Anadromous Fisheries Habitat Analysis of Asotin Creek for Pacific Lamprey

Asotin Creek Located in Asotin & Garfield Counties, Washington

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Cover Photo of juvenile lamprey contributed by:
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Image was obtained through the Department of Fisheries & Wildlife
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Abstract

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This analysis was conducted to assess usable spawning and rearing habitat for Pacific lamprey (*Entosphenus tridentatus, formerly Lampetra tridentata*) in Asotin Creek, Washington, a tributary to the Snake River. This analysis used an explicit geospatial model to quantify and qualify suitable habitat characteristics. Characteristics of usable habitat for Pacific lamprey were determined from a review of published literature for multiple species of lamprey, and through the assessment of juvenile Pacific lamprey in Asotin Creek (Figure 1) during electrofishing surveys. All site visits were positionally recorded using Global Position System location recorders.

Geospatial data assembled for this project were analyzed using the Soil and Water Assessment Tool (SWAT ver 2005) through an interface of the Automated Geospatial Watershed Assessment (AGWA) Tool (ver 2.0) within ESRI ArcMap/ArcINFO (ver. 9.3.1). These data and analyses tools provided estimated discharge for ungauged streams, sedimentation, siltation and nutrient rates, stream bed structure, geologic parent materials, and other components. These data were combined with habitat projections derived from existing geospatial data, spatial modeling results, and field observations. The analysis resulted in a combination of databases showing critical habitat features, maps showing the juxtaposition of favorable habitat within the Asotin Creek watershed, Geographic Information Systems (GIS) data, and incorporated physical barriers to Pacific lamprey upstream passage.

SWAT software was used to predict the effects of management decisions on water, sediment, and nutrient yields. The SWAT model analysis was conducted using historical daily weather data (75 years), Natural Resource Conservation Service (NRCS) soil survey data, US Geological Service (USGS) digital elevation model data (10 meter resolution), and vegetative cover to predict stream reach characteristics (width, depth, and velocity), sedimentation (and source contribution areas), surface runoff, return flow, percolation, evapotranspiration, transmission losses, reach routing, nutrient loading, and water transfer. Results were combined with gauged river basin data to calibrate the model.

Although several potential threats hinder the Pacific lamprey during its life cycle, this effort has concentrated on the portion of the Pacific lamprey's life cycle spent in the freshwater river network of Asotin Creek and the environmental characteristics consistent with ensuring their health and viability.

We have identified suitable habitat for adult Pacific lamprey spawning and aestivation sites within the main channel of Asotin Creek. Unsuitable habitat was identified within George Creek and all of its sub-basin tributaries. One physical barrier, the headgate dam, to adult Pacific lamprey passage has been identified near river kilometer marker 15, and should be considered for either removal or the placement of a lamprey ladder to facilitate upstream passage.

Introduction

Lampreys, jawless fishes of the family Petromyzontidae, are among the oldest existing vertebrates, having changed little since emerging about 530 million years ago (Dawkins 2004). Pacific lamprey (*Entosphenus tridentatus formerly Lampetra tridentata*) is a native anadromous species common to this region but has undergone drastic declines over the past few decades. Causes for the declines are largely unknown, although poor passage at mainstem dams can limit adult escapement to upstream watersheds. We still have significant gaps in our knowledge of the basic life history and ecology of this species. These gaps impede our ability to effectively manage and restore declining populations. For example, we do not know how long juvenile lamprey rear in freshwater or the potential production capacity of freshwater rearing areas. For this project, our goal was to use one watershed, Asotin Creek, a tributary of the Snake River in southeast Washington State (Figure 1) to develop geospatial tools to estimate suitable spawning and rearing habitats for Pacific lamprey. This work will be combined with adult and juvenile survey methods in the same watershed to test the effectiveness of tools and improve our understanding of lamprey production potential in the Columbia Basin.

Native American Tribes from the Pacific Ocean coast to the interior Columbia and Snake Rivers value the Pacific lamprey for subsistence, religious, medicinal, spiritual and cultural purposes. The Asotin watershed (approximately 207,191 acres, 83,847 hectares, Figure 1) has historically supported substantial populations of anadromous Pacific lamprey according to the Nez Perce Indians (Nimíipuu) that have occupied these lands since time immemorial (Pinkham 2002). There are numerous oral recollections of fishing for lamprey as an alternative subsistence food source by Nimíipuu and members of other tribes (Close 2002). The name of the town and stream called Asotin is derived from the Nimíipuu word “Heustiin” meaning the “place of eels” (Landeen & Pinkham 1999).

Personal interviews reported by the Nez Perce Tribe (2003), conveyed that Asotin County resident Frank Schiebe, the operator at Headgate Dam from 1954 – 1960 on the mainstem Asotin Creek, recalls that numerous lampreys could be seen maneuvering over the dam during spawning runs. He also recalled that “lampreys were taken out of Asotin Creek for use as sturgeon bait by local fishermen.”

Fish habitat in Asotin Creek has been affected by many factors including agricultural development, grazing, tilling practices, logging, road development, home-site development, recreational activities, and implementation of flood control structures (Neilson 1950). Several habitat improvement projects have been implemented by a wide array of cooperators, with the primary focus on developing improved habitat for anadromous salmonids in the watershed. The geomorphology of the watershed also exerts a strong influence on biologic conditions for fish within the stream (Bumgartner 2002).

Adult Pacific lamprey migrate from the ocean and spawn in freshwater rivers. There the eggs hatch and juvenile fish float downstream until reaching quiet waters with silt and sand substrate. Approximately 4 to 6 years pass with the juvenile Pacific lamprey (ammocetes) growing in the river before they transform to the migrant stage (macropthalmia) and move to the ocean where they grow to adults (Close 2002). While in their 4-6 year larval stage, lamprey ammocetes occupy a special niche in the stream ecosystem, filtering microscopic plants and animals, and nutrients, from the bottom sediments. They fall prey to a wide variety of species including trout, crayfish, and birds (PMFC 2006).

The first 4 to 6 years of the Pacific lamprey's life are critical times. Animals that filter water and sediments for food are likely susceptible to pollutants in the water column and particularly those that accumulate in sediments. Because this species depend on sand and silt bottoms, backwater and low gradient areas during its juvenile life stage, it is affected by loss of wetlands, side channels, back eddies, or beaver ponds resulting from agricultural, forestry or urban development practices or channelization. High water temperatures and lack of stream cover may also reduce the lampreys' food supply and habitat suitability (PMFC 2006).

Adults have a jawless sucker-like mouth and are parasitic on other fish while in the ocean. The adults live at least 1-2 years in the ocean and then return to fresh water to spawn (Close 2002). It is not well understood if Pacific lamprey return to their natal streams. It has been determined that spawning sea lamprey (native to the Atlantic ocean) seek spawning areas based at least in part on chemical pheromones (Petromyzonol sulfate) released by the gall bladders of growing ammocetes (Li *et al.* 1995) and Pacific lamprey exhibit sensitivity to bile acids (Robinson *et al.* 2009). Thus, upstream areas with sizable juvenile populations will attract adults to potential spawning sites (Close 2000). The stream distance between spawning and aestivation sites may help to define the quality of a stream's habitat for Pacific lamprey (Gunckel *et al.* 2009). Pacific lamprey typically spawn in habitat similar to that of salmon and trout. Lamprey construct a nest (redd) in small diameter gravel and females can lay over 100,000 eggs, which are fertilized externally by the male. Like salmon, Pacific lamprey do not feed while migrating in streams to spawn (PMFC 2006).

Efforts are underway to characterize habitats usable for adult lamprey spawning and larval and juvenile lamprey rearing in freshwater basins. This information is needed for further development of management plans to restore and conserve lamprey populations throughout the Columbia River system. A critical step in this process is the development of GIS datasets and GIS tools that can be used to quantify available usable habitat at a stream or watershed scale.

This study complements ongoing efforts to classify habitats selected by Pacific lamprey in tributary streams of the Columbia River system, including the Snake River, and initiates development of GIS-based products that address these needs. This effort also showcases a reliable procedure that can be replicated in other drainages.

Although several potential threats hinder Pacific lamprey during its life cycle, this effort will concentrate on the portion of Pacific lamprey's life cycle spent in the headwater river networks and the environmental characteristics consistent with ensuring their health and viability.

Analysis Data & Tools

This analysis used existing and available data and analysis techniques to determine suitable habitat for Pacific lamprey spawning and aestivation sites. Commercial software utilized in this effort was the GIS software provided by ESRI ArcGIS (version 9.3.1), and Microsoft Access database (version 2003).

Existing Geospatial Data

Our analysis of Pacific lamprey suitable habitat relied on readily available geospatial data (also known as Geographical Information Systems - GIS data). A summary of data utilized for this effort included:

1. Digital Elevation Models (DEM) at 10 meter resolution or better (raster format) supplied by the US Department of Agriculture NRCS - National Cartography & Geospatial Center.
2. Color aerial photography at 1 meter resolution, from 2009 flights supplied by the USDA's Farm Service Agency (FSA) through the Aerial Photography Field Office in Salt Lake City. National Agriculture Imagery Program images (NAIP) are commonly referred to as 2009 NAIP aerial imagery.
3. Soil survey data in vector format, provided by the USDA, Natural Resources Conservation Service, inclusive of tabular component data for each soil type polygon. The Asotin Creek watershed spanned lands in Washington State that required the combination of soil surveys in Asotin County (WA603 – 6/9/2009), and Garfield County (WA623 – 7/6/2009). The headwaters of Asotin Creek extend beyond the SSURGO datasets (the highest detail soil survey available at the time of this analysis) and necessitated the use of the General Soil Map dataset for Washington State last updated on 7/6/2006. All soil map combinations were made to use the higher detail of the SSURGO datasets and GIS shapefiles first, and the General Soil Map data second. Tabular datasets were combined using the Microsoft Access database (Access 2003) SSURGO templates (version 2003).
4. Stream Gauge station data maintained by the US Geological Survey (USGS) Water Resources Division showing daily stream flow at one gauging station within Asotin Creek (near the confluence with the Snake River).
5. Geology of the region maintained by the USGS showing the parent materials and geologic formations.
6. Weather Station Data maintained by NOAA National Weather Service to record daily records of minimum and maximum daily temperature, and total precipitation. These data are used within the SWAT model to provide the environmental inputs critical to projecting a stream's movement through the geologic substrate and soils when predicting stream flow, stream width and depth.
    a. Data from the Pomeroy, Washington, weather station was used in this effort primarily because the station at Asotin did not provide daily temperature data (only precipitation).
7. Average monthly minimum, and maximum temperature, and average monthly precipitation at a resolution of 800 meters (raster data) created and maintained by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate

mapping system, developed by Dr. Christopher Daly, PRISM Climate Group director at Oregon State University. These data were used in the creation of ten pseudo-weather stations all distributed throughout the Asotin Creek watershed to modify the reported observed weather (daily precipitation, minimum and maximum temperature) based on daily timing and frequency observed at Pomeroy, Washington.

8. Digital road networks and stream crossings maintained by a variety of data stewards and publicly available were used.
9. Vegetation Cover and Canopy Coverage generated by the National Land Cover Database (NLCD) last updated in 2006 (Homer *et al.* 2004). Canopy coverage estimates were updated by project staff to reflect observations correlated with observations made while visiting these sites, and by using 2009 NAIP aerial imagery.

Derivative Data & Analyses

Derivative data are those data that are generated using existing published data to determine useful attributes for further investigation. Derivative data creation used the data listed in the previous sub-section of this report to create:

1. **Fill-DEM**; a raster data layer that represents the DEM without sink holes or water ponding, for use in determining accurate surface water flow estimates.
2. **Water Flow Direction Grid** (FDG) calculating the direction of surface water flow over the Fill-DEM used for calculating where water flows from one 10 meter square pixel to the next. Ultimately, this FDG determined the location and magnitude of the stream segments leading from the headwaters to the terminal pour point.
3. **Water Flow Accumulation Grid** (FAG) based on the Fill-DEM and FDG raster data listed above to calculate the volume of water subject to surface water flow.
4. **Watershed boundaries** for the Asotin Creek watershed showing the extent of the drainage area. This was used to determine surface water flow contribution area. For example, the Asotin Creek drainage was determined to be approximately 207,191 acres, 83,847 hectares, using this technique.
5. **Shreve Stream Order Layer** (Figure 2). The Shreve Stream Order analysis is a method of ordering stream segments by magnitude proposed by Shreve (1967). All links with no tributaries are assigned a magnitude (order) of one (1). Magnitudes (orders) are additive downslope. When two links intersect, their magnitudes are added and assigned to the next downslope link. For instance, within the Asotin Creek watershed, there are approximately 1,357 stream segments representing 1,136 km (706 miles) of horizontal stream segments ranging from a low Shreve Stream Order of 1 (the minimum) to a maximum of 678 where the stream enters the Snake River at the City of Asotin.
6. **Curve Numbers, Intercept, Manning's N, and impervious area** calculations, are all hydrologic parameters used in the derivation of water flow calculations for each stream segment in the analysis. These values are determined interactively and sometimes are set by calculation (such as the impervious area determined by the amount of space covered by roads, parking lots, and compacted soils) (Table 1).
7. Using the S.W.A.T. analytical model (described more below) **additional derivative GIS data** were generated to include:

a. Basins subdivided into sub-basin watersheds to account for differences in soils, land use, vegetation, topography, weather, etc. (Figure 3, Figure 4),
b. Soil profile is divided into multiple layers and based on the sub-basin watershed extents,
c. Reach routing to route and add water flows downslope in the stream network,
d. Sub-basins were simulated into spatially displayed outputs,
e. Surface water flow models estimating nutrients and sedimentation,

8. **Slope of Stream** for all stream segments was calculated in conjunction with the determination of stream width and depth (Table 6),
9. All of these derivative data and heuristic data analyses were modeled to generate meaningful projections of **suitable habitat** for Pacific lamprey spawning, rearing, and aestivation sites.

