Ecological Classifications of the Upper Columbia Evolutionarily Significant Unit for Spring Chinook Salmon and Summer Steelhead Trout

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Introduction

Background and Objective

NOAA Fisheries, the Bonneville Power Administration, the Salmon Recovery Funding Board, and other entities have undertaken the development of a large-scale comprehensive salmon monitoring program to be implemented in three Columbia River subbasins. The primary objective of their project is to develop a set of rules guiding the implementation of large-scale monitoring and evaluation programs across the Columbia River basin.

Pacific Biodiversity Institute (PBI) has undertaken a portion of this greater project, which is described in this report. Specifically, this report addresses issues of developing standardized approaches to landscape-scale classifications of aquatic and terrestrial habitats using GIS and remote sensing technologies. The data and classification methods developed by Pacific Biodiversity Institute followed initial recommendations described by Tracy Hillman in the Monitoring Strategy for the Upper Columbia Basin draft report (Hillman 2003).

Numerous approaches exist regarding the classification of aquatic and terrestrial habitats using GIS and remote sensing at the landscape scale. Many of these approaches seek to standardize the process by which remotely sensed data is interpreted and reduced. For instance, multi-spectral imagery covering large spatial extents is often lumped into functional classes through a process called classification, thereby converting complex pictures into simplified raster datasets. However, each separate approach to standardization may be different, and there can be many versions of a "functional class". Therefore, applications of "standard approaches" can in fact generate non-standard, non-transferable data; say if two different entities are not using the same "standardized approaches". As part of the development of a rule set to guide monitoring and evaluation for anadromous fishes and their habitat, it is necessary to directly compare the diversity of "standard" approaches and assess their ability to describe aquatic and terrestrial habitat features in a useful and meaningful way.

This report describes and evaluates the work that Pacific Biodiversity Institute has undertaken to produce landscape-scale classification data collection, generation and reduction methods to assist the overarching Columbia Basin salmon monitoring program. The tasks described here were completed by Pacific Biodiversity Institute under contracts with regional entities other than NOAA Fisheries; however, a complete analysis and assessment of the data, methods and application was not covered or completed under these previous contracts. Therefore, this report, sponsored by NOAA Fisheries, fills a gap in providing a detailed description of the methods, results and data developed by Pacific Biodiversity Institute under the previous contracts. This report also provides an assessment of the utility of these methods in generating guidance for standardized monitoring approaches.

The spatial datasets discussed in this report have already been supplied to the various federal and state agencies and associated consultants responsible for salmon monitoring and recovery efforts in the Upper Columbia ESU region. To assist the users of our data, we have included details on the input datasets used, accuracy and spatial limitations of input data and subsequent data products produced, suggestions on improving data products based on improving input data sets, descriptions of macro language codes used to process datasets (in the Appendices), and various other details concerning the quality and integrity of the GIS data and tabular data. A GIS data dictionary with the data layer names developed for the UCESU is included as Appendix A. Our aim in this report is to provide all the users of the data with a comprehensive manual that will enrich their understanding of the data and help them avoid problems that often result from the misapplication of GIS datasets. We also aim to provide users with ideas for potential applications of the data.

Geographic Scope

This report is relevant to the watersheds in the portion of the Upper Columbia Evolutionarily Significant Unit (UCESU) region within the national boundaries of the United States of America. This area was divided into the following sub-basins and watershed groupings for analysis purposes (Figure 1).

- Wenatchee River Basin
- Entiat River Basin
- Methow River Basin
- Okanogan River Basin (including a small portion of the Similkameen River Basin)
- Douglas County watersheds in the UCESU
- Other small watersheds in the UCESU

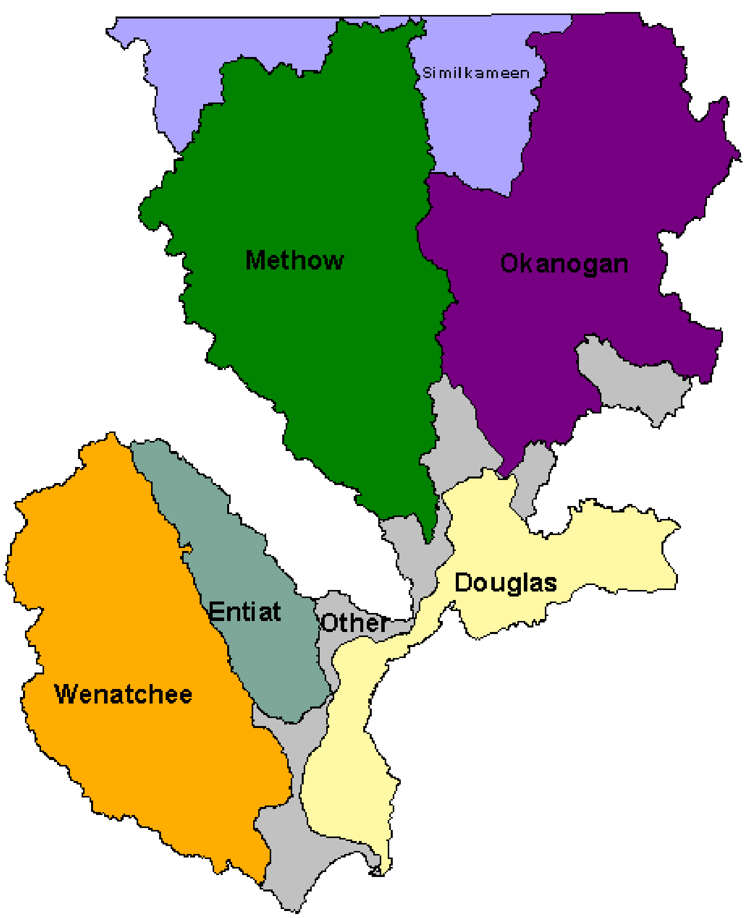

Figure 1. Boundary of the Upper Columbia River Evolutionarily Significant Unit and subbasins within the study area.

Description of ecological classification variables and methods of data collection, generation, and reduction

In this section we describe some of the base data used in the project and the various ecological classification variables that we addressed at multiple spatial scales and the methods we used to develop GIS data for these variables. The following levels of analysis are addressed:

- Regional setting classification
- Basin-level classification
- Valley segment classification
- Channel segment classification
- Riparian vegetation classification
- Watershed Condition

Hydrography Data Used in Project

One of the most important input data types necessary for the successful completion of this project was hydrography data. In this case, hydrography data refers to surface water drainage networks, which keep track of the direction of flow of water in surface water bodies including lakes, reservoirs, streams, and rivers. Many entities have created and maintain hydrography data that cover all or part of the project area. However, much variation exists between the accuracy and usefulness of the various datasets. We examined a wide variety of hydrography layers produced by different state and federal agencies for use in this project, and we found that each had their own advantages and disadvantages. Table 1 provides a brief review of the various hydrography datasets that cover the UCESU region.

As a result of our review of the datasets listed in Table 1, we selected different datasets to be used as input layers in the different environmental variable analyses we conducted during this project. For analyses requiring stream networks we used the following datasets (Figures 2 -4):

- 1:100,000-scale StreamNet layer (2002) (Figure 2) - used for Strahler Stream Order and Channel Gradient analyses
- 1:24,000-scale SSHIAP layer (2003) (Figure 3)- used for Drainage Basin Classification, Valley Segment Classification, Channel Segment Classification, Riparian Classification, and Riparian / Road Index analyses.

For analyses requiring accurate spatial depictions of surface water bodies we used these following datasets:

- 1:24,000-scale WDNR Water Body/Water Shoreline layer (2004) - used for Riparian Classification analysis
- 1:24,000-scale USFWS National Wetlands Inventory layer (2000) - used for Riparian Classification analysis

Table 1. Hydrography datasets reviewed for suitability in meeting the needs of this project.

Hydrography Layer Name	Map Scale	Source	Comments
StreamNet	1:100,000	WDFW	Networked, but scale is too large to capture actual stream locations accurately. Contains attributes distinguishing irrigation ditches/canals from natural streams/rivers.
SSHIAP	1:24,000	WDFW	Networked, better scale, and captures actual stream locations more accurately. However, this is not uniformly available on a regional level. Does not contain attributes distinguishing irrigation ditches/canals from natural streams/rivers.
USFS Wenatchee and Okanogan stream layers	1:24,000	USFS	In some cases more accurate than SSHIAP 1:24,000 streams, but does not adequately cover areas outside the National Forests. Some problems with network connections.
WDNR watercourse lines	1:12,000 and 1:24,000	WDNR	Inconsistent mapping between 1:12,000 and 1:24,000-scales. Not networked.
WDNR water body polygons	1:24,000	WDNR	Best layer for surface water polygons (lakes and larger rivers)
National Wetlands Inventory polygons	1:24,000	USFWS	Contains some information on surface water polygons.

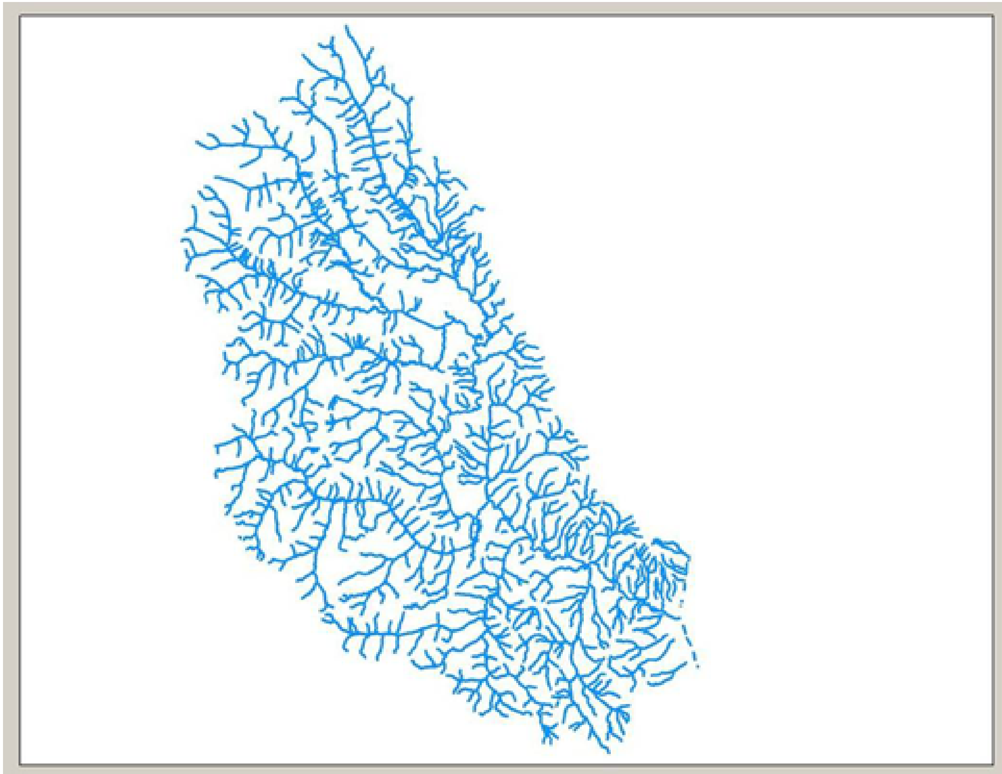

Figure 2. Wenatchee Basin, 1:100,000-scale stream layer from StreamNet 2002 (irrigation systems removed)

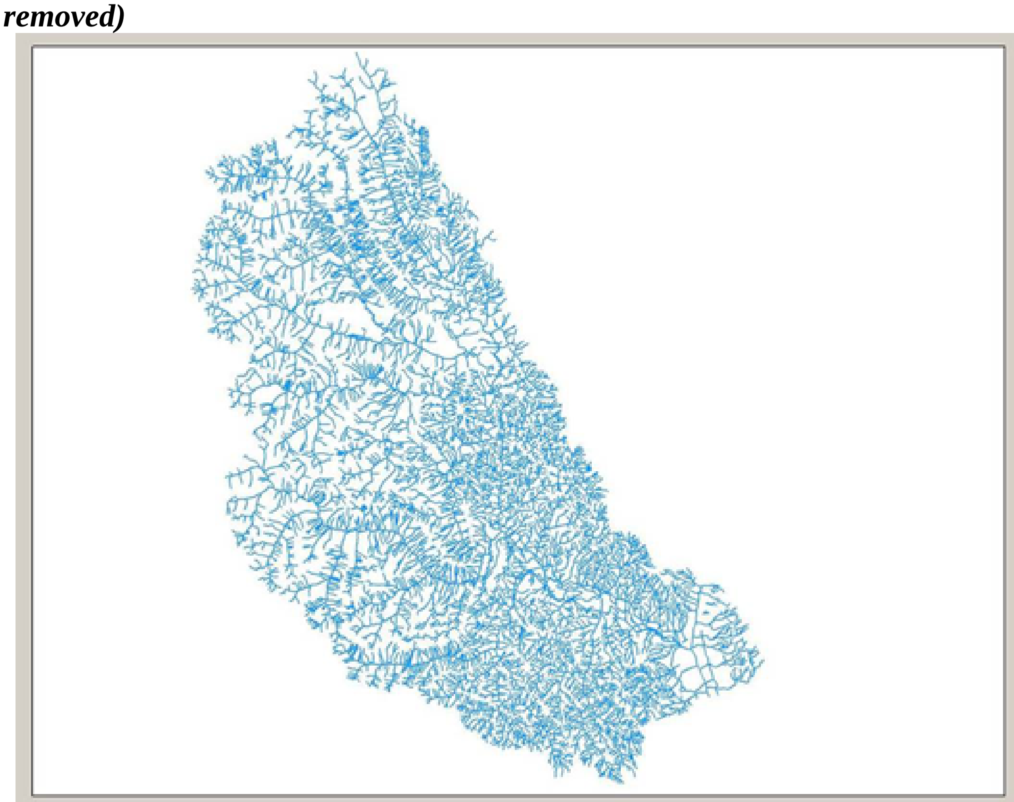

Figure 3. Wenatchee Basin, 1:24,000-scale stream layer from SSHIAP 2003 (includes irrigation systems)

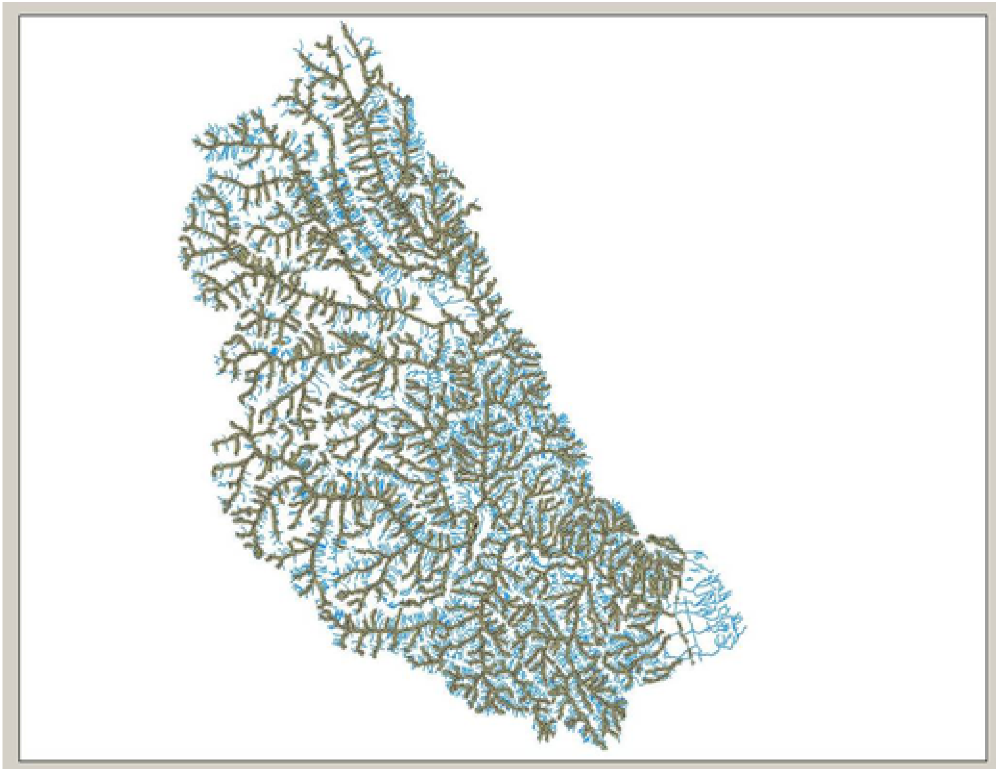

Figure 4. Wenatchee Basin, 1:100,000-scale streams overlaid on the 1:24,000-scale streams

It is important to note that none of the available hydrography data is perfect or error free. Figure 5 illustrates an area where both the SSHIAP and StreamNet data layers only partially reflect the actual location of two major rivers. The SSHIAP 1:24,000-scale layer matches the actual location better than the StreamNet 1:100,000-scale layer, but even the SSHIAP data is still off from the actual stream location, sometimes by as much as 50 meters, as seen in the aerial photography. Some of the locational discrepancies seen between the hydrography data and aerial photography or current on-the-ground conditions come from stream meandering and channel changes after floods or other peak flow events.

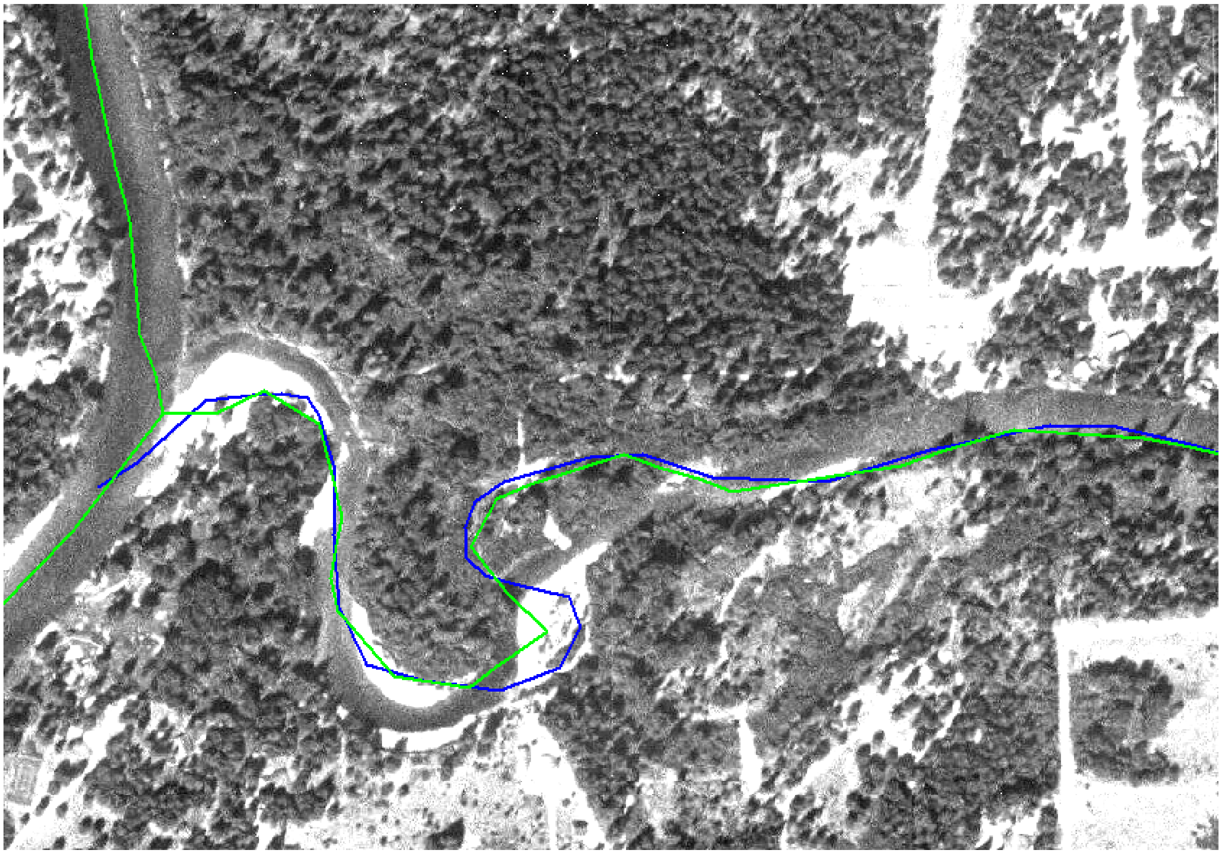
Figure 5. Comparison of 1:100,000-scale stream GIS layer (green line) with 1:24,000-scale stream layer (blue line) with actual rivers as shown on 1998 orthophotography (where the Chiwawa River enters the Wenatchee River).

Another potential pitfall in both the SSHIAP and StreamNet data has to do with the ability to separate out irrigation ditches and secondary channels from the naturally occurring primary stream and river channels. Inclusions of such features as ditches and secondary channels can severely disrupt Strahler stream order calculations, not to mention skew riparian / road index calculations and riparian vegetation mapping. For the StreamNet data, adequate attribute descriptions exist to distinguish most ditches and secondary channels from primary channels, which is why we chose this layer to be used in the Strahler stream order analysis. However, a few miss-labeled streams were found to exist in this layer during our review period of the hydrography datasets in the Wenatchee Subbasin work, though we hope this to be an isolated error. The SSHIAP data has no attribute data whatsoever that describes the status of an arc as representing a primary stream/river channel, or an irrigation ditch or secondary channel. Hence, the SSHIAP data is not suitable for some of the analyses we needed to perform for this project. Figures 6 and 7 illustrate some of the problems concerning the depiction of irrigation ditches (or lack thereof) in the two layers.

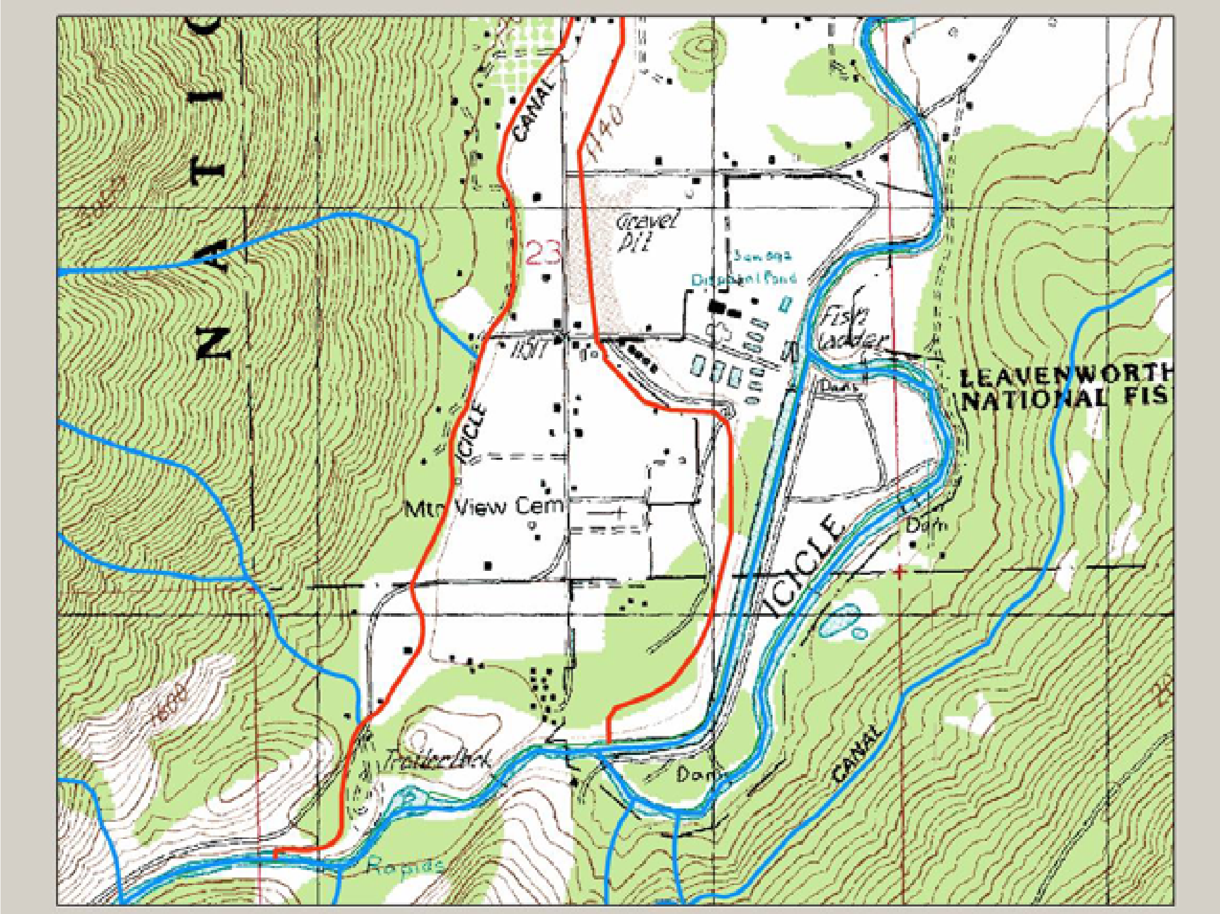

Figure 6. Illustration of stream labeling and location errors in both the SSHIAP and StreamNet hydrography data. The red line on the left is a non-attributed stream segment from the SSHIAP 1:24,000-scale data layer. It is clear from the underlying DRG map that what is actually being depicted here is actually a canal and not a natural stream. The SSHIAP data does not provide attributes that distinguish between the two. The red line on the right is from the StreamNet 1:100,000-scale data layer. This line may or may not be depicting a ditch or underground irrigation channel, but it is incorrectly attributed as being a "stream/river" in the layer's attribute table.

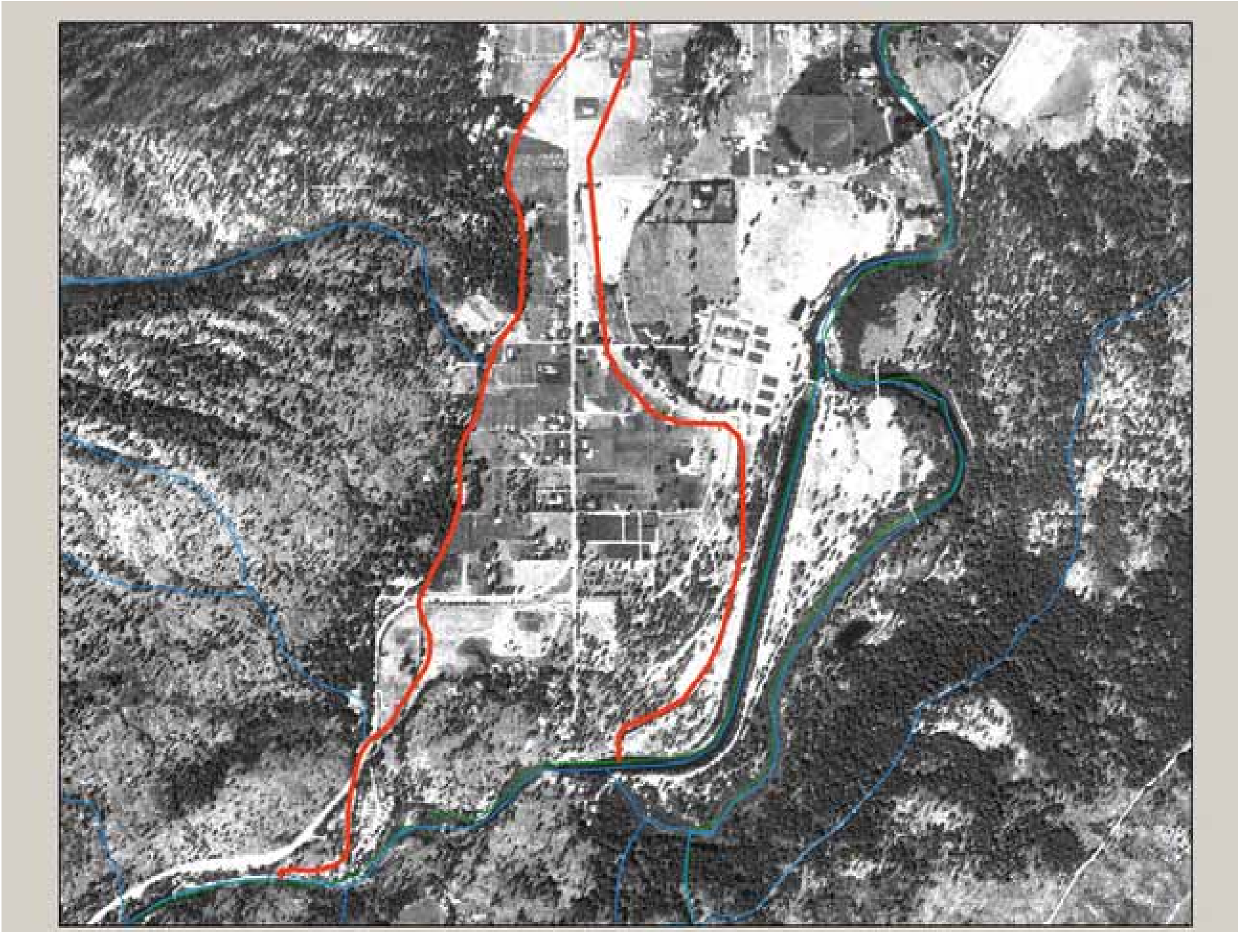

Figure 7. This illustrates the same hydrography data as the previous figure, but this data is displayed over a 1998 digital orthophoto. Again you can see that the red lines are not depicting actual streams at all, but if one did not scrutinize either of the datasets with additional information such as DRGs and DOQs, such features could erroneously be included in analyses of the natural stream networks, skewing data and altering the analyses results.

In the case of these errors in the Icicle Creek area, we did our best to manually correct the problems discussed above and improve the integrity of the hydrography data for use in our analyses. However, given the large size of our project area and the amount of streams and rivers occurring within the UCESU region, we did not perform any other systematic review or enhancements of the original hydrography data.

For better or for worse the SSHIAP and StreamNet data was used as is to complete the environmental variable mapping and analysis that this project was created for. Though many errors and limitations did exist in these two datasets, they still provided the best available data to use as inputs into our analyses. Such inherent errors in the original hydrography data should be considered when using our data products.

Digital Elevation Data Used in the Project

We acquired seamless ten meter digital elevation models (DEMs) for use in this project. Ten meter DEMs consist of a raster grid of regularly spaced elevation values (10 meters by 10 meters) that have been primarily derived from the 7.5 minute USGS topographic map series. The seamless dataset we used was created by mosaic of 7.5 minute USGS DEMs by Harvey Greenberg, formerly in the Department of Earth and Space Sciences at the University of Washington.

Figure 8. Ten meter DEM displayed as a shaded relief image and cut to the boundary of the UCESU.

Satellite Imagery and Aerial Photography Used in the Project

We incorporated both ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and TM7 (Enhanced Thematic Mapper) satellite imagery for use in this project. Level 1b ASTER imagery is available from the Land Processes Distributed Active Archive Center (LP DAAC). We incorporated both visible and near infrared (VNIR) and shortwave infrared (SWIR) swaths for our analysis work. TM7 data is available from Earth Resources Observation and Science (EROS) at USGS.

We used the most current cloud-free satellite imagery in our analyses, typically ranging from 1999 – 2003. We also used older Landsat TM7 and multi-spectral scanner (MSS) images to look for changes in vegetation cover between the newer image sets and the old.

Figure 9. VNIR true color ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) scene of portions of the Methow and Okanogan Subbasins

We obtained the most recent digital orthophoto quads (DOQs) and quarter-quads (DOQQs) available from the Washington State Geospatial Data Archive (WAGDA) as our aerial photography. WAGDA provides a library of USGS and USFS 7.5 minute black and white 1 meter resolution digital orthophotos. The dates of the photos we obtained ranged from 1990 to 1998.

Regional Setting Classification

We obtained GIS data for the four regional setting classification variables (Table 2). USGS hardcopy maps for each of the regional setting classifications provided the baseline inputs for the digital datasets created and/or updated by the various federal agencies listed below. The ecoregion classification variables are derived from maps produced by Bailey (1978, 1998) and Omernik (1987). We incorporated each agency's data without alteration for the UCESU project. Dataset information on creation methodologies, managing agencies, scale, and other pertinent details are provided within the associated metadata for each data layer.

Table 2. Regional setting classification variables.

General characteristics	Classification variable	Example protocols	Data Source and Data Layer Date	Scale of Data Layer
Ecoregion	Bailey classification	Bain and Stevenson (1999)	USFS (1994)	6th field HUC
	Omernik classification	Bain and Stevenson (1999)	EPA (2003)	1:250,000
Physiography	Province	Bain and Stevenson (1999)	USGS (2002)	1:7,000,000
Geology	Geologic districts	Overton et al. (1997)	USGS (1995)	6th field HUC

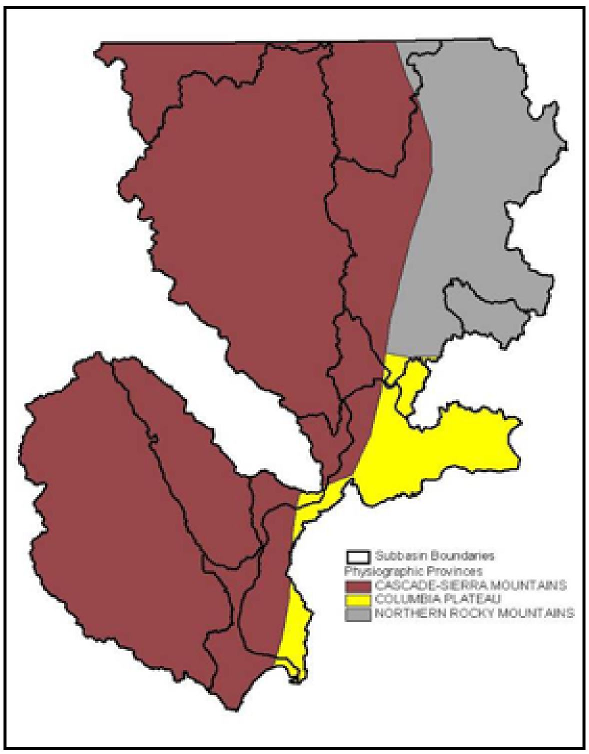

Figure 10. Physiographic provinces in the UCESU.

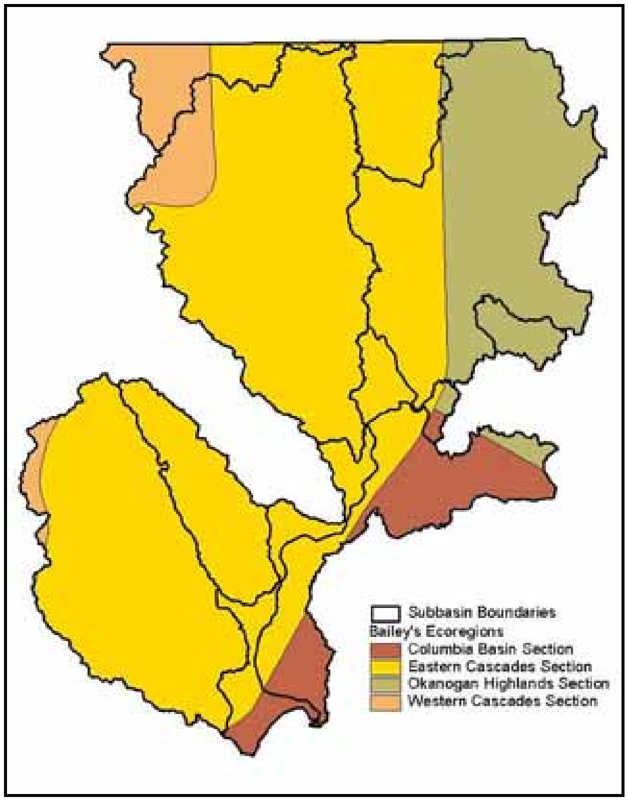

Figure 11. Bailey's ecoregions in the UCESU.

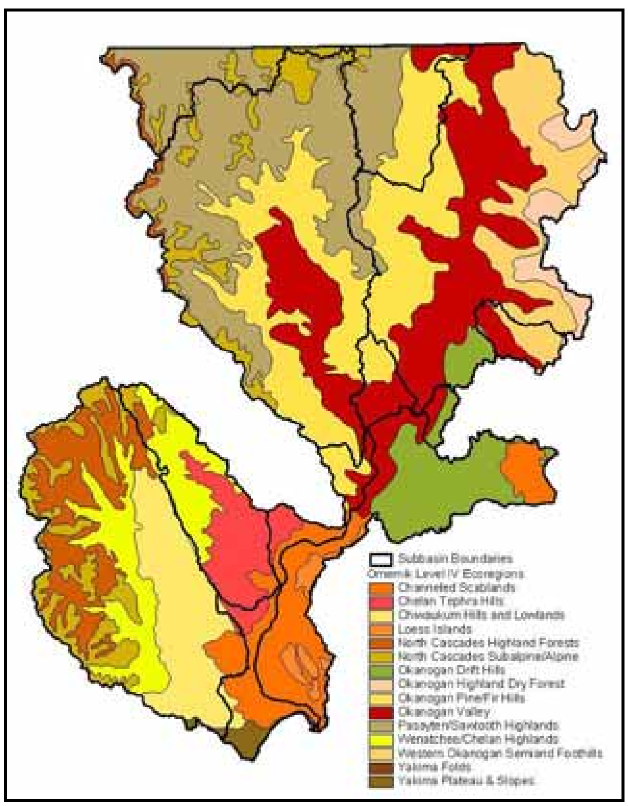

Figure 12. Omernik's ecoregions in the UCESU.

