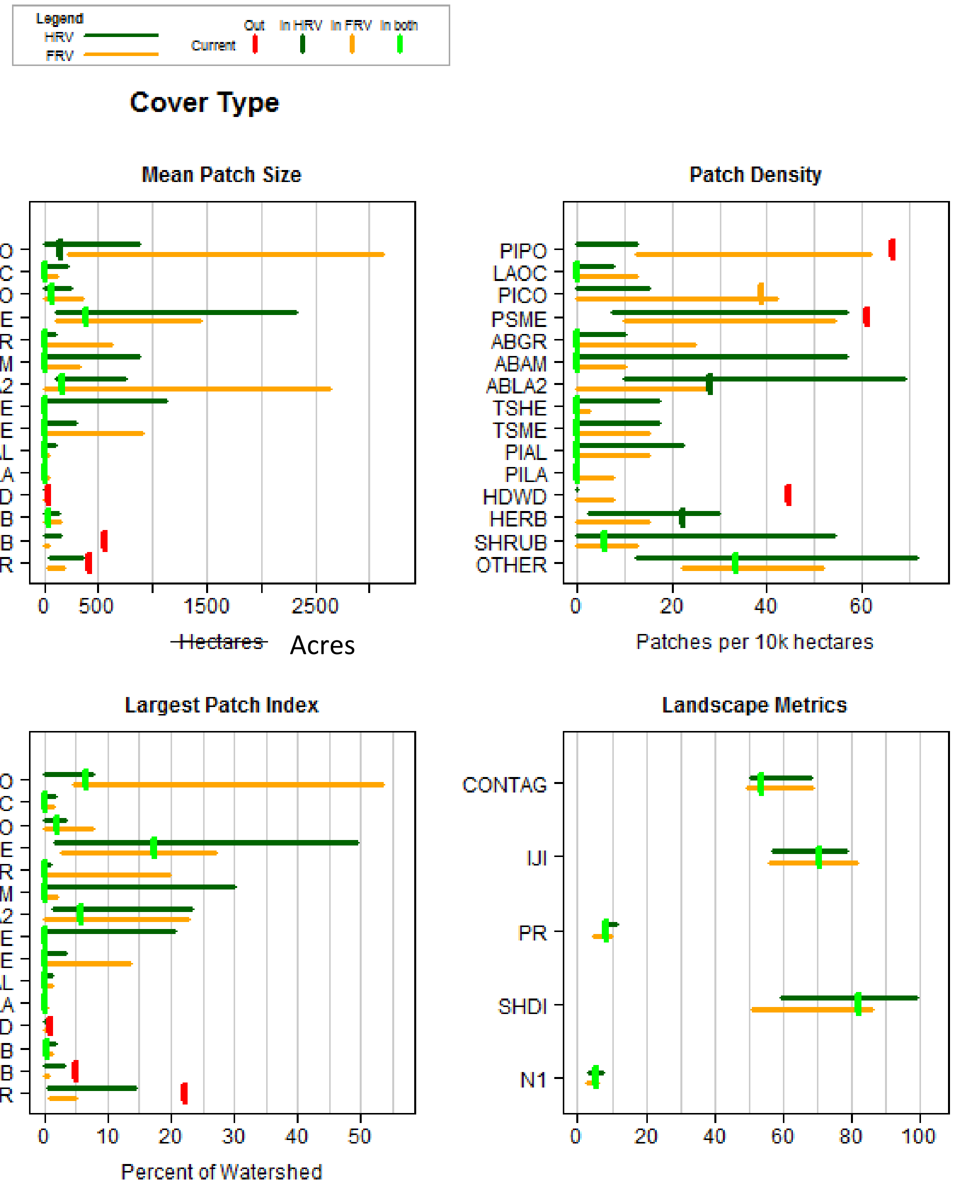


Figure 21: Ecological sub-regions of the Chelan Pilot project area

APPENDIX D: Terrestrial Departure Graphics Example



APPENDIX E: Aquatic Departure Tables

Lower Chiwawa/Big Meadow

catchment _#	Acres	BaseRdDensity _misqmi	RipRdDensity BaseRd_misqmi	RdDrainIncrease _BaseRds	BaseRdStrmCross _PerStrmMile	RipRdLen_to_ StreamLength _Ratio
2	1873.75	0.64	0.67	0.12	0.30	0.074
6	1078.52	1.08	0.47	0.05	0.26	0.051
9	1223.79	0.83	0.58	0.06	0.53	0.067
11	794.62	1.89	2.22	0.24	1.63	0.238
12	594.63	3.35	0.62	0.14	0.00	0.067
14	1294.96	4.78	5.63	0.70	1.42	0.628
15	1838.54	1.63	2.08	0.22	1.14	0.227
16	799.26	1.11	0.81	0.05	0.73	0.088
17	1415.17	4.24	4.48	0.63	2.16	0.512
19	509.48	0.64	1.03	0.10	0.78	0.117
21	1043.11	4.99	2.59	0.45	0.93	0.284
22	1745.54	5.72	3.99	0.49	1.20	0.447
23	1633.29	2.11	5.30	0.59	2.25	0.534
24	1035.10	4.15	0.12	0.00	0.00	0.013
26	576.74	4.52	6.93	0.00	0.00	0.812
27	689.97	6.51	0.00	0.71	0.62	0.000
28	787.35	4.95	5.84	0.52	1.66	0.629
29	1489.06	5.80	5.70	0.84	1.08	0.641
30	541.25	5.94	4.57	0.50	0.80	0.455
33	1010.81	2.44	3.26	0.43	1.52	0.366
34	717.13	6.58	10.66	2.14	4.02	0.564
36	1397.46	4.76	1.43	0.20	0.00	0.161
37	828.69	3.23	4.55	0.55	2.64	0.516
38	576.27	3.47	13.15	1.60	1.08	1.510
40	1063.39	4.52	5.34	0.72	2.13	0.608
41	813.26	6.54	4.92	1.38	1.27	0.547
42	904.56	5.35	4.85	0.47	0.86	0.454