Analysis Software

Development of suitable habitat estimates focused on two critical elements: 1) potential spawning sites, and 2) potential aestivation sites. For both, this assessment sought to define the ecological functions within the Asotin Creek watershed that defined the stream channels and those that have been modified by external forces such as road building and land management. These conditions were evaluated through the analysis of tabular and geophysical data and through field site visits.

GIS Software and Operating Systems

All geospatial analyses were completed using Environmental Systems Research Institute, Inc., (ESRI) ArcMap/ArcINFO version 9.3.1 software. Several extensions to this software were used in this analysis. Analyses were completed using a combination of Windows XP Pro and Windows 7 Ultimate operating systems. Both operating systems were used because of the higher efficiency of the Windows 7 operating system (64-bit), and the required Windows XP Pro architecture (32-bit) for operating some of the extensions to ArcMap (discussed below). All of the operations could be completed using the Windows XP Pro (32-bit), but some could not be completed using the Windows 7 (64-bit) operating system.

All geospatial data used in this effort was either created natively or projected into NAD83UTM11N (North American Datum ’83, Universal Transverse Mercator Zone 11N), Geographic Coordinate System North American 1983.

Soil Data Viewer

Summarized from the Soil Data Viewer Guide (SDV 2008): The Soil Data Viewer is a software tool built as an extension to ESRI ArcMap software that allows a user to create soil-based thematic maps. The application can also be run independent of ArcMap, but output is then limited to creating tabular reports.

The soil survey attribute database associated with the spatial soil map is a complicated database with more than 50 tables for each survey area. Soil Data Viewer provides users access to soil interpretations and soil properties while shielding them from the complexity of the soil database. Each soil map unit, typically a set of polygons, may contain multiple soil components that have different use and management. The Soil Data Viewer makes it possible to compute a single value for a map unit and display results, relieving the user from the burden of querying the database, processing the data, and linking the results to the spatial map.

The Soil Data Viewer contains processing rules to enforce appropriate use of the data. This provides the user with a tool for efficient and consistent geospatial analysis of soil data for use in resource assessment and management.

Automated Geospatial Watershed Assessment Tool

According to Automated Geospatial Watershed Assessment Tool website (AGWA 2010) planning and assessment in land and water resource management are evolving from simple, local-scale problems toward complex, spatially explicit regional ones. Such problems have to be addressed with distributed models that can compute runoff and erosion at different spatial and temporal scales. The extensive data requirements and the difficult task of building input parameter files, however, have long represented an obstacle to the timely and cost-effective use of such complex models by resource managers.

The USDA-ARS Southwest Watershed Research Center, in cooperation with the U.S. EPA Office of Research and Development Landscape Ecology Branch, developed a GIS tool to facilitate this process. A geographic information system provides the framework within which spatially-distributed data are collected and used to prepare model input files and evaluate model results. AGWA uses widely available standardized spatial data. The data are used to develop input parameter files for the SWAT watershed runoff and erosion model.

Soil and Water Assessment Tool

The Soil and Water Assessment Tool is a quasi-distributed model developed at the USDA-ARS to predict the impact of land management practices on water, sediment and agricultural chemical yields in large (basin scale) complex watersheds with varying soils, land use and management conditions over long time periods (> 1 year). SWAT is a continuous time long-term yield model using daily average input values and was not designed to simulate detailed, single-event flood routing. All analyses used for this effort were done using SWAT version 2005.

AGWA & SWAT Description and Uses

Using digital data in combination with the automated functionality of AGWA greatly reduced the time required to use the SWAT watershed model. Once an outlet (mouth of Asotin Creek) was identified, AGWA was used to delineated and discretize the watershed using the data of the DEM. The watershed elements were then intersected with soil, land cover, and precipitation data layers to derive the requisite model input parameters. The SWAT model used historical and current daily weather data with soil survey data, topographic data, and vegetative cover to predict surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, vegetative growth, groundwater flow, reach routing, nutrient loading, and water transfer. These data were combined with gauged river basin data to calibrate the model and increase the model's predictive accuracy. Results from the SWAT model were imported back into AGWA and ArcGIS for visual display.

AGWA was designed to evaluate relative change and can only provide qualitative estimates of runoff and erosion. It could not provide reliable quantitative estimates of runoff and erosion without careful calibration. It is also subject to the assumptions and limitations of its component models, and should always be applied with these in mind.

Model Parameters

Several model parameters were set interactively for this effort. These included the data presented in Table 1 and Table 2.

Table 1. Hydrologic parameter table used for calibrating the SWAT model with respect to vegetative cover.

COVER TYPE NAME	Curve Numbers A	B	C	D	Percent Cover	Intercept	Manning's N	Fraction Impervious
Open Water	100	100	100	100	0	0.00	0.000	0.00
Developed, Open Space	68	79	86	89	6	2.50	0.040	2.00
Developed, Low Intensity	77	85	90	92	6	0.10	0.150	10.61
Developed, Medium Intensity	81	88	91	93	0	0.08	0.120	53.57
Developed, High Intensity	89	92	94	95	2	0.05	0.010	1.39
Barren Land	82	88	91	93	15	0.00	0.010	0.00
Deciduous Forest	55	55	75	80	50	1.15	0.015	0.00
Evergreen Forest	55	55	70	77	57	1.15	0.015	0.18
Mixed Forest	55	55	75	80	50	1.15	0.015	0.00
Scrub/Shrub	63	77	85	88	32	3.00	0.055	0.64
Grasslands/Herbaceous	49	69	79	84	5	2.00	0.015	1.13
Cultivated Crops	71	81	87	91	57	1.75	0.040	0.78
Woody Wetlands	85	85	90	92	28	1.15	0.060	0.00
Emergent Herbaceous Wetlands	85	85	90	92	85	1.15	0.050	0.00

Table 2. Vegetation Cover and Land Cover within the Asotin Creek Watershed as determined using MRLC data circa 2006, updated using NAIP 2009 and site visits in 2010.

Vegetation Cover	Acres	Hectares	Percent of Total
Open Water	7.78	3.15	0.00%
Developed, Open Space	5,292.77	2,141.91	2.55%
Developed, Low Intensity	419.88	169.92	0.20%
Developed, Medium Intensity	20.91	8.46	0.01%
Developed, High Intensity	3.11	1.26	0.00%
Barren Land	3.34	1.35	0.00%
Deciduous Forest	77.39	31.32	0.04%
Evergreen Forest	58,126.67	23,523.03	28.05%
Mixed Forest	14.90	6.03	0.01%
Scrub/Shrub	32,213.45	13,036.32	15.55%

Table 2. Vegetation Cover and Land Cover within the Asotin Creek Watershed as determined using MRLC data circa 2006, updated using NAIP 2009 and site visits in 2010.

Vegetation Cover	Acres	Hectares	Percent of Total
Grasslands/Herbaceous	73,237.29	29,638.08	35.35%
Cultivated Crops	37,597.63	15,215.22	18.15%
Woody Wetlands	150.34	60.84	0.07%
Emergent Herbaceous Wetlands	31.36	12.69	0.02%
Total	**207,196.82**	**83,849.58**	

Watershed Characteristics

The Asotin Creek watershed rests within an elevation range of 228 meters (750 feet) at the City of Asotin, the pour point of the watershed, to a maximum of 1,891 meters (6,200 feet) in the western extent of the watershed. This topographic profile influences the composition of weather patterns, the geologic setting, stream channel form, and vegetative composition and growth. The Asotin Creek watershed supports fescue-wheatgrass (*Festuca idahoensis -Agropyron cristatum*), fescue-snowberry (*Symphoricarpos albus*), and fescue-hawthorn (*Crataegus spp.*) associations, as well as ponderosa pine (*Pinus ponderosa*) savanna and open ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) forests. Native fish species include Chinook salmon *Onchorhynchus tshawytscha*, steelhead and resident rainbow trout *O. mykiss*, Pacific lamprey, bull trout (*Salvelinus confluentus)* and several sculpin and minnow species.

Weather Data

A series of ten pseudo-weather stations were created within the Asotin Creek watershed to estimate daily weather station information for various points within the region. Currently there is a NOAA National Weather Service station located in Asotin; however, this station collects precipitation data but not daily maximum and minimum temperatures - the three inputs required to operate the SWAT model accurately. Within the Asotin Creek watershed the variation in daily temperature and precipitation extremes is striking. For instance, during the month of May, the average precipitation is approximately 35.56 mm (1.4”) in Asotin while it is 88.9 mm (3.5”) in the headwaters of the watershed (PRISM 2010).

A National Weather Service station located in Pomeroy, Washington, approximately 21 km (13 miles) from the northwestern extent of the Asotin Creek watershed provided daily precipitation, maximum and minimum temperatures. Data in the Pomeroy weather station extended from November 1, 1923 and continued through April 30, 2010, and provided a robust record of recent weather patterns.

Pseudo-weather station data were created to convert the daily weather data observed in Pomeroy, Washington, to apply to the Asotin watershed using adjustments calculated within the 50 years of data utilized in the PRISM model. The adjustments first created a relationship between the PRISM data summarized for the location of the Pomeroy weather station and the PRISM data collected for each of the ten pseudo-weather stations in the Asotin Creek watershed. Daily records collected in Pomeroy were then converted to daily records for each of the pseudo-weather stations using these monthly precipitation and temperature conversions. The result was a consistent record of observations for each of the ten pseudo-weather stations that displayed the variations reported in the PRISM data combined with the daily observations in Pomeroy. This relationship between the sites within the Asotin Creek watershed and the Pomeroy weather station relied on the assumption that weather systems that conveyed precipitation to Pomeroy also conveyed precipitation to sites within the Asotin Creek watershed. Since the distance between the watershed sites and Pomeroy is relatively minor (less than 35 km, 22 miles), the potential for bias is minimal.

Geologic Setting

Basalt is typical of large igneous provinces and is one of the most common rock types in the world. The ocean floor is almost completely made from basalt (Reidel 2006). Above sea level, basalt is common in hotspot islands and around volcanic arcs, especially those on a thin crust.

However, the largest volumes of basalt on land correspond to continental flood basalts (Hyndman 1985). The Columbia River Plateau is made of continental flood basalts (Reidel 2006) where the Asotin Creek watershed is located. Basalt rock parent materials dominate the geologic substrate of the Asotin Creek watershed.

The Columbia Plateau is in a geologic and geographic region that lies across parts of the U.S. states of Washington, Oregon, and Idaho. It is a wide flood basalt plateau located between the Cascade Range and the Rocky Mountains, cut through by the Columbia River (Hyndman 1985). In one of its various usages, the term "Columbia Basin" refers to more or less the same area as the Columbia Plateau (USGS 2000).

The Asotin Creek watershed is dominated by a substrate of basaltic formations such as the relatively young columnar basalt frequently seen in the lower reaches of the basin near the Snake River. During the cooling of a thick lava flow, contraction joints or fractures form. If a flow cools relatively rapidly, significant contraction forces build up (Sobolev *et al.* 2007). While a flow can shrink in the vertical dimension without fracturing, it cannot easily accommodate shrinking in the horizontal direction unless cracks form; the extensive fracture network that develops results in the formation of columns (Reidel 2006). The topology of the lateral shapes of these columns can broadly be classed as a random cellular network (Hyndman 1985). The size of the columns depends loosely on the rate of cooling; rapid cooling may result in small (<1 cm diameter, 0.40") columns, while slow cooling is more likely to produce larger columns (Sobolev *et al.* 2007, USGS 2000).

Compared to other rock types, basalts weather relatively fast. Chemical weathering of basalt minerals release cations such as calcium, sodium and magnesium, which give basaltic areas a strong buffer capacity against acidification (Hance 2010). Calcium released by basalts binds up carbon dioxide (CO_2) from the atmosphere forming Calcium Carbonate ($CaCO_3$) thus acting as a CO_2 trap (Sobolev *et al.* 2007; USGS 2000).