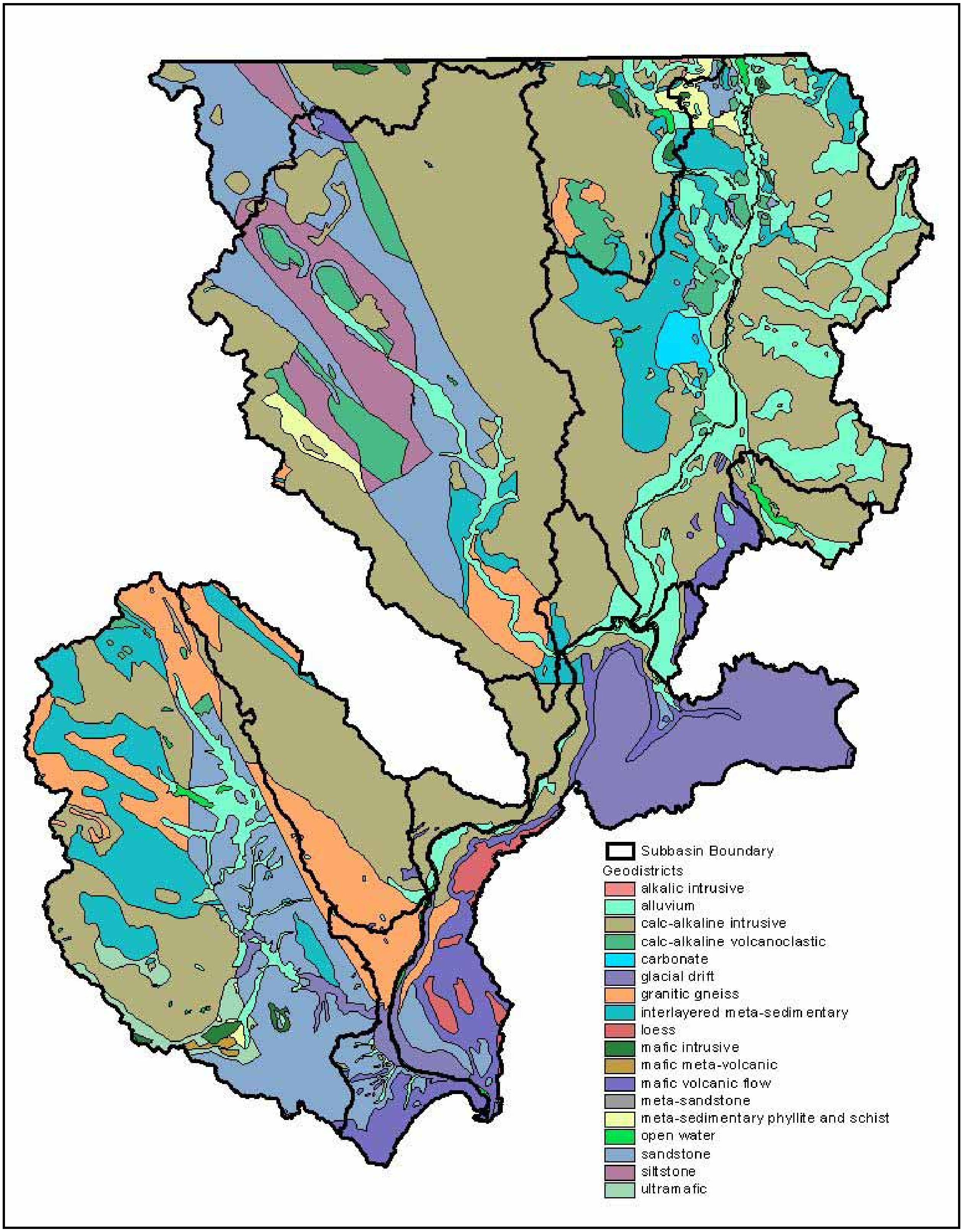

Figure 13. Geologic districts in the UCESU.

Basin Level Classification

Basin level classification data layers and information were compiled using standardized techniques. Table 3 lists the basin level classification variables that we developed.

Table 3. Basin level classification variables.

General characteristics	Classification variable	Example protocols	Data Source and Data Layer Date	Scale of Data Layer
Geomorphic features	Basin area	Bain and Stevenson (1999)	NOAA (2003)	1:250,000
	Basin relief	Bain and Stevenson (1999)	USGS (2001)	10-meter DEMs
	Drainage density	Bain and Stevenson (1999)	SSHIAP (2001)	1:24,000
	Stream order	Gordon et al. (1992)	StreamNet (2002)	1:100,000

Basin Area

Basin areas were automatically calculated in a GIS environment for the regions specified in our work contract using 2003 Upper Columbia ESU boundary GIS data from NOAA. In order to accurately measure basin areas for the regions defined in our contract, some geo-political boundaries and major barriers to fish passage were used to modify the original NOAA ESU boundaries GIS data. The Methow, Entiat, and Wenatchee subbasins were unaffected by our alterations of the NOAA GIS data. However, the rest of the Upper Columbia Spring Chinook ESU was modified in the following ways:

We eliminated some HUC6 watersheds that did not show direct above-ground hydrologic linkages with the Okanogan River drainage system. These HUC6 watersheds were re-classified as being part of the Other Small Watersheds analysis region (a catch all assignment for all small watersheds within the ESU that are not part of the major subbasins, or in Douglas County).
The HUC6 watershed labeled “Mouth of the Similkameen River” was manually divided into two smaller watersheds based on topographic ridgelines and the placement of the lower Similkameen Dam along the Similkameen River. All regions of the original HUC6 watershed that flowed into the below dam portion of the Similkameen River were included as part of the Okanogan Subbasin, while all before dam inputs were labeled as being part of the Similkameen Subbasin. We did not include the Similkameen Subbasin in the analyses covered in this report.
We divided all HUC 6 watersheds straddling the Columbia River into separate watershed units based on the mapped location of the Columbia River in the WA DNR Watershed Administrative Units 0500 GIS layer from 2000. All divided watershed units on the non-Douglas County side of the Columbia River were labeled as being part of the Other Small Watersheds analysis region, while all watershed units on the Douglas County side of the Columbia River were labeled as being part of the Douglas County analysis region.

Basin Relief

We used the 2003 Upper Columbia ESU boundary GIS data from NOAA, modified as described above (see Basin Area), and a 2001 USGS 10-meter DEM covering all of Washington State to derive basin relief variables for the regions defined in our contract. In Arc/INFO Workstation, we clipped the statewide 10-meter DEM to the UCESU boundary. Then we clipped out a section of the resulting ESU DEM for each subbasin or analysis region using the modified 2003 Upper Columbia ESU boundary GIS data. Lastly, we opened each new 10-meter DEM for the various subbasins or analysis regions into ArcView 3.3, opened up the associated variable attribute table, and exported the table to Microsoft Excel format. There, using the "value" column, we were able to perform all the calculations necessary to complete the basin relief variables. Table 4 illustrates the results we obtained on basin relief for the subbasins of the UCESU.

Table 4. Topographic Relief of Each Subbasin in the Upper Columbia ESU

	Basin Name					
	Wenatchee	Entiat	Methow	Okanogan (U.S. portion only)	Douglas County	Other Areas
Max Elevation (meters)	2869	2818	2724	2514	1296	2079
Min Elevation (meters)	185	216	237	273	174	174
Mean Elevation (meters)	1515	1490	1450	1381	735	1121
Mode Elevation (meters)	569	829	728	278	216	216

Drainage Density

Drainage density was calculated for each subbasin and analysis region in the UCESU using SSHIAP 1:24,000 meter scale hydrography data from 2001. A master layer of SSHIAP hydrography data was created for the entire UCESU by appending together SSHAIP's available hydrography coverages for WRIA's 44 through 50. The 2003 Upper Columbia ESU boundary GIS data from NOAA, modified as described above (see Basin Area), was then used to clip out the hydrography data relevant to each subbasin or analysis region defined in our contract. A statistics summary command, run on the "length" item in each subbasin's or analysis region's new hydrography attribute table yielded the total stream length (using 1:24,000 hydrography) for each given region. The stream length variable was then divided by the basin area variable (km / sq. km) to yield the drainage density values. Table 5 illustrates the results we obtained on drainage density for the subbasins of the UCESU.

Table 5. Drainage Density in Each Subbasin in the Upper Columbia ESU

	Basin Name					
	Wenatchee	Entiat	Methow	Okanogan (U.S. portion only)	Douglas County	Other Areas
Density (km / sq. km)	1.91	2.41	2.29	1.56	1.09	2.16
Drainage Area (sq. km)	3440.55	1083.02	4723.05	4027.15	1828.52	1412.36
Total Stream Length (km)	6572.66	2606.34	10801.23	6262.81	1988.77	3052.93

Stream Order

Stream order values were calculated using an ArcView v3.x extension from ESRI ArcScripts. The extension is based on an algorithm created by K. Lanfear (1990) that calculates stream order variables on individual stream segments within a drainage network according to the Strahler method (Strahler, 1964). We ran the stream order extension on the StreamNet 1:100,000 meter scale hydrography data from 2002. All secondary channels and artificial drainage features such as irrigation canals and ditches had to be manually removed from the StreamNet data in order for the stream order extension to work correctly. In the case of the Okanogan Subbasin, for which much of the actual drainage basin exists north of the US/Canadian border, we had to manually increase the Strahler variables for the Similkameen and the Okanogan Rivers proper because the much of the upstream hydrography network was not available for the automated calculations. Figure 14 illustrates the results for the Wenatchee subbasin.

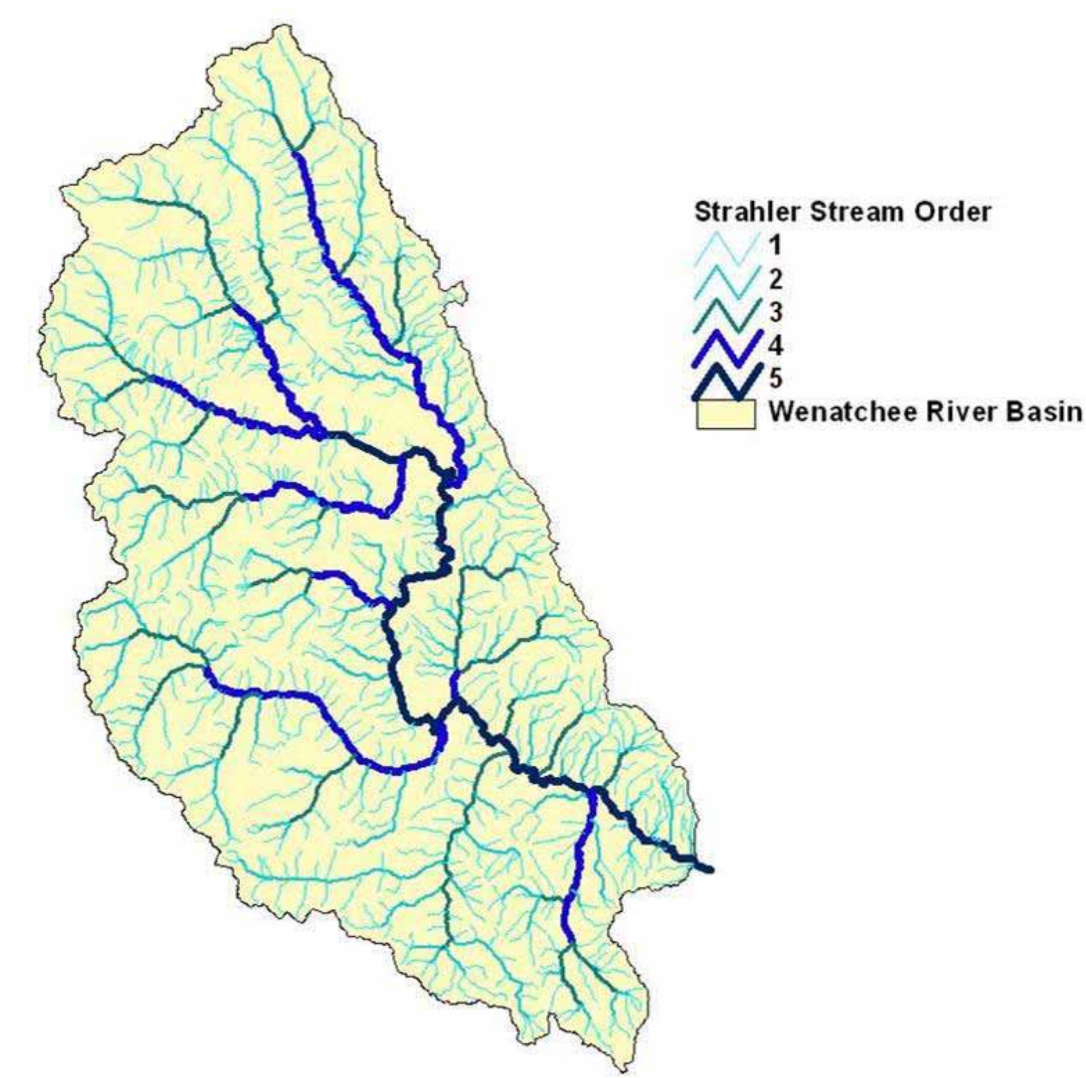

Figure 14. Strahler stream order of the Wenatchee River Subbasin.

Basin Ownership

We developed information on public land ownership within each basin or grouping of subbasins. Table 6 lists the results for public land ownership in the subbasins of the UCESU. Figure 15 illustrates these results in the Wenatchee Basin.

Table 6. Government Agency Ownership in Each Basin - from 2003 Major Public Lands Layer from WA-DNR (sq. km)

	Basin Name					
Ownership	Wenatchee	Entiat	Methow	Okanogan (U.S. portion only)	Douglas County	Other Areas
National Park Service			1.33			
Tribal				869.06	0.11	356.1
US Bureau of Land Management	12.4656	13.1	16.41	112.63	62.11	57.86
US Dept. of Defense					0.17	
US Fish and Wildlife Service	0.9476		4.62	0.34		
US Forest Service	2793.9468	931.2	3970.01	563.14		216.3
Washington Department of Fish and Wildlife	6.056	5.41	97.15	84.9	22.62	88.74
Washington State DNR	50.521	37.96	163.15	502.58	309.72	109.9
Washington State Parks	1.91		3.15	0.62	1.13	1.59

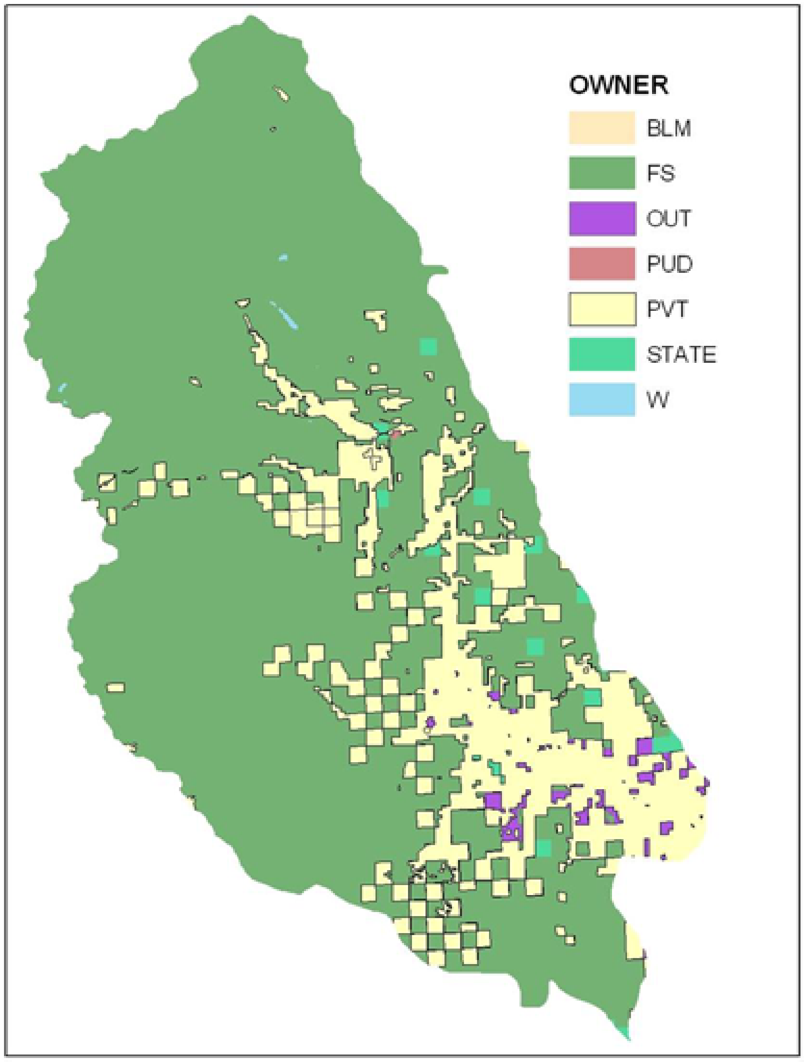

Figure 15. Ownership of Wenatchee River Basin.

Valley Segment Classifications

Valley segment classifications (Table 7) were calculated in an automated fashion using an inverted variable assignment strategy. Because Cupp and Naiman's definitions for each valley bottom type specify a particular valley bottom width, valley bottom gradient, and valley containment variable (Table 8), we submitted finalized data sets containing only the valley bottom type variables seeing that the other variables were inherent to the valley bottom type classification. This methodology is consistent with the approach put forth by Hillman in the *Monitoring Strategy for the Upper Columbia Basin* (2003).

Table 7. Valley segment classification variables.

General characteristics	Classification variable	Example protocols	Data Source and Data Layer Date	Scale of Data Layer
Valley segment	Valley bottom type	Cupp (1989); Naiman et al. (1992)	Pacific Biodiversity Institute (2003)	1:100,000 meters
	Valley bottom width	Naiman et al. (1992)		1:100,000 meters
	Valley bottom gradient	Naiman et al. (1992)		1:100,000 meters
	Valley containment	Bisson and Montgomery (1996)		1:100,000 meters

In some cases, we had to create new valley bottom type classes to account for the valley bottom type characteristics in our analysis regions. Landform features such as large coulees, which abound in the Columbia Basin, were not covered under the valley bottom types given by Cupp or Naiman. We also added additional higher gradient classes for the type "F", "M", "V", and "U" valley bottom groups. Under Cupp and Naiman's original class structure, some possible stream characteristic assortments were not dealt with, meaning the stream segments we analyzed would not have been assigned a valley bottom type if we used only Cupp and Naiman's original class structure and definitions. Table 8 presents an updated version of valley bottom type definitions.

Table 8. An updated version of Naiman's valley bottom type definitions (new classes developed by Pacific Biodiversity Institute are highlighted in yellow).

Valley bottom type[a]	Valley bottom gradient[b]	Side-slope gradient[c]	Valley bottom width[d]	Channel patterns	Strahler stream order	Landform and geomorphic features
Estuarine delta - F1	≤0.5%	<5%	>5X	Unconstrained; highly sinuous; often braided	Any	Occur at mouth of streams on estuarine flats in and just above zone of tidal influence
Alluviated lowlands - F2	≤1%	>5%	>5X	Unconstrained; highly sinuous	Any	Wide floodplains typically formed by present or historic large rivers within flat to gently rolling lowland landforms; sloughs, oxbows, and abandoned channels commonly associated with mainstream rivers
Wide mainstream valley - F3	≤2%	<5%	>5X	Unconstrained; moderate to high sinuosity; braids common	Any	Wide valley floors bounded by mountain slopes; generally associated with mainstream rivers and the tributary streams flowing through the valley floor; sloughs and abandoned channels common.
Wide mainstream valley - F4	≤1-3%	≤10%	>3X	Variable; generally unconstrained	1 - 3	Generally occur where tributary streams enter low-gradient valley floors; ancient or active alluvial/colluvial fan deposition overlying floodplains of larger, low-gradient stream segments; stream may actively downcut through deep alluvial fan deposition.
Gently sloping plateaus and terraces - F5	≤2%	<10%	1-2X	Moderately constrained; low to moderate sinuosity	1 - 3	Drainage ways shallowly incised into flat to gently sloping landscape; narrow active floodplains; typically associated with small streams in lowlands, cryic uplands or volcanic flanks.

Valley bottom type[a]	Valley bottom gradient[b]	Side-slope gradient[c]	Valley bottom width[d]	Channel patterns	Strahler stream order	Landform and geomorphic features
High sloping drainage entering wide mainstream valley - F6	3 - 11%	≤10%	2 -4X	Variable; generally moderately constrained	1 - 3	Generally occur where tributary streams enter low-gradient valley floors; ancient or active alluvial/colluvial fan deposition overlying floodplains of larger, low-gradient stream segments; stream may actively downcut through deep alluvial fan deposition.
Moderate sloping plateaus and terraces - M1	2-5%	<10-30%	<2X	Constrained; infrequent meanders	1 - 4	Constrained, narrow floodplains bounded by moderate gradient side-slopes; typically found in lowlands and foothills, but may occur on broken mountain slopes and volcano flanks.
Alluviated, moderate slope bound - M2	≤2%	<5%, gradually increase to 30%	2-4X	Unconstrained; moderate to high sinuosity	1 - 4	Active floodplains and alluvial terraces bounded by moderate gradient hillslopes; typically found in lowlands and foothills, but may occur on broken mountain slopes and volcano flanks.
Higher gradient drainage through gently sloping plateaus or terraces - M3	5 - 11%	<10-30%	<2X	Constrained; infrequent meanders	1 - 4	Constrained, narrow floodplains bounded by moderate gradient side-slopes; formation frequently related to channel downcutting in plateaus or terraces, typically found in lowlands and foothills, but may occur on broken mountain slopes and volcano flanks.
V-shaped moderate-gradient bottom - V1	2-6%	30-70%	<2X	Constrained	≥2	Deeply incised drainage ways with steep competent side-slopes; very common in uplifted mountainous topography; less commonly associated with marine or glacial outwash terraces in lowlands and foothills.

Valley bottom type[a]	Valley bottom gradient[b]	Side-slope gradient[c]	Valley bottom width[d]	Channel patterns	Strahler stream order	Landform and geomorphic features
V-shaped high-gradient bottom - V2	6-11%	30-70%	<2X	Constrained	≥2	Same as above, but valley bottom longitudinal profile steep with pronounced stair-step characteristics.
V-shaped, bedrock canyon - V3	3-11%	70%+	<2X	Highly constrained	≥2	Canyon-like stream corridors with frequent bedrock outcrops; frequently stair-stepped profile; generally associated with folded, faulted or volcanic landforms.
Alluviated mountain valley - V4	1-4%	Channel adjacent slopes <10%; increase to 30%+	2-4X	Unconstrained; high sinuosity with braids and side-channels common	2 - 5	Deeply incised drainage ways with relatively wide floodplains; distinguished as "alluvial flats" in otherwise steeply dissected mountainous terrain.
V-shaped highest-gradient bottom - V5	> 11%	Channel adjacent slopes <10%; increase to 30%+	< 2X	Highly constrained	≥2	Deeply incised drainage ways with relatively wide floodplains; distinguished as "alluvial flats" in otherwise steeply dissected mountainous terrain.
U-shaped trough - U1	<3%	<5%; gradually increases to 30%+	>4X	Unconstrained; moderate to high sinuosity; side channels and braids common	1 - 4	Drainage ways in mid to upper watersheds with history of glaciation, resulting in U-shaped profile; valley bottom typically composed of glacial drift deposits overlain with more recent alluvial material adjacent to channel.
Incised U-shaped valley, moderate-gradient bottom - U2	2-5%	Steep channel adjacent slopes, decreases to <30%, then increases to >30%	<2X	Moderately constrained by unconsolidated material; infrequent short flats with braids and meanders	2 - 5	Channel downcuts through deep valley bottom glacial till, colluvium, or coarse glacio-fluvial deposits; cross-sectional profile variable, but generally weakly U-shaped with active channel vertically incised into valley fill deposits; immediate side-slopes composed of unconsolidated and often unsorted coarse-grained deposits.

Valley bottom type[a]	Valley bottom gradient[b]	Side-slope gradient[c]	Valley bottom width[d]	Channel patterns	Strahler stream order	Landform and geomorphic features
Incised U-shaped valley, high-gradient bottom - U3	6-11%	Steep channel adjacent slopes, decreases to <30%, then increases to >30%	<2X	Moderately constrained by unconsolidated material; infrequent short flats with braids and meanders	2 - 5	Channel downcuts through deep valley bottom glacial till, colluvium, or coarse glacio-fluvial deposits; cross-sectional profile variable, but generally weakly U-shaped with active channel vertically incised into valley fill deposits; immediate side-slopes composed of unconsolidated and often unsorted coarse-grained deposits.
Active glacial out-wash valley - U4	1-7%	Initially <5%, increasing to >60%	<4X	Unconstrained; highly sinuous and braided	1 - 3	Stream corridors directly below active alpine glaciers; channel braiding and shifting common; active channel nearly as wide as valley bottom.
Incised U-shaped valley, highest-gradient bottom - U5	> 11%	Steep channel adjacent slopes, decreases to <30%, then increases to >30%	<2X	Moderately constrained by unconsolidated material; infrequent short flats with braids and meanders	2 - 5	Channel downcuts through deep valley bottom glacial till, colluvium, or coarse glacio-fluvial deposits; cross-sectional profile variable, but generally weakly U-shaped with active channel vertically incised into valley fill deposits; immediate side-slopes composed of unconsolidated and often unsorted coarse-grained deposits.
Moderate-gradient valley wall/head-water - H1	3-6%	>30%	<2X	Constrained	1 - 2	Small drainage ways with channels slightly to moderately entrenched into mountain toe-slopes or head-water basins.
High-gradient valley wall/head-water - H2	6-11%	>30%	<2X	Constrained; stair-stepped	1 - 2	Small drainage ways with channels moderately entrenched into high gradient mountain slopes or headwater basins; bedrock exposures and outcrops common; localized alluvial/colluvial terrace deposition.

Valley bottom type[a]	Valley bottom gradient[b]	Side-slope gradient[c]	Valley bottom width[d]	Channel patterns	Strahler stream order	Landform and geomorphic features
Very high-gradient valley wall/head-water - H3	11%+	>60%	<2X	Constrained; stair-stepped	1 - 2	Small drainage ways with channels moderately entrenched into high gradient mountain slopes or headwater basins; bedrock exposures and out-crops common; localized alluvial/colluvial terrace deposition.
Pre-historic flood carved drainage / coulee - low gradient - C1	< 3%	< 5 - 30%	> 2 X	Variable, generally unconstrained	Any	Drainage characteristics greatly influenced by ancient river paths or great floods - substrate of bedrock, colluvium, or alluvium; side-slopes very in steepness and composition.
Pre-historic flood carved drainage / coulee - moderate gradient - C2	3 - 6%	< 5 - 30%	> 2 X	Variable, generally unconstrained	Any	Drainage characteristics greatly influenced by ancient river paths or great floods - substrate of bedrock, colluvium, or alluvium; side-slopes very in steepness and composition.

[a]Valley bottom type names include alphanumeric mapping codes in italic (from Cupp 1989a, b).
[b]Valley bottom gradient is measured in length of about 300 m (1,000 ft).
[c]Sideslope gradient characterizes the hillslopes within 1,000 horizontal and about 100 m (300 ft) vertical distance from the active channel.
[d]Valley bottom width is a ratio of the valley bottom width to active channel width.

To create the valley segment classification GIS layers for each subbasin or analysis region in the UCESU, we adapted a default AML created by Pacific Biodiversity Institute which classifies valley bottom types for stream segments in any hydrography GIS layer containing the correct input attribute items. For our purposes, the AML incorporated outputs from the Strahler stream order extension, a stream gradient analysis using the 2001 10-meter DEM for the region, a side-slope analysis using the 2001 10-meter DEM for the region, and a stream sinuosity analysis conducted on the SSHIAP 1:24,000 meter scale hydrography data. We also included glacial history data adapted from the USFS Land Types Association GIS layer covering the Wenatchee and Okanogan National Forests. Table 9 illustrates the relationships between the AML's input parameters and the resulting valley segment classifications. A sample of the default AML can be found attached to this report in Appendix B.

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Table 9. Naiman.AML - Input Parameters for Valley Segment Classification Variables

	Valley Segment Types												
	F3	M1	M1	M2	M2	M3	V1	V1	V1	V2	V3	V4	V4
Strahler	>3	>2	2	2	3	>2	>2	3	2	>2	3	>2	3
Gradient	0 - 2	2-5	2-6	0-2	0-2	5-12	3-6	0-3	0-6	6-11	3-11%	2 -3	0-2
Glacier	0	0	0	0	0	0	0	0	0	0	0	0	0
Sinuosity	any	1 - 1.5	> 1.2	> 1.2	1-1.5	any	any	1 - 1.5	>1.2	any	any	> 1.5	> 1.5
Side Slope	any	0-25%	0-25%	0-25%	0-25%	0-25%	25-70%	25-70%	25-70%	25-70%	>70%	any	any
	V5	U1	U1	U2	U2	U2	U3	U5	H1	H1	H2	H3	
Strahler	>2	>2	1 or 2	>2	2	>2	>2	>2	1-2	1	1-2	1-2	
Gradient	>11	0-1	0-3	1- 6	3-6	0 - 1	6-11	>11	0 - 6	0-6	6-11	>11	
Glacier	0	1	1	1	1	1	1	1	0-1	0	0-1	0-1	
Sinuosity	any	> 1.2	> 1.2	any	> 1.2	< 1.2	any	any	<1.2	any	any	any	
Side Slope	any	any	any	any	any	any	any	any	<70%	<70%	<70%	any	

We decided the best way to provide the valley segment type classifications in a spatial format was to attribute the input hydrography data layer with the output valley segment type variables. In most cases there is a one to one relationship between a segment of stream and the valley segment through which it passes, hence the hydrography layer works well in providing the spatial context of the continuum of a particular valley segment type. It is important to remember that the variable covers a much greater area in three dimensional space than what the hydrography layer actually depicts. The variable assignment is not limited to just the stream, but represents a characterization of the entire drainage area perpendicular to the to stream's general direction through which a given stream segment is passing through. Figures 16 and 17 provide an illustration of this point.

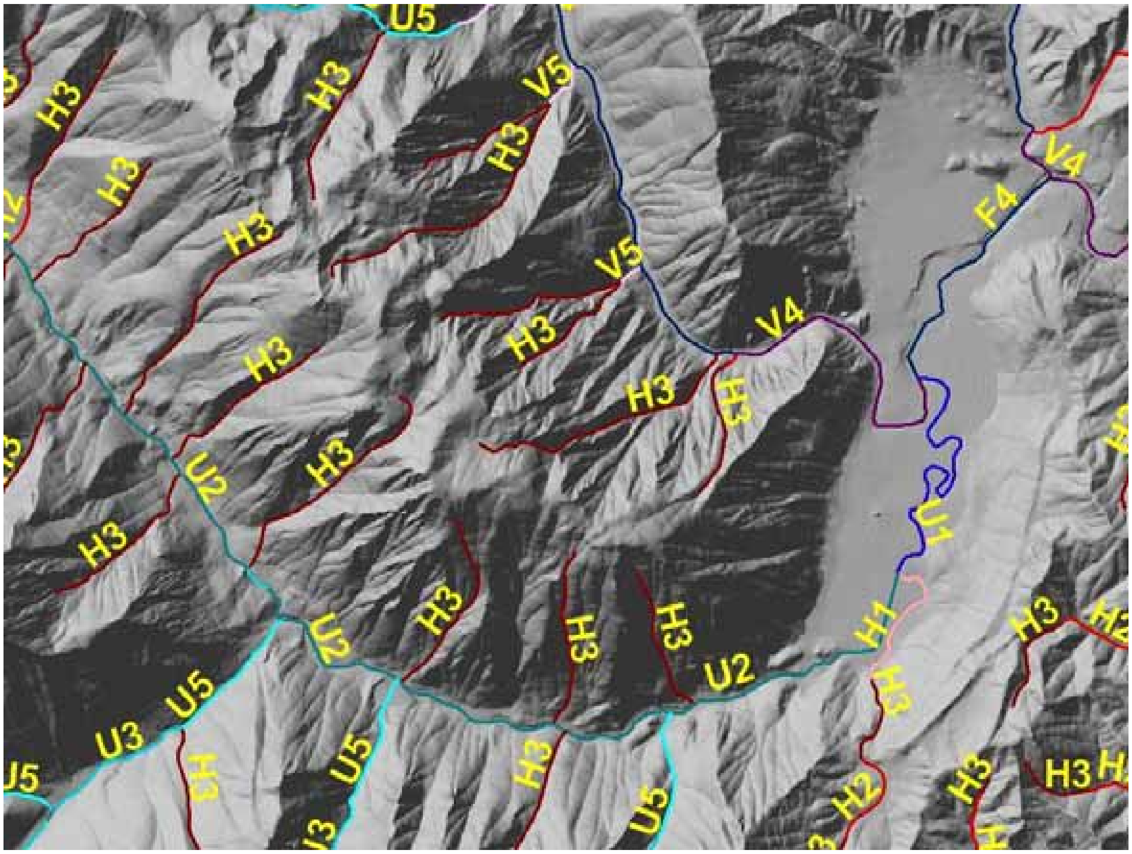


Figure 16. *Valley segment classifications attributed to various stream segments overlying a shaded relief image of the topography in the Icicle Creek area around Leavenworth, WA.*

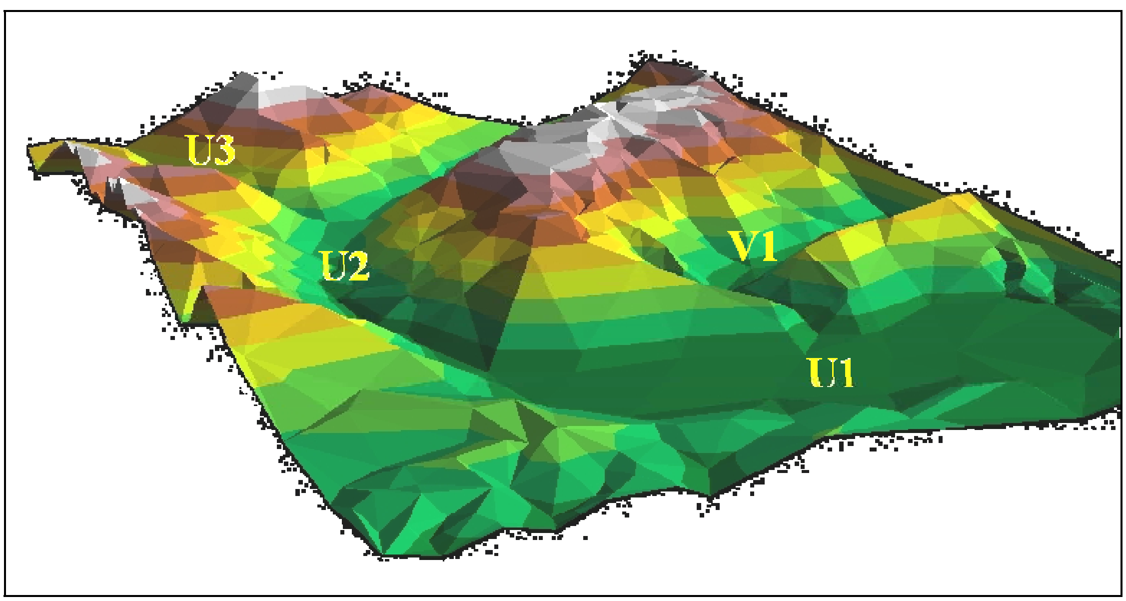


Figure 17. *Variable assignments related to the three dimensional context of a valley segment type in the same region as Figure 14 (we eliminated most of the smaller streams to simplify the illustration).*

The methodology for determining valley bottom type variables for each stream segment went as follows:

A) All 1:100,000 meter scale streams from the SSHIAP 1:24,000 meter scale hydrography data were selected out into a new hydrography coverage using the "llidsrc" attribute item in the SSHIAP data tables. This provided a more spatially accurate stream layer at the 1:100,000 meter spatial scale than the StreamNet 1:100,000 meter scale hydrography data.

B) The new SSHIAP hydrography data's attribute table was then populated with the following classification variables:

1) The SSHIAP 1:100,000 meter scale hydrography data was processed to attribute Strahler stream order variables to each stream segment.
2) A gradient analysis was conducted on the SSHIAP 1:100,000 meter scale hydrography data using the ArcView extension Line Slope Analyst (Hurvitz, 2003). This extension calculates the slope of a line segment by dividing the difference in elevations (elevations stored in a DEM) between the "from" node and "to" node by the length of the line segment. The output is given in both percent slope and degrees.
3) A sinuosity analysis was conducted on the SSHIAP 1:100,000 meter scale hydrography data using the AML "sinuous" (Arya, 1998). This AML calculates sinuosity variables for each line segment in a coverage by dividing the actual length of a line segment by the length of the straightest distance between the "from" node and "to" node. All output variables are greater than 1, with values nearest 1 representing the lowest sinuosity.
4) A glacial history variable was added to each stream segment based on whether or not that particular segment appeared to have been within the extent of the advancing alpine glaciers or continental ice-sheet during previous geologic ice ages. The USFS Land Types Association (LTA, 2000) GIS data contains spatially explicit information regarding glacial histories for the Wenatchee and Okanogan National Forests, which cover much of the previously glaciated portions of the UCESU. In some cases, the USGS 10-meter DEM displayed in a shaded relief format also reveals glacially impacted regions by displaying distinguishable glacially caused landform features.
5) A side slope analysis was conducted on the SSHIAP 1:100,000 meter scale hydrography data using an adapted version of the ArcView extension Line Slope Analyst (Hurvitz, 2003). Apart from calculating line slope, Hurvitz's extension can also calculate the slope of a line at any specified distance from the midpoint of that line at a perpendicular direction of the stream direction. For use in valley segment classifications, we adjusted Hurvitz's extension to calculate side slope gradients for 5 set distance points away from the stream segment center point on each side of the stream segment (one set of variables was calculated for the left side of the stream, another for the right side of the stream). The five distances that side slopes were calculated for were 10 meters, 50 meters, 100 meters, 500 meters, and 1000 meters. These distances accounted for micro to macro slopes and slope changes, giving an empirical depiction of the landscape topography along the banks and hillsides of each stream segment. From this information, we calculated an average side-slope variable for each side of a line segment in the SSHIAP 1:100,000 meter scale hydrography layer, where high averaged side slope percentages (> 70%) indicated the likelihood of a stream flowing through a canyon or valley bottom type "V3", while lower side slope averages helped decipher the difference between "V" type valley bottom classes and "M" types.

C) With the data table populated with the necessary classification variables, we input the SSHIAP 1:100,000 meter scale hydrography layer into our default “Naiman” AML which output the proper valley bottom types for each stream segment based on the array of input values. This AML gave an initial output which we could display categorically in a GIS application with complementary base layers, allowing us to assess the accuracy of the output and, when necessary, redefine the value parameters of the AML for each valley bottom type so that the AML’s output would work better for the particular subbasin or analysis region we were analyzing at that time. Valley bottom segments that we could see were mislabeled by the AML were marked and attributed with a descriptor of what that segment should have been labeled and why. This information went back into adapting an assortment of “Naiman” AMLs, each manipulated to increase the output accuracy for a given subbasin or analysis region in the UCESU.

D) Once a satisfactory AML was created for a given analysis region, the SSHIAP 1:100,000 meter scale hydrography was processed with that AML and from there forth human interpretation of the perceived landscape based on complimentary spatial data was used to correct any glaring classification errors output from the AML script.