44	578.52	4.28	7.39	0.60	4.69	0.876
47	970.25	4.69	0.00	0.00	0.00	0.000
49	898.28	5.32	5.14	1.17	0.43	0.573
50	1059.74	4.88	6.00	0.76	3.49	0.683
51	606.25	5.16	8.12	1.14	1.67	0.893
54	954.20	4.51	7.47	1.19	4.18	0.863
56	512.47	4.90	1.90	0.22	0.31	0.200
57	1145.46	4.51	4.98	0.50	2.86	0.494

Lake Wenatchee/Beaver Creek

Catchment Number	Area (Acres)	RdDensity (mi/mi²)	RipRdDensity (mi/mi²)	RdDrainIncrease_Base Rds	Crossings per Stream Mile (#/mi)	Combined Impact (%)
8	805	.0	.0	.0	.0	17
11	1262	.5	.3	.0	.0	21
36	729	1.7	.0	.0	.0	25
37	452	1.9	.0	.0	.0	25
9	942	4.4	.0	.0	.0	33
6	1620	4.6	.0	.0	.0	33
3	1669	6.4	.0	.0	.0	38
12	948	1.4	2.2	.0	.0	38
32	1080	3.0	1.4	.1	.0	50
2	1107	2.0	1.2	.1	1.7	50
20	434	2.8	1.6	.2	.0	50
27	774	3.0	1.8	.2	.3	50
13	1849	2.9	1.5	.1	.7	54
17	737	3.1	1.1	.1	1.0	54
34	856	2.5	2.2	.2	.4	58
30	1723	1.0	2.6	.3	.9	58
33	713	1.4	4.4	.5	.0	58
49	1618	7.1	3.3	.2	.1	63
10	667	1.5	2.4	.3	1.9	63
29	1172	2.0	3.3	.4	1.1	67
21	1305	3.0	3.7	.4	.6	71
15	1583	10.4	7.9	.4	.0	75
14	1239	7.8	3.9	.3	1.3	79
31	728	5.1	4.5	.4	1.8	79
1	1486	3.8	3.6	.4	2.4	79
18	1374	4.1	4.7	.5	2.3	79
44	652	5.4	7.0	.7	.0	79
5	1787	5.1	4.0	.4	3.0	83
24	1026	5.9	4.9	.4	2.3	88
85	949	8.8	7.4	.7	3.0	92
23	1656	5.1	8.1	.9	2.3	92
16	1029	8.0	8.9	1.0	2.9	92
19	700	8.2	6.8	.7	3.4	96
25	1436	7.6	10.4	1.2	3.7	96
22	1168	7.2	11.7	1.2	3.8	96