The underlying basalt in this region is up to 3 km (1.9 miles) thick and partially covered by thick loess soil deposits. Where precipitation amounts are sufficient, the deep loess soils have been extensively cultivated for wheat and other dry-land and irrigated farming crops.

Loess soils were deposited here by westerly prevailing winds near the end of the last glacial period. The Missoula Floods (also known as the Spokane Floods or the Bretz Floods) refer to the cataclysmic floods that swept periodically across eastern Washington and down the Columbia River Gorge at the end of the last ice age (Williams 2002). These glacial lake outburst floods were the result of periodic ruptures of the ice dam on the Clark Fork River that created Glacial Lake Missoula. After each ice dam rupture, the waters of the lake would rush down the Clark Fork River and the Columbia River, inundating and scouring much of eastern Washington and the Willamette Valley in western Oregon. After each rupture, the ice dam would reform, recreating Glacial Lake Missoula. Geologists estimate that the cycle of flooding and reformation of the lake lasted an average of 55 years and that the floods occurred several times over a 2,000-year period between 15,000 and 13,000 years ago (Bjornstad 2006).

The cumulative effect of the floods was to excavate 210 cubic kilometers (50.4 cubic miles) of loess soils, sediment and basalt to create the channeled scablands of eastern Washington and transport it downstream where the materials formed a great earthen dam across the Columbia River. Westerly winds conveyed the light soil materials in the earthen dam along prevailing winds to be deposited in the Mid- and Upper-Columbia Plateau.

Today, the loess soils are considered some of the most productive farming soils in the world but they are easily eroded (Getis *et al.* 2000). Loess is an Aeolian sediment formed by the accumulation of wind-blown silt and lesser and variable amounts of sand and clay (Neuendorf *et al.* 2005) that are loosely cemented by calcium carbonate. It is usually homogeneous and highly porous and is traversed by vertical capillaries that permit the sediment to fracture and form vertical bluffs. The fertility of Loess soils is not solely due to organic matter content (Getis *et al.* 2000). The organic matter productivity of loess soils, where native forestlands and shrub plant communities are present, can generate the organic matter needed to augment the nutrient profile. The areas farmed for agricultural purposes generally do not produce the organic matter recruitment to streams in the same quantities nor with the same timing as the native forestland and rangeland vegetation.

The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities and for soil classification. Soil structure is determined by how individual soil granules clump or bind together and aggregate, and the arrangement of soil pores between them. Soil structure has a major influence on water and air movement, biological activity, and root growth.

Soil structure describes the arrangement of the solid parts of the soil and of the pore space located between them (Marshall & Holmes 1979). It is dependent upon the soil's parent materials, the environmental conditions forming the soils, the abundance of clay materials, the organic materials present, and recent land management history.

Agricultural soils are considered to have good structure, when it is of "an aggregated, low density/high porosity condition" (Charman & Murphy 1998). From an aquatic biota productivity perspective, a well structured soil will enable robust biological activity by readily accepting, storing, and transmitting water, gases, nutrients, and energy, and by providing adequate and suitable surfaces and space for biochemical exchange (Charman & Murphy 1998).

Soil structure refers to the aggregation and structure of soil particles. Soil provides a habitat media for microbes including bacteria and fungi, and for microfauna such as aprotozoa and nematodes, mesofauna such as microarthropods and enchtraeids, and macrofauna such as earthworms, termites and millipedes (Bardgett 2005). The primary role of soil biota is to recycle and convert organic matter derived from the above-ground plant-based biota. Through this process, the biologic productivity of the soils is made available to aquatic vertebrates, and other biota.

Percent Clay

Clay as a soil component consists of mineral soil particles that are less than 0.002 millimeter (0.00008 inches) in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters (0.08 inch) in diameter. The amount and kind of clay affects the fertility and physical condition of the soil and the ability of the soil to adsorb cations and to retain moisture. They influence shrink-swell potential, saturated hydraulic conductivity (Ksat), plasticity, the ease of soil dispersion, and other soil properties. The amount and kind of clay in a soil also affects tillage and earth moving operations. Clay colloids play an important role in aggregation between the full range of soil particles (Leeper & Uren 1993). Adhesion between particles is accomplished through electrostatic force (flocculation) or cementing substances, such as clay, organic matter, and particulate minerals. An abundance of clay can lead to clumping of the soil while an absence of clay can lead to excessive wind and water erosion.

Most of the material in the Asotin Creek watershed is in one of three groups of clay minerals or a mixture of these clay minerals. The groups are kaolinite, smectite, and hydrous mica, the best known member of which is illite.

High clay concentrations expressed as a percent are neither favorable to Pacific lamprey spawning nor aestivation. Generally, sites with a clay content in the stream greater than about 25% by weight have not been observed as suitable lamprey habitat. The Asotin Creek watershed does not exhibit sites with clay content greater than about 30% (Table 3).

Percent Sand

Sand as a soil component consists of mineral soil particles that are 0.05 millimeter (0.002 inch) to 2 millimeters (0.08 inch) in diameter. In the soils database generated for this effort, the estimated sand content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters (0.08 inch) in diameter (Figure 5).

Although Pacific lamprey ammocetes have been found in most substrate sizes, densities are highest in areas with moderate to high sand and silt content and slow (<40 cm/s) water velocities (Claire 2004). In areas with large (cobble and boulder) substrate, ammocetes are likely inhabiting fine sediments between larger substrate. High sand concentrations expressed as a percent are considered favorable to Pacific lamprey aestivation sites when it is observed in combination with relatively high silt content (greater than 50% in combination) (USFWS 2010). Generally, stream sites are influenced by the sand content recruited in the stream and from contributory sites that are transported into the stream. The Asotin Creek watershed exhibits sites with sand content in excess of 30% of the total mass by weight (Table 3).

Percent Silt

Silt as a soil component consists of mineral soil particles that are 0.002 (0.00008 inches) to 0.05 millimeter (0.002 inch) in diameter. In the database created for this watershed, the estimated silt content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters (0.08 inch) in diameter (Figure 6).

The share of the soil derived from the combination of sand and silt has a contributory effect on determining the quality of a stream segment for aestivation. The Asotin Creek watershed exhibits several sites with silt content in excess of 30% of the total mass by weight (Table 3). Where sand and silt is combined to make up in excess of 50% of the particle matter in the stream segments, those reaches are considered beneficial for aestivation sites.

Surface Texture

Surface Texture conveys the representative texture class and modifier of the surface horizon. Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. "Loam," for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is ≥15%, an appropriate modifier is added, for example, "gravelly." These textures are summarized by area of the total watershed in Table 3.

Table 3. Surface Soil and Geologic Characteristic Suitability for contribution to Spawning and Aestivation Sites in Asotin Creek.

Surface Texture	Acres	Hectares	Expressed as % by Weight			Spawning Habitat	Aestivation Sites
			Sand	Clay	Silt		
Clay loam	16,671	6,747	39.2%	23.5%	37.3%	■	■
Cobbly silt loam	103	42	26.1%	21.5%	52.4%	▲	▼
Extremely cobbly loamy sand	248	100	81.1%	2.5%	16.4%	▲	▲
Extremely stony sandy loam	40	16	66.8%	14.0%	19.2%	▼	▼
Loam	481	195	45.9%	10.2%	43.9%	▼	▲
Loamy fine sand	480	194	85.9%	7.5%	6.6%	▼	▼
Silt loam	115,069	46,567	25.2%	16.9%	57.9%	▲	▲
Silty clay loam	13,216	5,348	19.0%	30.6%	50.4%	▼	▼
Stony loam	3,618	1,464	40.8%	20.9%	38.3%	▲	▼
Stony silt loam	4,703	1,903	27.4%	18.8%	53.8%	▼	▼
Very cobbly loam	528	214	39.2%	23.5%	37.3%	▼	▼
Very cobbly sandy loam	24	10	65.9%	15.0%	19.1%	▼	▼
Very gravelly sandy loam	21	8	65.9%	15.0%	19.1%	▼	▼
Very stony clay loam	16,076	6,506	35.1%	30.3%	34.6%	▼	▼
Very stony loam	20,651	8,357	42.1%	20.0%	37.9%	▼	▼
Very stony silt loam	15,259	6,175	24.8%	22.5%	52.7%	▼	▼
Total	**207,191**	**83,847**					

Key

▲ Suitable
▼ Unsuitable

■ Not Applicable

Organic Matter

Organic matter is the plant and animal residue in the soil at various stages of decomposition. The estimated content of organic matter is expressed as a percentage, by weight, of the soil material that is less than 2 millimeters (0.08 inch) in diameter.

The content of organic matter in a soil is contributed by plants during the annual cycle of dropping leaf and needle litter, and at other times, and it can be maintained while farming by returning crop residue to the soil. Organic matter has a positive effect on available water capacity, water infiltration, soil organism activity, and tilth. It is a source of nitrogen and other nutrients for aquatic life, vegetation including crops, and soil organisms. An irregular distribution of organic carbon with depth may indicate different episodes of soil deposition or soil formation. Soils that are very high in organic matter have poor engineering properties and subside upon drying.

Organic matter in the soil is considered a necessary component of the nutrient cycle providing nutrients in the hydrologic cycle to aquatic plants, invertebrates and eventually fish. Two components of the organic matter cycling into streams is considered: 1) organic matter contributed directly into a stream (detritus dropped directly into a stream), and 2) organic matter contributed to the soil surface that is transported through surface-water flow and subsurface water flow into the streams.

Within the Asotin Creek watershed, the western headwaters, where deciduous and conifer tree species are found, the contribution of organic matter is substantially higher than the contributions made by the rangelands and grasslands of this region (Table 4). Approximately 75% of this watershed shows an organic matter content between 2.0% and 4.5% by weight. The highest content of organic matter is located on those sites that are currently, and were historically, occupied by evergreen tree species. This juxtaposition of relatively high organic matter content in the headwaters of the watershed provides a favorable transport mechanism to the stream sites where aestivation occurs (Table 4, Figure 7). It is doubtful that the organic matter content is a driving factor in the selection of sites for spawning; however, to the extent that Pacific lamprey spawning may be influenced by the presence of juvenile lamprey upstream of the potential spawning site, the organic matter content may be considered significant.

Table 4. Organic Matter Content for contribution to Spawning and Aestivation Sites in Asotin Creek.

Organic Matter Percent by Weight	Group	Acres	Hectares	Percent of Total Area
0.5	<=2	248	100	0.12%
0.75	<=2	480	194	0.23%
1.5	<=2	22,805	9,229	11.01%
2	<=2	13,662	5,529	6.59%
2.5	>2 and <=3.5	31,862	12,894	15.38%
3	>2 and <=3.5	30,312	12,267	14.63%
3.5	>2 and <=3.5	17,529	7,094	8.46%
4	>3.5 and <=5.5	51,439	20,817	24.83%
4.5	>3.5 and <=5.5	10,649	4,310	5.14%
5	>3.5 and <=5.5	4,517	1,828	2.18%
5.5	>3.5 and <=5.5	807	327	0.39%
6	>5.5 and <=7	18,507	7,490	8.93%
6.5	>5.5 and <=7	2,170	878	1.05%
7	>5.5 and <=7	2,204	892	1.06%
Total		**207,191**	**83,849**	

Hydrologic Setting

Based on the most recent 17-year time span (1991-2008), Asotin Creek has a median discharge of 236,584 m^3/day (96.7 ft^3/second) at the confluence with the Snake River in the City of Asotin (USGS 2010). Based on the 75-year period extending from 1934 through 2009, the analysis conducted in SWAT estimated an average discharge of 248,400 m^3/day (101.5 ft^3/second) at the confluence with the Snake River in the City of Asotin. The USGS acknowledges that the quality of the records of measure for discharge in this sub-basin watershed is rated as “poor”, owing to the several diversions in the stream used for irrigation (USGS 2010). That being considered, the daily discharge between the measured quantity (by the USGS) and the projected quantity (through the use of the SWAT model) provides rates within about 5% of each other. This quantity of difference can easily be dismissed as owing to the surface water diverted to irrigation. At the same time, we note that the SWAT model is not a "regulatory" tool for watershed modeling, but should be considered a robust means to assess watershed processes and management actions.

The results of the SWAT analysis reveal several factors of significance and are summarized by stream segment in Table 6, and by sub-basin watershed in Table 7. The sub-basins and stream segments are displayed graphically in Figure 4 - Figure 17.