E) Because the nature of short segments inherent in the hydrography data skewed the automated sinuosity and gradient calculations in some cases, we devised a variable overrule strategy for segments less than 300 meters in length. The overrule strategy was only conducted on “H” class streams as this is where it was most needed and proved most efficient. We started by selecting all “H1” streams under 300 meters in length. We then compared this with the valley bottom type variable of the adjacent “H” class streams to see if the classification remained H1, or whether another “H” class variable had been assigned. In the cases where “H1” was an adjacent variable, the valley bottom type assignment was not changed. In cases where a short segmented H1 was not adjacent to a longer segment labeled H1, we changed the variable to reflect the adjacent segment’s valley bottom type, either H2 or H3. Because the segments being changed were so short, we did not attempt to do any further analysis of whether a short stream segment labeled H1, but bordered by an H2 segment on one side and an H3 segment on the other, should be labeled with the H2 or H3 based on complimentary spatial data. We simply assigned the most convenient adjacent variable being assigned to a selected group of short segments at a given time.

F) Short segments from other valley bottom type classes were also selected out for valley bottom type reassignment to insure classification consistency within a continuous valley bottom. We evaluated these short segments by hand and made manual corrections to the valley bottom type variable if needed.

Figures 18 - 20 provide some illustrations of the finished valley segment GIS products within the UCESU.

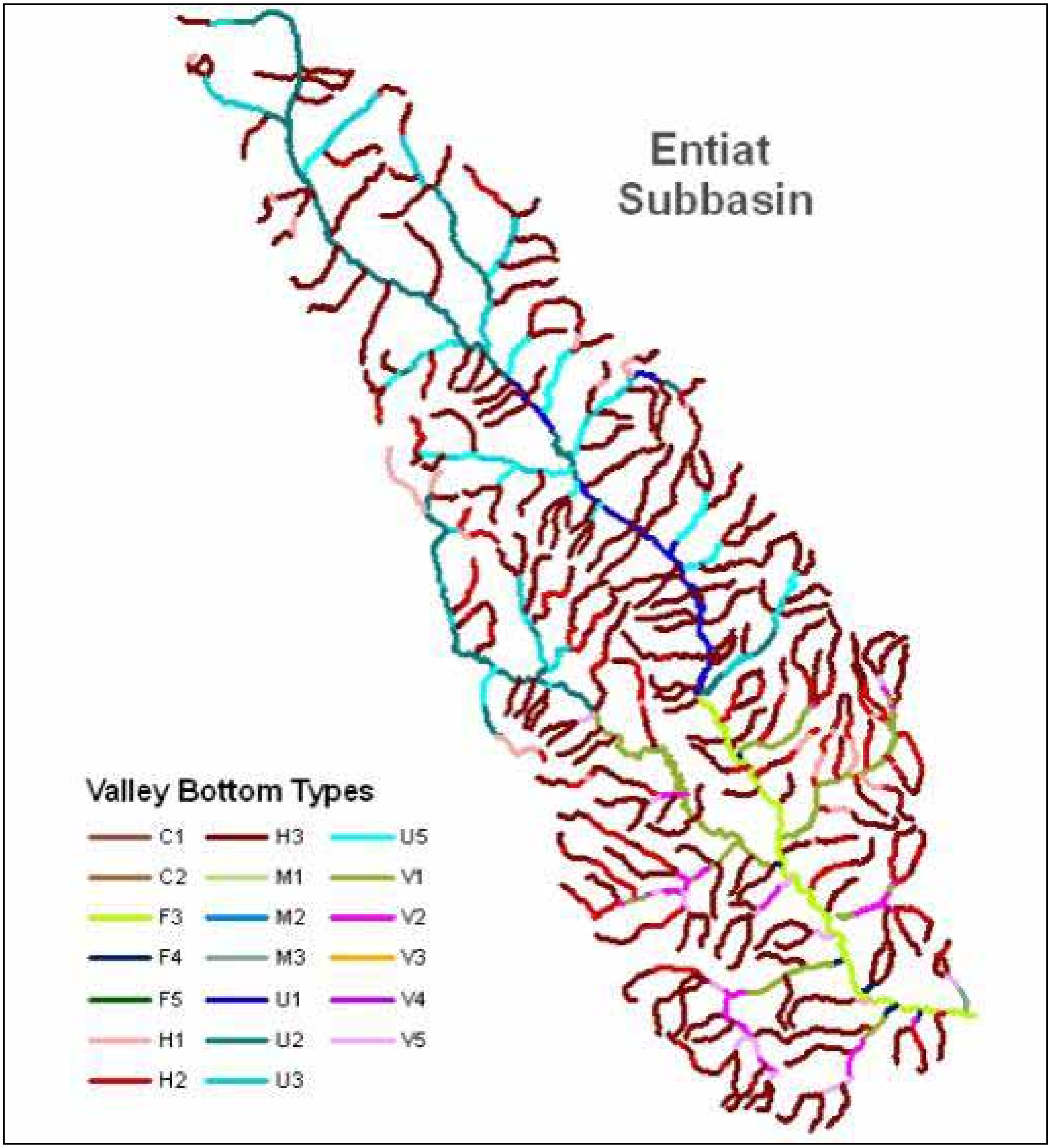


Figure 18. Valley bottom types in the Entiat Subbasin.

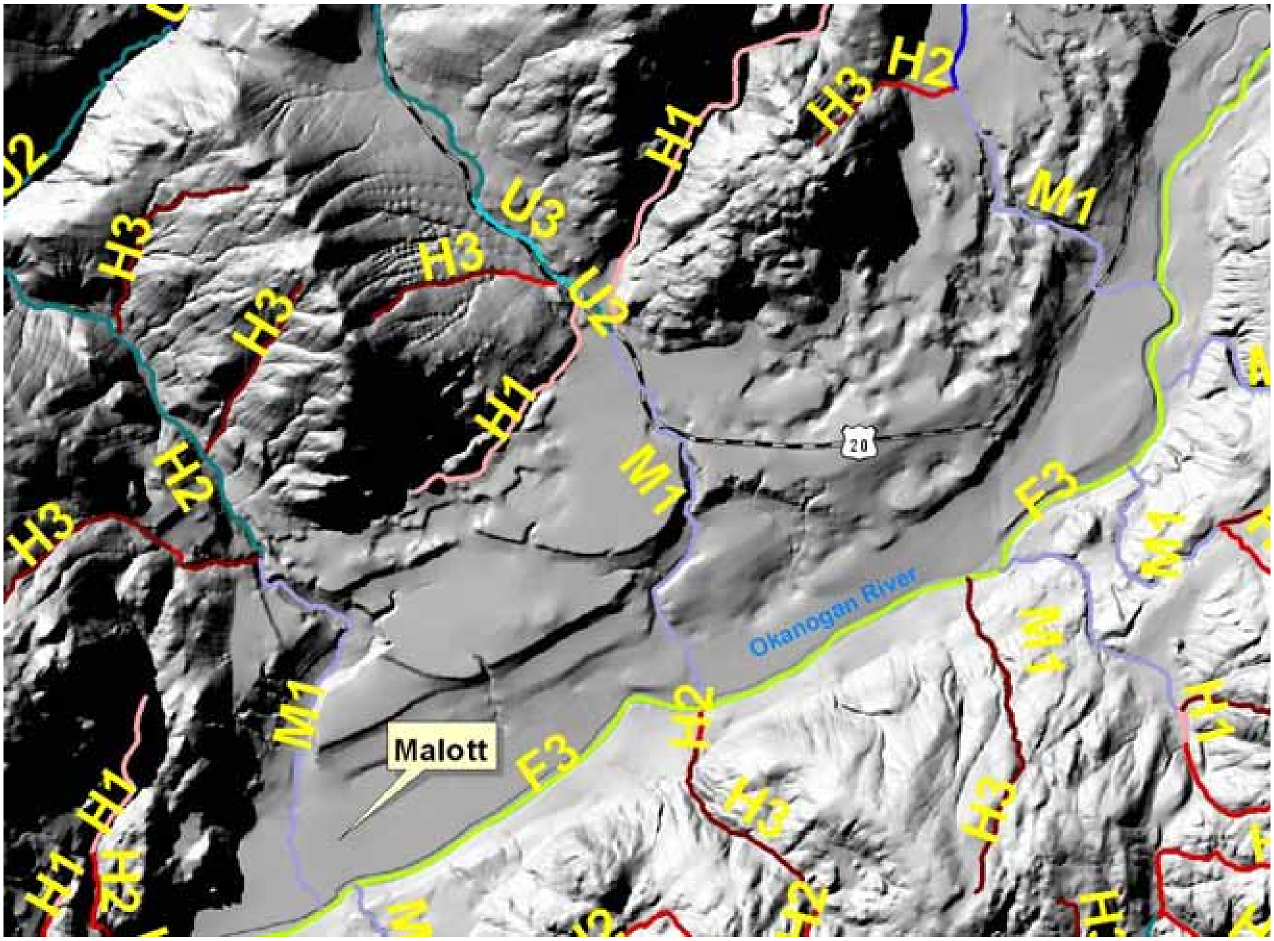


Figure 19. Valley Segment Classification within the Malott Area along the Okanogan River.

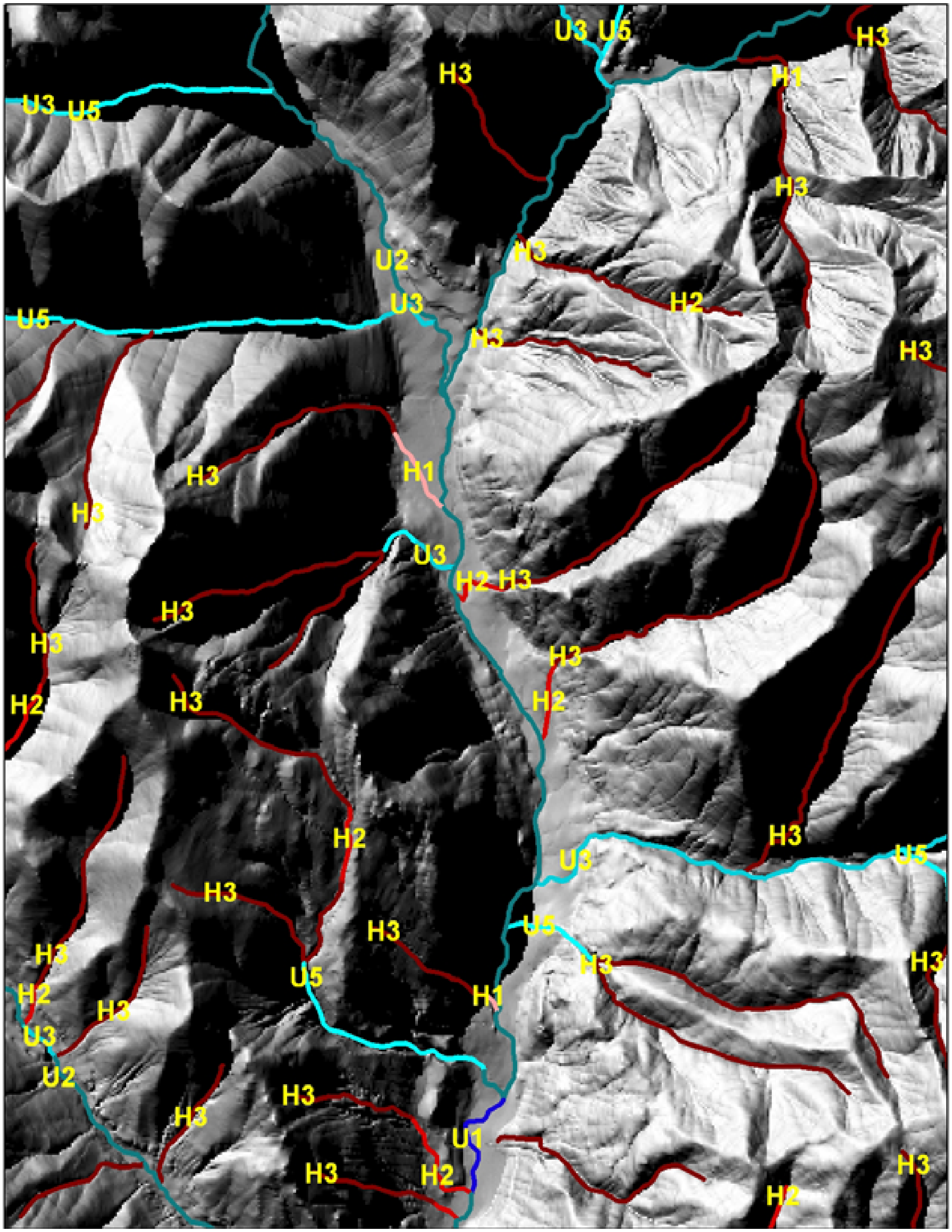


Figure 20. Valley segment classification of the Upper Chewuch River

Channel segment information and classification

Channel characteristics for channel gradient, fish passage barriers and stream segment classification were derived using both existing methods and new methods developed by Pacific Biodiversity Institute specifically for this project. Table 10 lists the channel and stream segment classification variables that we addressed in our study. Each of these is discussed in more detail in the following sections.

Table 10. Channel and stream segment characteristics

Classification variable	Example protocols
Channel type (Rosgen)	Rosgen (1996)
Bed-form type	Bisson and Montgomery (1996)
Channel gradient	Overton et al. (1997)

We classified over 10,000 miles of streams in the UCESU during this project (Table 11). All the stream channel segments received a channel gradient value and a Rosgen classification.

Table 11. Miles of stream classified in each basin of the UCESU.

Stream miles classified in each subbasin in the Upper Columbia ESU	Entiat	Methow	Okanogan	Douglas County	Other Areas	Wenatchee	Total
Stream Miles	598	2546	1586	738	643	4046	10,157

Channel Gradient

Channel gradient variables were calculated using the StreamNet 1:100,000 meter scale hydrography data from 2002. Because the original StreamNet data contained arcs of varying lengths, ranging anywhere from a few meters to thousands of meters long, we altered the StreamNet data to produce a dataset with much more uniform stream segment lengths with which to calculate channel gradient. Segments that were too short (< 10 meters) would not cover enough length to get a meaningful gradient output, since the input elevation dataset had a cell size of 10 meters by 10 meters. On the other hand, calculating gradient on a very long stream segment caused the possible variation of gradients along that segment to be overlooked. To diminish these problems, we attempted to push as many stream segments as possible to a length between 10 and 300 meters long. Using the DENSIFYARC command in Arc/INFO, we were able to bring most stream segments within the various StreamNet subbasin coverages to around 300 meters in length. Because of the original arc/node topography inherent in the StreamNet data, some arcs stayed below 10 meters, and some stayed above 300 meters, but a vast majority was brought within our desired segment length parameters. This allowed for a more reliable and meaningful calculation of channel gradients as opposed to simply calculating gradient on the original StreamNet datasets with the wide variation in stream segment lengths.

Once the StreamNet datasets were properly re-segmented, we used the ArcView extension Line Slope Analyst (Hurvitz, 2003) to calculate the channel gradients. We used 10-meter DEMs as the input raster elevation dataset for the extension. Once the percent slope calculations were finished for each segment, we rounded the percent slope output to the nearest integer value eliminating the decimals. Then we ran the DISSOLVE command in Arc/INFO to bring together any contiguous arcs possessing the same gradient values. This produced our final channel gradient data layers which provide gradient measurements per stream segment in percent gradient. Figure 21 illustrates the final channel gradient data layer produced for the Methow Subbasin.

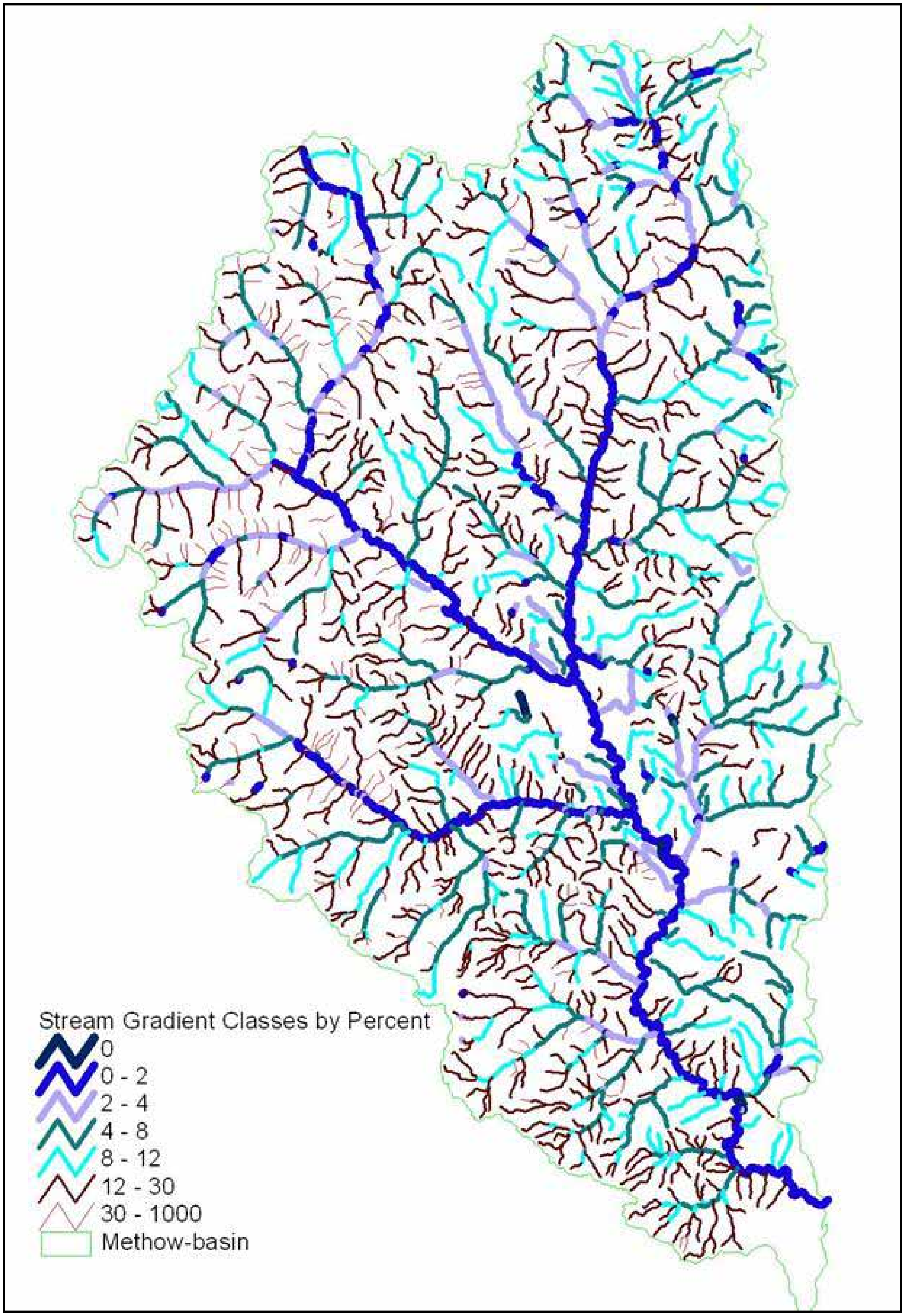


Figure 21. Channel gradients for the Methow Subbasin.

Barriers to Fish Passage

For the Wenatchee Basin, we included a large assortment of fish barrier datasets (representing both definite and possible fish barriers) that have been produced for the Wenatchee Subbasin. These datasets have not been standardized to a single GIS layer or data table. We included the original attributes of each layer and metadata describing the attribute definitions.

In the Wenatchee Basin fish barrier datasets from the following public agencies or projects are included (Figure 22):

- US Army Corps of Engineers
- SSHIAP
- SSHEAR
- StreamNet
- US Forest Service
- Chelan County

For the remaining basins and watersheds in the rest of the UCESU, we compiled fish barrier data from the following datasets:

- StreamNet Fish Passage Barriers – 1999 fish barriers data layer for Upper Columbia ESU (produced at 1:100,000 scale).
- StreamNet Dams – 2002 dam data layer for Upper Columbia ESU basin (produced at 1:100,000 scale)
- SSHIAP- Fish Passage Barriers – 2003 fish barriers data layer for Upper Columbia ESU (produced at 1:24,000scale).

An example of the barriers in the Methow River Basin is shown in Figure 23.

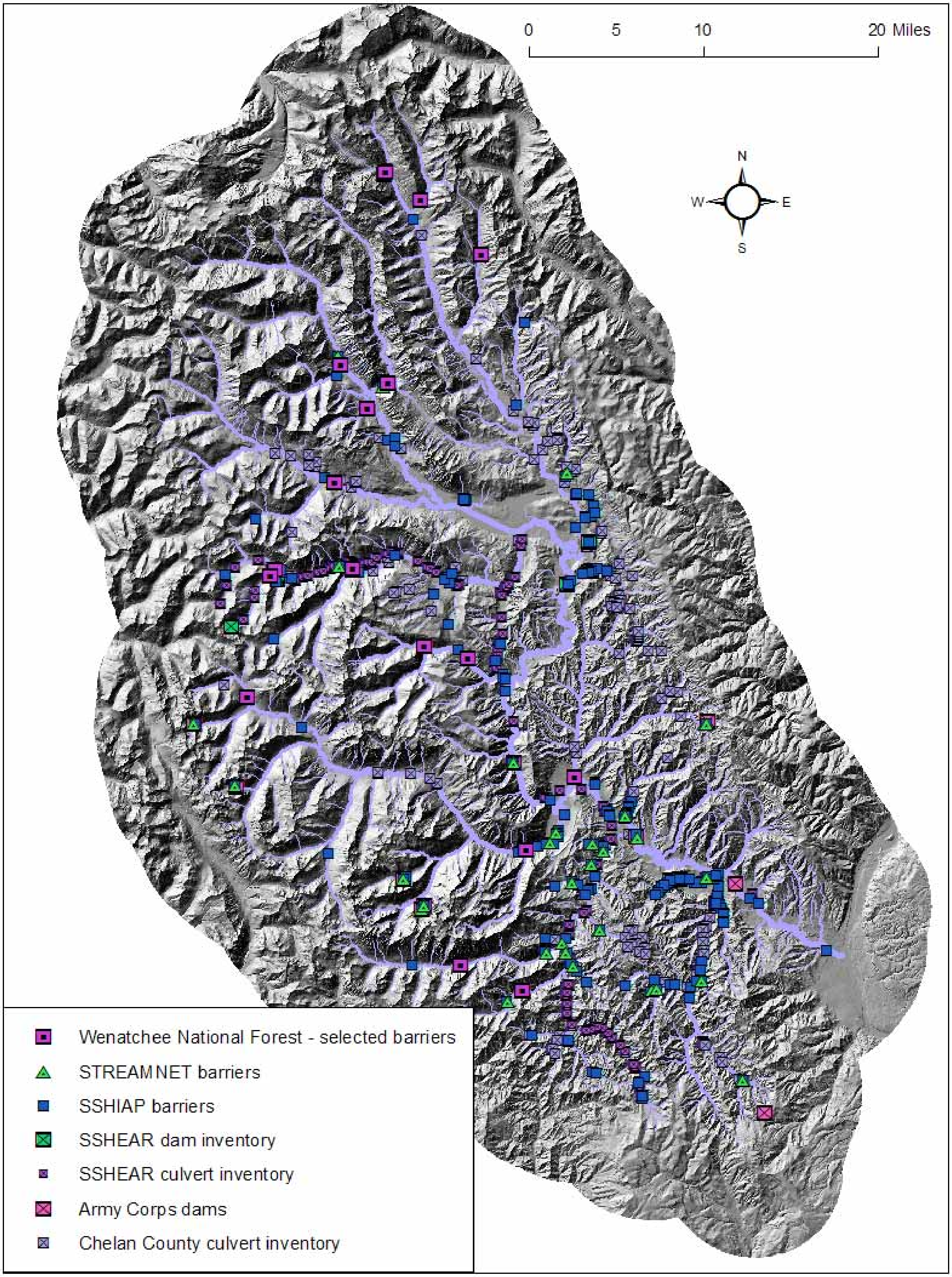


Figure 22. Barriers to fish passage in the Wenatchee Basin and 1:24,000-scale streams.

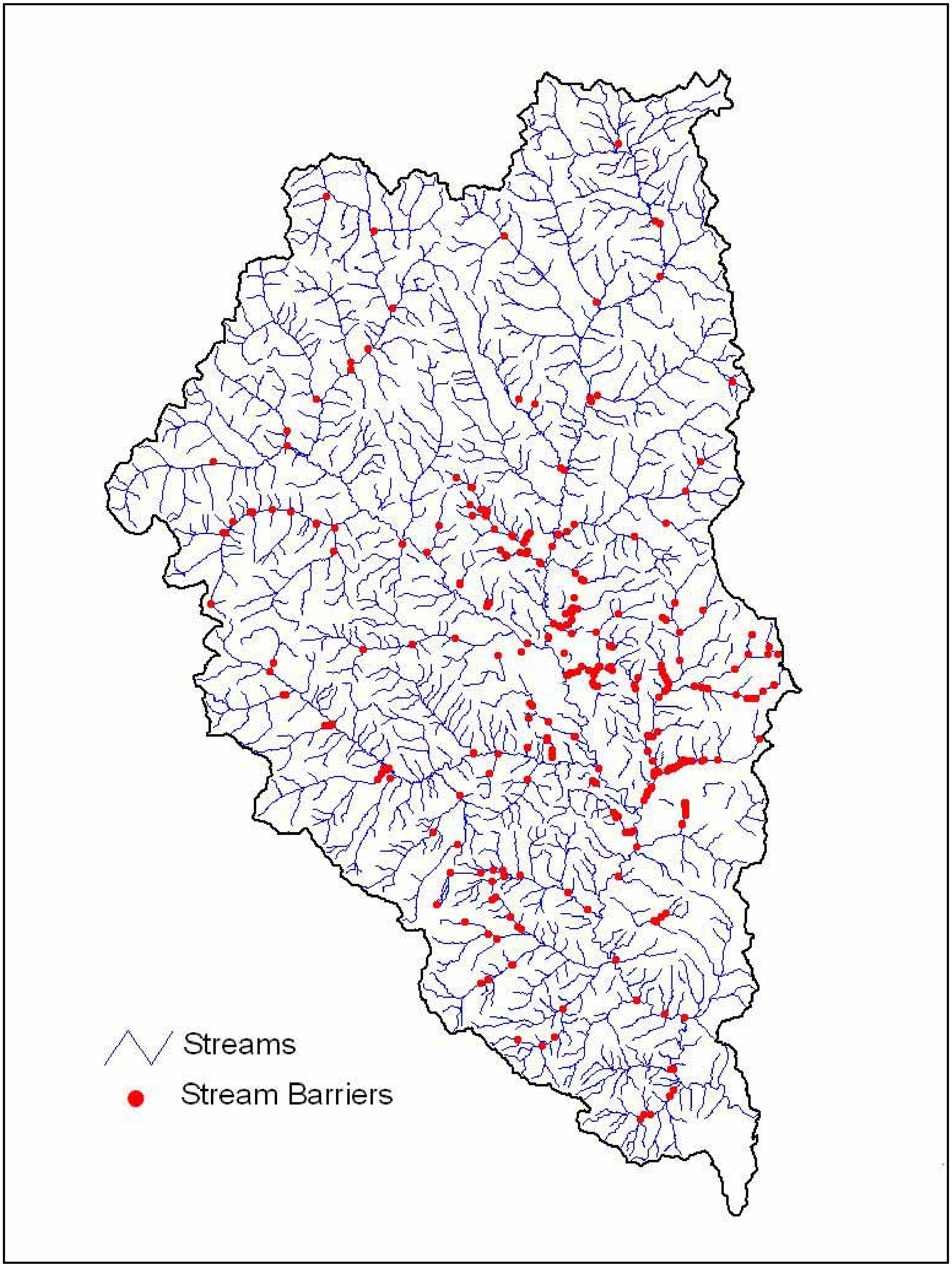


Figure 23. Barriers to fish passage in the Methow Basin and 1:24,000-scale streams.

Rosgen channel classification methods

After exploring the use and results from existing GIS-based automated methods of Rosgen stream channel classification (Neier and Reid 1997, Barbour et al 2002, Hemstrom et al 2002) we decided that these approaches did not yield reliable results and decided to develop our own approach that combines estimates made by manual interpretation of aerial photography and other data with a semi-automated approach that extracts information from stream hydrography data and high resolution digital elevation data. We used manual interpretation to develop data for the major rivers and streams and the semi-automated approach to develop similar data for the smaller streams. In both cases, we attempted to follow the basic classification approach originally outline by Rosgen (1996) where streams are first classified according to these attributes in descending order (Figure 24):

1. channel type: single or multiple threaded
2. entrenchment ratio
3. width to depth ratio
4. channel sinuosity
5. channel gradient (or slope)

The first characteristic (single or multiple threaded channels) is relatively easy to interpret from aerial photography. It is also apparent in some of the 1:24,000-scale hydrography data.

The second characteristic (entrenchment ratio) requires measurement of both the bankfull width of the stream and the twice bankfull width or floodplain width of the stream. The bankfull width can be estimated fairly accurately from high resolution aerial photography. We also found that the floodplain width could be estimated from a combination of FEMA floodplain mapping, topographic data and aerial photography. The entrenchment ratio is the ratio of these two values (floodplain width divided by the bankfull width).

The third characteristic (width to depth ratio) requires measurement of both the bankfull width of the stream and the stream depth. The bankfull width was estimated as described above. The stream depth was estimated based on a small subset of stream measurements that we made in the field and stream survey data obtained from the US Forest Service. From these stream depth measurements, we developed a rough correlation between Strahler stream order and potential depth range. Aerial photo interpretation was also used to guide our estimates of stream depth within this potential depth range.

The fourth characteristic (steam sinuosity) was estimated based on the stream sinuosity calculated by an automated GIS procedure. We used the original Rosgen AML developed by Neier and Reid (1997) to calculate stream sinuosity and gradient.

The fifth characteristic (steam gradient) was estimated based on the stream gradient calculated by an automated GIS procedure. We used the original Rosgen AML developed by Neier and Reid (1997) to calculate stream gradient.

Once these attributes were calculated, we developed an automated GIS classification procedure and corresponding AML to classify each stream segment into an initial Rosgen class. This AML is included in this report as Appendix C.

The last step of our stream channel classification was to review the Rosgen stream channel classifications we developed using automated procedures. In this review, we compared the automated Rosgen classifications to field-based Rosgen classifications previous determined by other observers. We also manually reviewed the automated results against a background of a variety of relevant GIS data layers and digital imagery, GIS data. We went through several iterations of improvement of this automated classification procedure before we were satisfied that the classifications were adequate.

The data and methodology used in our Rosgen stream channel classification of the UCESU is described in detail below.

Input Data for Rosgen Classifications

The following data was used in determining the stream channel classification for the UCESU:

- Aerial photography (DOQs and 1:6000 color)
- Digital elevation data – 10-meter DEMs
- Hydrography data - 1:24,000
- ASTER satellite imagery (2003)
- USGS 1:24,000 topographic maps (DRGs)
- Landscape-level precipitation data

Derived Information

We derived the following data using automated and manual procedures from the data listed above. In addition to the Rosgen classification, this data is available for use in evaluating stream channel characteristics and associated habitat conditions for all the streams in the UCESU.

- Entrenchment Ratio
- Width / Depth Ratio
- Sinuosity
- Stream Gradient / Slope
- Stream Channel Calculations
- Entrenchment Ratio (from bankfull width and 2x bankfull width (floodplain) remote measurements)
- Width / Depth Ratio (from width and depth remote measurements & estimates)
- Sinuosity – (calculated by AML)
- Gradient/Slope – (calculated by AML)

Determination of stream channel parameters for major rivers

We used aerial photography to measure the stream width (approximate bank full width). We estimated the width to the area covered during annual high water. This includes the wetted area and annually-flooded gravel bars. For each reach, the width was measured multiple times perpendicular to the stream channel (Figure 25). The stream width sampling interval averaged about 100-meters along the main axis of the channel.

We also used aerial photography and topographic maps and digital elevation data to estimate the flood plain width, (twice bank full width). These widths were measured at the same locations as the stream width (Figure 25). From these two paired measurements, we could determine the ratio of the normal stream width and the flood width.

During this process, we also evaluated each stream and grouped stream segments along the major rivers and streams into stream reaches (Figure 26). We attempted to assign a reach number to adjacent stream segments that had similar gradients, widths and floodplain characteristics.

We made an attempt to determine stream depth based on stream order, relative stream flow (determined by estimates of precipitation levels in the subwatersheds), and correlation with actual stream survey data. Stream depth estimates were probably the weakest metric that we used. But these were only used to calculate stream width-to-depth ratio. The width-to-depth ratio was one of the parameters used to estimate Rosgen class. Because the Rosgen class determination is based on broad width-to-depth ratio classes, the depth estimates that we used could have deviated by a factor of 2 or 3 and still would not have affected the Rosgen class determination. For the larger streams, the Rosgen class determination is relatively insensitive to the depth measurement.

A simple Arc/INFO AML was used to average the stream widths and flood widths in each stream reach and to calculate width-to-depth ratio and degree of entrenchment for each reach. The AML then attributed each stream reach with these values.

Determination of stream channel parameters for smaller streams

Estimation of stream width and depth for the major streams and rivers was feasible through the methods described above. However, the UCESU contains thousands of miles of smaller streams, which also needed a Rosgen stream channel classification. To accomplish this, we developed a semi-automated GIS method to estimate the potential floodplain width from digital elevation data. Stream width and depth were estimated based on stream order, stream gradient and potential stream flow volumes. Potential stream flow volumes were estimated by simulating precipitation on a basin-wide stream flow accumulation model, implemented in ESRI's Arc/Info GRID module.

The potential floodplain width was estimated from a calculation of the amount of area on each side of each stream segment that contained a flat slope that could potentially flood in a high precipitation event. This was estimated by calculating the average slope of incremental bands of area adjacent to the right and left banks of each stream and then using these average slope estimates to calculate the approximate "valley flat width" or potential flood width for each stream segment.

An automated AML then used the estimates for stream width, stream depth and potential flood width to calculate width-to-depth ratio and degree of entrenchment for each stream reach of the smaller streams.

Calculation of stream sinuosity and gradient for use in Rosgen classification

We used the original ROSGEN AML developed by Neier and Reid (1997) to calculate stream sinuosity and stream gradient for all stream segments in the UCESU. After this was accomplished we had all the data necessary to undertake a Rosgen Level 1 classification of the streams in the UCESU.

Classification of rivers and streams into Rosgen classes using an automated GIS procedure

Once all the streams and rivers were attributed with the appropriate values needed to determine a basic Rosgen stream class, we applied an automated GIS classification procedure and corresponding AML (see Appendix C) to classify each stream segment into an initial Rosgen class. We went through several iterations of improvement of this automated classification procedure before we were satisfied that the classifications were adequate.

Review and revision of automated procedure results

Finally, we reviewed the Rosgen stream channel classifications obtained with the above procedures using a variety of aerial imagery, GIS data and maps – making corrections and adjustments as necessary. We also compared the resulting Rosgen classification to US Forest Service stream measurements and Rosgen classifications conducted in the field (obtained from Jackie Hastert and Pierre Dawson, Wenatchee National Forest). Along the Entiat River, we were also able to compare our Rosgen classification to that determined by Justin Erickson (2004) in his Masters thesis on the lower Entiat River valley. All modifications to the preliminary classification are documented.

Stream Channel Classification Results

All the streams within each river basin were classified to a Rosgen Class. We proceeded basin by basin until all the streams in the UCESU were classified. Figure 27 presents our classification results for the Methow River Basin. Table 12 illustrates the amount of stream miles per Rosgen class in each subbasin.

Table 12. Stream miles in each Rosgen channel class within the Subbasins of the UCESU.

	Basins					
Rosgen Class	Douglas	Entiat	Methow	Okanogan	Wenatchee	Other Small Watersheds
A	266.37	87.95	499.63	734.95	350.81	207.20
Aa+	163.31	409.70	1624.78	349.95	3152.11	370.63
Af					44.35	
B	135.96	41.87	141.27	198.22	84.77	41.74
Ba	4.51	3.47	75.94	34.37	45.50	28.64
Bc	4.99	9.68	27.96	39.00	95.36	1.63
Bf					18.33	
C		11.79	96.94		159.08	
Cb		1.48	13.08	7.71	11.34	
Cc		2.36	0.47	18.32	13.22	
Cf					11.01	
D					6.83	
DA				7.79	5.72	
E	118.20		16.26	89.17	24.31	20.08
Eb	8.98		7.37	14.43	1.26	7.97
Eg					11.71	
F		15.93	36.90	70.83	3.41	
Fb		10.39	5.23	0.04	4.60	
G					1.24	
Gc	35.50			0.99	1.00	

Figures 28-31 provide detailed views of two sections of classified streams in the Methow River Basin.