Discussion

Aestivation Sites

Favorable habitat criteria for Pacific lamprey have been determined for this assessment to consider first the sites conducive to aestivation. Some conditions are believed obligatory (no long-term dewatering), while others can be expressed as increasing in quality as the characteristic increases (e.g., increased amounts of nutrient laden organic matter in the stream). These characteristics include:

1. Sites that are not prone to dewatering from regular stream-flow patterns,
2. Sites that possess a combination of:
    a. Combined sand and silt expressed as a percent by weight, greater than 50% in combination,
    b. Neither sand nor silt individually, below 25% each expressed as a percent of weight,
    c. Locations within the stream bank that can support pooling and sedimentation in association with stream side vegetation that do not remain dewatered for extended periods of time,
3. Nutrient cycling within Sub-basin Watersheds that contribute;
    a. Organic matter contents of stream-conveyed particles greater than 2.5% by weight
    b. Organic Nitrogen in excess of 5.0 kg/ha (4.5 pounds/acre)
    c. Nitrogen Surface Runoff in excess of 0.50 kg/ha (0.45 pounds/acre)
    d. Organic Phosphorus in excess of 1.0 kg/ha (0.89 pounds/acre)
    e. Sediment Phosphorus in excess of 0.10 kg/ha (0.9 pounds/acre)
    f. Soluble Phosphorus in excess of 0.010 kg/ha (0.009 pounds/acre)
4. Nutrient Transport by Stream Segments that convey;
    a. Mineral Phosphorus in excess of 1,000 kg/year (2,204 pounds/year)
    b. Organic Nitrogen in excess of 200,000 kg/year (440,925 pounds/year)
    c. Organic Phosphorus in excess of 25,000 kg/year (55,116 pounds/year)

Dewatering

Dewatering as estimated here is the event of additional water not being added to the stream network from either surface water flows, or from upstream segments. The occurrence of one day of dewatering does not generally mean that the stream becomes completely “dry”. Dewatering that continues for extended periods of time can lead to a dry stream, but depending on the water storage capacity of the stream, it does not necessarily mean a complete evacuation of all waters. A temporary dewatering event can be seen as pools of stagnant water throughout the stream segment. Prolonged dewatering event will witness these pools shrinking, followed by complete evacuation of the waters.

Dewatering can happen because of:

1. Lengthy periods without precipitation,
2. Freezing weather stopping stream flow,
3. Irrigation removals incompatible with the stream flow,
4. Or a combination of these events.

Dewatering can be problematic for Pacific lamprey aestivation sites because the juvenile fish rear in freshwater habitats for 4 years or more after hatching. Salmonid species begin their life cycle in much the same way as lamprey, but after hatching, their life cycle involves mobilization to lower reaches of the river networks, often to major rivers such as the Snake River within a few months of hatching. Although we do not know of the level of mobility of lamprey juveniles in streams, dewatering events in Asotin Creek could conceivably trap juvenile lamprey in stream bank sediments leading to desiccation and death.

Within Asotin Creek, this analysis effort has identified 29 unique stream reaches (Figure 4). A single reach has been identified as a stream segment that carries water from one sub-basin watershed (Figure 4) and conveys water through one continuous stream. When the stream segment intersects another stream segment, a new segment (additive) is formed.

In our analysis, dewatering has occurred within 21 of the 29 streams assessed (72%). Only 8 stream segments have remained completely watered during this 15 year period of analysis (Table 5). The most frequent month of dewatering, in this watershed, was July with 661 dewatering events (Figure 9) combined for all 29 stream segments over the 15 years of investigation (Figure 10).

An event of a single day of dewatering may not be sufficient to completely expatriate the juvenile lamprey in that segment. However, when dewatering continues for several consecutive days, it is reasonable to assume that mortality will be probable. Table 5 includes a column titled "**Maximum Consecutive Days Dewatered**" for each stream segment. The longest period of dewatering was estimated for segment №33 (Pintler Creek) where 46 consecutive days were estimated in one event. Other segments experienced lengthy dewatering periods as well (Table 5).

The George Creek subbasin and all of its upstream tributaries show problematic conditions because of dewatering. Site visits confirm George Creek to be mostly dewatered during the summer of 2010, with few fine sediment deposits available, mostly disconnected from the stream channel. The main fork of Asotin Creek, continuing through the lower 42 km of stream segments appears to maintain a consistently watered condition (Figure 10).

Sand and Silt

Juvenile lamprey are common along stream banks and sometimes in the main channels where the composition of sand and silt is sufficient to provide cover.

Sediment concentration for each stream segment is presented graphically within the Asotin Creek watershed (Figure 4), and in tabular form for sub-basin watersheds (Table 7) and that amount conveyed by stream segments (Table 6). The components of sediment recruitment and conveyance downstream appear to provide relatively high concentrations of sand and silt within the mainstem Asotin Creek, but not within the George Creek sub-basins. George Creek uplands are used to a high degree for agricultural purposes, while much of the main fork of the upper Asotin Creek drainage supports forest tree species (Figure 4).

As noted above, deposits of fine sediments were lacking in George Creek and those present were largely dewatered. The middle and upper segments of the mainstem Asotin Creek appeared to have usable levels of fine sediment deposits as predicted, however, the lower reaches (< rkm 10) contained noticeably fewer fine depositional areas (Figure 3). This segment of the valley floor has the higher density of residential housing and may be disproportionately affected by channelization and other land use practices.

Geologically, the Asotin Creek sub-basin is composed of a greater manifestation of aged basalt soils that convert sand and silt to the streams more readily than those derived from columnar basalt formations where the basalt is "younger". For these reasons, and other identified here, the main fork of Asotin Creek would seem to provide a higher quality of Pacific lamprey aestivation sites.

Nutrient Cycling

Pacific lamprey in their juvenile state feed on algae and other microfauna and detritus moving through the water column and found within the sediments. It is logical to conclude that stream segments providing the conditions to support these stream biotic and abiotic conditions would present a favorable aestivation site. The contribution of nitrogen (Figure 16, Figure 17), phosphorus (Figure 12, Figure 13, Figure 15), and organic matter (Figure 7), show the differential contributions of the sub-basin watersheds to the streams in this watershed. Tabular data confirms these concentrations for sub-basin watersheds (Table 7) and that amount conveyed by stream segments (Table 6).

While organic contributions are relatively low in the lower reaches of the watershed, where rangeland grasses dominate the vegetative profile, the upper reaches of the watershed uniformly provide higher concentrations of organic matter. The forestland vegetative profile found in the headwaters of Asotin Creek provide the highest concentration of small organic debris to the stream.

Preferred Aestivation Site Potentials

The analysis of the graphical and tabular data presented in this section of the analysis identifies the main fork of Asotin Creek as the preferred stream channel network capable of supporting Pacific lamprey aestivation sites. This stream as a linear network, provides the potential for nearly 40 km of suitable habitat for juvenile lamprey rearing. Of notable mention is the low number of dewatering events experienced within this series of stream segments, the high concentration of organic matter supplied to the stream to support primary production, the presence of sands and silts, and the occurrence of suitable substrate during the prolonged period of aestivation. As noted, approximately the lower 10 km of Asotin Creek appears to have lower levels of juvenile rearing habitat than were predicted by the models possibly due to impacts from current land use practices that confine the stream channel and effectively increase stream gradient.

It is doubtful that the George Creek watershed can support substantial populations of Pacific lamprey aestivation. Several deficiencies have been identified that limit the potential for these sites to provide the obligatory conditions for Pacific lamprey rearing.

Concerns for sustained aestivation site potential within these sub-basin watersheds include the presence of irrigation drafting points along this network. Several sites were observed in September 2010, actively pumping water out of the river for irrigation and livestock. Natural dewatering events can be exacerbated by irrigation removals and should be monitored closely to prevent population-level mortality events. Other concerns within the Asotin Creek watershed include the presence of roads that confine the historical floodplain and limit the natural occurrence of shore-line vegetation and sand and silt deposits where juvenile Pacific lamprey are commonly found.

Stream crossings within the Asotin Creek watershed are uniformly built to elevate the crossing above the high water mark of the streams while not constricting the stream's width or flow capacity. In other drainages across the west, this condition has not been so favorably managed.

Spawning Sites

The quality of adult Pacific lamprey spawning sites is influenced by barriers that may prevent Pacific lamprey from reaching spawning areas, adequate substrate suitable for creating redds, and potentially presence of juvenile Pacific lamprey that may serve as an attractant.

Spawning Substrate

Spawning substrate has been articulated within Figure 18 and Figure 19 in terms of the parent site materials available for spawning fish. Realistically, the ability of geospatial models to accurately predict where suitable, or favorable, spawning habitat is located, is marginal. The only feasible analysis is limited to observing the presence or absence of potential spawning habitat.

Pacific lamprey cannot spawn within all the stream segments that salmon can utilize mainly due to lamprey's smaller size. Lamprey require a small diameter gravel, with silt and sand overburden in order to create a redd and spawn. These conditions are observed within the main fork of Asotin Creek from the confluence with the Snake River up to approximately river kilometer 27, and possibly as far as river kilometer 30. Along these stretches of the stream network, the presence of stony loam and silt loam materials is frequent. Upstream from this point substrate size increases and likely produce poor spawning habitat.

Physical Barriers

Pacific lamprey are relatively weak swimmers compared to anadromous salmonids. When faced with high water velocities (>4-6 fps) they resort to attaching to substrate using their sucker-like mouth and burst movements as a means to traverse passage bottlenecks. If conditions allow, they have been known to climb vertical surfaces to traverse obstacles, but structures such as hanging culverts and overhangs can block lamprey passage. On the main fork of Asotin Creek, Headgate Dam (rkm 15.5) may act as a passage barrier under moderate to low flow conditions. This in-stream feature was constructed for the purposes of irrigation water retrieval and appears passable for anadromous salmonids.

In the introduction to this report, a story was conveyed that Asotin County resident Frank Schiebe, who was the operator of Headgate Dam from 1954 – 1960, on the main Asotin Creek, recalls that numerous lampreys could be seen maneuvering over the headgate dam during spawning runs. Although this report confirms that Pacific lamprey can traverse the barrier to passage, it is asserted in this report that the existing headgate dam is a barrier to "free passage" for the adult spawners. The removal of this dam, now non-operational, or the installation of a lamprey passage structure, would facilitate use of available habitats upstream from this structure.

Habitat Modifications

The modification of natural vegetation habitat associations and the removal of large woody debris in and around Asotin Creek channels have decreased the resilience of the hydrologic system to natural disturbances and increased the rate of potential fisheries habitat transformations. Higher rates of habitat transformation may result in the loss of complex life history patterns as well as the widespread variation in physical traits and behavior that are beneficial for lamprey aestivation sites. The construction of roads, bridges, road structures (such as riprap armoring within the lower Asotin Creek watershed) has altered or blocked terrace tributaries and historically active overflow channels used as lamprey habitat.

The impacts of riprap amoring of the roads within the watershed are pronounced near the pourpoint into the Snake River from rkm 2.0 to rkm 2.6, and along the main channel of Asotin Creek from rkm 3.5 to rkm 4.6, from 9.8 to rkm 11.4, from rkm 12.0 to rkm 13.5, from rkm 15.2 to rkm 15.8, from rkm 17.6 to rkm 18.3, from rkm 19.2 to rkm 20.0, near rkm 21.5, and from rkm 23.9 to rkm 24.5. The long term impact of the riprap has been to remove the riparian habitat historically located along the northern stream terraces where Asotin Creek Road is currently located. The riprap materials extend into the current stream meanders where sediment deposition has been decreased in part due to increased stream velocity through these large rock materials. Further alteration of the stream’s natural hydrologic process can be witnessed on the adjacent, but opposite shorelines, where the stream has become entrenched in the substrate due to the increased stream velocity and reduced sediment deposition.

The Asotin Creek long-term restoration goals, for all anadromous fish species, needs to provide for population enhancements (spawning and rearing), ecological processes, and increased opportunity for ceremonial harvesting. Barriers to passage for adults and aestivation site usage must be addressed in this watershed to return it to historical productivity.

Proximity of Spawning and Rearing Habitats

We are just starting to lean of the interactions that occur between juvenile and adult lamprey life stages. Once larvae lamprey hatch, they enter the water column and drift downstream, likely seeking low velocity areas that contain fine sediment deposits that appear to be their preferred rearing habitat. In surveys we have conducted in Asotin and other streams, we have found that rearing habitats should occur within 1 km, and probably within 0.5 km of spawning areas and, since juvenile lamprey do not appear to move upstream, are usable only downstream of areas used for spawning (C. Peery, USFWS, unpublished data). Our understanding of the factors that attract adult Pacific lamprey to select spawning areas is limited. One current theory is that adult Pacific lamprey are attracted to chemical cues released by conspecific adults and juveniles. Specifically, adult migrants will enter tributary streams with rearing juvenile lamprey in response to pheromones released by juveniles (Fine *et al.* 2004; Wagner *et al.* 2006). This theory has not been tested with Pacific lamprey although the ability to detect lamprey bile acids has been demonstrated (Robinson *et al.* 2009). If this effect occurs with Pacific lamprey, use of Asotin Creek for spawning will be modified by the presence or absence of juvenile production within the basin.

Conclusions

This report summarized the findings of a virtual analysis of the Asotin Creek watershed with a minimal amount of site specific reconnaissance. Although electrofishing surveys were conducted within the watershed, the results have not been fully integrated into the findings of this report. We have documented that the watershed was positively affected by the release of adult Pacific lamprey collected within the lower Columbia River basin. The electrofishing surveys revealed juvenile lamprey in measurable numbers near and approximately 3 km downstream of the adult lamprey release sites. Few juvenile lamprey were observed in the lower segment of Asotin Creek previously identified as having relatively poor rearing habitat. The adult release sites were selected for their “favorable” characteristics also identified in this report. Thus, the use of those electrofishing data to support any watershed-specific usage frequency associated with the habitat analysis conducted will be biased to areas were adult lamprey were released.

Future use of these data can be applied to the selection of favorable habitat conditions and applied management activities that support the site’s inherent ability to sustain populations of Pacific lamprey. In this case, the support of management activities along the main fork of Asotin Creek would be appropriate, while the same efforts within the George Creek sub-basin may be less effective. Specifically, removing the passage barrier at Head Gate Dam and improving the quantity and quality of habitat in the lower segment of Asotin Creek appear to be the management actions that would have the greatest positive effect on lamprey production potential within the watershed.

The analyst and site manager is encouraged to acquire these geospatial data, understand the implications, and implement targeted management activities to improve Pacific lamprey habitat where site conditions show a positive response potential to change.

Figure 1. Asotin Creek Locator Map.

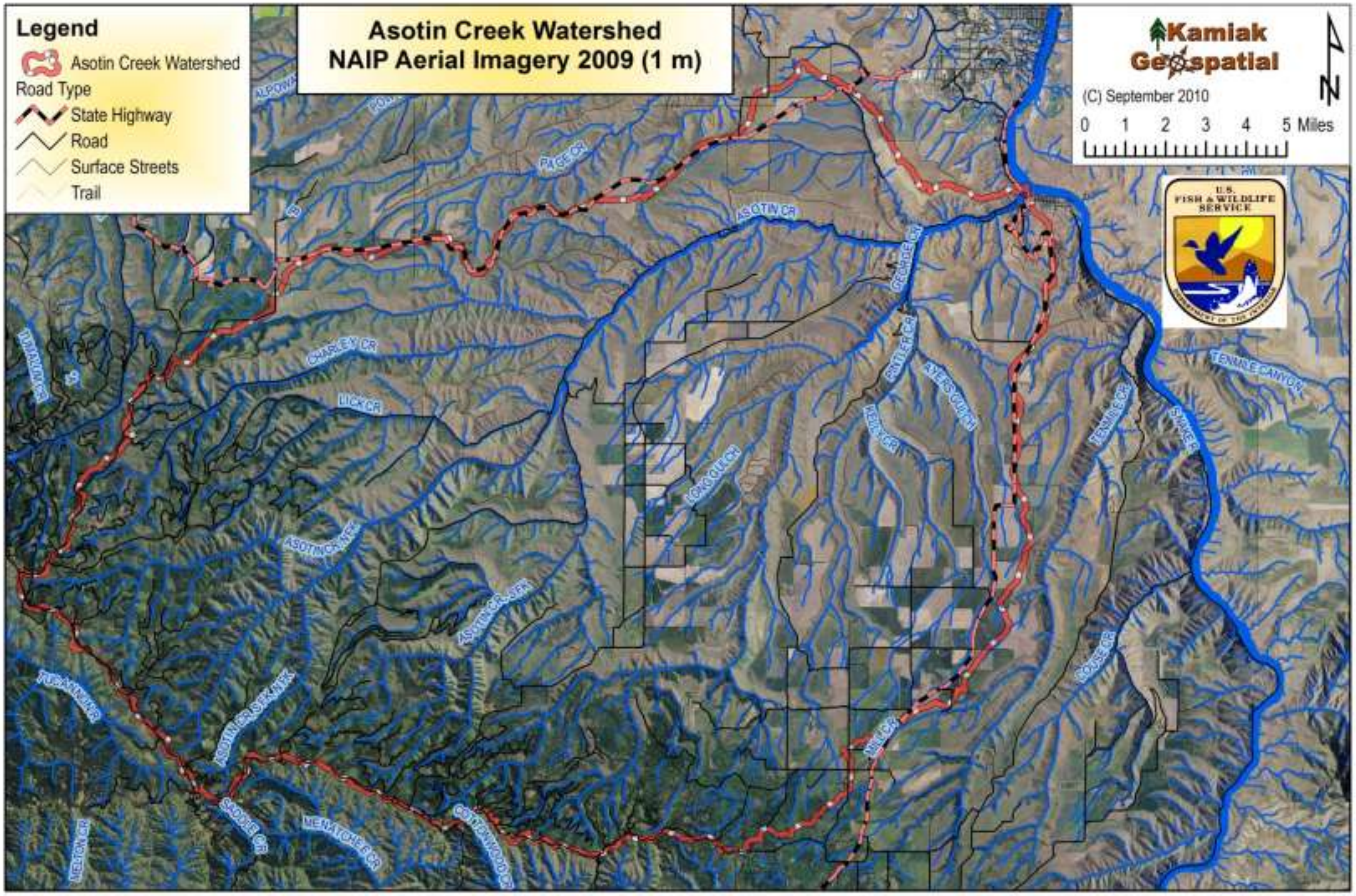


Figure 2. Asotin Creek Watershed boundaries and NAIP color aerial imagery, 2009.

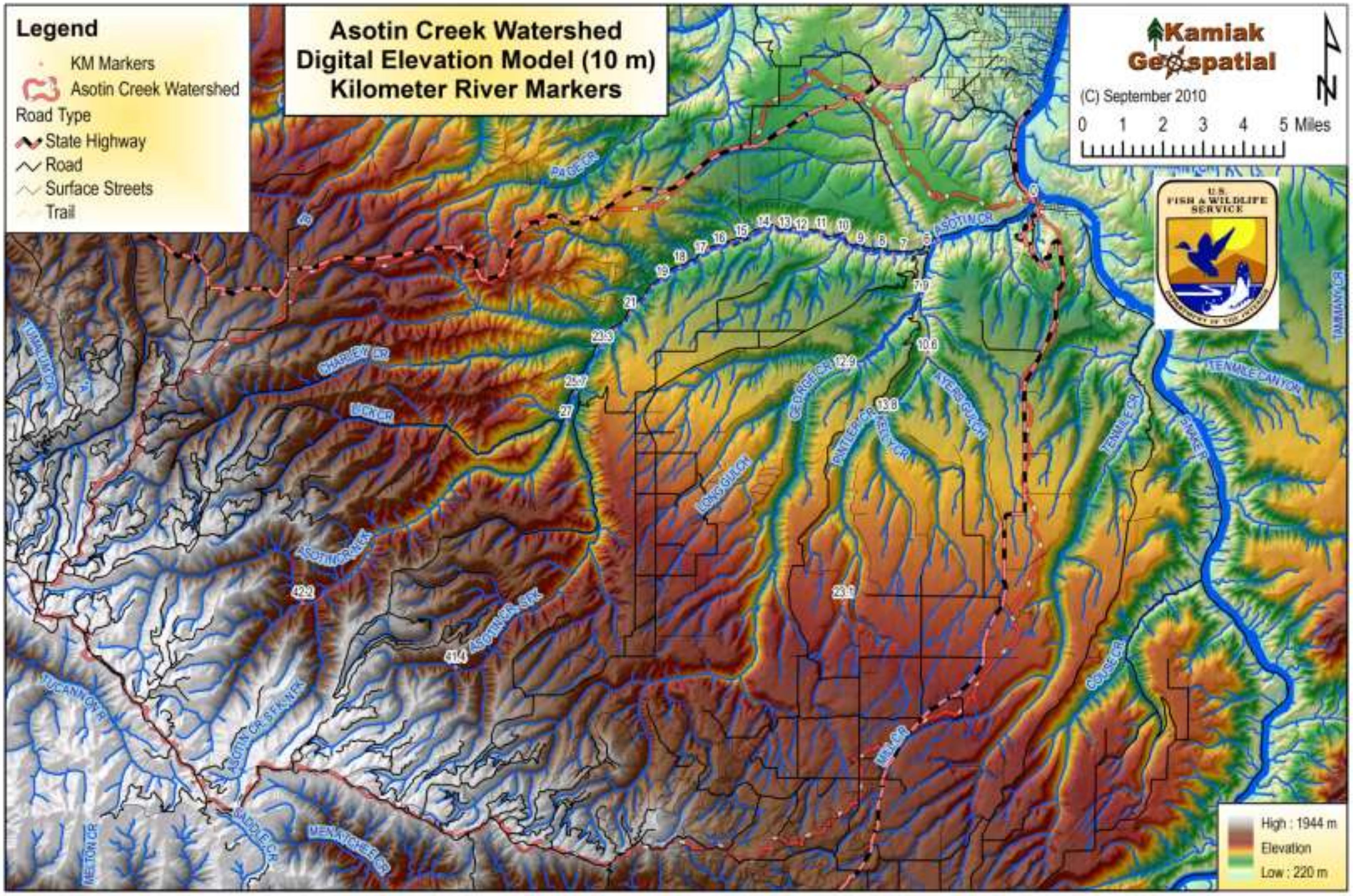
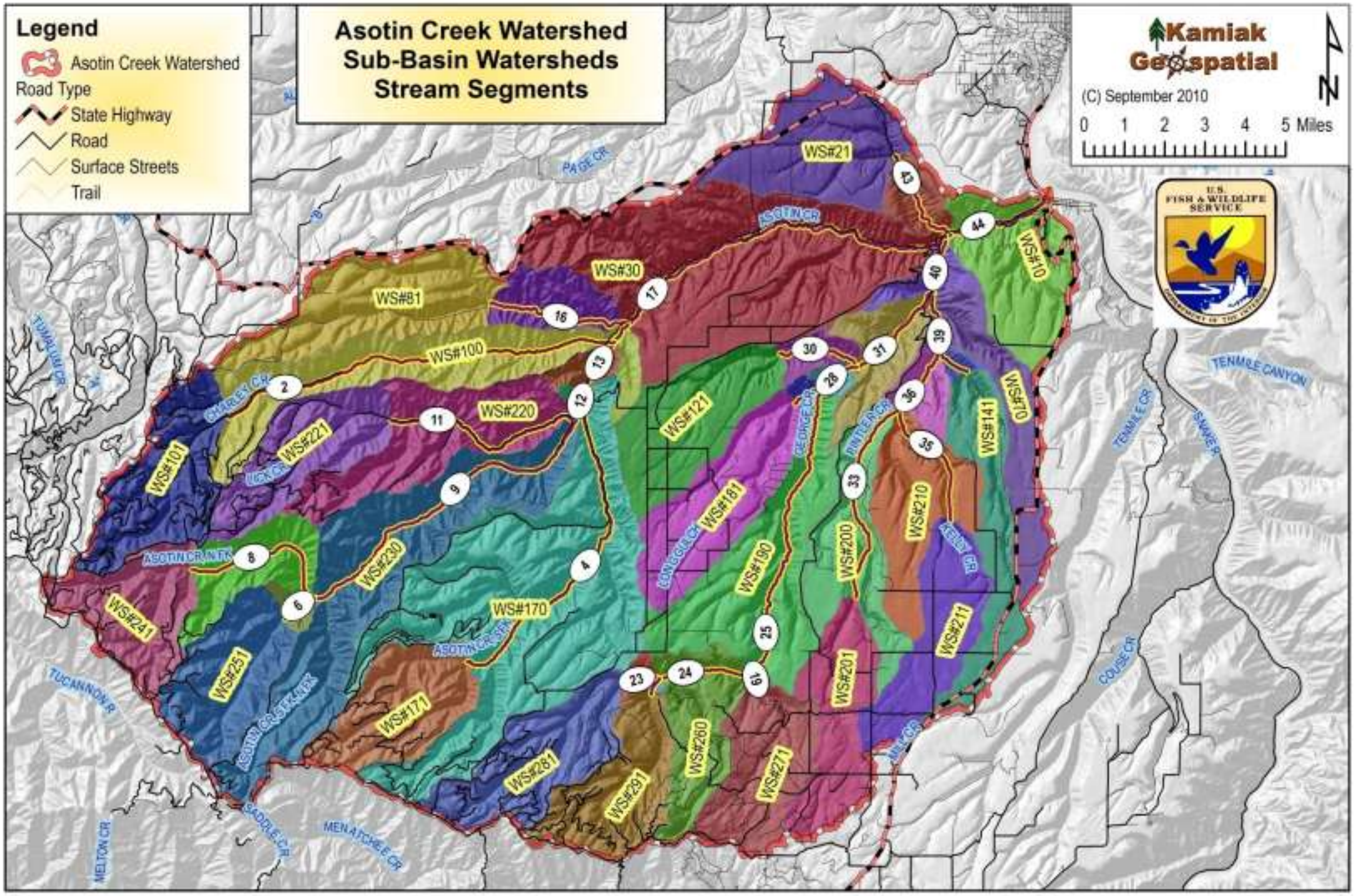


Figure 3. Topography and kilometer markers from pour point.

Figure 4. Sub-Basin Watersheds and Stream Segments.