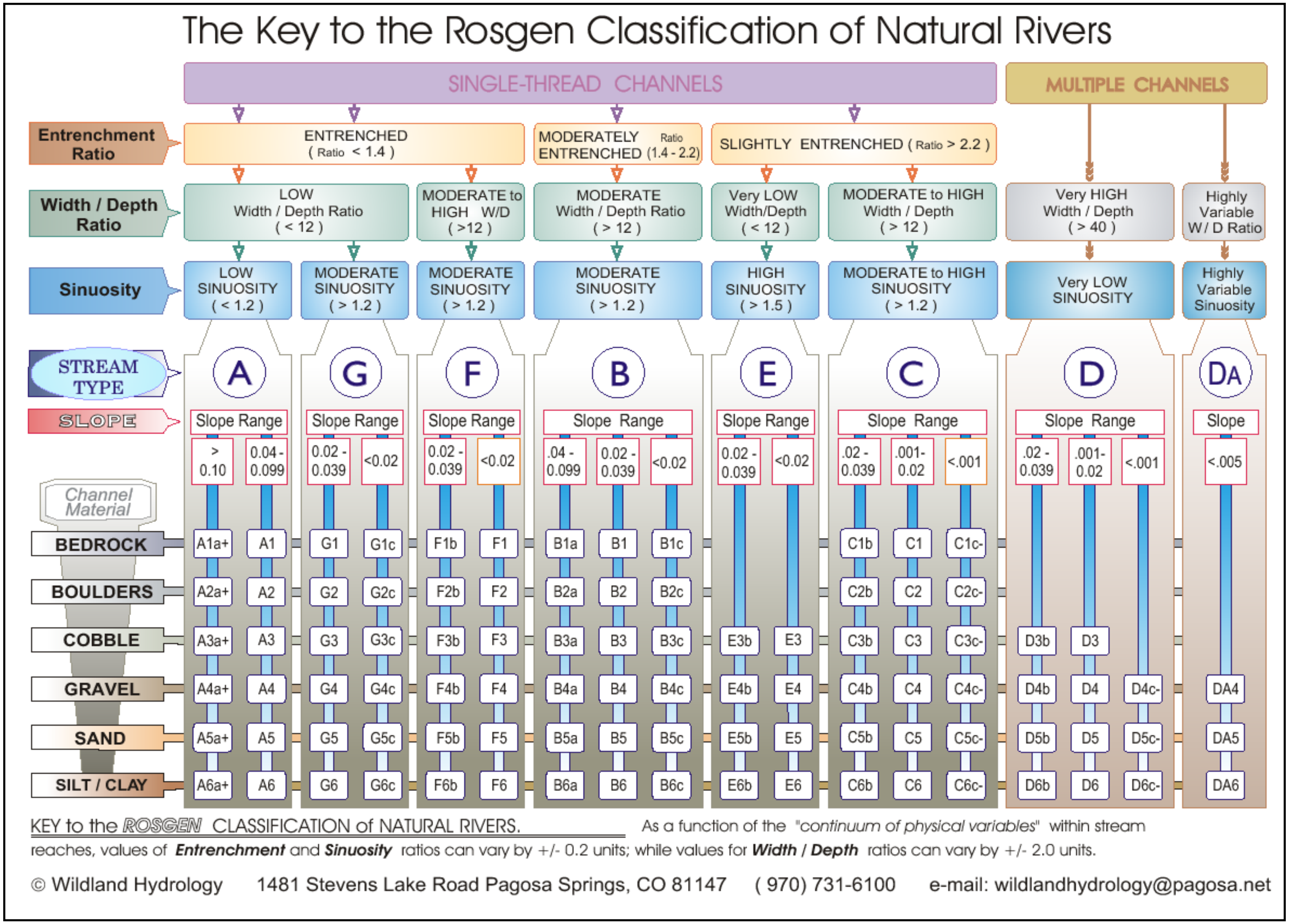


Figure 24. Rosgen stream and river classification system

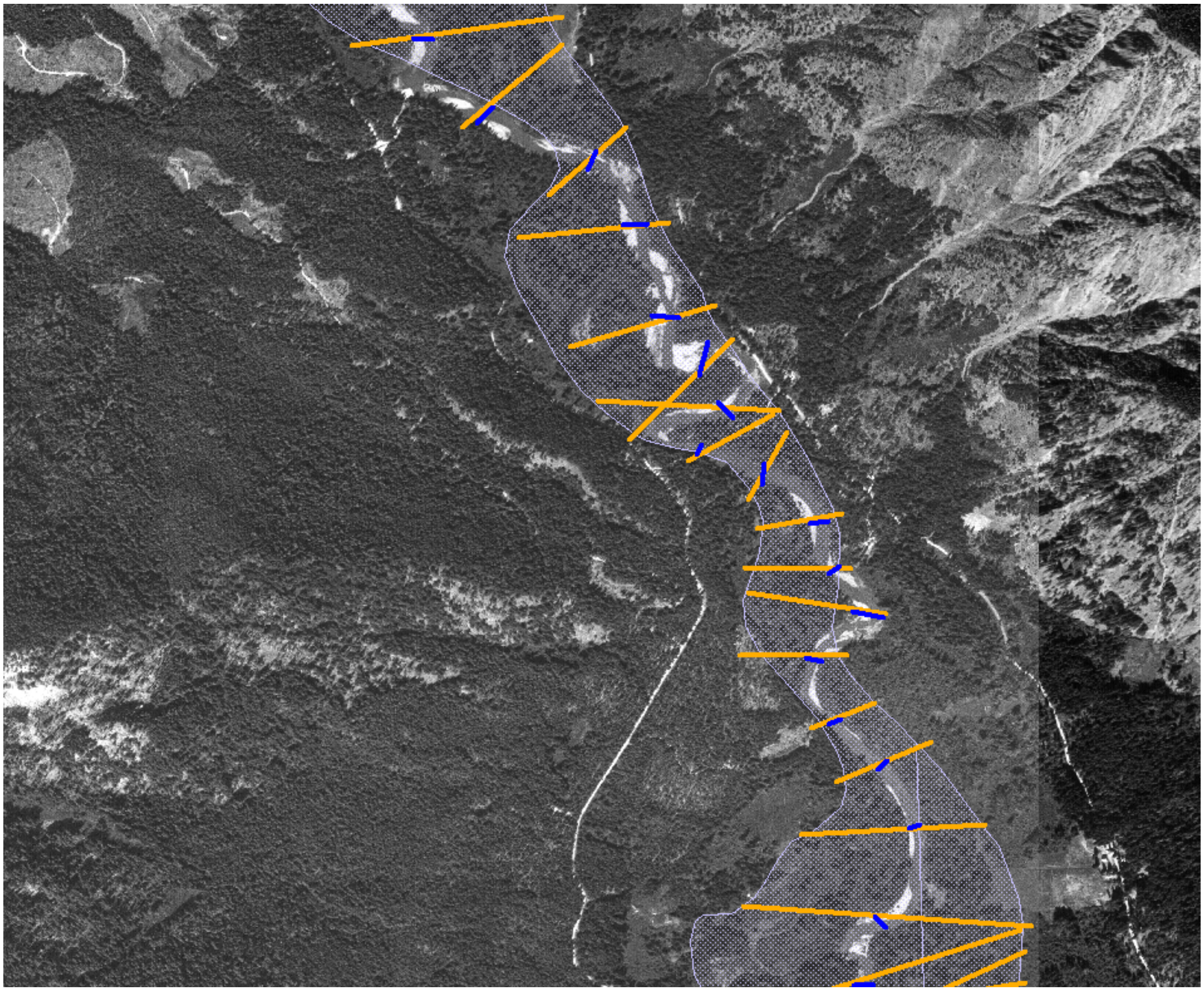


Figure 25. Measuring Bankfull Width and Flood Width (2x bankfull).

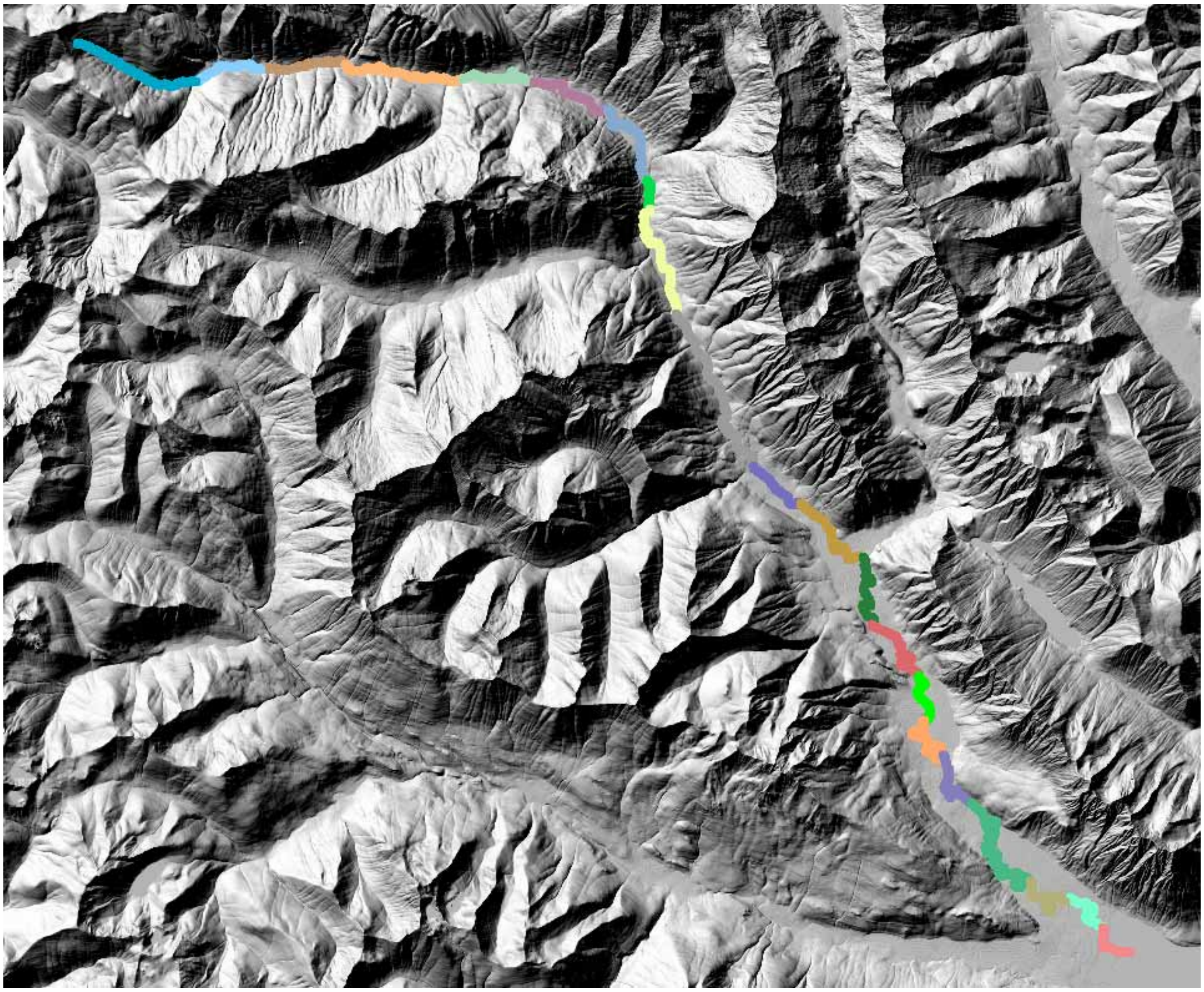


Figure 26. Grouping Stream Arcs into Reaches.

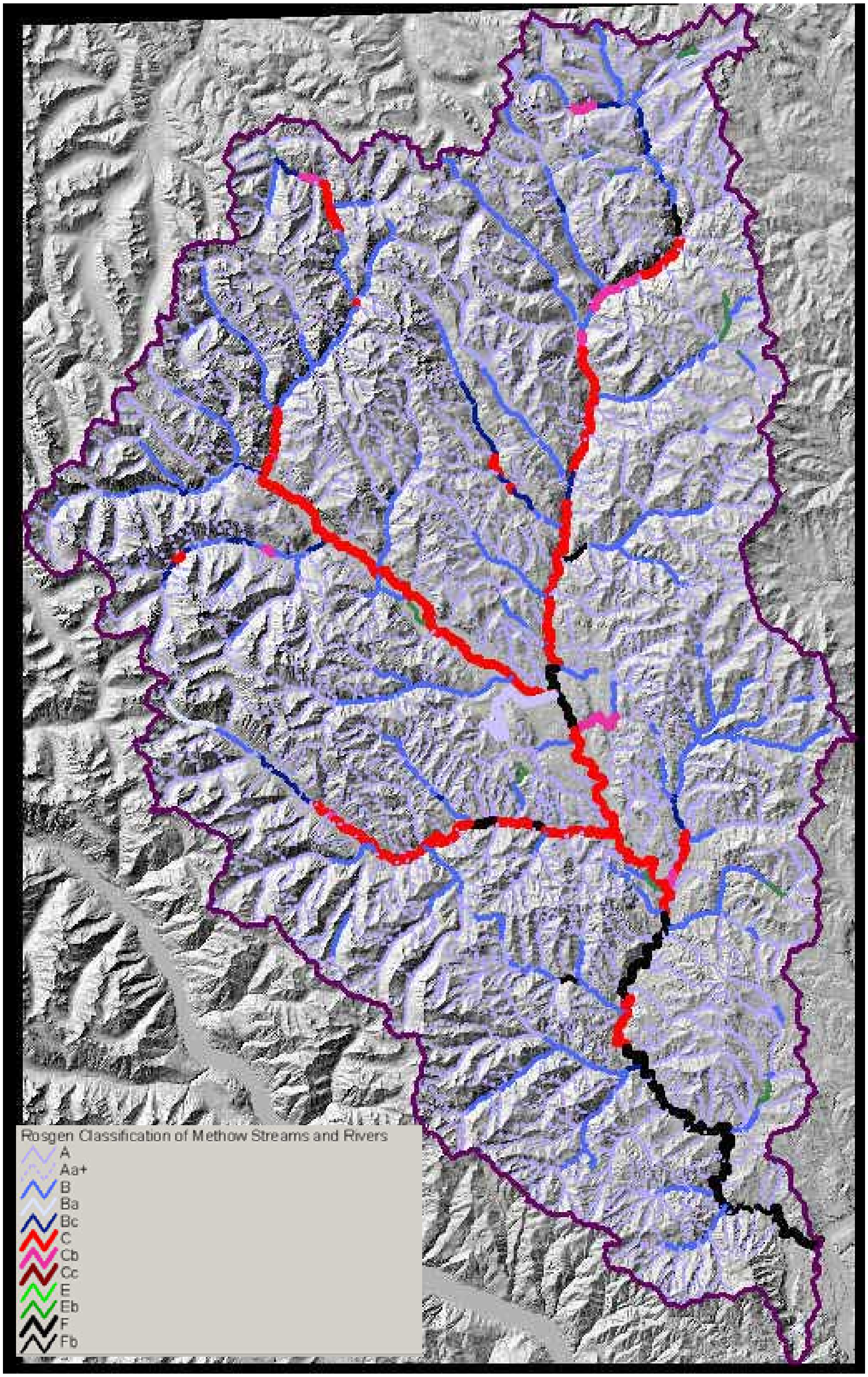
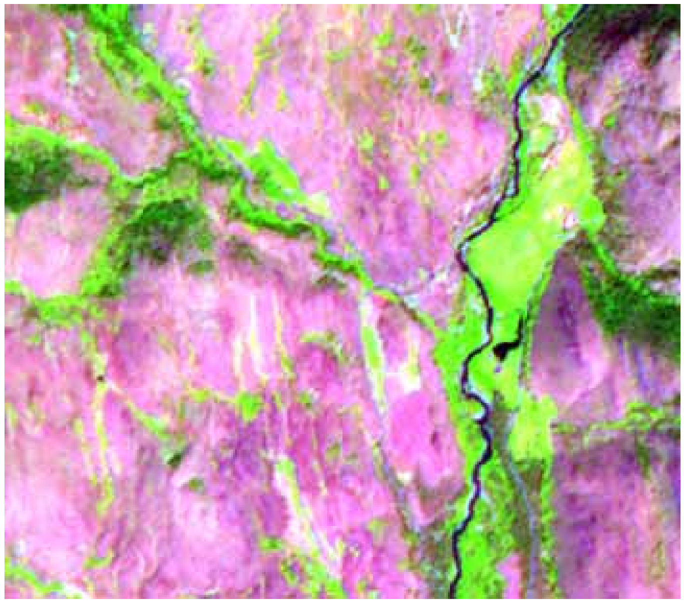
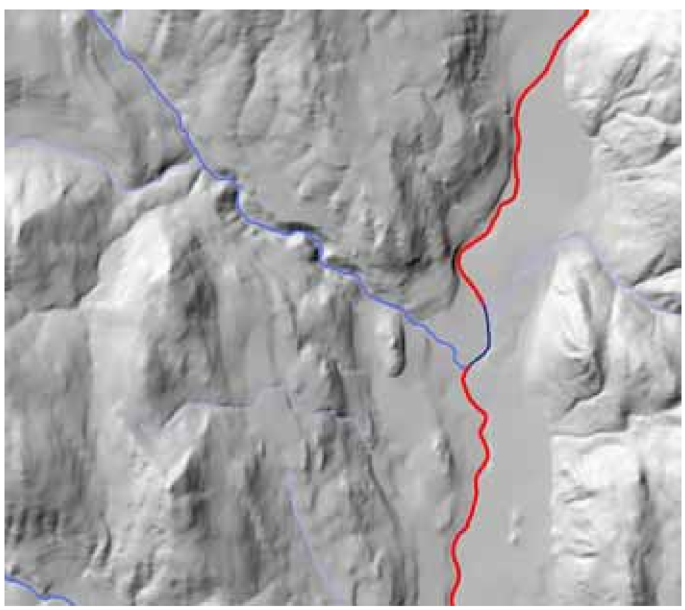


Figure 27. Rosgen Classification of Methow River Basin.

Chewuch River and Cub Creek



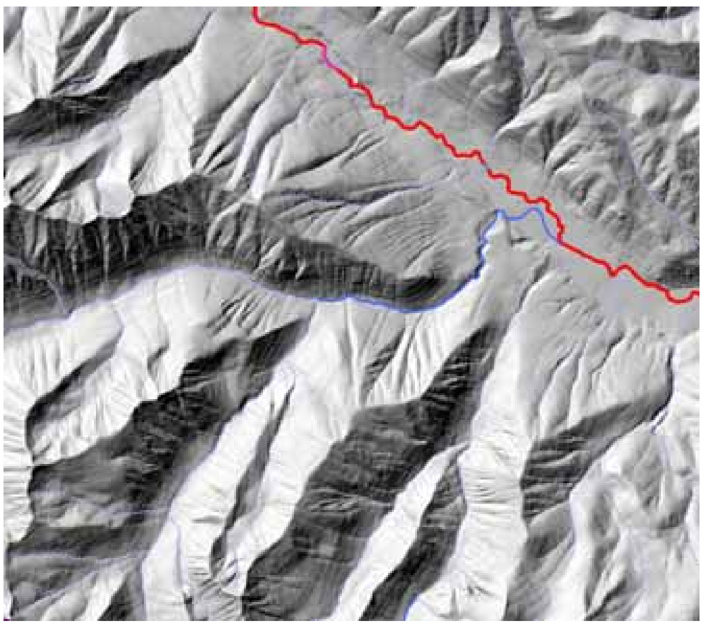
Chewuch River and Cub Creek



Figures 28 (aerial imagery) and 29 (shaded relief image). Detailed view of stream channel classification of a portion of the lower Chewuch River and Cub Creek – Methow River Basin.

Upper Twisp River

Upper Twisp River



Figures 30 (aerial imagery) and 31 (shaded relief image). Detailed view of stream channel classification of a portion of the upper Twisp River – Methow River Basin.

Riparian vegetation classification

Determination and Mapping of Riparian Zone of Extent

Riparian vegetation was mapped for all areas falling within a riparian zone extent created by Pacific Biodiversity Institute under the guidance of riparian mapping parameters suggested by Hillman (2003). The riparian zone extent was functionally a polygon feature developed to guide decisions of where to map and where not to map vegetation features within the UCESU. All areas falling within the riparian zone extent polygon were mapped into one of nineteen classes of vegetation/cover types, including areas that may not have been actual zones of riparian influence. Likewise, all areas not falling within the riparian zone extent polygon were not mapped, even though a non-mapped region could theoretically be in a riparian zone of influence.

To create the riparian zone extent polygon, we incorporated the following GIS data sets: WA DNR waterbody data (2004), SSHIAP 1:100,000 meter scale hydrography data (2001), SSHIAP 1:24,000 meter scale fish bearing streams data (2003), and FEMA floodplains data (1998). First, we buffered the SSHIAP 1:100,000 meter scale hydrography data by 30 meters on both sides of the stream segment. Then we buffered the SSHIAP 1:24,000 meter scale fish bearing streams data by 100 meters on both sides of the stream segment. Additionally, we buffered all DNR waterbody polygons in “bodytype” attribute classes ‘412’ and ‘423’ (‘streams’ and ‘sand or gravel in open water’, respectively) by 100 meters on all sides of the selected polygons. These three buffered layers were then merged together to form one GIS layer. We merged this new GIS layer with the FEMA floodplains layer for all floodplains mapped up to and including the 500 year floodplain. Lastly, we removed any polygons of the resulting GIS layer that were not directly attached to the greater hydrological network polygon resulting in our final riparian zone extent polygon (we assumed that salmon cannot access ‘disconnected’ stream reaches, so these areas were not mapped). Figure 32 illustrates the details of some aspects of the riparian extent mapping. Figure 33 illustrates the riparian extent zone in the Methow River Basin.

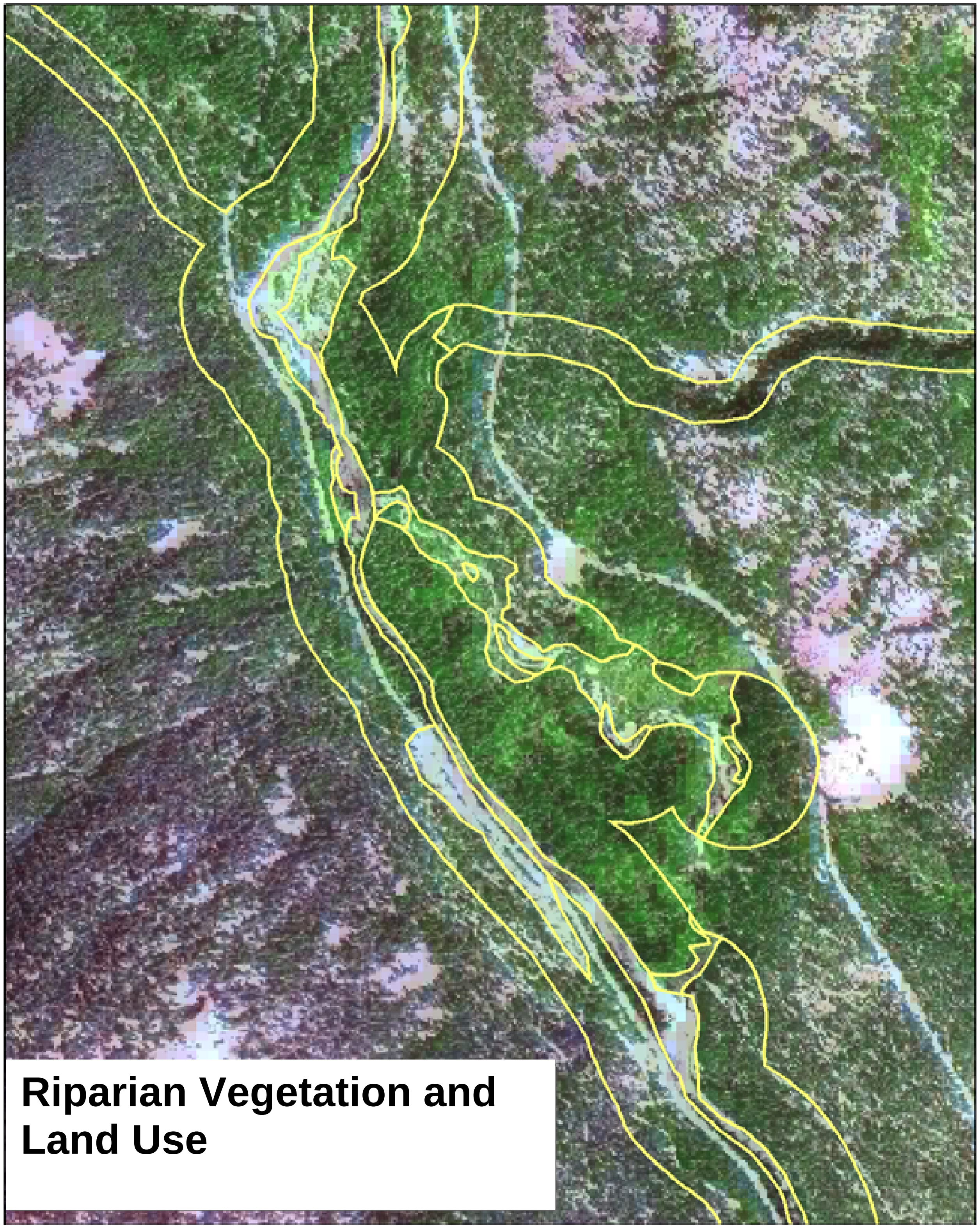


Figure 32. Riparian extent zone and vegetation type boundaries (yellow lines) along a portion of the mid-Chewuch River and tributaries.

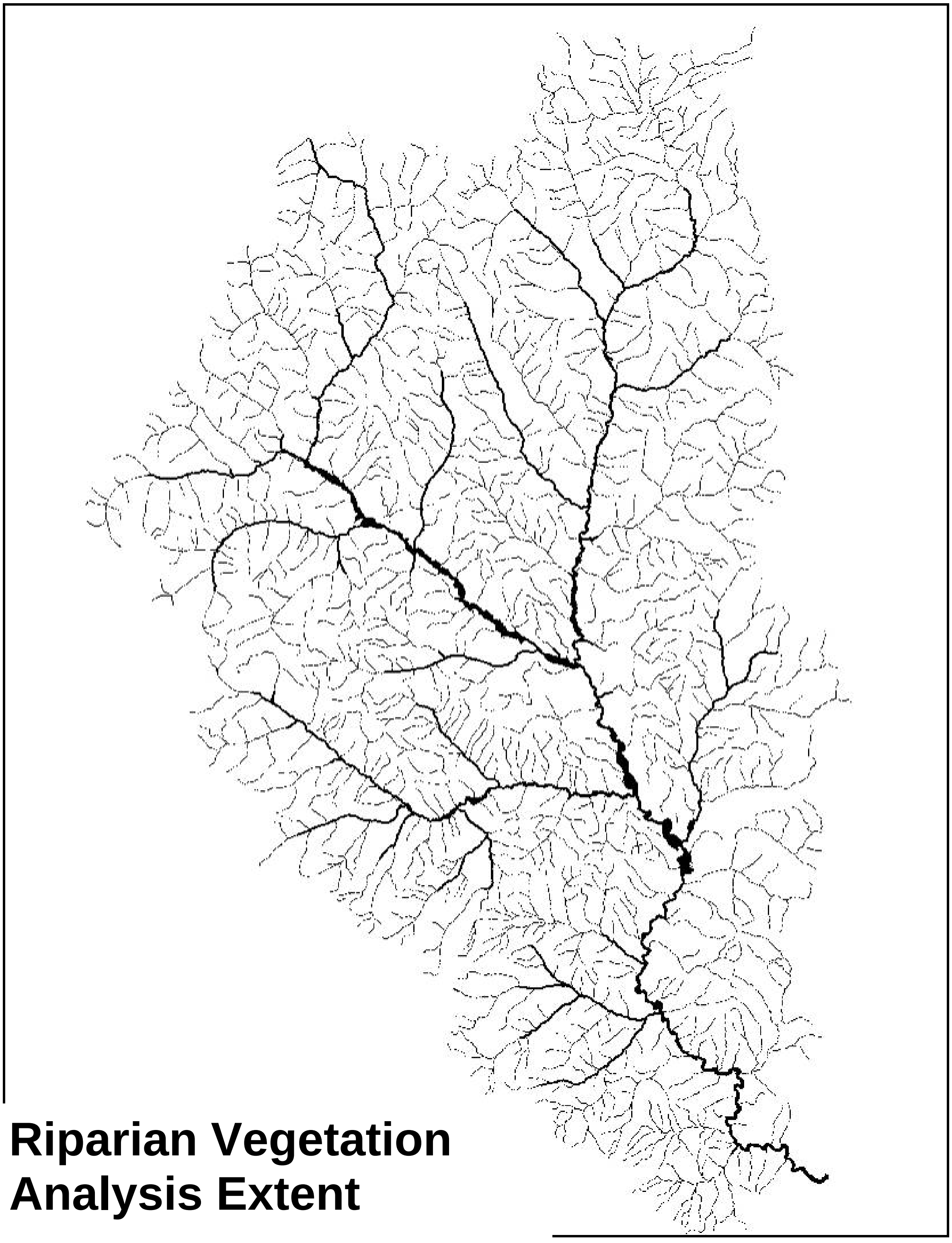


Figure 33. The black areas in the map represent the riparian extent zone in the Methow River Basin.

Development of Riparian Vegetation and Cover Type Classes

Vegetation and cover type mapping was done principally through manual interpretation of black and white aerial photography and multi-spectral satellite imagery, combined with automated and manual comparison between external vegetation maps of various degrees of resolution. To create consistency between the heterogeneous land cover possibilities throughout the UCESU, a total of nineteen class types were agreed upon by Pacific Biodiversity Institute staff and the UCESU regional technical team (RTT) as being the best compromise between maintaining a useful level of detail and accuracy, while promoting efficiency of mapping. These nineteen cover types significantly expand the amount of detail available about riparian vegetation when compared to the four cover types originally proposed in the *Monitoring Strategy for the Upper Columbia Basin* (2003). The cover types mapped are listed in Table 13. The final riparian vegetation and cover type GIS layer that we developed is illustrated in Figure 34.

Table 13. Riparian cover types mapped within the riparian zone extent throughout the UCESU.

Class	Class Name
1	water
2	ice, snow
3	exposed rock, bare ground, soil
4	meadow, grasslands, native herbaceous vegetation
5	riparian shrubs and brush
6	shrub-steppe vegetation
7	deciduous forest
8	mixed deciduous/conifer forest
9	coniferous forest
10	recently burned forest
11	recently logged or disturbed forest
12	orchard
13	agriculture fields
14	denuded and/or highly disturbed areas (mines, gravel pits, scrapped areas, etc.)
15	developed recreational sites
16	residential-low density
17	commercial, industrial, residential-high density
18	transportation corridors (roads and railroads)
19	electrical transmission line corridors

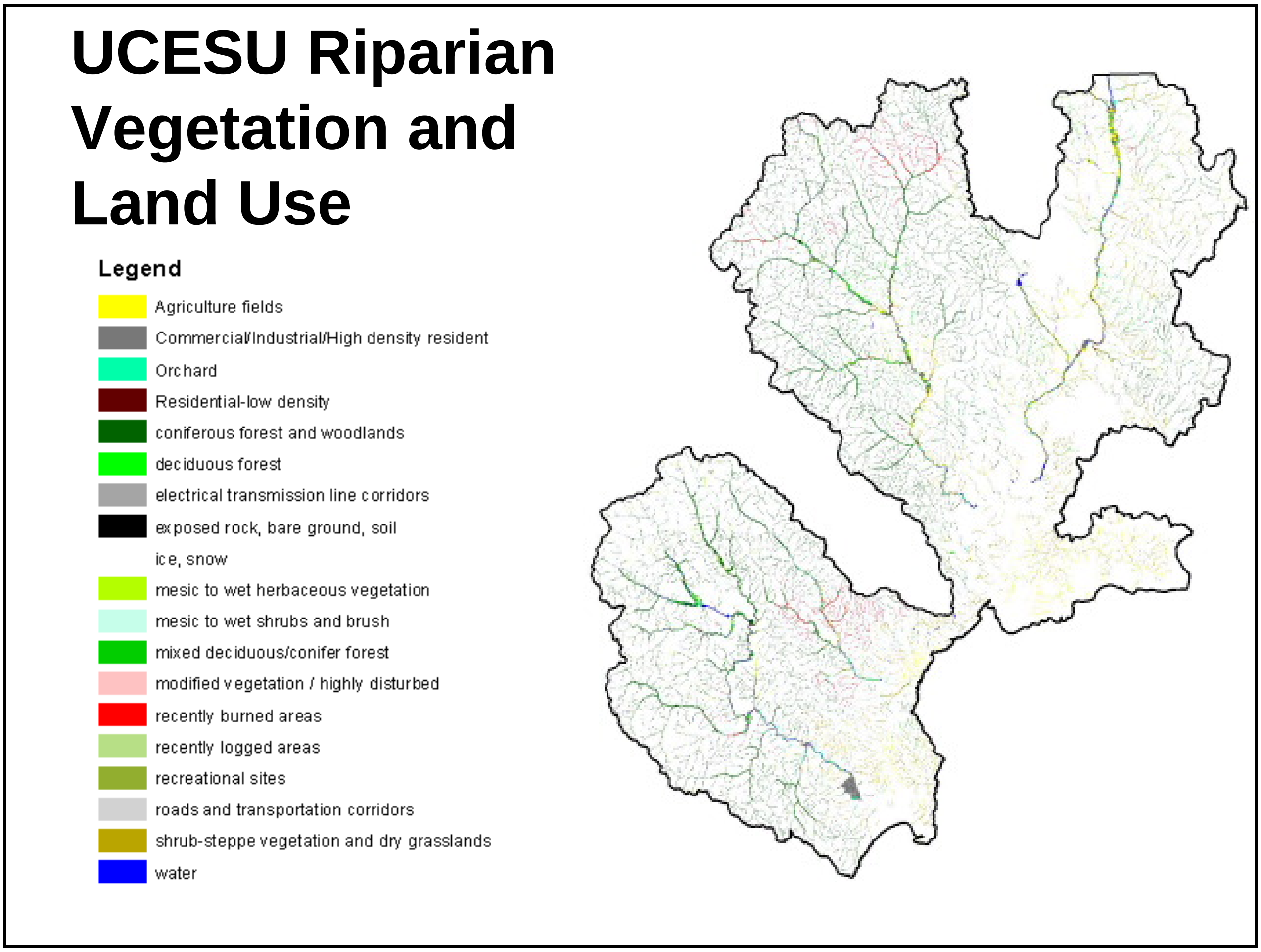


Figure 34. Final map of riparian vegetation and land use in the UCESU.

Aerial Photo Interpretation Methods

We created an “information stack” consisting of 1-meter orthophotography, 10-meter resolution DEMs, 15-meter resolution ASTER satellite images from 2003, and a chronosequence of LANDSAT satellite images from 1972 to 2000 were the principal data components used to manually delineate riparian cover type polygons within the riparian zone extent for the entire UCESU. We added additional GIS data to this information stack, including county parcel databases, roads and transportation corridor databases, utility line data, national wetlands inventory data, fire complex data, and agricultural lands data from various sources to inform our riparian cover type polygon delineation and classification (Table 14). Some of these input data layers are illustrated in Figure 35. For a given area, Pacific Biodiversity Institute staff manually digitized polygons at a standard view scale of 1:10,000 in ArcMap (ArcGIS version 8). The 1998 black and white ortho-rectified aerial imagery was used as the base layer for determining horizontal accuracy of mapped features in coordinate space. Figure 36 illustrates an example of the resulting vegetation and land cover map for a small portion of the Entiat River Basin.

During the manual riparian vegetation mapping process, we examined the stack of information layers described above and evaluated vegetation signatures and land use status and change that can be observed using satellite and aerial photo chronosequences. Rather than basing our decision on one layer, our decisions were based on information on a combination of layers.

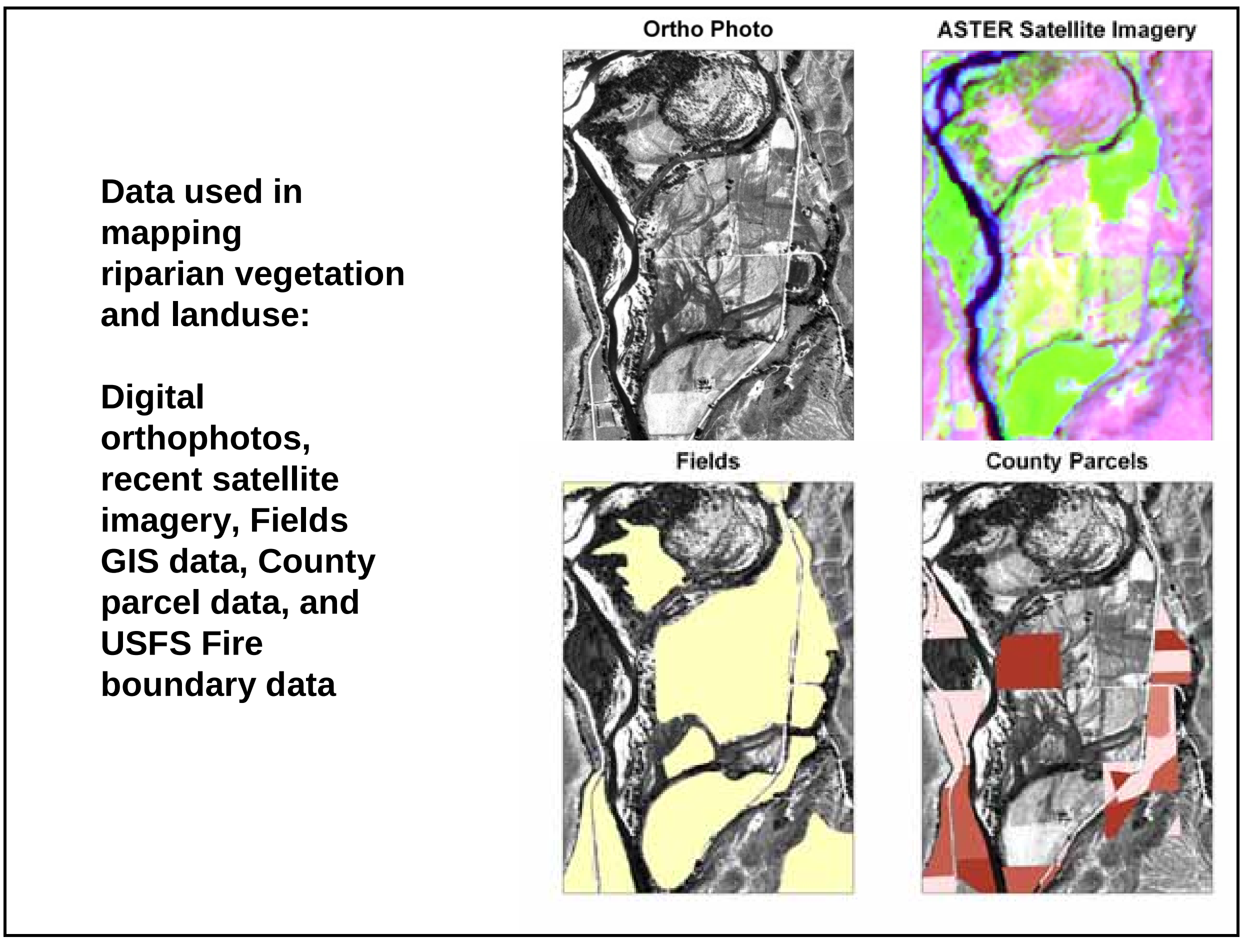
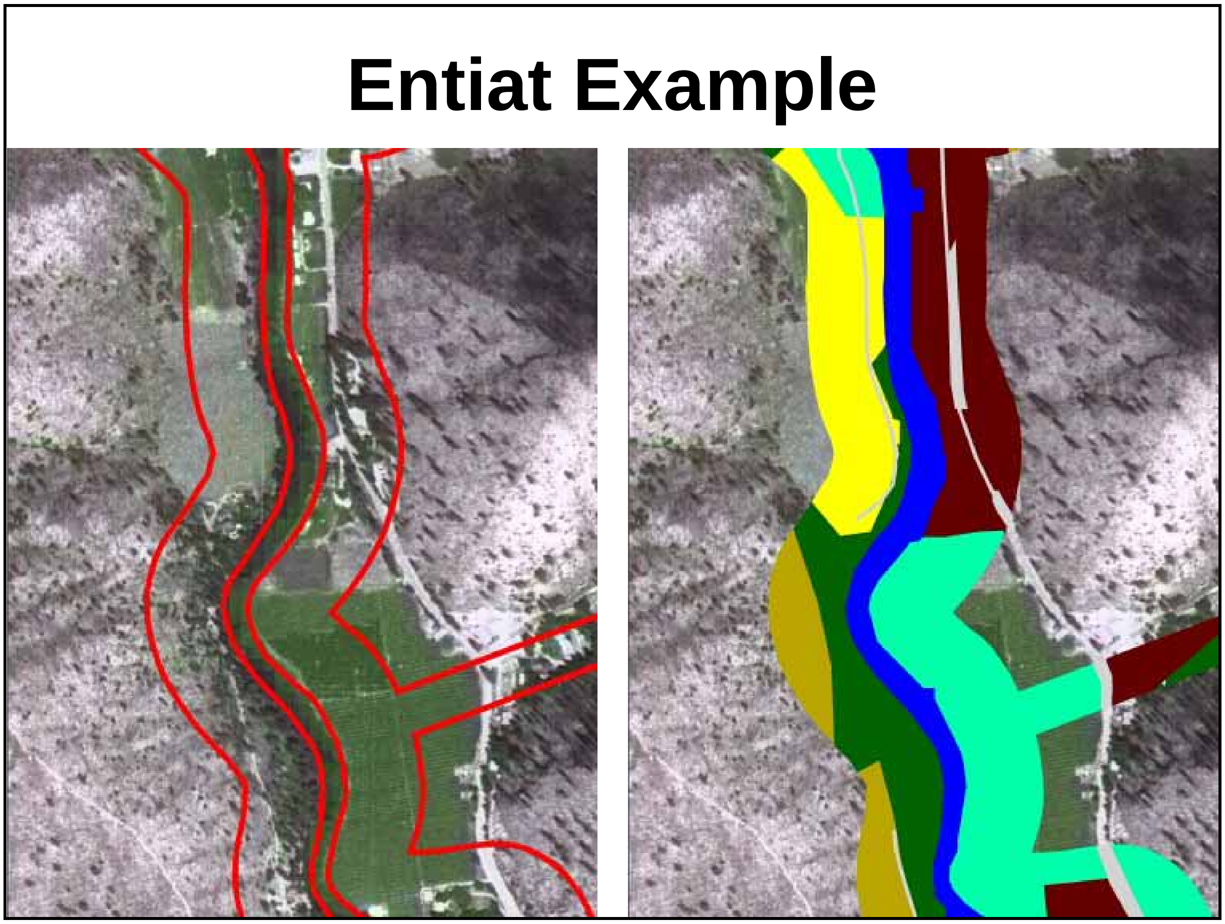


Figure 35. Examples of some of the input data used to map riparian vegetation and land use.