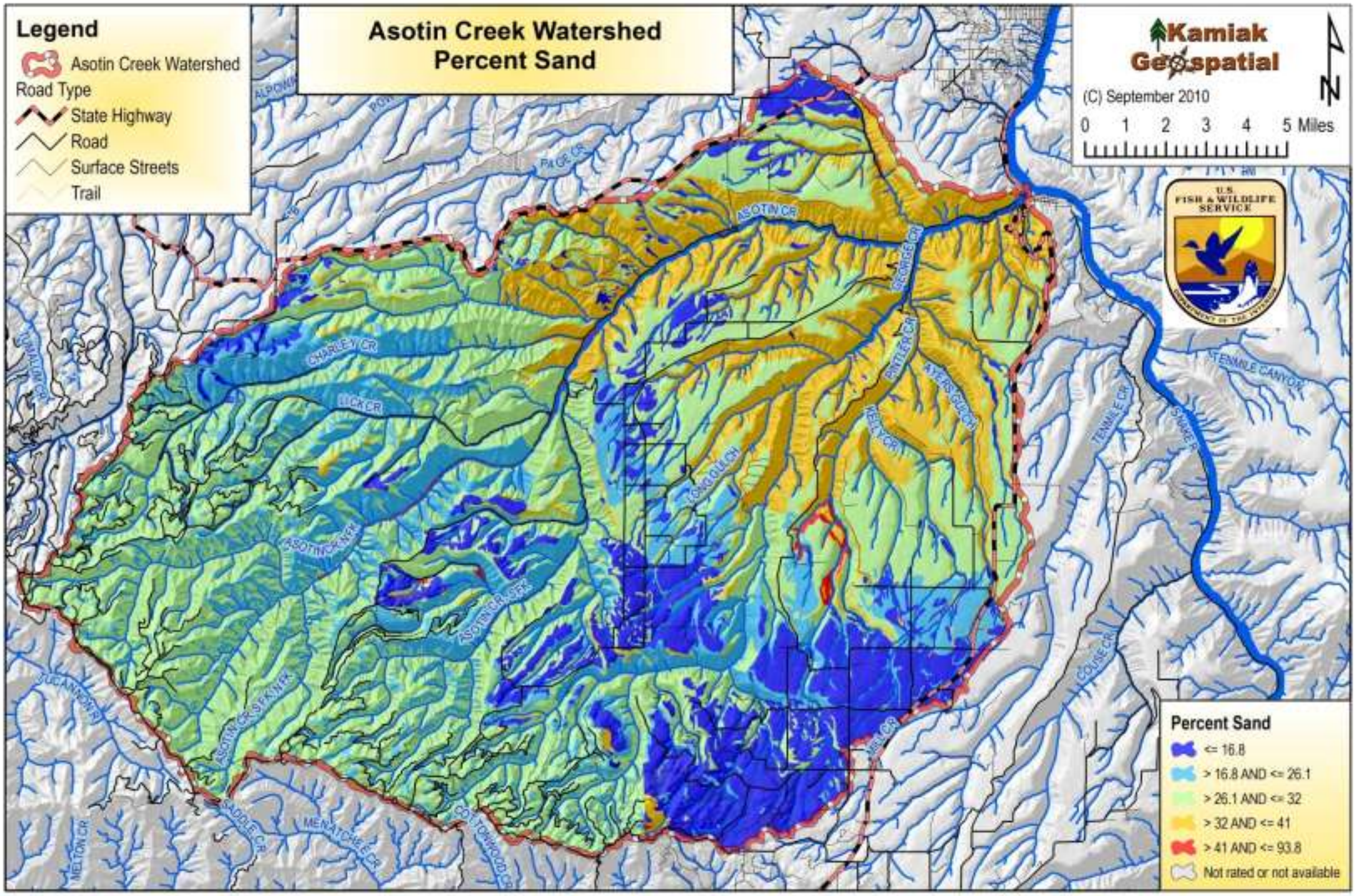
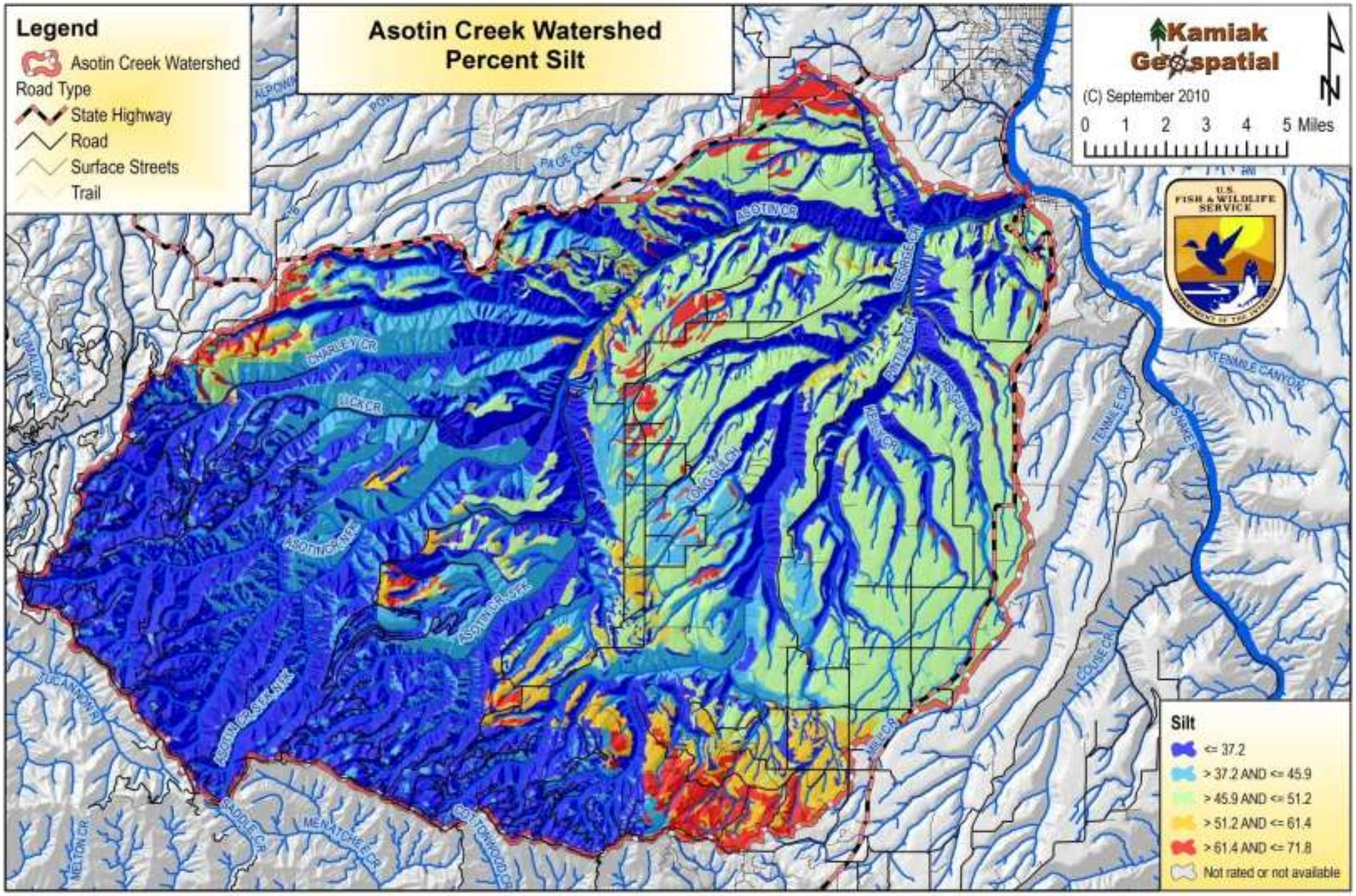


Figure 5. Sub-Basin Watershed Sand Contribution Potential to Streams.

Figure 6. Sub-Basin Watershed Silt Contribution Potential to Streams.



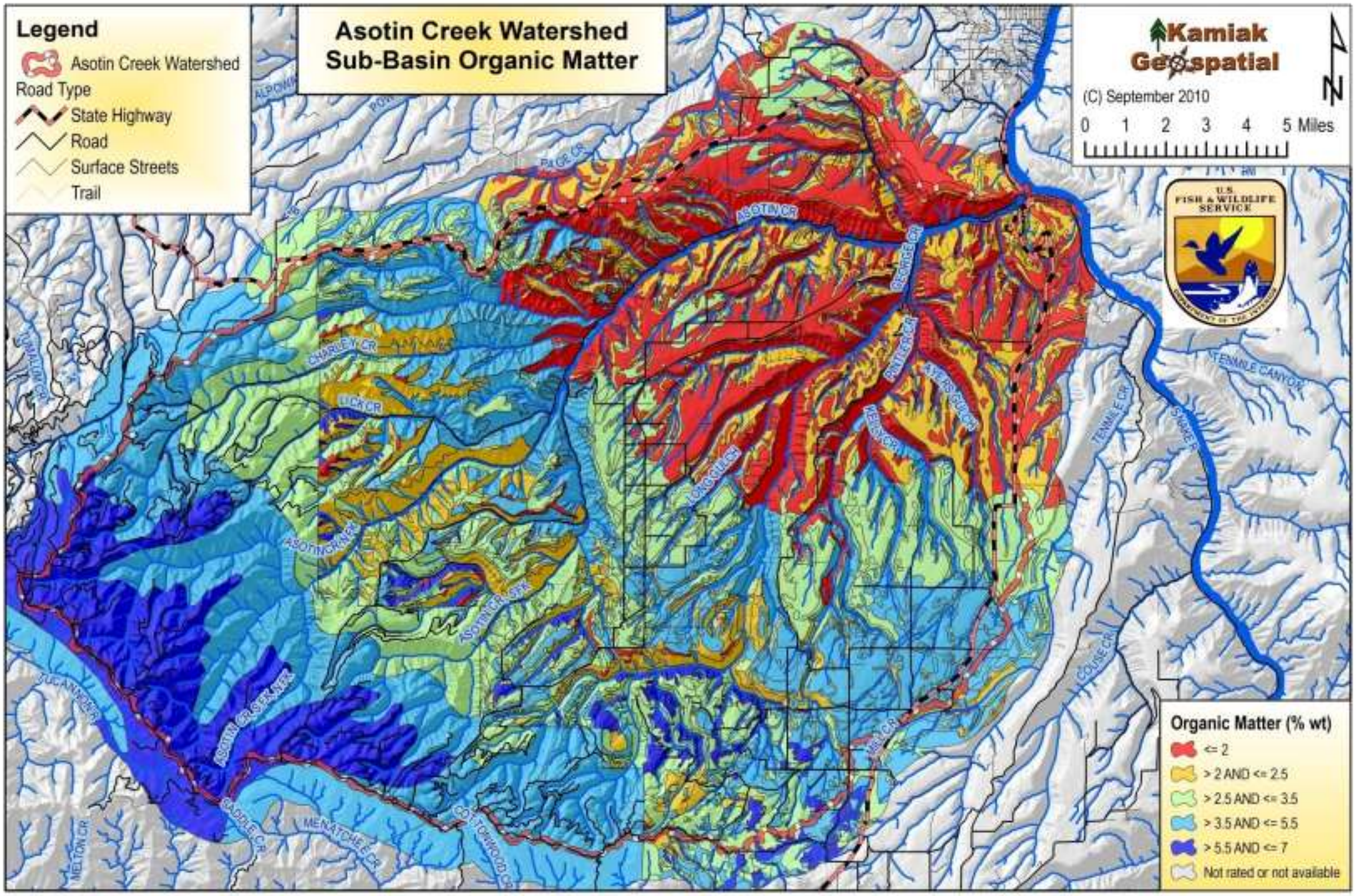


Figure 7. Sub-Basin Organic Matter.