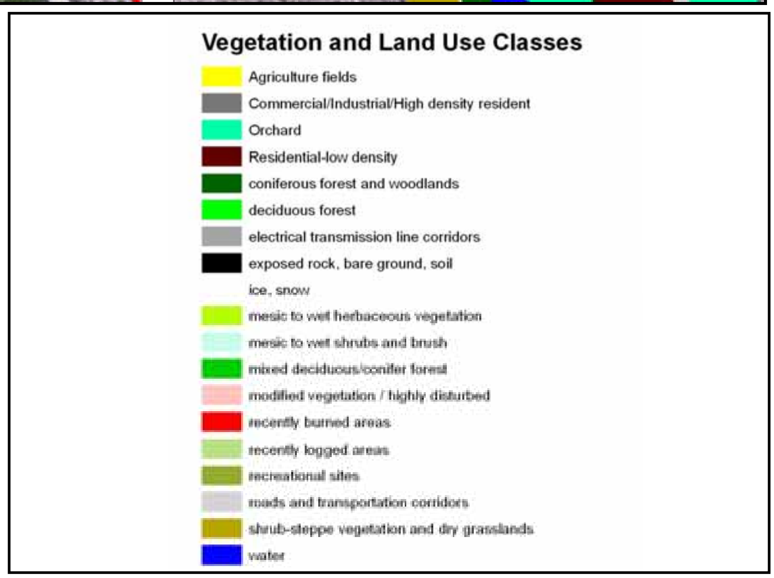


Figure 36. Example of riparian vegetation map produced from manual digitizing along a portion of the Entiat River.

Table 14. Input data used in riparian vegetation and land cover mapping

Data Type	Source
Riparian Extent Polygon	Pacific Biodiversity Institute (described above)
Existing Vegetation and Land Use Data	USFS Lake Wenatchee – Leavenworth District vegetation data (Wenatchee Basin only), USGS National Land Cover Data, North Cascades Grizzly Bear Habitat Project vegetation data, and WDFW-NHI vegetation data
1 meter Digital Orthophotos (1998)	US Forest Service
15 meter ASTER Satellite Imagery (2003)	NASA
A chronosequence of Landsat Satellite Imagery from 1972 to 2002	EROS Data Center and NASA
County Parcel Data	Chelan, Douglas and Okanogan Counties
National Wetland Inventory Data	US Fish and Wildlife Service
Transportation system data	Washington DNR, US Forest Service
Electrical Transmission Lines	Bonneville Power Administration
Logging history data	Pacific Biodiversity Institute, developed in previous projects
Areas burned in recent wildfires	US Forest Service and Pacific Biodiversity Institute

Differences in methods between the Wenatchee Basin and the rest of the UCESU

In the Wenatchee basin, we followed the approach described above on the non-federal lands. However, on the federal lands managed by the US Forest Service, we used vegetation data developed by the Leavenworth and Lake Wenatchee Ranger Districts. This data had been developed previously using a manual aerial photo-interpretation process. We had evaluated and used this data in an earlier project in the Wenatchee Basin (Pacific Biodiversity Institute 2002). In our current effort to map riparian vegetation in the Wenatchee Basin, we did minor revisions to the vegetation data we developed in 2002 and updated the data to take into account landscape changes that were apparent upon examination of 2003 ASTER satellite imagery.

Vegetation mapping using ASTER and LANDSAT satellite imagery

To supplement the mapping of the riparian areas of major streams and rivers, we used ASTER and LANDSAT ETM 7 satellite imagery. We found high quality ASTER satellite imagery for most of the study area except for parts of the Okanogan River Basin, where the available ASTER imagery contained too much smoke or cloud cover to be useful. For riparian areas with a 60-meter width (smaller order streams) we incorporated classified ASTER and Landsat satellite images covering each watershed from the summers of 2002-2003. We undertook a series of steps to process, georeference, classify and interpret the ASTER imagery.

Processing of ASTER and LANDSAT satellite imagery

We downloaded both ASTER and LANDSAT imagery from NASA or University of Maryland Global Land Cover Facility web or ftp sites. We also used TM and MSS Landsat imagery from Pacific Biodiversity Institute's satellite image archive. The LANDSAT imagery was already georeferenced and only required minimal processing to be prepared for analysis. This processing was done using ERDAS Imagine software. The ASTER imagery was downloaded in a raw format and required substantial processing. The processing was done using MultiSpec and ERDAS Imagine.

Georeferencing of ASTER satellite imagery

The ASTER satellite imagery was georeferenced in ESRI's ArcMap using the image georeferencing extension. Background layers of 1:24,000 streams and accurate transportation data layers along with 1-meter resolution DOQQs were used to obtain georeferencing control points. The ASTER images were often split into 3 or 4 subsets to aid in the georeferencing process and then merged back together after georeferencing. We used 50 to 100 control points in each image and were able to georeference the images to a spatial accuracy of within 5 meters in most situations (Figure 37).

Figure 37. Example of a portion of an ASTER satellite image that Pacific Biodiversity Institute georeferenced for the upper Twisp River.

Classification of ASTER satellite imagery

First, we examined the ASTER satellite image ephemeris data to determine the azimuth and altitude of the sun at the time the image was captured. Using this information, we created a solar illumination model from a 10-meter resolution DEM. This was done in Arc/INFO GRID, and is a similar process to creating a shaded relief image from a DEM. The solar illumination model can then be used to determine which portions of the satellite image are brightly sunlit, which areas are deeply shadowed and which areas have more normal illumination. Since the spectral responses of land surfaces in high-relief terrain is dramatically affected by the differential effects of solar illumination, it is important to take this into account, prior to classification of the imagery. We created three mask grids, which represent shadowed terrain, brightly sunlit terrain and more normally illuminated terrain. These illumination masks were then used to subset the satellite imagery into three subsets, representing the shadowed portion of the imagery, the brightly sunlit portion of the imagery and the normally illuminated portion of the imagery.

Then we classified each subset of the satellite image into 50 spectral classes with an unsupervised classification approach using ERDAS Imagine (ISODATA and maximum likelihood classification). This approach enabled us to classify the shadowed portion of the image separately from the brightly sunlit portion of the image. It allowed us to extract more information about vegetation characteristics from each image subset.

Interpretation of ASTER satellite imagery into vegetation classes

After the image subsets were classified, we determined the vegetation or land cover type of each of the resulting spectral classes. We used digital aerial photography, existing vegetation mapping and our own extensive field experience to assign the spectral classes to cover types. Once each image subset was classified and interpreted into cover types, the resulting grids were merged back together to form a continuous vegetation and land cover type map of the entire area covered by each satellite image.

Merging ASTER vegetation maps from multiple satellite images into a continuous vegetation map for a river basin

Multiple ASTER images were needed to cover an entire river subbasin, since the spatial extent of any one image was insufficient. Once each ASTER image that was needed to cover an entire river basin was transformed into a vegetation and land cover type grid, the resulting grids from each ASTER image were merged together to form a continuous vegetation grid for the entire river basin.

Incorporation of information about recent wildfires and their effect on vegetation

We used fire boundary information obtained from the US Forest Service and boundary delineations that we interpreted from visual examination of the ASTER satellite images to help classify areas that had been recently burned in wildfires. These areas were mapped as a separate map category - recently burned areas. However, we did not map unburned inclusions within the fire boundaries as recently burned areas.

Incorporation of information on shrub-steppe vegetation and separation from other non-forested areas

We digitized an approximate boundary that determines the upper elevation limit of shrub-steppe. This was created based on elevation and aspect data and extensive field knowledge about the distribution of shrub-steppe vegetation in the UCESU. This boundary was used to separate shrub-steppe vegetation from higher elevation non-forested vegetation with similar spectral responses.

Clipping vegetation map to riparian extent zone

Once a complete vegetation map was produced from the ASTER satellite imagery, as described above, it was clipped to the riparian extent zone to form a map of riparian vegetation and land cover.

Combination of aerial photo mapping, satellite image mapping and other information into a final riparian vegetation and land cover type map

We combined the maps described above that resulted from manual digitizing with the map produced from ASTER satellite classification and interpretation. The vegetation map resulting from manual digitizing was used for the riparian areas along all major streams and rivers. The map resulting from the ASTER satellite image was used for the riparian areas of all smaller streams. We also examined the areas of overlap between the two maps and used the ASTER satellite vegetation map to locate and fix errors that might be present in the manually digitized vegetation and land cover map. The resulting maps combine the benefits of careful aerial photo interpretation and interpretation of a multitude of ancillary GIS data with the comprehensive perspective derived from careful satellite image classification and interpretation. Figures 38 and 39 illustrate the resulting vegetation map for the portion of the upper Twisp River that was illustrated in Figure 37.

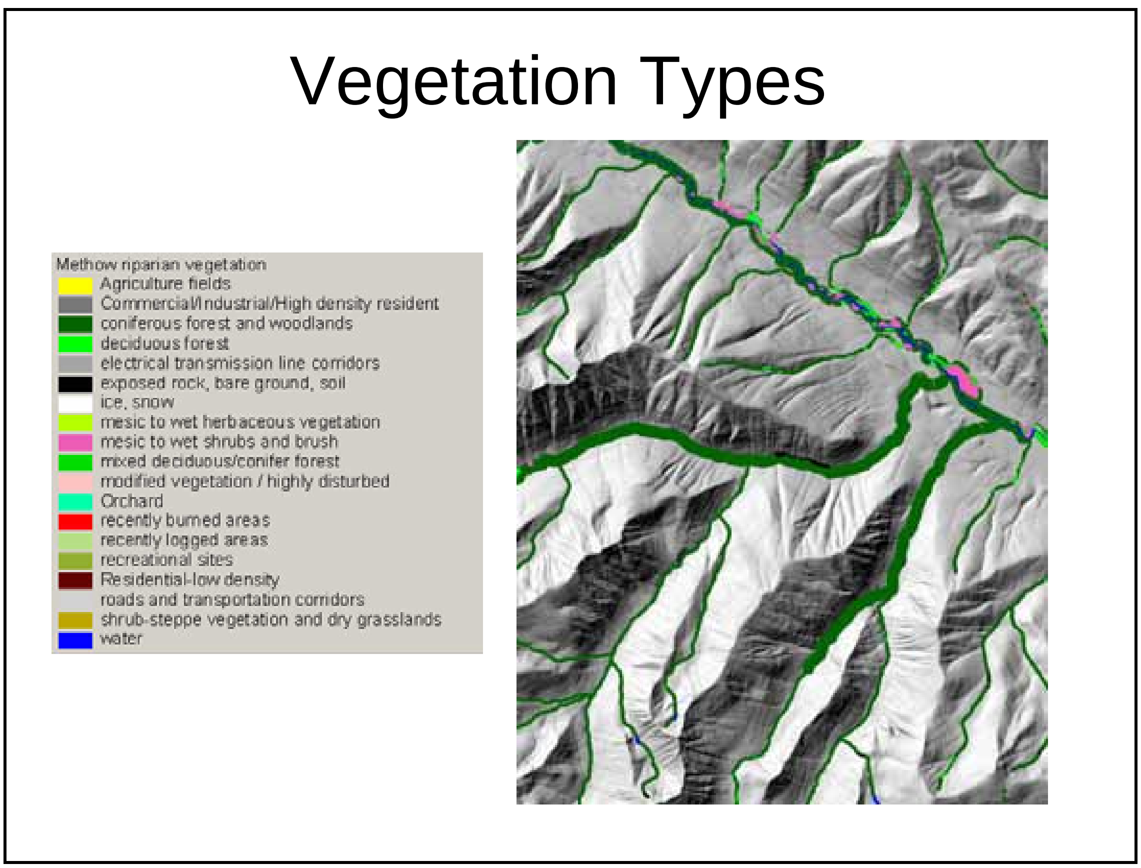


Figure 38. Final vegetation map for a portion of the upper Twisp River. The extent of this map is identical to the ASTER image shown in Figure 37.

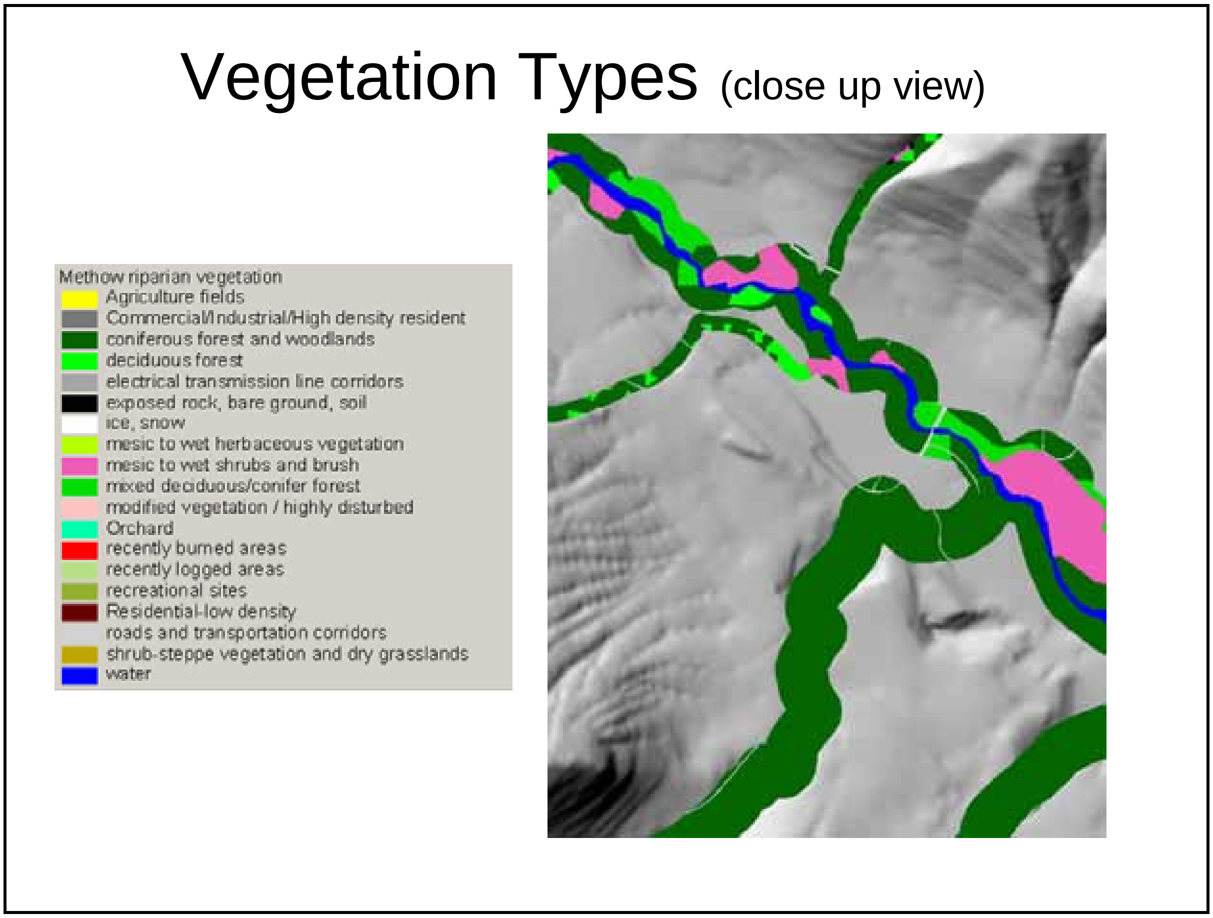


Figure 39. Detailed view of final vegetation map for a portion of the upper Twisp River. The extent of this map covers only the central area shown in Figures 37 and 38.

Similar results were produced in all the subbasins and watersheds of the UCESU. Figure 40 illustrates the riparian extent zone overlaid on an ASTER satellite image of an area in the Wenatchee Basin centered on the confluence of the Wenatchee River and Icicle Creek, near the town of Leavenworth. Figure 41 illustrates the resulting vegetation and land cover type map that we produced for that area using a combined manual digitizing and satellite image classification and interpretation approach. Figure 42 illustrates the competed vegetation and land cover type map of all the riparian areas in the Wenatchee River Basin.

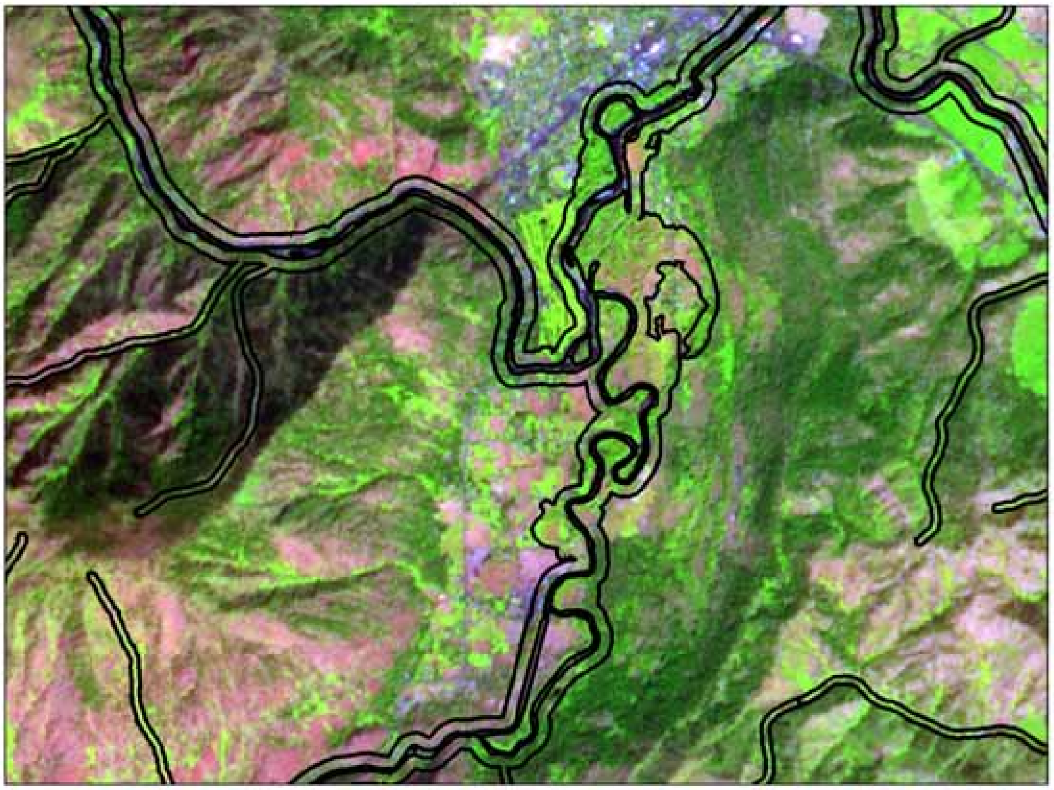


Figure 40. The riparian extent zone and an ASTER satellite image centered on the confluence of the Wenatchee River and Icicle Creek near the town of Leavenworth.

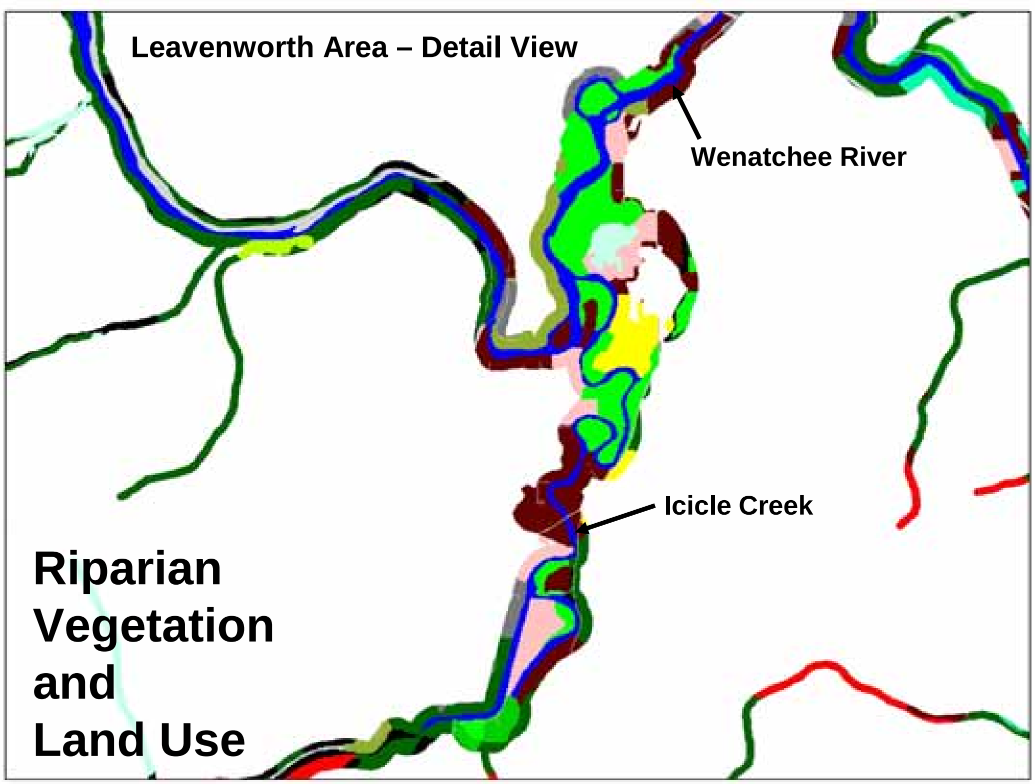


Figure 41. Final vegetation and land cover type map for area illustrated in Figure 40.

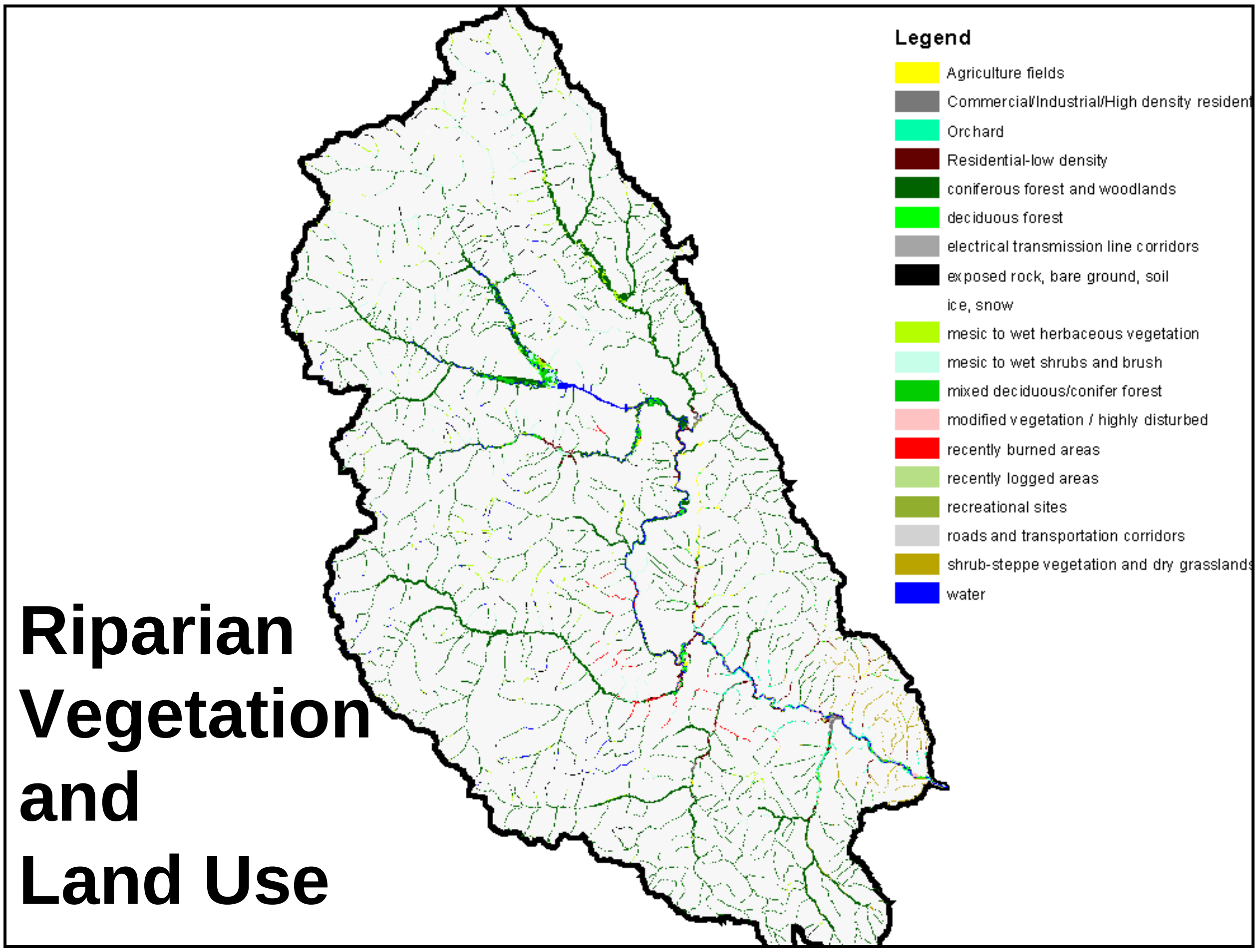


Figure 42. Final vegetation and land cover type map for the Wenatchee River Basin.

Watershed Conditions

We calculated the watershed condition indexes listed in Table 15 for the subbasins and subwatersheds of UCESU region.

Table 15. Watershed Condition Indexes

Watershed Condition Indexes	**Watershed road density**
	Riparian-road index

Calculating the road density and riparian-road index (RRI) of the various subbasins and major watersheds within UCESU provided a comparative view of watershed conditions throughout the analysis area. Road density is an index of the total miles of roads within a watershed. It is calculated as the total length of all roads (km) within a watershed divided by the area of the watershed (km^2). The RRI is expressed as the total mileage of roads (km) within riparian areas divided by the total number of stream kilometers within the watershed (Hillman, 2003).

Watershed Road Density

To calculate road density, we took the WA DNR transportation layer, selected out only the arcs attributed as roads, and performed an INTERSECT function on this roads theme with our customized version of the NOAA HUC6 watershed dataset. This provided us with a database table that contained all the input values we needed to compute the road density index for each HUC6 watershed. We simply summarized the road lengths for each HUC6 watershed, converted that value into kilometers, and then we divided the kilometer value by the square kilometer value of the HUC6 watershed's area. All of this data was provided in table format imbedded in a word document in our final data products CD. The riparian-road index for the Wenatchee Basin listed below in Table 15. Similar tables for the other subbasins and watersheds in the UCESU are included in Appendix D.

Riparian-Road Index

The riparian-road index was calculated for each entire subbasin or similar analysis region (such as the Douglas County analysis region) within the UCESU region. To perform this calculation we took the riparian zone extent polygon layers we created for the riparian vegetation classification and performed an INTERSECT function on these with the WA DNR transportation layer (selected for just the arcs designated as roads). With the resulting attribute database, we were able to calculate the total kilometers of road within the riparian areas of each subbasin or similar analysis region. Because we had already calculated the subbasin's total area for the Basin Level Classification, we were able to quickly compute the RRI. This data was provided in table format imbedded in a word document in our final data products CD. The riparian-road index for the Wenatchee Basin listed below in Table 16. Similar tables for the other subbasins and watersheds in the UCESU are included in Appendix D.

Table 16. Wenatchee Basin Road Classification

HUC6 Subwatershed Name	length of roads (km)	area of HUC6 (sq. km)	road density (km/sq. km)	length of streams - 100k hydrography (km)	length of roads in riparian areas (km)	Riparian Road Index
BEAVER	61.12	25.3	2.42	25.92	10.55	0.4069
BRENDER	73.29	27.86	2.63	18.27	11.68	0.6394
BUTCHER - KAHLER	135.47	41.12	3.29	29.49	17.54	0.5948
CABIN - FALL	0	30.08	0	25.47	0.00	0.0000
CAMAS	60.55	23.8	2.54	25.59	9.46	0.3696
CHIKAMIN	23.21	56.4	0.41	54.00	4.52	0.0837
CHIWAUKUM 1	0.02	74.97	0	53.65	0.02	0.0005
CHIWAUKUM 2	2.69	28.32	0.09	26.79	0.59	0.0221
DERBY	57.16	34.55	1.65	28.25	16.76	0.5933
DEVIL'S GULCH	5.13	42.09	0.12	36.18	0.00	0.0000
EAGLE	191.86	73.3	2.62	57.95	35.68	0.6158
EAST FORK MISSION	44.64	52.8	0.85	52.93	15.95	0.3014
EIGHTMILE	18	79.97	0.23	47.47	1.43	0.0302
ENCHANTMENTS	0.88	48.99	0.02	40.46	0.62	0.0154
FRENCH	0	64.52	0	51.83	0.00	0.0000
GILL - ROARING - COULTER	100.9	42.08	2.4	35.40	7.30	0.2061
HEADWATERS CHIWAWA 1	5	41.28	0.12	25.86	0.98	0.0380
HEADWATERS CHIWAWA 2	2.69	67.74	0.04	40.62	0.09	0.0022
HEADWATERS ICICLE	0	69.94	0	48.07	0.00	0.0000
HEADWATERS LIT. WENATCHEE	1.23	70.63	0.02	49.38	0.10	0.0021
HEADWATERS NASON	73.55	59.42	1.24	42.18	9.64	0.2286
HEADWATERS PESHASTIN 1	62.45	43.37	1.44	38.09	14.68	0.3852
HEADWATERS PESHASTIN 2	134.13	50.29	2.67	45.64	30.09	0.6594
HEADWATERS WHITE 1	0	55.25	0	27.53	0.00	0.0000
HEADWATERS WHITE 2	0	50.94	0	30.57	0.00	0.0000
INDIAN	0	53.11	0	31.81	0.00	0.0000
INGALLS 2	4.35	39.36	0.11	46.21	1.16	0.0251
INGALLS 1	0	56.25	0	24.16	0.00	0.0000
JACK	0.44	74.99	0.01	45.84	0.44	0.0096
LAKE	13.74	44.54	0.31	31.61	1.26	0.0400
LAKE WENATCHEE	62.38	42.04	1.48	25.44	3.00	0.1179
LOWER CHIWAWA 1	123.66	40.67	3.04	31.42	17.36	0.5524
LOWER CHIWAWA 2	104.44	49.72	2.1	59.22	10.71	0.1808
LOWER CHUMSTICK	136.74	63.5	2.15	61.99	33.36	0.5381
LOWER ICICLE 1	18.33	47.42	0.39	43.21	9.30	0.2153
LOWER ICICLE 2	72.33	39.15	1.85	28.33	20.66	0.7291
LOWER LITTLE WENATCHEE	68.32	51.78	1.32	31.51	11.24	0.3567
LOWER MISSION	83.24	70.35	1.18	59.93	37.86	0.6318
LOWER NASON	46.03	37.99	1.21	35.65	8.18	0.2294
LOWER PESHASTIN	94.15	47	2	38.30	20.88	0.5452
LOWER WENATCHEE 1	206.84	88.8	2.33	109.00	46.95	0.4308
LOWER WENATCHEE 2	64.57	28.34	2.28	37.67	23.53	0.6247
LOWER WHITE	45.73	40.83	1.12	33.93	12.71	0.3746
MEADOW - BRUSH	113.38	49.44	2.29	38.13	6.47	0.1698
MIDDLE CHIWAWA	24.99	26.38	0.95	32.97	4.70	0.1425
MIDDLE ICICLE	42.01	62.12	0.68	52.92	10.51	0.1987
MIDDLE WENATCHEE 1	114.16	42.63	2.68	32.27	20.47	0.6342
MIDDLE WENATCHEE 2	108.9	36.52	2.98	31.14	13.63	0.4378
NAHAHUM	70.78	32.12	2.2	33.95	16.45	0.4846
NAPEEQUA 1	0	54.17	0	30.75	0.00	0.0000
NAPEEQUA 2	1.85	50.06	0.04	39.57	1.07	0.0271
NEGRO	33.59	31.56	1.06	21.83	3.40	0.1556
OLALLA	68.32	25.5	2.68	23.09	16.56	0.7172
PANTHER	0	48.51	0	33.16	0.00	0.0000
RAGING	7.51	19.22	0.39	17.97	0.56	0.0311
RAINY	36.45	43.93	0.83	35.58	6.12	0.1720
ROCK	4.05	55.88	0.07	43.77	2.13	0.0486
SAND	80.75	48.32	1.67	46.26	13.21	0.2857
SKINNEY	74.61	29.1	2.56	16.77	6.99	0.4168
TUMWATER CANYON	49.26	53.62	0.92	52.03	20.96	0.4027
U. CHUMST. - LIT. CHUMST.	168.12	64.53	2.61	49.95	36.64	0.7336
UPPER CHIWAWA	19.46	81.21	0.24	70.39	6.45	0.0916
UPPER ICICLE	0.93	69.09	0.01	62.03	0.36	0.0058
UPPER LITTLE WENATCHEE	70.41	52.01	1.35	61.16	11.53	0.1885
UPPER NASON	22.8	31.79	0.72	29.84	8.13	0.2725
UPPER PESHASTIN	152.61	56.81	2.69	58.02	33.27	0.5735
UPPER WENATCHEE 1	98.32	50.99	1.93	48.95	26.51	0.5416
UPPER WENATCHEE 2	140.28	41	3.42	19.52	11.58	0.5931
UPPER WHITE	15.26	49.86	0.31	60.63	5.30	0.0875
WHITEPINE	3.42	63.32	0.05	40.95	0.12	0.0028
Entire Wenatchee Basin	**3721.46**	**3440.55**	**1.08**	**2816.40**	**729.40**	**0.2590**

An assessment of the methods and results

Regional setting classification

The methods used to produce these classification variables were very straightforward. We simply brought together and provided existing data produced by other agencies. We did clip the original datasets to the boundary of the UCESU region, but no other modifications were made from the original datasets.

The regional classification variables have limitations due to the spatial scale at which they were developed. The physiographic province data was developed at a 1:7,000,000-scale and should not be considered to be accurate accept at the regional scale. The same goes for the Bailey ecoregions, which were developed at a 1:7,500,000-scale. The Omernik ecoregions were developed at a 1:250,000-scale and represent a regional classification that has more meaning within and between subbasins within the UCESU. The Omernik ecoregions probably represent a more meaningful classification variable than the physiographic provinces or the Bailey ecoregions.

It is important to note that while the regional scale classification variables (ecoregion, physiographic province and geologic district) are useful as broad-scale classifications of sites, the province and ecoregion variables are gross generalizations of actual landscape conditions. In many cases sites on either side of a provincial or ecoregional boundary will have more similarity to each other than to other sites in the same province or ecoregion. The geologic district classification variables were mapped at a finer scale and have considerably more classification attribute classes than the province or ecoregion classification data. It may well prove to be more useful in separating sites based on regional setting characteristics.

Improvement of our results for the regional setting classification could be obtained by receiving updated versions of the classification variable datasets from the various managing agencies for each dataset - if they exist.

Basin-level classification

Land Ownership

We used the Washington State DNR managed public lands (MPL) dataset, along with the WA DNR managed lands dataset to calculate ownership acreages within each subbasin or analysis region. We described land ownership as “federal,” by agency; “state,” by agency, and “private” as all non-state or federal lands.

The DNR’s datasets are the most comprehensive and consistent ownership datasets covering all of Washington State. Complete accuracy of ownership boundaries and attributes regarding current ownership cannot be guaranteed. While comparing the DNR data to ownership data from the USFS or from various county governments many discrepancies and contradictions were apparent, though it was impossible to tell which was wrong and which was right.

In a separate study that we did on the natural resource characteristics of the Wenatchee River Subbasin (Pacific Biodiversity Institute 2002b), we discovered numerous discrepancies among different maps produced by different public agencies of land ownership. In that study, we examined maps from the Chelan County Assessor's Office, U.S. Forest Service (USFS), and Washington Department of Natural Resources (DNR). The maps disagreed about ownership of 3,106 map polygons, or over 33,000 acres (135 km^2) (Figures 43 and 44). This amounts to ownership disagreement on public lands covering of about 4% of the Wenatchee River Basin area. In this prior study, we determined that two problems are occurring:

Public agencies disagree about ownership of specific parcels. Although all three layers (County, US Forest Service, Washington State DNR) agree on ownership for most (96%) of the watershed, classification errors account for much (106 km^2, 79%) of the disputed land *area*. Classification problems could be resolved through parcel-by-parcel verification of ownership with original data sources. Although tedious, this could potentially increase map accuracy to >99% (based on area).

The second problem is there is an extensive disagreement over the location of parcel boundaries between public agencies. Even when the public agencies agree on who owns each parcel, discrepancies among the exact location of parcel boundaries create "slivers" of disagreement. In Figure 43, the many black lines and checkerboard patterns show areas where two or more of the data sources disagree on parcel boundaries. Boundary errors accounted for 2,990 (96%) of the disputed map *polygons*, and would be difficult to resolve without knowing which map has the most accurate boundaries. The problem may be exacerbated if no single map source was the most accurate (e.g., boundaries of forested parcels may be mapped most accurately by USFS, whereas boundaries of private parcels are mapped most accurately by the County Assessor's Office). Ideally, a single (and presumably accurate) map of parcel boundaries should be used by all agencies. Although the total map area affected by disagreement over boundary locations is less than the area affected by disagreement over ownership of specific parcels, the former problem may be more serious because these "slivers" of disagreement are carried into subsequent GIS layers when spatial analyses are conducted.

We did not conduct an intensive investigation of discrepancies in ownership data between various public agencies in other parts of the UCESU. However, it is apparent that similar problems occur in all the other parts of the UCESU. From our extensive work in the Methow River Basin over many years, we have encountered many problems with ownership discrepancies between various datasets. This appears to be a universal problem, but it could be resolved fairly easily by better communication and collaboration between public agencies.

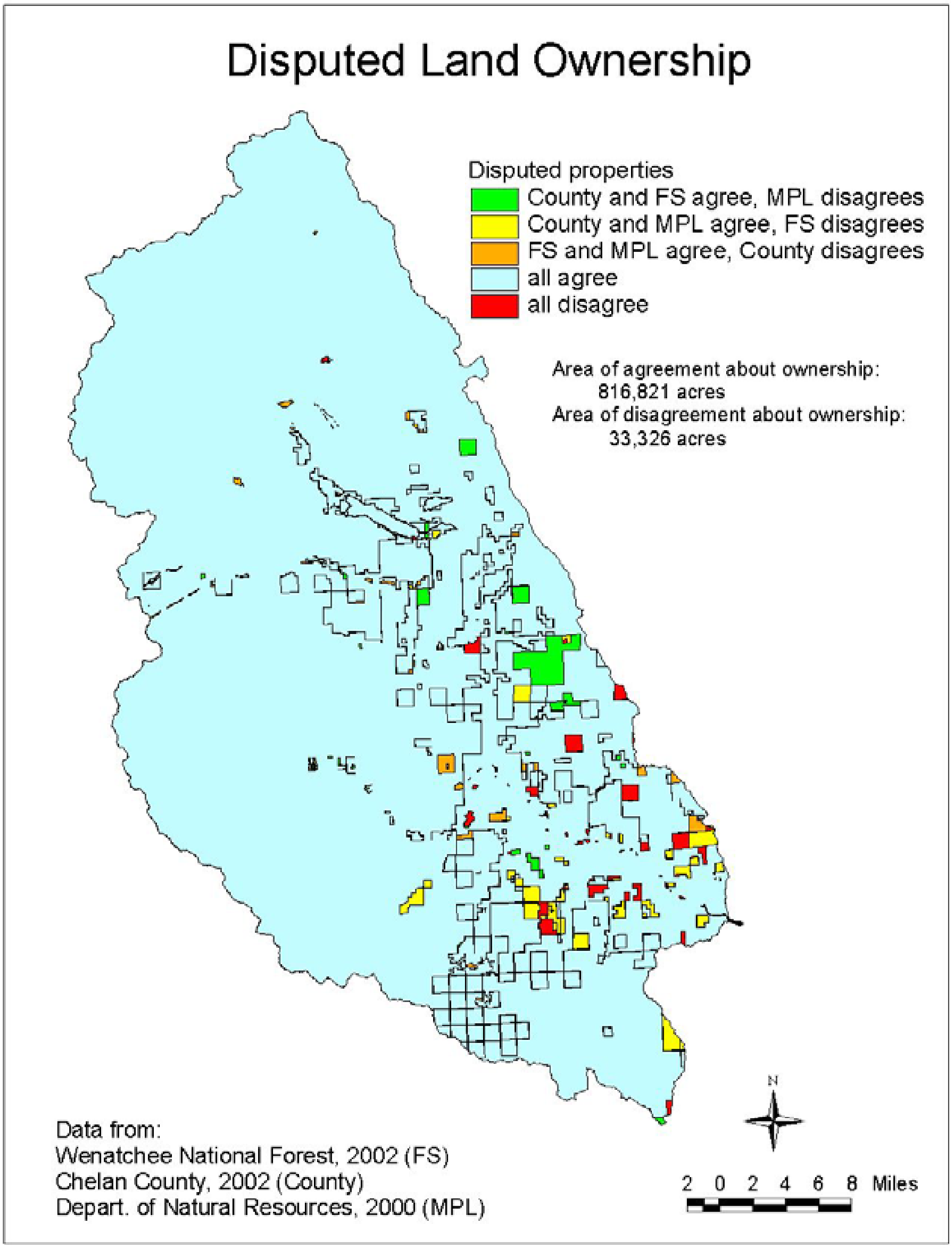


Figure 43. (From Pacific Biodiversity Institute (2002) Areas of disputed ownership information involving three agency ownership maps (WA DNR, Wenatchee National Forest and Chelan County).

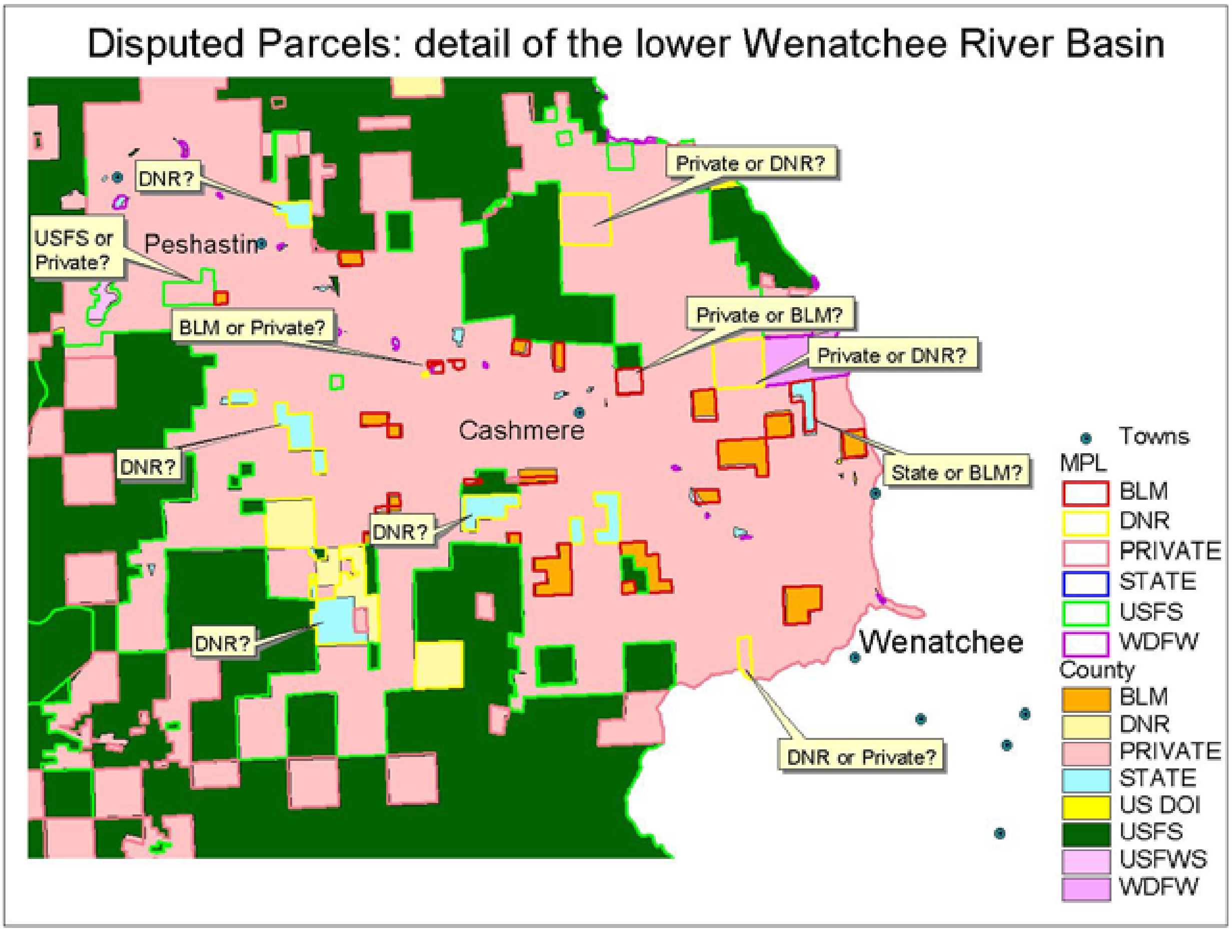


Figure 44. (From Pacific Biodiversity Institute (2002) View of eastern portion of Wenatchee Basin showing some of the details of ownership discrepancies between agency ownership maps.

The task of reconciling the differences between ownership maps of the various agencies was beyond the scope of the project discussed in this report. We decided that for the purpose of this study, we would use the Washington Department of Natural Resources Major Public Land GIS layer (MPL), as this is the only GIS layer that is consistent across the entire UCESU. However, it is worth noting that the MPL layer is not (in many cases) the most accurate layer in terms of land ownership and parcel boundaries.

Improvements in the accuracy and currentness of the land ownership calculations could be obtained by receiving updated versions of the DNR MPL and DNR managed land datasets as they are released.

Basin Relief

Barring large scale geologic changes in macro-topography, our basin relief calculations should remain valid regardless of elevation dataset updates. The 10-meter DEM datasets offer sufficient detail to make accurate calculations of basin elevation statistics. Basin area calculations should also remain valid unless future renditions of NOAA’s HUC 6 layer contain drastic alterations of some of the subwatershed boundaries.

It is important to note that some of the drainage basin calculations were not completed for an actual “drainage basin” at all. The Okanogan Subbasin elevation and basin boundary data we used was artificially cut off at the U.S. / Canada international border, so much of the actual Okanogan Subbasin was not included in the calculations. We also manually altered portions of the Okanogan Subbasin boundary to separate out all the above dam portions of the Similkameen River drainage. As a matter of fact, all of the Similkameen River drainage (much of which is in Canada as well) should be included as part of the Okanogan Subbasin given that the Similkameen River is a tributary of the Okanogan River. However the Similkameen River and its tributaries are not considered part of the UCESU region given the fish passage blockage created by the dam near the mouth of the Similkameen River. Also, the Douglas County and Other Small Watersheds analysis regions are not actual complete drainage basins, but are isolated networks of separate small subwatersheds. However, the basin relief statistics were calculated for these regions as if they were distinct drainage basins.

If actual drainage basin relief statistics are desired for each subbasin influencing the UCESU, the project analysis region would need to be expanded to include all of the Okanogan drainage basin, including the Canadian portions of the Similkameen River and its tributaries. This would require the existence of seamless cross border datasets that maintain the scale and accuracy of the datasets used in the rest of the UCESU.

Drainage Density

We used the SSHIAP 1:24,000-scale hydrography data along with our customized version of NOAA’s HUC 6 dataset to calculate drainage densities for our analysis regions. The same issues discussed in the Basin Relief section above also come into play in the drainage density calculations. Because of these issues, not all stream density calculations were calculated for an actual entire drainage basin.

The level of completeness of the SSHIAP 1:24,000-scale hydrography data in depicting all streams and stream reaches within the UCESU is not known. The WA DNR watercourse dataset provided selected glimpses of hydrographic mapping at the 1:12,000-scale. The DNR dataset was not appropriate to use for this project given that the streams data was not networked, nor was the mapping of streams consistently done at the 1:12,000-scale across the region. However, it was apparent from the areas where the 1:12,000-scale mapping had been completed that certain streams or stream reaches were not included in the SSHIAP 1:24,000-scale dataset. Some of these streams may have been ephemeral or intermittent, but this is unknown. Improvement of the drainage density calculations could come from obtaining updated versions of the SSHIAP 1:24,000-scale data, or obtaining other hydrographic datasets that maintain consistency and improve the spatial scale of the data over the entire UCESU region.

Stream Order

Stream order was calculated using Strahler’s methods (Strahler, 1964). We input the StreamNet 1:100,000-scale hydrography stream networks for each subbasin into a standardized AML designed by Duncan Hornby (2001). The automated outputs were manually scrutinized for accuracy and found to be correct each time. The stream order results would be different if the same process was run on 1:24,000-scale or even finer scale data.

The only subbasin with stream order classification problems was the Okanogan Subbasin. Due to the artificial cutoff of the Okanogan’s hydrography data at the U.S. / Canada border, much of the actual hydrography network existing on the Canadian side of the border was not used in the automated stream order calculations. To deal with this deficiency in the input data, we manually estimated, using hydrography maps from the Canadian side, the potential stream order value of the Okanogan and Similkameen Rivers as they cross into the U.S. side of the Okanogan Subbasin. Based on this estimate we increased the stream order values of these two rivers as necessary according to the guidelines put forth by Strahler.

Valley segment classification

The methods used to produce this classification variable were complex and required the development of original methods and approaches. As is typical of any large-scale project, we had to find a balance between production efficiency and product quality to make this classification element available on time and on budget. We realized early on that due to the discreet nature of each valley segment class along the continuum of input variables, we could use an automated process to accurately map most of the valley segment types within a given drainage. However the amount of input variables we had to deal with and the tendency for multiple input parameters to overlap between any two given valley segment classes made the creation of a classification formula difficult.

We did the best we could to create clear input parameter breaks based on Naiman's parameter descriptions for each valley segment type. In some cases, we had to decide to adjust a parameter value away from Naiman's definitions because of the tendency of a particular variable's parameter set to overlap with another variable's similar parameter set. These adjustments tended to be subtle, but they were necessary to create discreet variable classes to which an output variable could be assigned. Multiple iterations of the default Naiman.AML were run with the same input data, each one with finely adjusted parameter settings to test for which would yield the most accurate outputs. Once we were satisfied with the output results, that version of Naiman.AML became the default function for the automated classification process. It is possible that streams and rivers with input parameters near the cut off intervals for another class type were incorrectly classified by the Naiman.AML. We took great precaution to review the output datasets by hand and manually fix any glaring errors caused by the automated process, but it is possible that a few valley segments have been misclassified due to our arbitrary parameter cut off points.

We found that in some cases, Naiman's classes did not account for some combinations of the input variables, or there was an obvious geologic process shaping the valley characteristics that Naiman's original class types did not describe. In these cases, additional classes needed to be added to Naiman's original list of valley segment types to adequately describe all the landscape conditions encountered in the UCESU. We devised these new class types to fit as seamlessly as possible with Naiman's original classes, however it should be considered that these additional class types are Pacific Biodiversity Institute's own unique valley segment classes which have not been peer reviewed or accepted as adequate valley segment classifications by any scientific body.

Because some of the valley segment classes had too many overlapping variables to adequately separate them in an automated fashion, some of the valley segments were re-assigned class variables after the automated process was complete. For instance, the F classes, especially F4 and F5 tended to be difficult to distinguish based on our input parameters from subsequent U, V, and even H class types. Therefore we did not include these F classes in our Naiman.AML. There are significantly less F classes per drainage basin than U and V classes (assuming there are any U classes), and there are far less F classes than H classes, therefore it made more sense to have the Naiman.AML designate the more popular classes, leaving the rarer classes for us to hand delineate. These rarer classes tended to be in obvious areas which were easy for us to identify on-screen using shaded relief images, DOQs, and DRGs. Because some valley segment classifications were left up to manual interpretation, it is possible that some classification errors may have occurred or some misclassified segments were not re-assigned proper class types. We feel that our post classification scrutiny of the valley segment datasets took care of most, if not all of these types of errors.

We relied on the SSHIAP 1:100,000-scale hydrography data (selected out from the 1:24,000-scale dataset) as the input stream dataset with which to calculate parameters such as sinuosity, valley bottom gradient, and side slope gradient. Though this is the most accurate dataset we had available, as discussed earlier in this report we did find problems within this dataset depicting actual stream locations and form. It is possible that inaccuracies inherent in the dataset caused miscalculations of the valley segment input variables. Such miscalculations could have resulted in erroneous valley segment classifications that may not have been apparent to the manual scrutiny we conducted on the finished data products. Another input dataset, the US Forest Service's Land Types Association data, was used to estimate the extent of influence of ice age glaciers. This dataset was not created by the USFS with the expectation of being used for this purpose, so errors in assessing glacial influence could have resulted due to the use of this as our glacial extent information. We attempted to use other means of deciphering glacial influence, such as site observations, historical records, and manual interpretation of digital elevation models, but none of this can be guaranteed to have provided perfect results.

Channel segment classification

Channel Gradient

We altered the StreamNet 1:100,000-scale hydrography data to adjust the stream segment lengths on which to calculate channel gradient. Even though we used the DENSIFYARC command to create shortened stream segment lengths no greater than 300 meter long, some stream segments got reduced to drastically small segment lengths that may not have been ideal for calculating channel gradient. We eliminated all the segments shorter than 10 meters in length due to the fact that these segments would possibly not even reach over the edge of a single cell in the 10 meter by 10 meter cell size DEMs. But even the other small segments just over 10 meters in size could yield incorrect gradient results because the length values used in the calculation were so small. This potential for error is difficult to fix given the inherent arc/node complexity of a networked stream dataset. It is best when using or viewing the gradient data to remember that the effect of small segment lengths may have inflated some of the percent gradient values.

Barriers to Fish Passage

The barrier data that we produced for this project was taken from data produced by various federal, state and local agencies. We did not assess the accuracy of this data as part of this project. There is also some duplication of data between agencies, but no single data source provided all the current information of barriers to fish passage. A careful evaluation and synthesis of all the fish passage barrier data in the UCESU is recommended. This would provide an up-to-date single source of information about the status of fish passage barriers. Unfortunately, this task was beyond the scope of our work in the UCESU.

Stream Channel Type

The methods used to produce this classification variable were complex and required the development of new methods and approaches. We explored a variety of existing methods to derive stream channel classifications. Most of the existing methods required that each stream segment be surveyed in the field and then classified based on on-the-ground measurements and interpretations (Rosgen 1996, Montgomery and Buffington 1993, 1997). Due to the spatial extent of this project (over 10,000 miles of stream channel), timeframe and budget, field-based stream channel classification approaches were not possible.

There have been several iterations of an attempt on the part of researchers in the US Forest Service to develop an automated GIS-based approach to stream channel classification based on a Rosgen classification scheme (Neier and Reid 1997, Barbour et al 2002, Hemstrom et al 2002). We tried the various iterations of the ROSGEN AML (Neier and Reid 1997) that have been developed and found very mixed results. While this AML classified small headwater streams correctly, it often misclassified more complex, larger order streams. The approach that this AML takes is to classify streams based solely on stream sinuosity and gradient. It ignores (or does not incorporate) information on stream width, depth and entrenchment ratios. Since stream width and entrenchment ratios are one of the fundamentals of a true Rosgen classification, it is not surprising that an approach that ignores these stream channel characteristics would be less than accurate in determining a correct Rosgen class.

The approach that we developed attempted to mirror the original Rosgen field-based classification method. The success of our approach is significantly better than that obtained by running the Rosgen AML described above. But our results do suffer from the inability to determine attributes such as stream depth from aerial photography, topographic maps or digital elevation data. The accurate determination of floodplain width was also a limiting factor for the approach we adopted. In many cases, our remote sensing approach using aerial photography, topographic maps and digital elevation data yielded a good approximation of stream width, floodplain width and entrenchment ratio. Most of the time, this remotely sensed estimate falls easily within the broad ranges for entrenchment ratio use in the Rosgen classification:

- entrenched (< 1.4),
- moderately entrenched (1.4 to 2.2)
- slightly entrenched (>2.2)

In some borderline cases, the accuracy of classification into a Rosgen class might improve from field measurements.

Likewise, the width to depth ratio calculation that is used in a traditional Rosgen classification has a broad range of values:

- low width to depth ratio (<12)
- moderate width to depth ratio (12 to 40)
- and very high width to depth ratio (> 40)

In most cases, we felt that our remotely sensed estimates of stream width and depth were adequate enough to fall clearly within one of these broad classes.

The next stream attribute used by Rosgen in his classification is stream sinuosity. The automated GIS approach that we used can calculate stream sinuosity very accurately. The only uncertainty is how well the GIS hydrography layer reflects the actual stream location. It was apparent to us that the 1:100,000-scale hydrography layer did not reflect the actual stream location adequately and often grossly underestimated stream sinuosity, especially for highly sinuous streams. Therefore we used 1:24,000-scale stream data which reflects the actual stream location more accurately and usually will give a good estimate of actual stream sinuosity.

The next stream attribute used by Rosgen in his classification is stream gradient. The automated GIS approach that we used can calculate stream gradient very accurately. The only uncertainty is how well the GIS hydrography layer and the DEM reflect the actual stream location and elevation of the beginning and ending nodes of stream segments. As describe above, the 1:100,000-scale hydrography layer may not reflect that actual stream location. It may result in erroneous estimates of stream gradient. Because of the locational errors present in the 1:100,000-scale hydrography layer it may actually result in reverse gradients being calculated where the downstream node overlays an area of higher elevation than the uphill node due to misfits between the DEM and the stream layer. Therefore we used 1:24,000-scale stream data for the stream gradient calculations used to determine Rosgen stream classes. The use of the 1:24000-scale data avoids most of the problems discussed above.

Riparian vegetation classification

The methods that we used to classify riparian vegetation are fairly straightforward and robust. Most existing vegetation maps do not have sufficient detail to adequately map riparian areas. The available vegetation data that covers the UCESU was all derived from interpretation and classification of 30-meter resolution LANDSAT satellite imagery. The resulting vegetation maps often have substantial spatial and thematic inaccuracies. They were designed to describe vegetation characteristics across the larger landscape, but usually fail to adequately capture riparian vegetation. To adequately map the vegetation and land-use in riparian areas, we decided that higher resolution imagery was necessary and that manual aerial photo interpretation would enhance accuracy along the major riparian areas. Our approach also used ASTER satellite imagery with has four times the resolution of LANDSAT TM and greater spectral resolution. Our combined approach used both satellite imagery and manual aerial photo-interpretation and was able to achieve significantly higher accuracy for riparian zone vegetation than any previous study had achieved. Slight errors in horizontal spatial representation can occur in the final vegetation data, especially in steep topography and areas of extreme topographic relief. We determined that the spatial accuracy was normally within 10 meters. This is quite accurate when compared to most vector GIS data and georeferenced satellite imagery.

Aerial photo interpretation of vegetation and land use

There is always some degree of subjectivity involved in aerial photo interpretation of vegetation and land use types. But we were able to reduce the effect of subjectivity by two approaches:
We kept the vegetation and land use classes fairly simple and ensured that they could be readily interpreted and separated from each other using a combination of aerial photography, satellite imagery and the wide array of ancillary GIS data we used in the mapping process.
The photo interpretation results were regularly checked by an experienced, independent observer and corrected where necessary. If errors were detected, then the original photo interpreter was notified and the issue was discussed. This process helped the projects photo interpreters remain consistent with each other and improved the overall accuracy of the results.

Vegetation mapping using ASTER satellite classification

The second method that we used for mapping the riparian vegetation for the upper portions of the watersheds in the UCESU was based on a classification of ASTER satellite imagery. The use of ASTER satellite imagery allowed us to map the vegetation along all the smaller streams in the UCESU with a standardized approach that could be repeated through out the basin. In order to achieve relatively high vegetation classification accuracy, we employed a moderately complex approach that classified each portion of the landscape based on the amount of sunlight reflecting off the landform surfaces. This yielded a higher accuracy vegetation classification compare to that which would have resulted from a simple approach that did not account for variation in landscape illumination.

Vegetation mapping of the entire UCSEU required processing of many ASTER satellite images, and often several images were needed for each sub-basin. There were some spectral differences between images due to the time of the year the image was taken and the atmospheric qualities at the time of image acquisition. It was not possible to obtain satellite image coverage for the entire UCESU at the same date, or even month. This was impossible, even within a sub-basin. Therefore, it was necessary to perform vegetation classification procedures on each image as a unique entity. The vegetation classification results were then merged for multiple images after vegetation classification.

Watershed Conditions

We used the WA DNR transportation dataset (2004) as our roads input layer for these calculations. The DNR dataset does not contain all the roads that actually occur in each watershed, however no transportation GIS layer we reviewed for this project contained all the roads we knew of in each watershed. The DNR dataset has the advantage over other similar datasets by being consistent in its mapping over the entire project area, and by containing useful attribute information that distinguishes roads from railroad lines and trails.

Watershed Road Density Index

The calculation of this index was straight forward and easily repeatable. Only errors inherent in the input datasets could have spawned errors in the index calculations. Improvements to our data products could be made by obtaining updated versions of the WA DNR transportation layer, or obtaining similar transportation data that possesses more road information while maintaining the spatial accuracy and data consistency over the entire project area.

Riparian-Road Index

This index is less straight forward to calculate than the road density index. The calculations suffer from the same inherent data flaws in the WA DNR transportation data as described above. However, the arbitrary boundary extents of the riparian zone extent polygon layers add another component of potential error to the calculations. Although we followed suggestions by Hillman in how to objectively designate the riparian zone extent, there is no guarantee that the zone we mapped measures up to the actual extent of riparian zones with the UCESU region. Therefore the RRI is more a calculation of road density within a hypothetical riparian region from each subbasin, than an accurate calculation of riparian area road density with each subbasin. The difference in the RRI outputs between the hypothetical versus the real riparian regions may or may not be significant, but it is important to note that such a difference potentially exists. It should also be noted that if we were to change the defining parameters used to map the hypothetical riparian zone extent, the RRI would also change, perhaps substantially in some instances.

A comparison of the methods for data collection, generation, and reduction for the Wenatchee basin with the remaining parts of the UCESU

The Wenatchee Subbasin environmental classifications were done as a pilot project preceding duplication of the classification methods in the rest of the UCESU region. Between the pilot project and this project we learned how to improve the efficiency and accuracy of mapping some of the classification themes. This section shall review some of the differences in methods we incorporated for data collection, generation, and reduction between the Wenatchee Subbasin and the rest of the UCESU region.

Regional setting classification

There is no difference in the methods used between the Wenatchee Basin and the rest of the UCESU.

Basin-level classification

There is no difference in the methods used between the Wenatchee Basin and the rest of the UCESU.

Valley segment classification

There are only minor differences between the Wenatchee Basin and the rest of the UCESU.

We added a few more valley segment classes to Naiman's variables for the classification of the UCESU region, but these classes probably do not occur in the Wenatchee Subbasin. We did not take side-slope measurements in the Wenatchee Subbasin, so we did not include it as an input parameter in our Naiman.AML. Hence, neither M classes nor the V3 class were included in the automated process classifying valley segment types in the Wenatchee Subbasin.

Channel segment classification

Channel Gradient

We used the same methods in both the Wenatchee Basin and the rest of the UCESU.

Barriers to Fish Passage

Chelan County Conservation District had previously developed an inventory of culverts and other barriers to fish passage. This was included in the fish passage barrier data set for the Wenatchee Basin. Similar datasets were not available for the rest of the UCESU, therefore we only included data from the StreamNet and SSHIAP projects.

Stream Channel Type

There are only minor differences between the Wenatchee Basin and the rest of the UCESU. We improved methods between the Wenatchee and the rest of the UCESU.

As we moved from the Wenatchee Basin to other parts of the UCESU, we found that some basins had more of certain stream channel types than other types. However, we found that we did not have to modify our methods. For some stream segments in the Wenatchee Basin we were able to compare our stream channel classification with that determined by the US Forest Service during their stream surveys. In the lower Entiat River we were able to compare our Rosgen classification to that done by Erickson (2004). In both cases, we modified our Rosgen classification in a few instances when there was evidence that the other stream channel classifications were superior.

Riparian vegetation classification

There are significant differences in the methods used between the Wenatchee Basin and the rest of the UCESU.

As discussed in a prior section, we based our Wenatchee riparian vegetation classification on prior work we had completed in the Wenatchee Basin (Pacific Biodiversity Institute 2002). This earlier work focused on mapping vegetation and land use classes for the entire Wenatchee Subbasin (not just the riparian areas), and much of it was based on vegetation maps created by the USFS Leavenworth and Lake Wenatchee districts. We incorporated ASTER and TM7 satellite imagery, as well as DOQs and other ancillary GIS data to review and update the accuracy of the Wenatchee Subbasin riparian maps, but for the most part we just clipped out the Icicle Fund derived map to the riparian extent polygons we created to produce our final product.

In the rest of the UCESU, the vegetation mapping work was done without incorporating USFS produced vegetation maps. Instead we relied on satellite imagery, DOQs, and ancillary GIS data along with new mapping methods to produce our results. Because the UCESU riparian mapping relied on more current data than the USFS products, and we mapped vegetation and land use polygons by hand at such a small spatial scale (around 1:10,000 meters), the accuracy is probably better in the rest of the UCESU than in the Wenatchee Subbasin - particularly in areas where we relied on the original unaltered USFS data.

Watershed Condition

There is no difference in the methods used between the Wenatchee Basin and the rest of the UCESU.

A review of the original classification recommendations

Overview

The UCESU ecological classification project followed initial recommendations developed by Tracy Hillman in the Monitoring Strategy for the Upper Columbia Basin draft report (Hillman 2003). The biological and physical/environmental indicators recommended by Hillman are listed in Table 17.

Table 17. Biological and physical/environmental indicators recommended by Hillman (2003)

Spatial scale	General characteristics	Classification variable	Example protocols	Sampling frequency (years)
Regional setting	Ecoregion	Bailey classification	Bain and Stevenson (1999)	20
		Omernik classification	Bain and Stevenson (1999)	20
	Physiography	Province	Bain and Stevenson (1999)	20
	Geology	Geologic districts	Overton et al. (1997)	20
Drainage basin	Geomorphic features	Basin area	Bain and Stevenson (1999)	20
		Basin relief	Bain and Stevenson (1999)	20
		Drainage density	Bain and Stevenson (1999)	20
		Stream order	Gordon et al. (1992)	20
		Riparian-Road Index	(WFC 1998)	5
Valley segment	Valley characteristics	Valley bottom type	Cupp (1989); Naiman et al. (1992)	20
Channel segment	Channel characteristics	Elevation	Overton et al. (1997)	10
		Channel type (Rosgen)	Rosgen (1996)	10
		Channel gradient	Overton et al. (1997)	10
	Riparian vegetation	Primary vegetation type	Platts et al. (1983)	5

The goal of this project was to develop comprehensive and uniform data for the above classification variables across the ESU. These variables were intended to capture physical/environmental differences spanning from the largest scale (regional setting) down to the channel segment that incorporates the entire spectrum of processes influencing stream features and recognizes the tiered/nested nature of landscape and aquatic features.

Pacific Biodiversity Institute did not design nor influence the creation of the list of classification variables for this project. We produced GIS datasets and information tables based on an itemized task list developed by Hillman and approved by the UCESU Regional Technical Team (RTT). While meet the information needs as outlined by Hillman and the RTT, the scope of our contracts did not incorporate any evaluation or modification of the original classification recommendations. Under a secondary requisition with NOAA Fisheries, which covers the production of this report, we were asked to evaluate the original recommendations and discuss whether we think that they could be improved to better meet the needs of salmon habitat monitoring efforts, based on our knowledge of fulfilling the original recommendations.

In this section, we reflect on the lessons we learned and put forth some of the ideas spawned during our work with regards to the suitability of the original classification recommendations and how they could be enhanced.

Classification variables we would subtract

Some of the larger landscape classification recommendations proved to be too coarse to be useful in any analytical sense within our project region. The Bailey ecoregions and physiographical provinces datasets were created at scales below 1:3 million, meaning that their actual boundary delineations are extremely generalized. Hence, these datasets are probably not all that spatially accurate at the ESU level. These indicators might be useful in comparing generalized regional characteristics between expansive ESU regions, for instance between the Upper Columbia ESU and the Puget Sound ESU, but their usefulness within an ESU region seems nominal. It may be desirable to keep these indicators for regional or national analyses, but we think they will prove to be largely irrelevant for analyses conducted within the UCESU. On the other hand, these datasets and classification variables were some of the easiest to produce and there is no great benefit derived from their elimination.

Classification variables we would improve

The following landscape classification recommendations required improvements of the original example protocols provided to us in the Hillman's *Monitoring Strategy for the Upper Columbia Basin* (2003):

- Naiman method of valley segment classification
- Rosgen method of channel classification
- Riparian vegetation mapping

Further improvements in some of these classification variables may also be warranted. Below, we discuss the improvements that we made over the original classification recommendations and other improvements that could be made that may prove useful in the future.

Stream channel classification

We chose the Rosgen stream channel classification method, as this appears to be the most widely used method of stream channel classification and one that may be somewhat adaptable to semi-automated approaches. The original Rosgen method of channel classification was designed to be conducted while in the field, hence certain information that the Rosgen method relies on would not be available during our remote sensing and semi-automated GIS analysis. Conducting the channel classification analysis via remote sensing and semi-automated GIS analysis was necessary because of the scope of area that needed to be classified. It would have been cost prohibitive to attempt to apply Rosgen's exact protocol for stream classifications because the number of stream miles within the UCESU is so large. We adapted Rosgen's methods to work with the elements of stream reaches that were measurable via remote sensing and semi-automated GIS techniques that queried stream data and digital elevation data.

Further improvement in this approach could be achieved through use of higher resolution DEM data. We used 10-meter horizontal resolution DEMS. If 1-meter resolution DEMS were available, substantial improvement could be achieved. Likewise, if more field-based measurements were available, particularly for stream depth, improvements in accuracy could be achieved. Stream depth is very difficult to estimate from remote sensing and GIS analysis.

An alternative to using the Rosgen stream channel classification approach would be to devise a stream channel classification that employs some of the ideas incorporated in both the Rosgen and Montgomery-Buffington classification approaches, but is designed to be implemented in a GIS environment using digital topographic data (DEMs) with perhaps some information derived from photo-interpretation or other forms of remote sensing. This may have advantages over the Rosgen method in that it could be consistently applied to large areas. It could result in useful classification variables that would be a significant indicator for use in salmon habitat monitoring efforts.

Valley segment classification

The valley segment classifications were not possible to complete using only the variables designed by Cupp or Naiman. Unique valley bottom types such as those contained within coulees were not included by either author in their respective literature. Also, some valley bottom type definitions contained enough ambiguity between discreet input variables that objective assignment of resulting classification variables was not possible. We had to develop additional valley bottom types, and further define existing types in order to complete the creation of datasets concerning valley bottom types. Because we were not contracted to assess and improve upon classification variables designed by Cupp and Naiman, we adjusted their classification variables with only the minimum level of effort and review so as to complete our tasks as efficiently as possible. A more robust assessment of the adequacy and objectiveness of the original valley segment classification variables and subsequent improvement of these variables via adjusting existing input parameters and designing new valley segment types may help improve the accuracy and legibility of the resulting GIS data products.

Riparian vegetation classification

The riparian vegetation classification that we used was fairly simple. We classified the riparian areas into 19 basic land cover / land use types. It might be useful for some aspects of salmon habitat monitoring and development of priorities for salmon habitat protection and restoration to also classify the vegetation based on a more ecological classification scheme. For example, it would be possible to classify the vegetation based on a series, association group or association level of classification.

Improvement in the Wenatchee subbasin riparian vegetation layer could be achieved by implementing a mapping procedure similar to that which we employed in the rest of the UCESU. Our incorporation of a US Forest Service vegetation layer as one of the initial base layers in our mapping of the Wenatchee subbasin introduced errors that would be avoided by more thorough review and modification using the techniques we employed in the rest of the UCESU.

Classification variables we would add

- Additional basin relief variables:
    - Average slope steepness by subwatershed and adjacent to channels within the riparian extent zones
    - Topographic roughness indicators summarized by basin and by subwatershed
- Modeled stream flows through the drainage networks of the UCESU developed from spatially explicit precipitation data, flow accumulation and snow melt modeling.

- Climate data:
    - Precipitation: yearly and seasonal averages for subbasins and subwatersheds
    - Temperature: yearly and seasonal averages for subbasins
- Spatial catalogue of real time stream channel data sources (flow monitoring stations, fish traps, pollution monitoring stations)
- Watershed condition:
    - One or more fragmentation indices based on ownership and parcel size, road network and habitat conversion
    - Estimates of industrial, residential, or agricultural lands within the riparian extent
    - Estimates of recent logging activity and harvest methods occurring within riparian extent zones and within each subwatershed
    - Estimates of rangeland condition, levels of livestock stocking and non-native plant population status
- Recent fire activity data compiled on a subwatershed basis
- Large scale erosion activity compiled on a subwatershed basis
- Construction permits and building activity in riparian areas
- Information available on point and non-point sources of water pollution, perhaps summarized by amount and type of pollution created upstream from each salmon habitat monitoring point.

An analysis and discussion of the applicability of the techniques used in the UCESU project to other parts of the Columbia River basin and other western USA basins

The methods of data creation we developed for this project were intentionally designed to be suitable for use in other parts of the Columbia River basin and other western US basins. All of our methods were designed to produce results that are repeatable, and the output values are directly based on objective and measurable input variables. The largest limiting factor in successfully applying these data creation and analysis methods elsewhere depends on the availability of suitable existing spatial datasets, such as high-quality 1:100,000 or 1:24,000-scale hydrography data, complete transportation datasets, accurate watershed boundary delineations, and recent digital aerial photography and satellite imagery. If these types of digital data are available for a basin of interest in the western USA, we see no reason a similar set of data products cannot be produced for that region using the methods that we have developed.