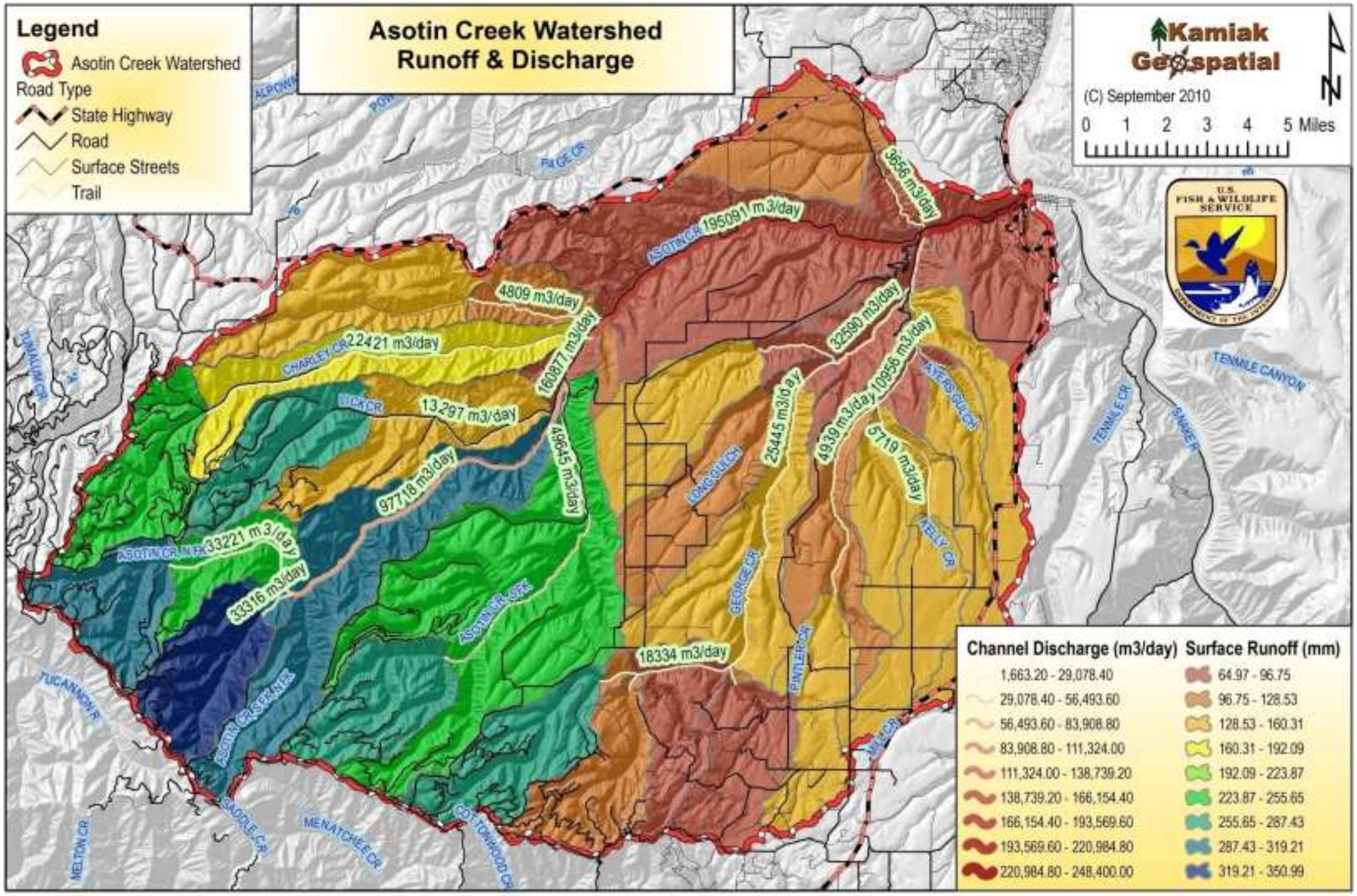
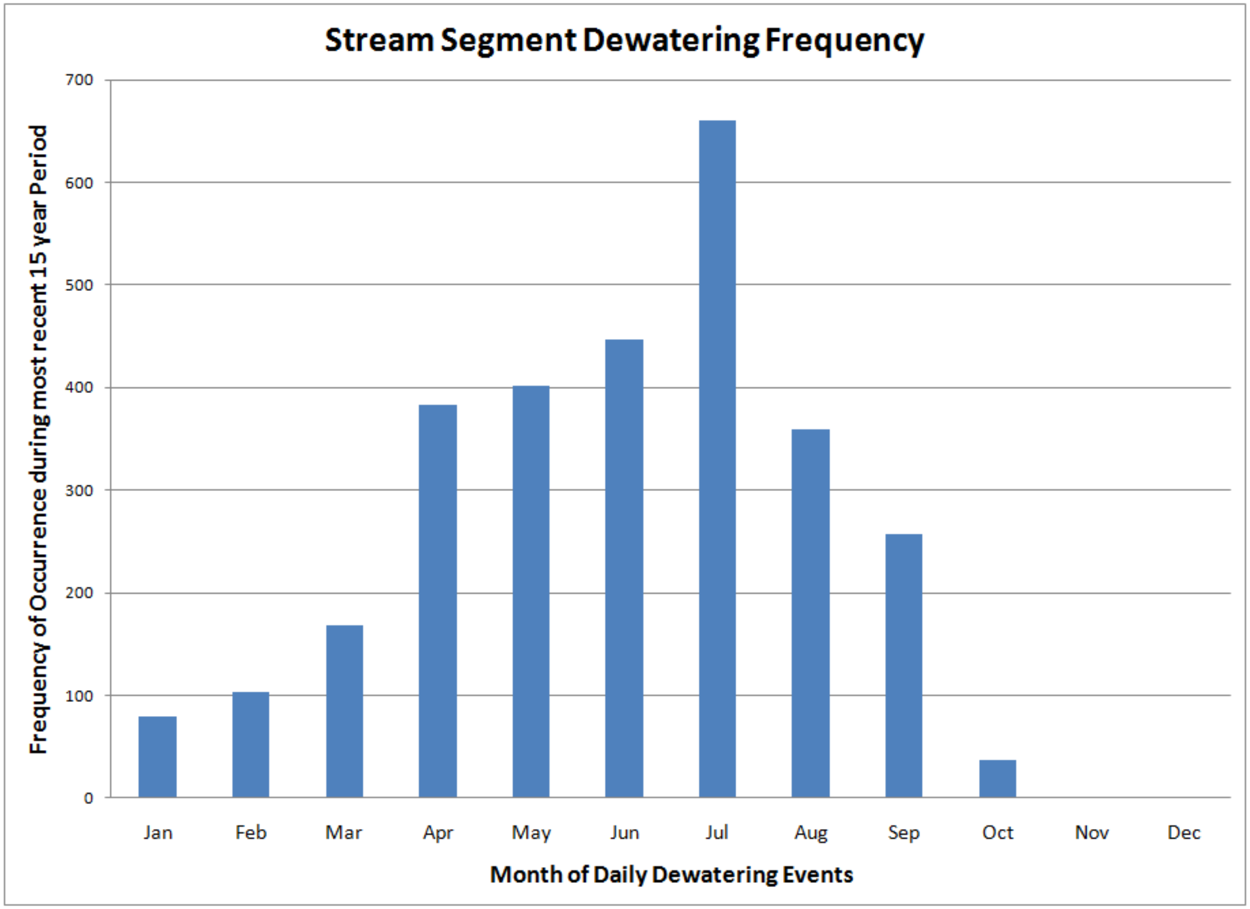


Figure 8. Surface Runoff and Channel Discharge.

Figure 9. Stream Reach Dewatering Frequency, 1994-2009.



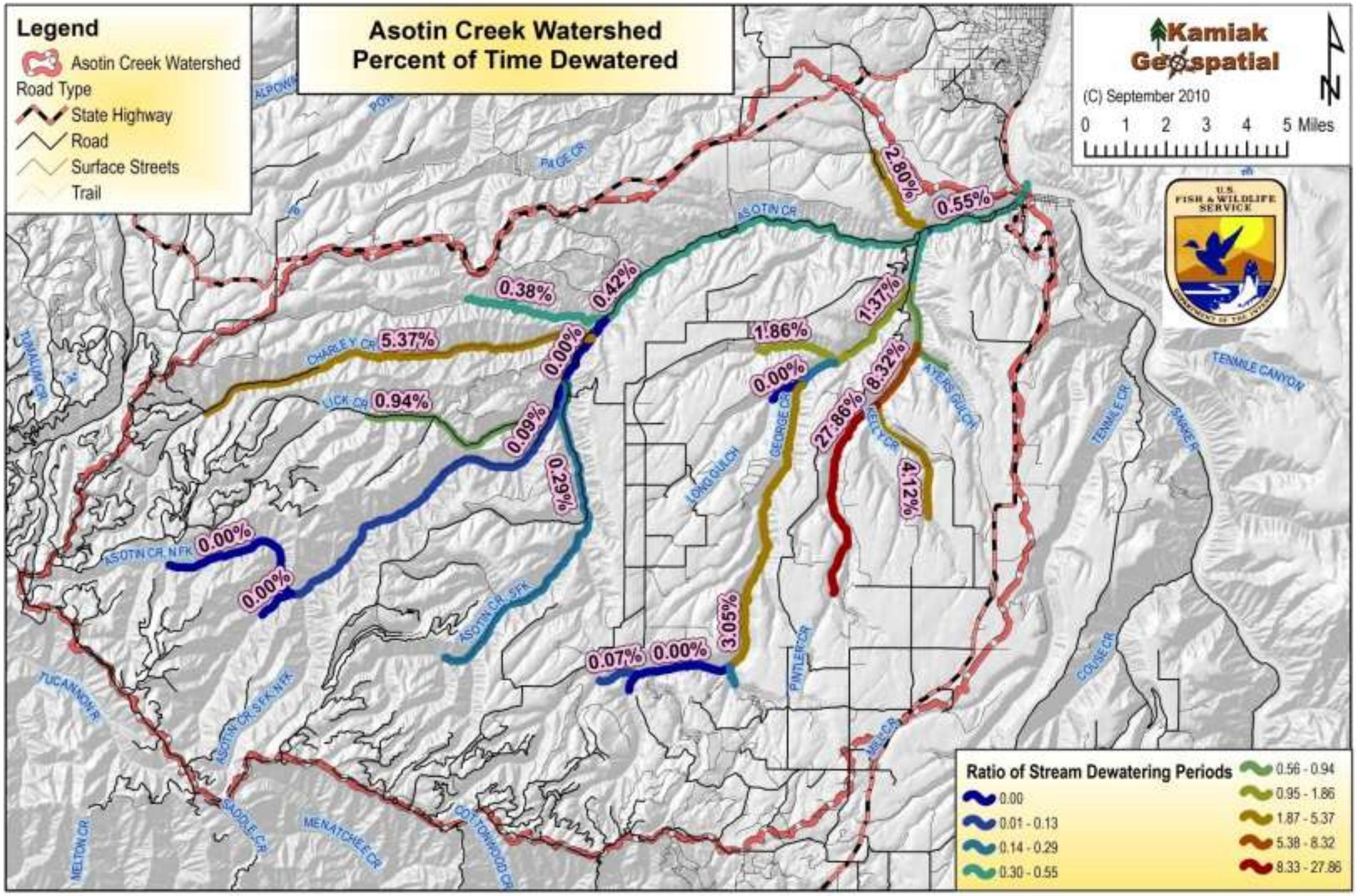


Figure 10. Stream dewatering frequency, during a 15 year period (1994-2009).

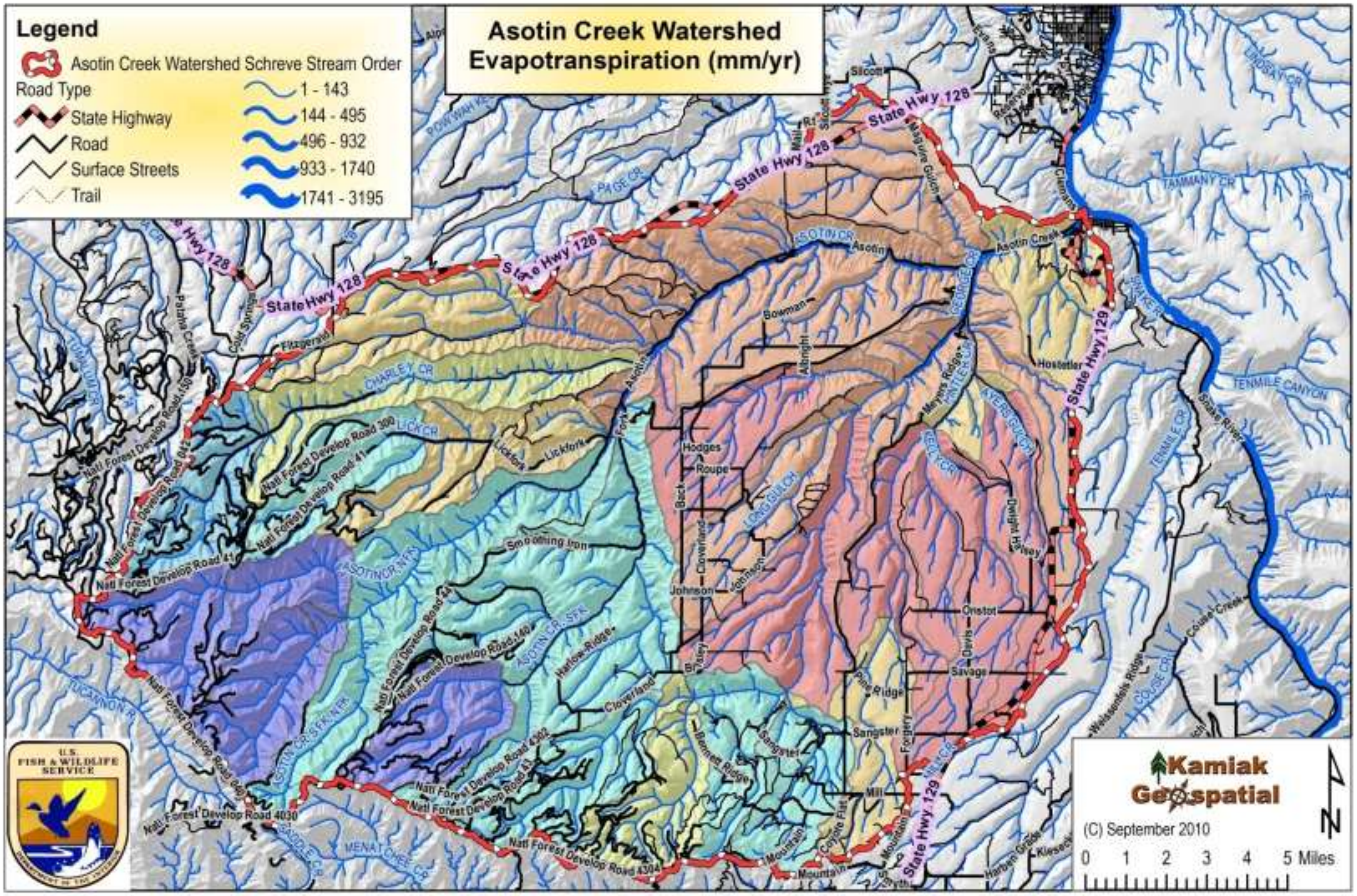


Figure 11. Evapotranspiration within Sub-Basin Watersheds.