As a matter fact, we feel that because we developed the methods and analysis techniques described in this report in the Upper Columbia ESU region, our methods are well adapted to handle a wide variety of biophysical and geomorphologic parameters. The UCESU region contains a vast amount of physiographic and ecosystem diversity, ranging from high alpine ridges and lush forested valleys, to dry coulees and shrub-steppe dominated basalt plateaus. Through volcanism, continental plate uplift, repeated glaciations, glacial outburst floods and thousands of years of more subtle erosional processes, the landscape of the UCESU has become a mosaic of widely differing landforms. The annual precipitation in UCESU ranges from well over 100 inches to less than 5 inches. Ecological communities range from sparsely vegetated cold desert steppe to old-growth riparian cedar forests. Whatever conditions might be encountered within another northwestern US basin, there is a high likelihood that we have encountered similar conditions and tested our methodology for that condition within the UCESU.

An assessment of the application of the data developed in the UCESU to salmon recovery monitoring efforts

Currently, Tracy Hillman is using the data we developed, along with additional data and modifications to the data produced by Steve Rentmeester at the request of Chris Jordan, NOAA Fisheries. The focus of Tracy's analysis is to determine how effective the watershed restoration efforts are. Tracy is analyzing 88 sites from the Wenatchee Basin and 21 from the Entiat. His analysis included both upstream catchment characteristics and site-level characteristics. The upstream catchment characteristics are a summary of the entire catchment above the monitoring point.

The following are the parameters that Steve Rentmeester extracted for Tracy Hillman to use in the analysis of the monitoring site data:

- Bailey ecoregion
- Omernik ecoregion
- Province
- Geologic district
- Basin area
- Basin relief
- Strahler order
- Stream gradient
- Stream sinuosity
- Valley segment
- Road density
- Land ownership
- Land use - NLCD
- Elevation
- Rosgen channel class and sinuosity
- Drainage density

While our original contracts and task lists called for us to produce data for basins, subwatersheds, and stream channel segments, we found from discussing the use of the data that some characteristics that we measured would have been more useful if we had summarized the data based on the entire catchment above each monitoring point. This was not part of our original contracts and the monitoring points were not established at the time that we conducted our work. But future work on this nature might be conducted more efficiently if the monitoring points were established in advance and evaluation of the entire catchment above each monitoring point was conducted as a part of the original classification work.

Our understanding is that the summarization that Steve Rentmeester and Tracy Hillman have done for many variables is a simple averaging or summing of the classification variable in the entire catchment above a monitoring point. This may be problematic, particularly when a monitoring point is located along a mainstream river in the lower part of a subbasin. In the large subbasins of the UCESU, a characteristic such as riparian vegetation may be averaged over hundreds of thousands of acres and may result in a gross homogenization. Perhaps a better way to summarize the characteristics that influence a monitoring point would be to incorporate a distance-weighted analysis of the important classification variables. With this approach, stream segments or riparian areas that are above and relatively close to the monitoring site would have more weight than sites that are very distant from the monitoring point. It would be interesting to incorporate a distance-weighted catchment area analysis and then analyze and report the results from both this and the approach that was used by Hillman and Rentmeester.

An assessment of the application of the data developed in the UCESU to prioritization of areas for salmon recovery efforts and other watershed restoration and protection work

The data we developed for this project has great potential for use in development of conservation priorities for habitat protection and restoration. In fact, we have already used the data in such a project. Below, we discuss two projects that we have been involved in that use data like this for establishing conservation priorities from an objective, science-based perspective. The first project, called the Methow Conservation Needs Assessment was undertaken in 2005, after we completed data development for the UCESU. The second project, preceded our work in developing data for the UCESU, but illustrates the potential for use of this kind of data in establishing conservation priorities. In that project, we focused on the Wenatchee Basin, and developed data and a GIS-based conservation priorities decision-support system that has been used by conservation organizations involved in habitat protection and restoration. Some of the data we developed in the Wenatchee Conservation Project became the foundation of data we produced for the UCESU. The third example of the use of the data we developed for the UCESU is a hypothetical project that would also use and/or develop additional data to create a very robust dataset for use in a wide variety of projects that focus on habitat protection and restoration. Such a dataset could significantly enhance the reliability of existing approaches such as limiting factors analysis, Environmental Diagnosis and Treatment (EDT), subbasin planning, ecoregional planning, and other more advanced methods for locating specific areas to protect, restore, or treat in some way to enhance habitat conditions for listed fish species, or other elements of biodiversity.

Example of Conservation Prioritization from the Methow Conservation Needs Assessment

In 2005, the Methow Conservancy, in cooperation with Pacific Biodiversity Institute and CommEn Space, conducted a conservation needs assessment in the Methow Subbasin. The conservation needs assessment was designed to determine conservation elements and sensitive areas in need of further conservation effort, assess the status of current conservation projects in the Methow and help prioritize areas in need of protection in terms compatible with the Conservancy's mandates and abilities. The conservation needs assessment required the use of the best available spatial information with regards to wildlife habitat and riparian functions. Naturally, much of the data we created for the UCESU salmon monitoring project proved to be very useful in determining the most important areas for conservation activities in the Methow Valley.

Specifically, our data was used to produce maps of stream condition and riparian vegetation and land use that assisted a panel of 18 fish, wildlife, ecology, botany and conservation biology experts. This panel was drawn from people in academia, state, federal and private organizations that had specific local knowledge that was useful in determining areas of superb habitat quality for salmon and other native fish species, large carnivores, ungulates, birds, amphibians, reptiles, and rare plants. Using our habitat maps as a guide, the panel of experts added "sensitive area points" and field-derived notes and descriptions on the ecological condition of different stream segments and riparian areas throughout the Methow Subbasin (Figure 45). The resulting maps and database was provided the Methow Conservancy so that they will have the ability to know exactly where high quality stream and riparian habitat exists within their project area. It also provides them with information on the location of degraded habitats and areas in need of restoration. The resulting maps illustrate the spatial context of these differing habitat conditions and provide a context for examination of options to restore connectivity through corridor protection and restoration of linkages. Using the Okanogan County Assessor's parcel database, the Conservancy can determine the ownership of these riparian areas and explore options for conservation purchase, easements and other opportunities for conservation. At this point, the Methow Conservancy advisory council is using our maps and spatial data to work through various options to enhance conservation of sensitive areas in the Methow.

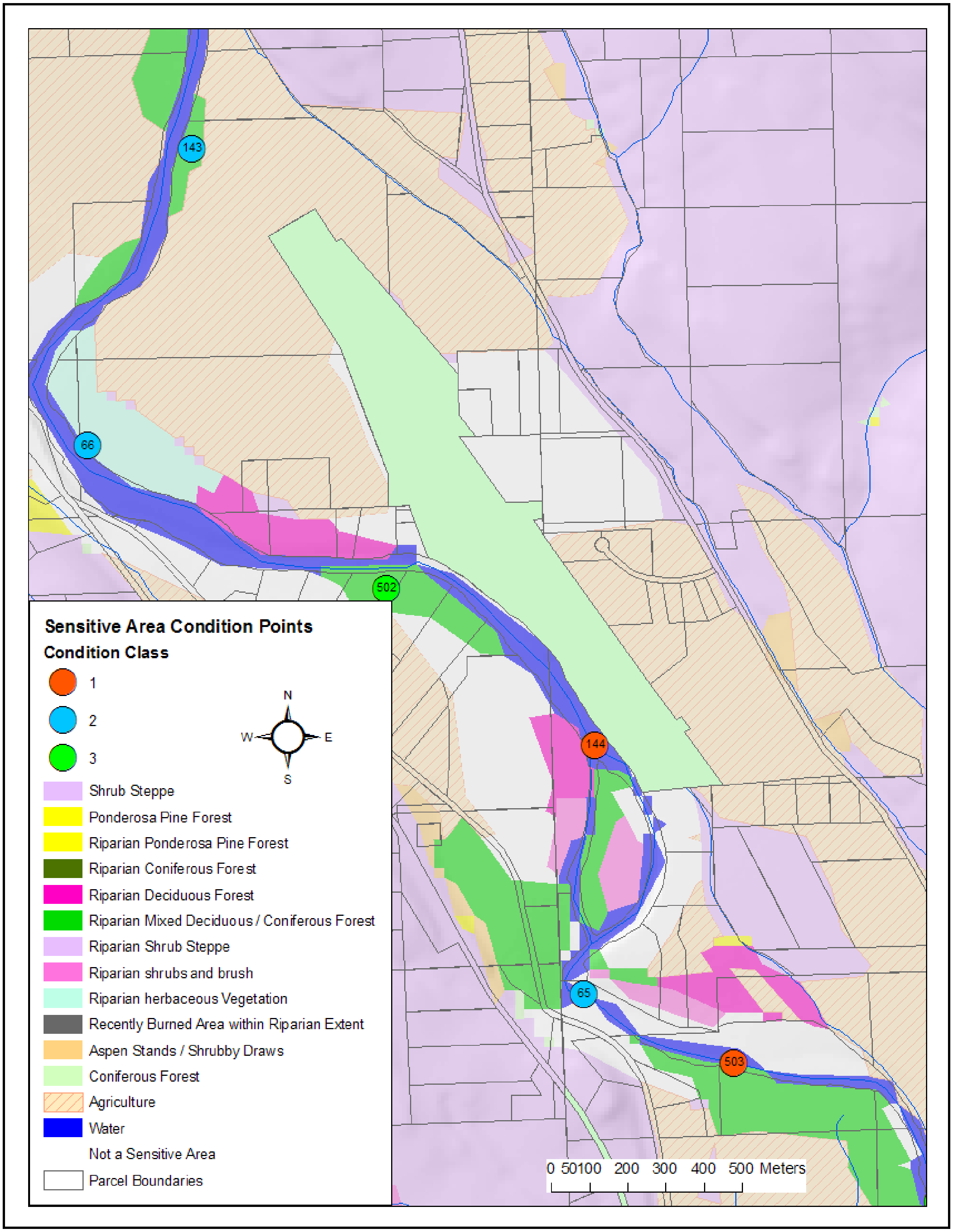


Figure 45. Illustration of sensitive area condition points data along mid-section of Methow River.

Example from our Prior Work on Conservation Priorities in the Wenatchee River Basin

In 2001, Pacific Biodiversity Institute undertook a project in the Wenatchee River Basin to gather information on natural resources of the basin and develop an initial set of conservation priorities that conservation organizations active in the basin could use to guide their activities (Pacific Biodiversity Institute 2001). We developed an initial system of establishing conservation priorities based on a wide array of terrestrial and aquatic factors. These are illustrated below in Figure 46.

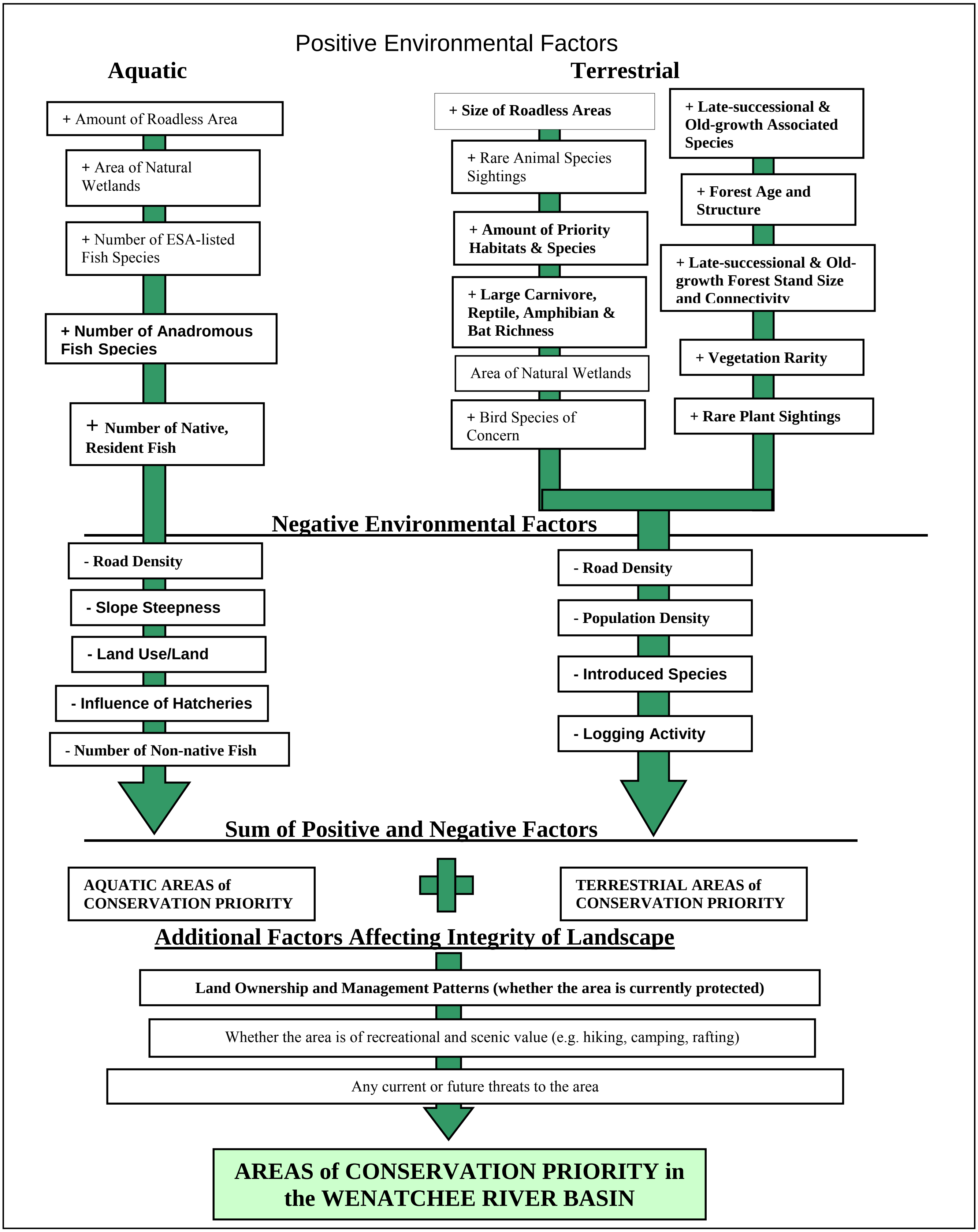


Figure 46. Flow chart for determination of initial conservation priorities in the Wenatchee River Basin (from Pacific Biodiversity Institute (2001).

The result of our initial aquatic prioritization was a map of the Wenatchee Basin with each subwatershed (HUC6) assigned an initial conservation priority based on the factors listed above (Figure 47).

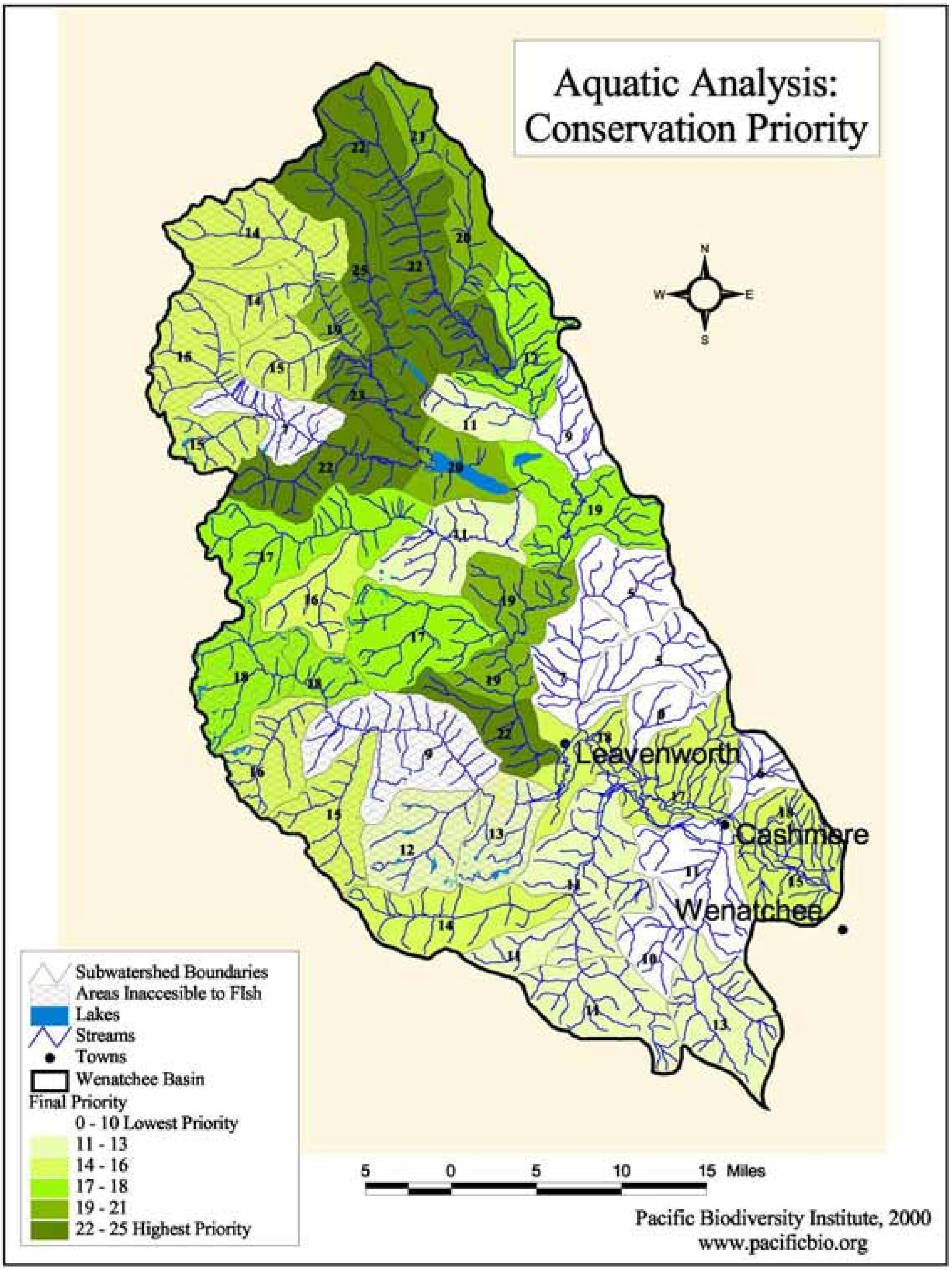


Figure 47. Final aquatic habitat conservation priorities for the Wenatchee River Basin. *The highest priority subwatersheds (dark green) have the highest values for positive factors and lowest values for negative factors.*

The result of our initial combined terrestrial and aquatic prioritization was a map of the Wenatchee Basin is illustrated in Figure 48.

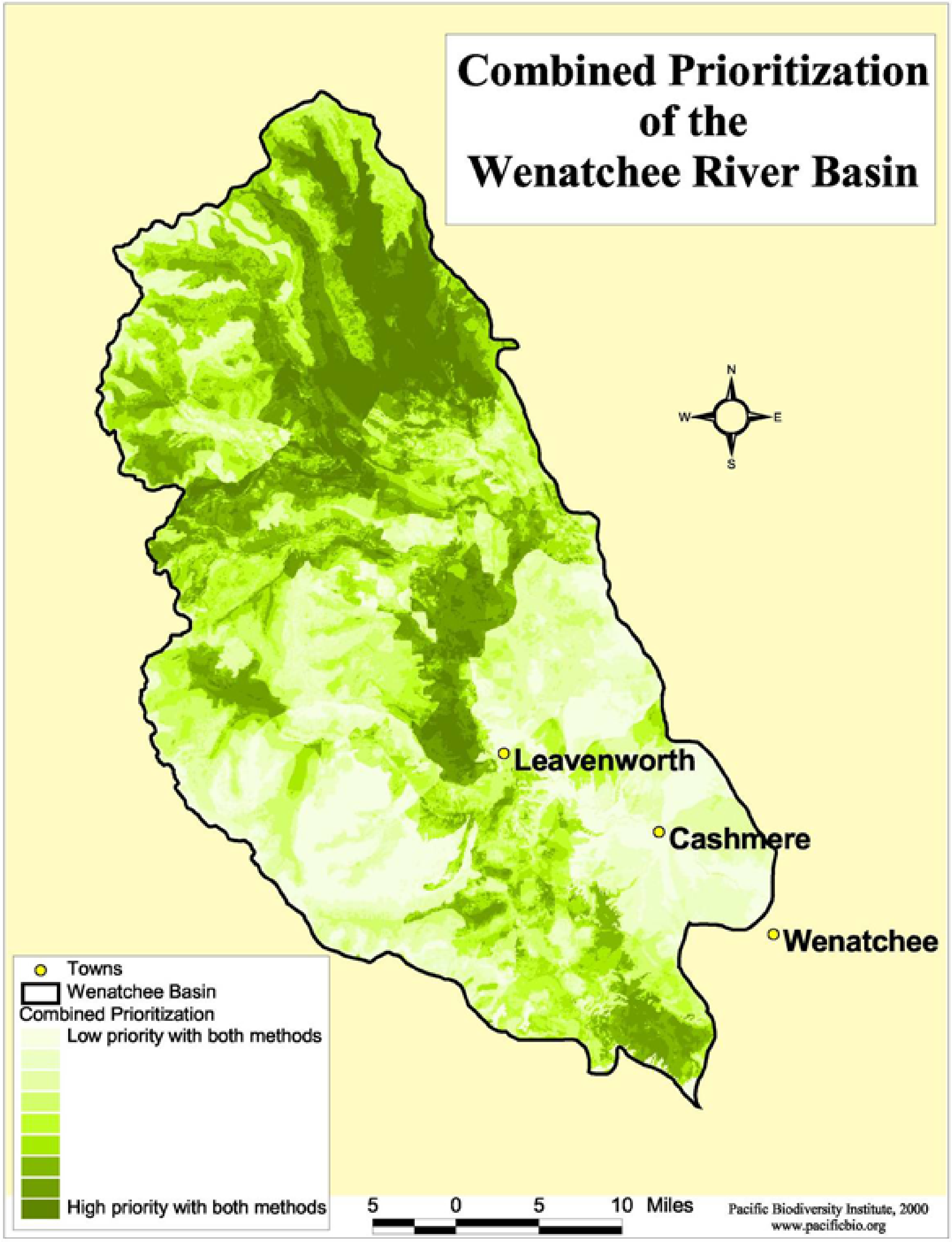


Figure 48. A combined aquatic and terrestrial prioritization for the Wenatchee River Basin. *This prioritization was created by adding the priority values for the aquatic and terrestrial prioritizations. Low resulting values are areas that both prioritization methods have ranked as low. High resulting values are areas that both prioritization methods have ranked as high.*

After our initial conservation priorities studies in the Wenatchee River Basin, we went on to develop more updated and refined data for many ecological and land management attributes. We also developed a Conservation Decision Support System (DSS) to allow individual user and stakeholders to determine conservation priorities based on a wide variety of parameters and weightings that could be changed depending on their own sense of priorities (Pacific Biodiversity Institute 2002). In the DSS, the user is able to first choose the parameters to be used in the prioritization (Figure 49).

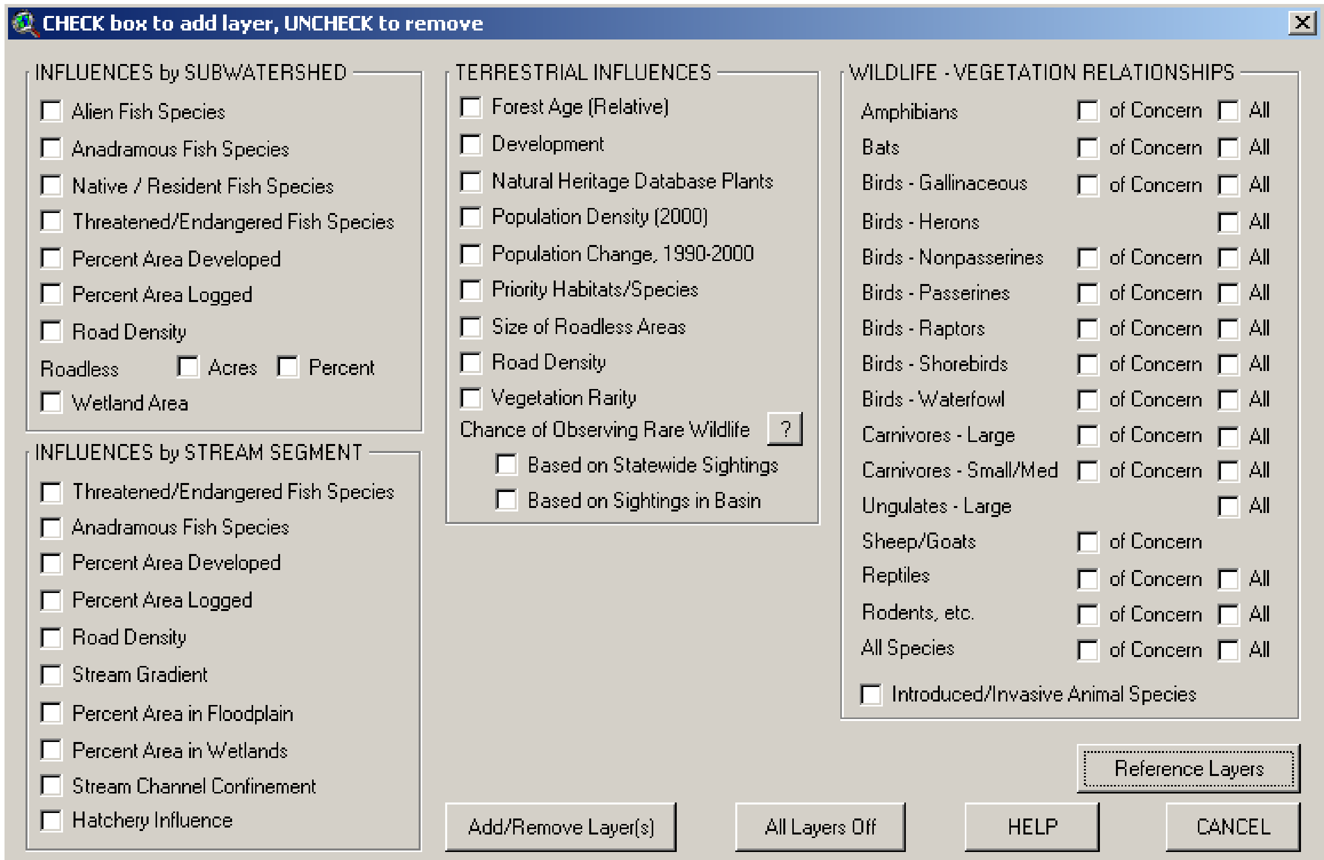


Figure 49. Parameters to be used in a determination of conservation priorities

Using the DSS, one can easily visualize any parameter to see the actual data and help determine if it will be useful for determination of conservation priorities. One can examine priorities at a subwatershed level (Figure 50) at a stream segment scale (Figure 51) and at a landscape scale (Figure 52).

The next step is to weight the parameters that are chosen (Figure 53). Some parameters may be given positive weights (contributing to ecological significance or conservation value) while others may be given negative weights (degrading conservation values).

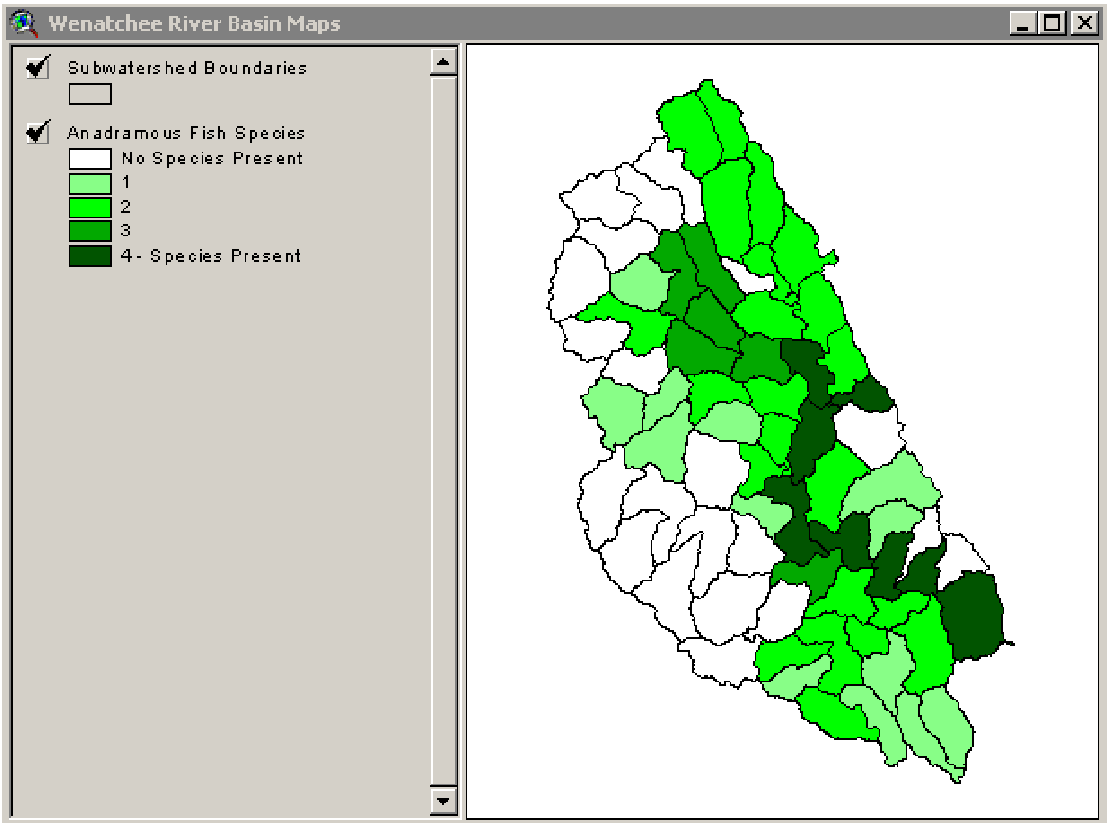


Figure 50. Example of data visualization at a subwatershed scale.

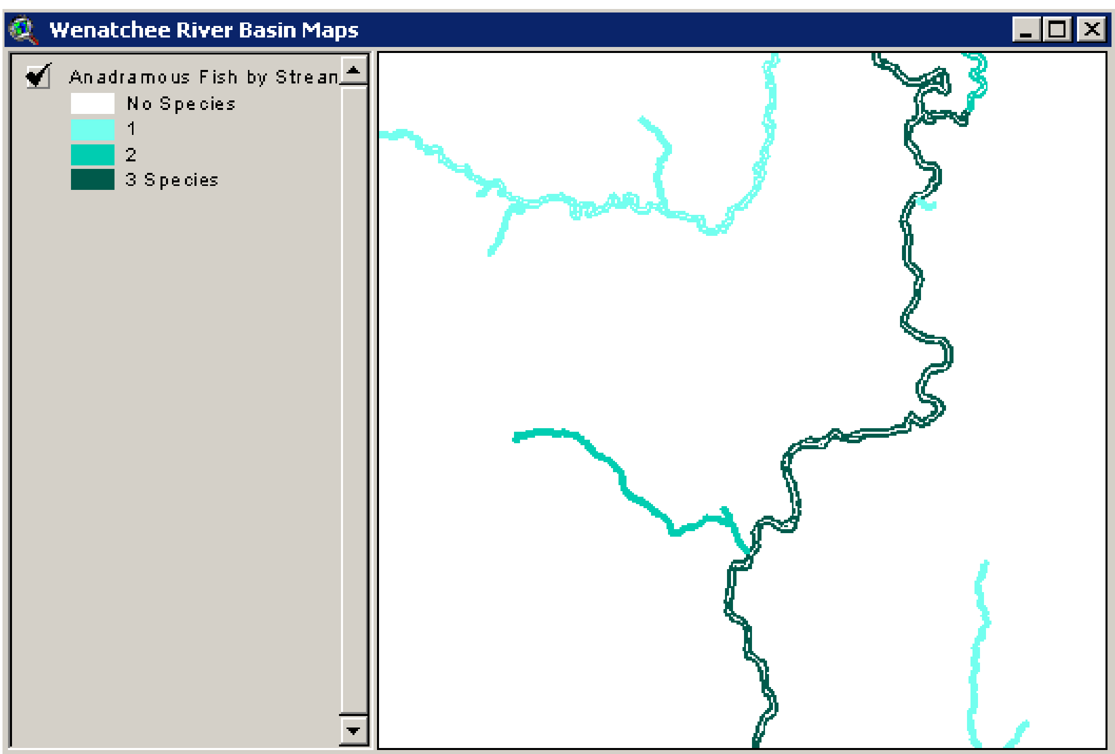


Figure 51. Example of data visualization at a stream segment scale.

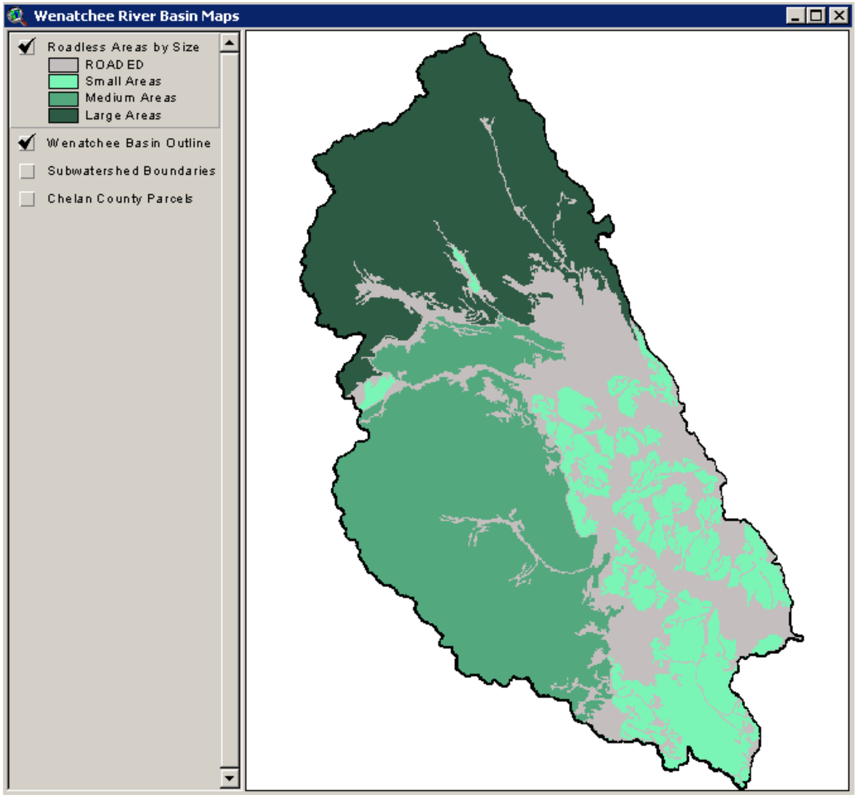


Figure 52. Example of data visualization at a landscape scale.

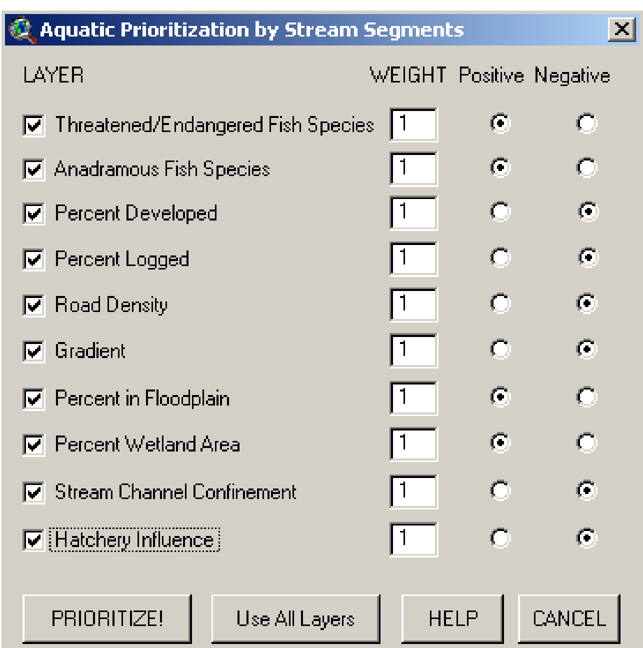


Figure 53. Determination of weighting of chosen parameters.

The results of the prioritization can then be visualized in both a spatial context and graphically (Figure 54).

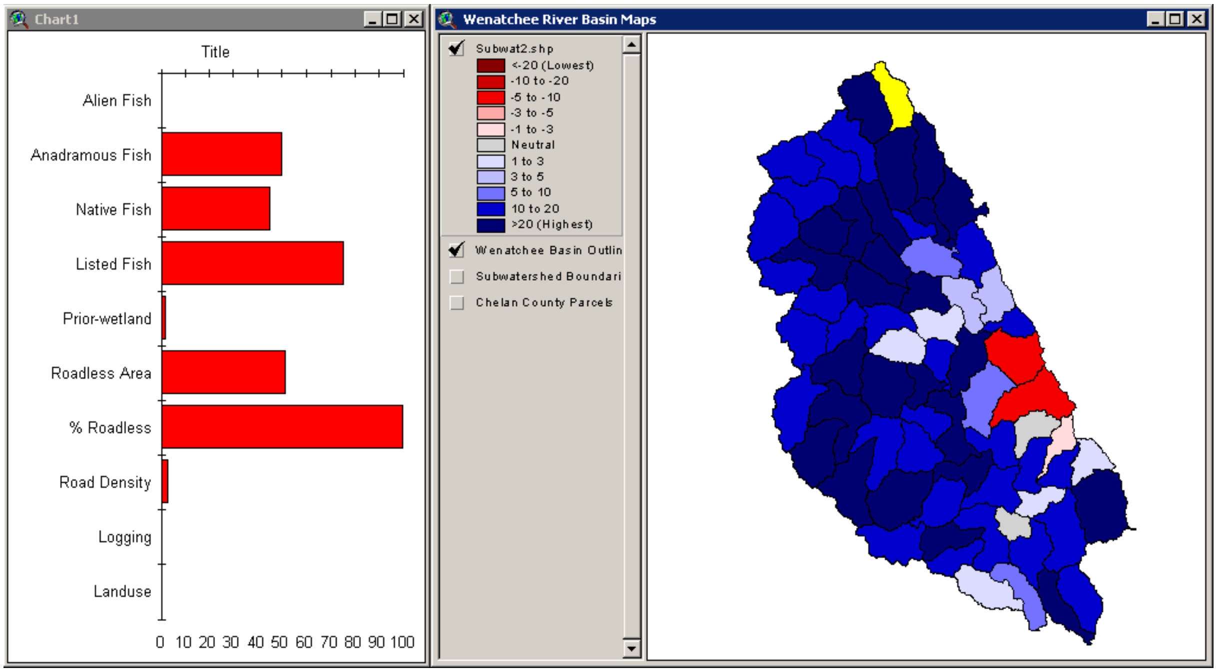


Figure 54. Results of a conservation prioritization conducted at a subwatershed scale.

Potential for state of the art salmon habitat prioritization in the UCESU

The data we developed for salmon habitat monitoring in the UCESU could be combined with other information to use as input data for a state-of-the-art decision-support system for determining priorities for salmon habitat protection, restoration and treatment. Such a system could combine some of the benefits and features from projects like the decision support system we developed for the Wenatchee Conservation Project. It could also incorporate elements from EDT analysis and limiting factors analysis. Such a decision-support system can be flexible and adaptable to help shed light on conservation targets for other species and habitat types - as we demonstrated in our work in the Wenatchee Basin. Therefore, it could have widespread applicability for a variety of conservation needs. It could also be easily adapted to other locations, once data was developed to populate its databases.

The following annotated list represents some of the information created during this project that might be used in a state-of-the-art conservation decision-support system. We also briefly provide some examples of how that data might be interpreted.

1. Valley segment types
   From the perspective of location of the best salmon habitat, the U1 & U2 valley segment types will often contain the best spawning and rearing habitat. Some V1 & V2 valley segments many also contain adequate spawning and rearing habitat. These valley segment types often provide migration habitat. In nearly all cases the H3 valley segment type has little to offer from a salmon habitat perspective, except that it produces the high quality water that native fish need to flourish.
2. Stream gradient
   From the perspective of location of the best salmon habitat the low gradient streams are usually the best for spawning and rearing as long as there is adequate current and substrate for spawning. Very high gradient streams can represent inaccessible habitat, or offer little to salmon.
3. Stream order
   Generally, the higher order streams are the best from the perspective of location of the best salmon habitat. The lowest order streams represent headwaters that provide the water and sediment conditions that salmon need to flourish.
4. Rosgen Channel type
   From the perspective of location of the best salmon habitat the Rosgen type C, E, D and DA streams usually contain the best spawning and rearing habitat. Moderate habitat conditions can exist in Rosgen type B, F streams, which typically offer good migration habitat. The Rosgen type A streams are often not good salmon habitat.
5. Riparian vegetation
   The best salmon habitat is often found where intact mature forests or native riparian shrubs border a stream. Native herbaceous or grass vegetation may also provide adequate conditions, but usually not as optimal as forest cover. Significantly lower habitat quality is usually associated with recently cut over land, agricultural land, or rural residential development. The lowest habitat quality areas are usually associated with higher density residential and urban development.
6. Road riparian index
   A low road riparian index is best for salmon, while a high road riparian index may represent habitat conditions that are degraded by road related sediment and pollution.
7. Road density
   a. high road density – worst
   b. low road density – best
8. Barriers to fish passage
   Barriers to fish passage will help streamline searches for quality habitat by indicating sections of hydgrographic networks that can be eliminated from consideration. Conversely, barriers can indicate areas of potential restoration or habitat expansion.

Additional conservation decision-support system components:

9. Anadromous fish abundance and diversity
10. Anadromous fish rarity and endangerment
11. Resident fish abundance and diversity
12. Resident fish rarity and endangerment
13. Presence of non-native and invasive aquatic and terrestrial organisms
14. Degree of catchment-level forest modification (logging and wildfire)
15. Degree of riparian zone forest modification (logging and wildfire)
16. Degree of catchment-level development and urbanization
17. Degree of riparian zone development and urbanization
18. Amount of hydrologically active floodplain area
19. Amount of wetland area
20. Ecological condition of wetlands
21. Degree of stream channel confinement
22. Influence of hatcheries on fish genetics
23. Influences of culverts and blockages to fish passage
24. Current human population density
25. Human population rate of change
26. Degree of landscape fragmentation
27. Parcel size and adjacency
28. Forest age and intactness
29. Vegetation community rarity
30. Presence of rare and imperiled plant and animal species (or critical habitat for them)
31. Pollution levels and point sources
32. Water withdrawal volumes for human uses
33. Artificial channel elements (culverts, rip rap, etc...)

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Appendix A - Upper Columbia ESU GIS Data Dictionary

All of the GIS layers listed below are in the following projection:

Washington State Plane North (4601), NAD 83, Meters

GIS Projects-

- **UCESU-GIS-Project1** - Portable GIS project that displays the following shapefiles in the projection listed below. Project includes scripts and Avenue extensions used to create GIS products.

Shapefiles-

Strahler Stream Order-

- **Dgls-strhl** – Streams in the Douglas County portion of the Upper Columbia ESU - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes attributed per stream segment.
- **Entiat-strhl** – Streams in the Entiat HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes attributed per stream segment.
- **Methow-strahl** - Streams in the Methow HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes attributed per stream segment.
- **Oka-strhl** - Streams in the Okanogan HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes attributed per stream segment.
- **Other-strhl** - Streams in the Upper Columbia ESU not in the Entiat, Methow, or Okanogan HUC4 subbasins, nor in Douglas County - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes attributed per stream segment.

Stream Gradients-

- **Dgls-grad** – Streams in the Douglas County portion of the Upper Columbia ESU - 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.
- **entiat-grad** – Streams in the Entiat HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.
- **methow-grad** – Streams in the Methow HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.
- **oka-grad** – Streams in the Okanogan HUC4 subbasin - 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.
- **other-grad** – Streams in the Upper Columbia ESU not in the Entiat, Methow, or Okanogan HUC4 subbasins, nor in Douglas County - 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.

Rosgen Stream Reach Classifications-

- **dgls-rosgen** - Streams in the Douglas County portion of the Upper Columbia ESU - 1:100,000 scale streams layer (from SSHIAP) depicting Rosgen stream segment classes as defined by Rosgen (1996).
- **Entiat-rosgen** - Streams in the Entiat HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting Rosgen stream segment classes as defined by Rosgen (1996).
- **methow-rosgen** - Streams in the methow HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting Rosgen stream segment classes as defined by Rosgen (1996).
- **oka-rosgen** - Streams in the Okanogan HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting Rosgen stream segment classes as defined by Rosgen (1996).
- **other-rosgen** - Streams in the Upper Columbia ESU not in the Entiat, Methow, or Okanogan HUC4 subbasins, nor in Douglas County - 1:100,000 scale streams layer (from SSHIAP) depicting Rosgen stream segment classes as defined by Rosgen (1996).

Naiman Valley Segment Classifications-

- **dgls-valleysegments** – Streams in the Douglas County portion of the Upper Columbia ESU - 1:100,000 scale streams layer (from SSHIAP) depicting valley segment classes as defined by Naiman et al. (1992) and updated by PBI.
- **entiat-valleysegments** – Streams in the Entiat HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting valley segment classes as defined by Naiman et al. (1992) and updated by PBI.
- **methow-valleysegments** – Streams in the Methow HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting valley segment classes as defined by Naiman et al. (1992) and updated by PBI.
- **oka-valleysegments** – Streams in the Okanogan HUC4 subbasin - 1:100,000 scale streams layer (from SSHIAP) depicting valley segment classes as defined by Naiman et al. (1992) and updated by PBI.
- **other-valleysegments** – Streams in the Upper Columbia ESU not in the Entiat, Methow, or Okanogan HUC4 subbasins, nor in Douglas County - 1:100,000 scale streams layer (from SSHIAP) depicting valley segment classes as defined by Naiman et al. (1992) and updated by PBI.

Riparian Vegetation and Land Use Classifications-

- **dgls-riparian_veg_landuse –** Riparian vegetation and land use mapping completed in 2004 by Pacific Biodiversity Institute for the Douglas County portion of the Upper Columbia ESU.
- **entiat-riparian_veg_landuse –** Riparian vegetation and land use mapping completed in 2004 by Pacific Biodiversity Institute for the Entiat Subbasin.
- **methow-riparian_veg_landuse –** Riparian vegetation and land use mapping completed in 2004 by Pacific Biodiversity Institute for the Methow Subbasin.
- **oka-riparian_veg_landuse –** Riparian vegetation and land use mapping completed in 2004 by Pacific Biodiversity Institute for the Okanogan Subbasin.
- **other-riparian_veg_landuse –** Riparian vegetation and land use mapping completed in 2004 by Pacific Biodiversity Institute for riparian areas not in the Entiat, Methow, or Okanogan HUC4 subbasins, nor in Douglas County.

Regional Data-

- **Strnet-bar –** 1999 fish barriers data layer for Upper Columbia ESU (produced at 1:100,000 scale).
- **Strnet-dam –** 2002 dams data layer for Upper Columbia ESU basin (produced at 1:100,000 scale).
- **Sshiap-bar** – 2003 fish barriers data layer for Upper Columbia ESU (produced at 1:24,000scale).
- **Omernik-4-epa** – EPA level IV ecoregions data layer for Washington State.
- **Bailey** – ICBEMP Bailey classification data layer (from Domain to Section)
- **Physio-province** – USGS Physiographic Provinces data layer.
- **Geo_districts** – 1995 ICBEMP lithology data layer for.
- **Basin-extent** – Drainage area for the UCESU. Area is in square meters.
- **Ownership** –WADNR Managed Public Lands layer clipped to the Upper Columbia ESU boundary.
- **Shaded.tif** - Shaded relief image for the UCESU in TIF format.

Wenatchee GIS Data-

GIS Projects-

- **Wenatchee-GIS-Projects** - Portable GIS project that displays the following shapefiles in the projection listed below. Project includes scripts and Avenue extensions used to create GIS products.

Shapefiles-

- **Strahler100** - 1:100,000 scale streams layer (from StreamNet) with Strahler Stream Order classes (1 – 5) attributed per stream segment.

- **Gradient100** – 1:100,000 scale streams layer (from StreamNet) with gradient in rounded percent originally calculated for segments under 300m. Adjacent segments possessing the same percent gradient were merged together so some segments may now be over 300m.

- **Valley-segment** – 1:100,000 scale streams layer (from SSIAP) depicting valley segment classes as defined by Naiman et al. (1992).

- **Streamnet-barriers –** 1999 fish barriers data layer for Wenatchee basin (produced at 1:100,000 scale).

- **Sshiap-barriers** – 2003 fish barriers data layer for WRIA 48 (produced at 1:24,000scale).

- **Wennf-selectedbarriers** – Selected fish barriers from USFS r6 data layer.

- **Armycorps-dams** - 1996 Fish barrier dams mapped by US Army Corps of Engineers

- **ChelanCo-culverts** – 2001 Chelan County culverts dataset.

- **SSHEAR-culverts –** 2001 SSHEAR culverts dataset.

- **SSHEAR-dams** – 2001 SSHEAR dams dataset.

- **Omernik-4-epa** – EPA level IV ecoregions data layer for Washington State.

- **Bailey** – ICBEMP Bailey classification data layer for Washington State (from Domain to Section)

- **Physio-province** – USGS Physiographic Provinces data layer for Washington State.

- **Geo_districts** – 1995 ICBEMP lithology data layer for Washington State.

- **Basin-extent** – Drainage area for the Wenatchee River. Area is in square meters.

- **Ownership** –WADNR Managed Public Lands layer clipped to the Wenatchee Basin.

- **Riparian-veg-landuse** - Pacific Biodiversity Institute's 2002 vegetation and land use layer updated using 2003 ASTER satellite imagery and clipped to the riparian zones of the Wenatchee Subbasin.

- **Rosgen-classification** - Pacific Biodiversity Institute's 2004 Rosgen classification of the Wenatchee River Basin's 1:24,000 stream layer.

Appendix B - Valley Segment Classification AML developed by Pacific Biodiversity Institute

```
/* AML to do preliminary valley segment classification
/* Peter Morrison and Hans Smith 15 Sept. 2004

&echo &br
&args streamcov
tables
additem %streamcov%.aat naiman 2 2 c
sel %streamcov%.aat

/* F3 selection
res strahler > 3
res gradient <= 2
res glacier = 0
res sinuous <= 10

move 'F3' to naiman

asel

/* V1 selection
res ave_a > 25 and ave_b > 20
aselect ave_a > 20 and ave_b > 25
res ave_a < 70
res ave_b < 70
res strahler > 2
res gradient > 3 and gradient <= 6
res glacier = 0
res sinuous <= 10
move 'V1' to naiman

asel

/* V1 selection
res ave_a > 25 and ave_b > 20
aselect ave_a > 20 and ave_b > 25
res ave_a < 70
res ave_b < 70
res strahler = 3
res gradient <= 6
res glacier = 0
res sinuous < 1.5
move 'V1' to naiman

asel

/* V1 selection
res ave_a > 25 and ave_b > 20
aselect ave_a > 20 and ave_b > 25
res ave_a < 70
res ave_b < 70
res strahler = 2
res gradient <= 6
res glacier = 0
res sinuous > 1.2
move 'V1' to naiman

asel

/* V2 selection
res ave_a > 25 and ave_b > 20
aselect ave_a > 20 and ave_b > 25
res ave_a < 70
res ave_b < 70
res strahler > 2
res gradient > 6 and gradient <= 11
res glacier = 0
res sinuous <= 10
```

```
move 'V2' to naiman

asel

/* V3 selection
res ave_a >= 70 or ave_b >= 70
res strahler > 0
res gradient > 0 and gradient <= 11
res glacier = 0
res sinuous <= 10
move 'V3' to naiman

asel

/* V4 selection
res strahler > 2
res gradient > 2 and gradient <= 3
res glacier = 0
res sinuous >= 1.5
move 'V4' to naiman

asel

/* V4 selection
res strahler = 3
res gradient <= 2
res glacier = 0
res sinuous >= 1.5
move 'V4' to naiman

asel

/* V5 selection
res strahler > 2
res gradient > 11
res glacier = 0
res sinuous < 10
move 'V5' to naiman

asel

/* M1 selection
res ave_a >= 25 and ave_b <= 20
aselect ave_b >= 25 and ave_a <= 20
aselect ave_a <= 25 and ave_b <= 25
res strahler > 2
res gradient > 2 and gradient < 5
res glacier = 0
res sinuous < 1.5
move 'M1' to naiman

/* M1 selection
res ave_a >= 25 and ave_b <= 20
aselect ave_b >= 25 and ave_a <= 20
aselect ave_a <= 25 and ave_b <= 25
res strahler = 2
res gradient > 2 and gradient <= 6
res glacier = 0
res sinuous > 1.2
move 'M1' to naiman

asel

/* M2 selection
res ave_a >= 25 and ave_b <= 20
aselect ave_b >= 25 and ave_a <= 20
aselect ave_a <= 25 and ave_b <= 25
res strahler = 3
res gradient <= 2
res glacier = 0
res sinuous < 1.5
move 'M2' to naiman
```

```
asel

/* M2 selection
res ave_a >= 25 and ave_b <= 20
aselect ave_b >= 25 and ave_a <= 20
aselect ave_a <= 25 and ave_b <= 25
res strahler = 2
res gradient <= 2
res glacier = 0
res sinuous > 1.2
move 'M2' to naiman

asel

/* M3 selection
res ave_a >= 25 and ave_b <= 20
aselect ave_b >= 25 and ave_a <= 20
aselect ave_a <= 25 and ave_b <= 25
res strahler > 2
res gradient >= 5
res glacier = 0
res sinuous < 10
move 'M3' to naiman

asel

/* U1 selection
res strahler > 2
res gradient < 2
res glacier = 1
res sinuous > 1.2
move 'U1' to naiman

asel

/* U1 selection
res strahler <= 2
res gradient < 3
res glacier = 1
res sinuous > 1.2
move 'U1' to naiman

asel

/* U2 selection
res strahler > 2
res gradient >= 2 and gradient < 6
res glacier = 1
res sinuous > 0
move 'U2' to naiman

asel

/* U2 selection
res strahler = 2
res gradient >= 3 and gradient <= 6
res glacier = 1
res sinuous > 1.2
move 'U2' to naiman

asel

/* U2 selection
res strahler > 2
res gradient < 2
res glacier = 1
res sinuous <= 1.2
move 'U2' to naiman

asel

/* U3 selection
res strahler > 2
```

```
res gradient >= 6 and gradient <= 11
res glacier = 1
res sinuous >= 1
move 'U3' to naiman

asel

/* U5 selection
res strahler > 2
res gradient > 11
res glacier = 1
res sinuous >= 1
move 'U5' to naiman

asel

/* H1 selection
res strahler <= 2
res gradient >= 0 and gradient <= 6
res glacier < 2
res sinuous <= 1.2
res ave_a < 70
res ave_b < 70
move 'H1' to naiman

asel

/* H1 selection
res strahler = 1
res gradient >= 0 and gradient <= 6
res glacier = 0
res sinuous >= 1
res ave_a < 70
res ave_b < 70
move 'H1' to naiman

asel

/* H2 selection
res strahler <= 2
res gradient > 6 and gradient <= 11
res glacier < 2
res sinuous >= 1
res ave_a < 70
res ave_b < 70
move 'H2' to naiman

asel

/* H3 selection
res strahler <= 2
res gradient > 11
res glacier < 2
res sinuous >= 1
move 'H3' to naiman

asel

res naiman = ''
move 'XX' to naiman

sel
q

&echo &off
&return
```

Appendix C – Rosgen stream channel classification AML developed by Pacific Biodiversity Institute

```
/*  AML TO CALCULATE ROSGEN CLASSES FOR SMALL STREAMS
/* Peter Morrison   3 October 2004
/* 'This only applies to single threaded channels'
&echo &br

&args streamname
&goto order1

sel %streamname%.aat


/* THIS FIRST SECTION CALCULATES THE WIDTH AND DEPTH BASED ON STAHLER ORDER AND PRECIPITATION
/* MEAN OF SUBWATERSHED.  IT IS GROUPED BY STREAM ORDER.

/* STRAHLER ORDER 1 STREAMS

/* aveprecip    23.7    26.4    32.1    37.1    47.8    54.4    65.0    67.9    92.8
/* width    0.2     0.3     0.4     0.5     0.6     0.75    0.9     1       1.5

&LABEL order1
&type ************************
&type STRAHLER ORDER 1 STREAMS

tables
sel %streamname%.aat
res strahler = 1
res aveprecip < 24
calc width = 0.2
asel
res strahler = 1
res aveprecip >= 24 and aveprecip < 27
calc width = 0.3
asel
res strahler = 1
res aveprecip >= 27 and aveprecip < 33
calc width = 0.4
asel
res strahler = 1
res aveprecip >= 33 and aveprecip < 38
calc width = 0.5
asel
res strahler = 1
res aveprecip >= 38 and aveprecip < 48
calc width = 0.6
asel
res strahler = 1
res aveprecip >= 48 and aveprecip < 55
calc width = 0.75
asel
res strahler = 1
res aveprecip >= 55 and aveprecip < 66
calc width = 0.9
asel
res strahler = 1
res aveprecip >= 66 and aveprecip < 68
calc width = 1
asel
res strahler = 1
res aveprecip >= 68 and aveprecip < 93
calc width = 1.5
asel
res strahler = 1
calc depth = width / 2
calc entrenchment = ( flatwidth + 1 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY
&GOTO ORDER2
```

```
&LABEL order2
&type ************************
&type STRAHLER ORDER 2 STREAMS

/* aveprecip        23.7    26.4    32.1    37.1    47.8    54.4    65.0    67.9    92.8
/* width    0.5     1       1.5     2       2.5     3       3.2     3.5     5

asel
res strahler = 2
res aveprecip < 24
calc width = 0.5
asel
res strahler = 2
res aveprecip >= 24 and aveprecip < 27
calc width = 1
asel
res strahler = 2
res aveprecip >= 27 and aveprecip < 33
calc width = 1.5
asel
res strahler = 2
res aveprecip >= 33 and aveprecip < 38
calc width = 2
asel
res strahler = 2
res aveprecip >= 38 and aveprecip < 48
calc width = 2.5
asel
res strahler = 2
res aveprecip >= 48 and aveprecip < 55
calc width = 3
asel
res strahler = 2
res aveprecip >= 55 and aveprecip < 66
calc width = 3.2
asel
res strahler = 2
res aveprecip >= 66 and aveprecip < 68
calc width = 3.5
asel
res strahler = 2
res aveprecip >= 68 and aveprecip < 93
calc width = 5
asel

res strahler = 2
calc depth = width / 10
calc entrenchment = ( flatwidth + 2 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY
&GOTO ORDER3


/* STRAHLER ORDER 3 STREAMS
/* aveprecip        23.7    26.4    32.1    37.1    47.8    54.4    65.0    67.9    92.8
/* width    1.5     2       3       3.5     4       5       6       7       10

&LABEL order3
&type ************************
&type STRAHLER ORDER 3 STREAMS

asel
res strahler = 3
res aveprecip < 24
calc width = 1.5
asel
res strahler = 3
res aveprecip >= 24 and aveprecip < 27
calc width = 2
asel
res strahler = 3
```

```
res aveprecip >= 27 and aveprecip < 33
calc width = 3
asel
res strahler = 3
res aveprecip >= 33 and aveprecip < 38
calc width = 3.5
asel
res strahler = 3
res aveprecip >= 38 and aveprecip < 48
calc width = 4
asel
res strahler = 3
res aveprecip >= 48 and aveprecip < 55
calc width = 5
asel
res strahler = 3
res aveprecip >= 55 and aveprecip < 66
calc width = 6
asel
res strahler = 3
res aveprecip >= 66 and aveprecip < 68
calc width = 7
asel
res strahler = 3
res aveprecip >= 68 and aveprecip < 93
calc width = 10
asel

res strahler = 3
calc depth = width / 15
calc entrenchment = ( flatwidth + 3 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY
&GOTO ORDER4

/* STRAHLER ORDER 4 STREAMS
&LABEL order4
&type ************************
&type STRAHLER ORDER 4 STREAMS

/* aveprecip        23.7    26.4    32.1    37.1    47.8    54.4    65.0    67.9    92.8
/* width     3      4       5       6       7       8       10      11      15

asel
res strahler = 4
res aveprecip < 24
calc width = 3
asel
res strahler = 4
res aveprecip >= 24 and aveprecip < 27
calc width = 4
asel
res strahler = 4
res aveprecip >= 27 and aveprecip < 33
calc width = 5
asel
res strahler = 4
res aveprecip >= 33 and aveprecip < 38
calc width = 6
asel
res strahler = 4
res aveprecip >= 38 and aveprecip < 48
calc width = 7
asel
res strahler = 4
res aveprecip >= 48 and aveprecip < 55
calc width = 8
asel
res strahler = 4
res aveprecip >= 55 and aveprecip < 66
calc width = 10
asel
```

```
res strahler = 4
res aveprecip >= 66 and aveprecip < 68
calc width = 11
asel
res strahler = 4
res aveprecip >= 68 and aveprecip < 93
calc width = 15

asel
res strahler = 4
calc depth = width / 15
calc entrenchment = ( flatwidth + 4 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY
&GOTO ORDER5


/* STRAHLER ORDER 5 STREAMS
&LABEL order5
&type ************************
&type STRAHLER ORDER 5 STREAMS

/* aveprecip        23.7     26.4     32.1     37.1     47.8     54.4     65.0     67.9     92.8
/* width     5      7        7.5      8        12       15       22       25       35
asel
res strahler = 5
res aveprecip < 24
calc width = 5
asel
res strahler = 5
res aveprecip >= 24 and aveprecip < 27
calc width = 7
asel
res strahler = 5
res aveprecip >= 27 and aveprecip < 33
calc width = 8
asel
res strahler = 5
res aveprecip >= 33 and aveprecip < 38
calc width = 9
asel
res strahler = 5
res aveprecip >= 38 and aveprecip < 48
calc width = 12
asel
res strahler = 5
res aveprecip >= 48 and aveprecip < 55
calc width = 15
asel
res strahler = 5
res aveprecip >= 55 and aveprecip < 66
calc width = 22
asel
res strahler = 5
res aveprecip >= 66 and aveprecip < 68
calc width = 25
asel
res strahler = 5
res aveprecip >= 68 and aveprecip < 93
calc width = 35
asel
res strahler = 5
calc depth = width / 35
calc entrenchment = ( flatwidth + 5 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY

&LABEL order6
&type ************************
&type STRAHLER ORDER 6 STREAMS
```

```
/* STRAHLER ORDER 6 STREAMS
/* aveprecip          23.7     26.4     32.1     37.1     47.8     54.4     65.0     67.9     92.8
/* width     25       26       27       28       32       35       40       41       55

asel
res strahler = 6
res aveprecip < 24
calc width = 25
asel
res strahler = 6
res aveprecip >= 24 and aveprecip < 27
calc width = 26
asel
res strahler = 6
res aveprecip >= 27 and aveprecip < 33
calc width = 27
asel
res strahler = 6
res aveprecip >= 33 and aveprecip < 38
calc width = 28
asel
res strahler = 6
res aveprecip >= 38 and aveprecip < 48
calc width = 32
asel
res strahler = 6
res aveprecip >= 48 and aveprecip < 55
calc width = 35
asel
res strahler = 6
res aveprecip >= 55 and aveprecip < 66
calc width = 40
asel
res strahler = 6
res aveprecip >= 66 and aveprecip < 68
calc width = 41
asel
res strahler = 6
res aveprecip >= 68 and aveprecip < 93
calc width = 55
asel
res strahler = 6
calc depth = width / 35
calc entrenchment = ( flatwidth + 5 ) / width
calc w_d-ratio = width / depth
&CALL CLASSIFY

&LABEL order7
/* STRAHLER ORDER 7 STREAMS
&type ***********************
&type STRAHLER ORDER 7 STREAMS

/* STRAHLER ORDER 7 STREAMS
/* aveprecip          23.7     26.4     32.1     37.1     47.8     54.4     65.0     67.9     92.8
/* width     30       32       35       40       45       55   60   61   65

asel
res strahler = 7
res aveprecip < 24
calc width = 30
asel
res strahler = 7
res aveprecip >= 24 and aveprecip < 27
calc width = 32
asel
res strahler = 7
res aveprecip >= 27 and aveprecip < 33
calc width = 35
asel
res strahler = 7
res aveprecip >= 33 and aveprecip < 38
calc width = 40
asel
```

```
res strahler = 7
res aveprecip >= 38 and aveprecip < 48
calc width = 45
asel
res strahler = 7
res aveprecip >= 48 and aveprecip < 55
calc width = 55
asel
res strahler = 7
res aveprecip >= 55 and aveprecip < 66
calc width = 60
asel
res strahler = 7
res aveprecip >= 66 and aveprecip < 68
calc width = 61
asel
res strahler = 7
res aveprecip >= 68 and aveprecip < 93
calc width = 65
asel
res strahler = 7
calc depth = width / 35
calc entrenchment = ( flatwidth + 5 ) / width
calc w_d-ratio = width / depth

&CALL CLASSIFY
&GOTO FINISH



/*                  Estimated stream width (meters) by strahler order
/* Strahler Order                      Mean Watershed Annual Precipitation
/*        23.7     26.4     32.1     37.1     47.8     54.4     65.0     67.9     92.8
/* 1      0.2      0.3      0.4      0.5      0.6      0.75     0.9      1        1.5
/* 2      0.5      1        1.5      2        2.5      3        3.2      3.5      5
/* 3      1.5      2        3        3.5      4        5        6        7        10
/* 4      3        4        5        6        7        8        10       11       15
/* 5      5        7        7.5      8        12       15       22       25       35


&ROUTINE CLASSIFY

/* First label all values that may not get classified
asel
move '?????' to rosgen

/* DEEPLY ENTRENCHED STREAMS
asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous le 1.2
res gradient lt 4
move 'AX' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous le 1.2
res gradient > 10
move 'Aa+' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous le 1.2
res gradient le 10
move 'A' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous ge 1.2
res gradient ge 4
```

```
move 'GX' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous > 1.2
res gradient > 2
move 'G' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio le 12
res sinuous ge 1.2
res gradient le 2
move 'Gc' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res sinuous < 1.4 or gradient ge 4
move 'Af' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res strahler >= 3
res sinuous < 1.4 or gradient ge 2
move 'Bf' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res sinuous < 1.4 or gradient ge 4
move 'Af' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res strahler < 3
res sinuous < 1.4 or gradient ge 2
move 'Af' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res sinuous ge 1.2
res gradient le 2
move 'F' to rosgen

asel
res entrenchment < 1.4
res w_d-ratio > 12
res sinuous ge 1.2
res gradient > 2 and gradient < 4
move 'Fb' to rosgen


/* MODERATELY ENTRENCHED STREAMS

asel
res entrenchment ge 1.4 and entrenchment le 2.2
move 'B' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio le 12
/* move 'Bwdlo' to rosgen
move 'B' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio > 12
```

```
res sinuous lt 1.2
/* move 'Bsnlo' to rosgen
move 'B' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio > 12
res sinuous ge 1.2
res gradient gt 10
move 'Bgrhi' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio > 12
res sinuous ge 1.2
res gradient < 2
move 'Bc' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio > 12
res sinuous ge 1.5
res gradient lt 1.2
/* move 'CB' to rosgen
move 'Cb' to rosgen

asel
res entrenchment ge 1.4 and entrenchment le 2.2
res w_d-ratio > 12
res sinuous ge 1.2
res gradient ge 4
move 'Ba' to rosgen


/* LOW ENTRENCHMENT STREAMS

asel
res entrenchment gt 2.2
res w_d-ratio le 12
move 'Eg' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio le 12
res gradient ge 4
move 'A' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio le 12
res gradient lt 4 and gradient ge 2
move 'B' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio le 12
res sinuous gt 1.5
res gradient lt 2
move 'E' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio le 12
res sinuous gt 1.5
res gradient ge 2 and gradient lt 4
move 'Eb' to rosgen


asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous gt 1.2
```

```
res gradient ge 4
move 'B' to rosgen
/* comment - this used to go to CX without the gradient criteria

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous le 1.2
res gradient gt 2.5
move 'B' to rosgen
/* comment - this used to go to CXX without the gradient criteria

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous le 1.2
/* move 'Csnlo' to rosgen
move 'C' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous le 1.2
res gradient gt 2.5
move 'Bc' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous gt 1.2
res gradient lt 0.1
move 'Cc' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous gt 1.2
res gradient ge 0.1 and gradient le 2
move 'C' to rosgen

asel
res entrenchment gt 2.2
res w_d-ratio gt 12
res sinuous gt 1.2
res gradient gt 2 and gradient le 4
move 'Cb' to rosgen

asel
res gradient gt 11
move 'Aa+' to rosgen

&RETURN

&LABEL FINISH
q


&echo &off
&return
```

Appendix D - Road Density and Riparian Road Index Tables for the UCESU Subbasins and Watersheds

(Note the Wenatchee results are presented in Table 16)

Okanogan Basin			
HUC 6 Name	**total road (km)**	**area of Huc 6 (sq. km)**	**road density (km/sq. km)**
Aeneas Creek	140.11	112.98	1.24
Chewiliken Creek	76.88	67.62	1.14
Chilwist Creek	255.73	114.29	2.24
Coulee Creek	115.95	98.91	1.17
Hicks Canyon	45.23	58.06	0.78
Johnson Creek	142.92	118.80	1.20
Loup Loup Creek	353.78	163.07	2.17
Lower Antoine Creek	88.42	62.99	1.40
Lower Bonaparte Creek	175.26	134.58	1.30
Lower Omak Creek	127.14	134.08	0.95
Lower Salmon Creek	119.77	116.73	1.03
Lower Siwash Creek	121.73	86.54	1.41
Mainstem Lower Okanogan River	183.49	184.23	1.00
Mainstem Okanogan River	218.73	150.59	1.45
Mainstem Okanogan River/omak Creek	84.46	60.91	1.39
Mainstem Upper Okanogan River	180.50	178.42	1.01
Middle Omak Creek	166.47	116.81	1.43
Mouth Of Silkameen River	43.75	42.26	1.04
Nine Mile Creek	49.29	62.17	0.79
North Fork Salmon Creek	121.57	144.15	0.84
Okanogan River/tallant Creek	197.06	148.57	1.33
Okanogan River/wanacut Creek	393.62	216.93	1.81
Peony Creek	185.78	111.19	1.67
Pine Creek	110.80	96.53	1.15
Soap Lake	162.07	200.86	0.81
South Fork Salmon Creek	70.37	53.61	1.31
Tonasket Creek	147.55	154.92	0.95
Tunk Creek	212.36	183.11	1.16
Upper Antoine Creek	91.63	96.79	0.95
Upper Bonaparte Creek	211.75	154.28	1.37
Upper Omak Creeek	158.63	115.31	1.38
Upper Siwash Creek	72.08	40.47	1.78
West Fork Salmon Creek	123.36	112.82	1.09
Whitestone Creek	111.51	99.74	1.12
Wiskey Cashe Creek	67.76	37.18	1.82
Grand Total	**5127.49**	**4030.51**	**1.27**

Okanogan Basin Road Riparian Index	
Length of Roads in Riparian Area (km)	359.61
Riparian Road Index (roads km / stream km)	0.06

Methow Basin			
HUC 6 Name	**total road (km)**	**area of Huc 6 (sq. km)**	**road density (km/sq. km)**
Andrews Creek	0.90	88.67	0.01
Bear Creek	60.54	43.60	1.39
Benson Creek	143.18	102.92	1.39
Black Canyon Creek	41.75	41.29	1.01
Boulder Creek	36.30	52.99	0.69
Buttermilk Creek	89.30	96.25	0.93
Cedar Creek	3.75	79.79	0.05
Chewuch River/kay Creek	2.62	87.92	0.03
Chewuch River/pearrygin Creek	162.12	102.90	1.58
Cub Creek	121.60	63.15	1.93
Davis Creek	136.74	104.42	1.31
Eagle Creek	1.92	34.81	0.06
Early Winters Creek	45.37	128.53	0.35
Eight Mile Creek	147.92	120.40	1.23
Falls Creek	61.61	69.23	0.89
Goat Creek	110.60	93.18	1.19
Gold Creek	198.53	190.58	1.04
Headwaters Chewuch River	0.00	135.14	0.00
Lake Creek	6.17	138.61	0.04
Libby Creek	123.75	104.14	1.19
Little Bridge Creek	62.30	63.24	0.99
Lower Beaver Creek	136.21	129.01	1.06
Lower Lost River	11.80	172.01	0.07
Lower Middle Methow River	184.19	130.90	1.41
Mainstem Lower Chewuch River	152.59	99.46	1.53
Mainstem Lower Methow River	124.89	230.40	0.54
Mainstem Lower Twisp River	142.43	113.87	1.25
Mainstem Upper Chewuch River	17.36	71.64	0.24
Mainstem Upper Twisp River	99.16	163.32	0.61
Methow River/texas Creek	64.92	81.99	0.79
Mouth Of Methow River	62.24	64.06	0.97
North Fork Boulder Creek	119.11	156.78	0.76
Rattlesnake Creek	74.46	99.46	0.75
Robinson Creek	1.85	51.10	0.04
South Creek	0.66	40.92	0.02
South Fork Lost River	0.00	93.62	0.00
Squaw Creek	48.45	86.25	0.56
Twenty Mile Creek	29.34	109.37	0.27
Upper Beaver Creek	232.54	162.17	1.43
Upper Lost River	0.00	168.99	0.00
Upper Middle Methow River	136.16	141.33	0.96
Upper Twisp River	3.49	52.06	0.07
War Creek	5.37	70.97	0.08
West Fork Methow River	7.58	128.91	0.06
Windy Creek	19.10	58.15	0.33
Wolf Creek	17.07	104.54	0.16
Grand Total	**3247.94**	**4723.05**	**0.69**

Methow Basin Road Riparian Index	
Length of Roads in Riparian Area (km)	440.98
Riparian Road Index (roads km / stream km)	0.04

Entiat Basin			
HUC 6 Name	total road (km)	area of Huc 6 (sq. km)	road density (km/sq. km)
Entiat River/lake Creek	116.16	151.03	0.77
Entiat River/mud Creek	272.06	107.68	2.53
Lower Entiat River	656.85	196.96	3.33
Mad River	607.47	236.30	2.57
Mud Creek	144.29	58.34	2.47
North Fork Entiat River	23.38	175.07	0.13
Preston Creek	185.87	67.63	2.75
Three Creek	18.87	90.01	0.21
Grand Total	**2024.94**	**1083.02**	**1.87**

Entiat Basin Road Riparian Index	
Length of Roads in Riparian Area (km)	156.65
Riparian Road Index (roads km / stream km)	0.06

Douglas County Basins			
HUC 6 Name	**total road (km)**	**area of Huc 6 (sq. km)**	**road density (km/sq. km)**
Antoine Creek	45.15	81.89	0.55
Cobaley Canyon	111.02	81.74	1.36
Dry Creek	67.93	40.81	1.66
Dry Gulch	20.07	15.89	1.26
Indian Dan Creek	106.20	94.11	1.13
Johnson Creek	249.27	139.14	1.79
Long Draw	60.97	63.44	0.96
Lower East Foster Creek	142.27	216.30	0.66
Middle Foster Creek	240.96	224.93	1.07
Rock Island Creek	183.84	221.92	0.83
Rock Island Dam	89.37	57.55	1.55
Second Canyon	245.27	89.80	2.73
Squilchuck Creek	57.01	18.56	3.07
Swakane Creek	58.19	57.15	1.02
Swamp Creek	0.00	0.03	0.00
Upper East Foster Creek	170.51	247.98	0.69
West Foster Creek	170.02	177.27	0.96
Grand Total	**2018.05**	**1828.52**	**1.10**

Douglas County Basins Road Riparian Index	
Length of Roads in Riparian Area (km)	491.57
Riparian Road Index (roads km / stream km)	0.25

Other Basins			
HUC 6 Name	**total road (km)**	**area of Huc 6 (sq. km)**	**road density (km/sq. km)**
Antoine Creek	174.71	119.69	1.46
Dry Creek	103.26	97.14	1.06
Dry Gulch	11.12	13.21	0.84
Indian Dan Creek	184.77	132.75	1.39
Johnson Creek	336.30	176.88	1.90
Long Draw	162.20	63.68	2.55
Lower Omak Lake	82.31	138.20	0.60
Rock Island Dam	71.16	39.59	1.80
Second Canyon	326.24	114.85	2.84
Squilchuck Creek	399.25	165.42	2.41
Swakane Creek	112.18	104.70	1.07
Swamp Creek	162.78	126.89	1.28
Upper Omak Lake	106.97	119.37	0.90
Grand Total	**2233.25**	**1412.36**	**1.58**

Other Basins Road Riparian Index	
Length of Roads in Riparian Area (km)	347.04
Riparian Road Index (roads km / stream km)	0.11