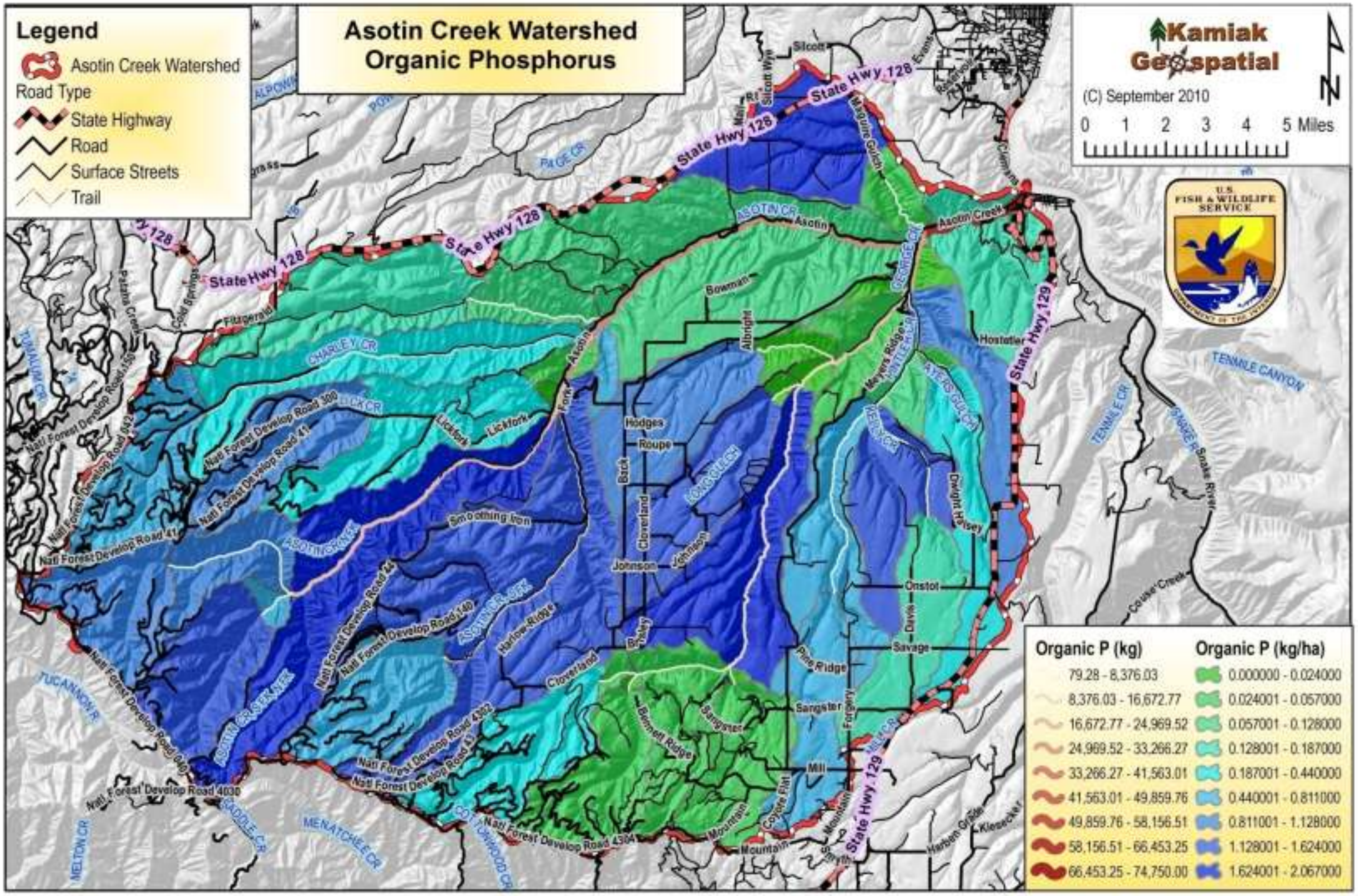


Figure 12. Sub-Basin Organic Phosphorus.

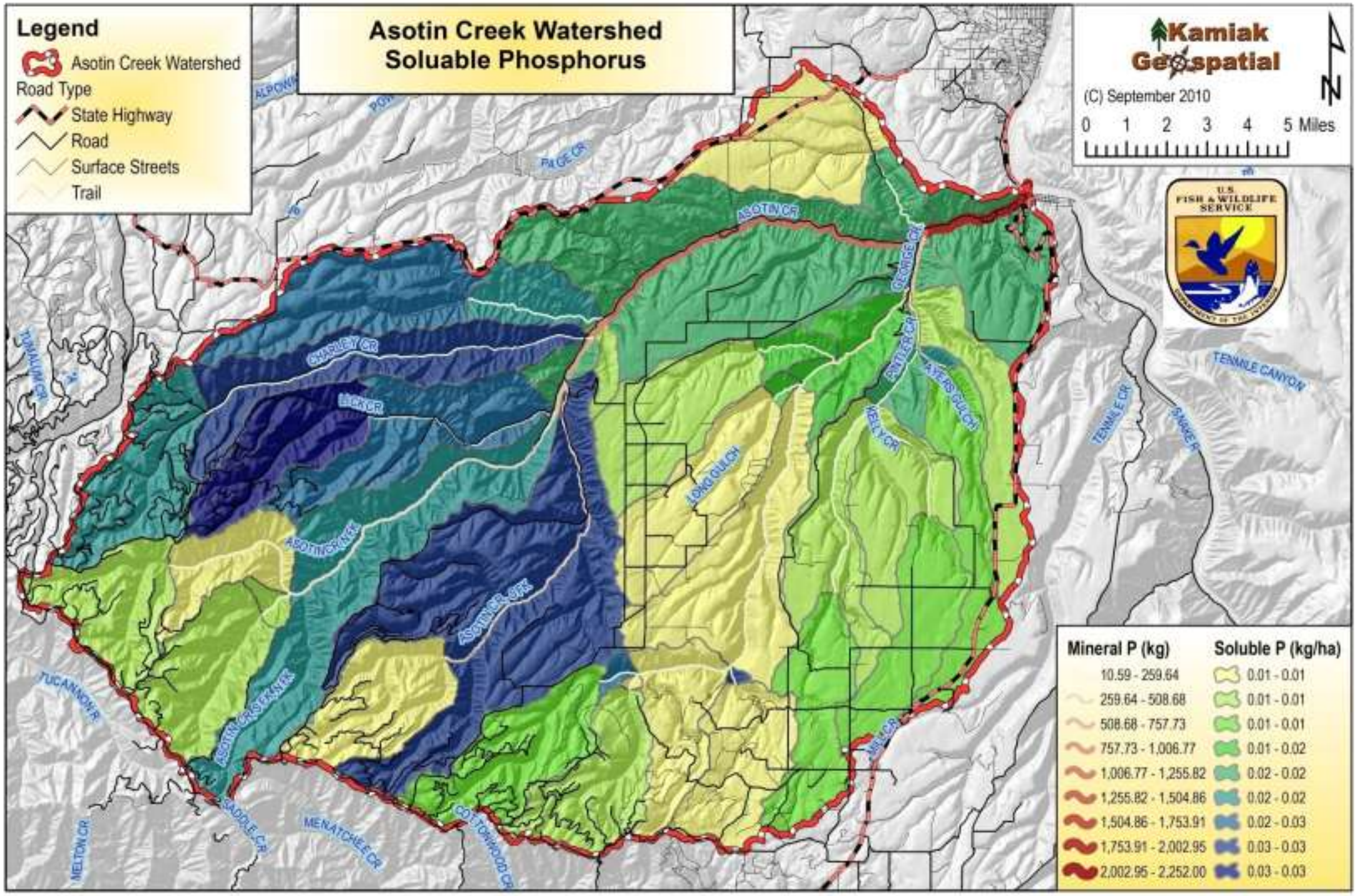


Figure 13. Sub-Basin Soluble and Mineral Phosphorus.

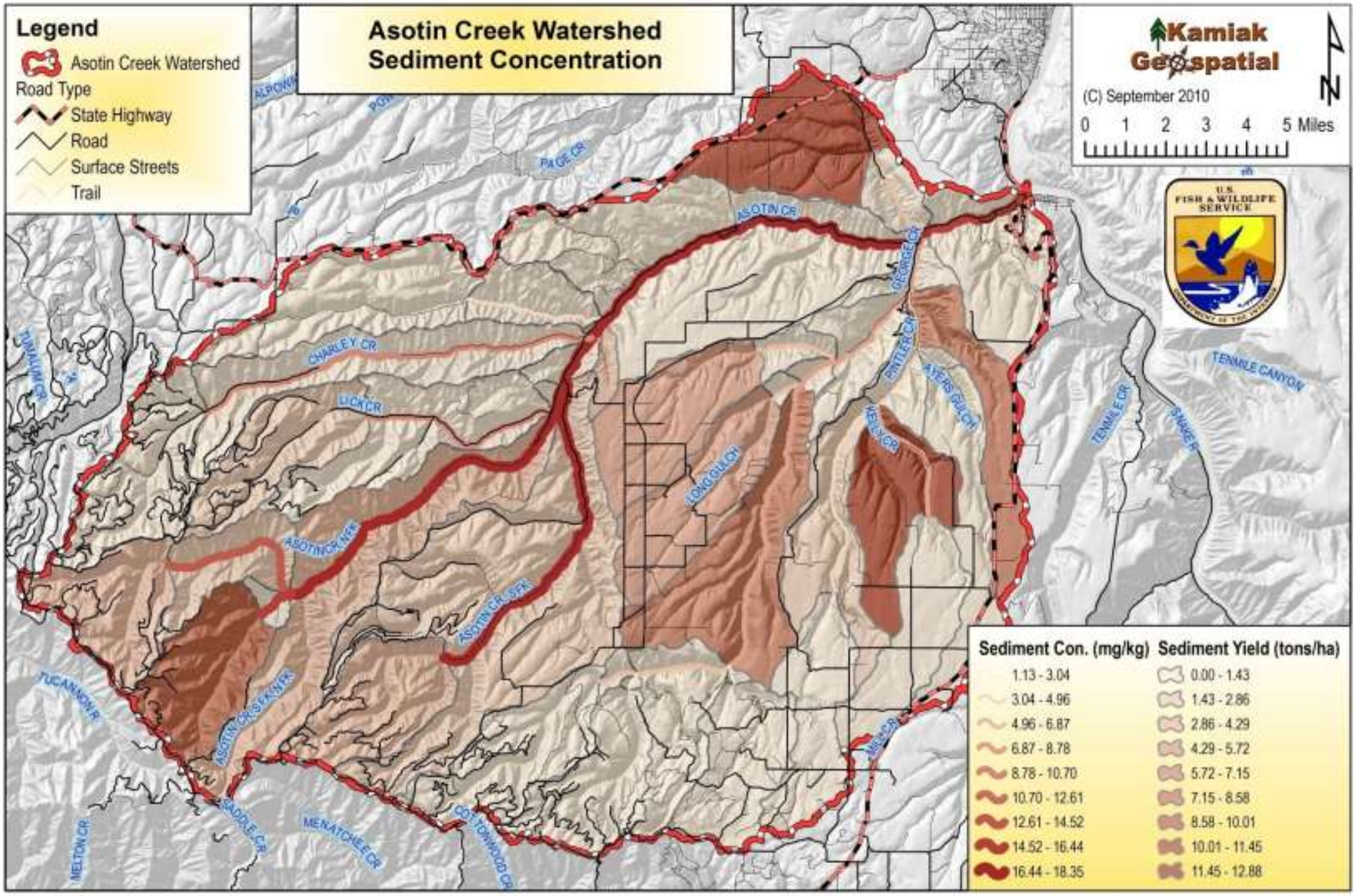


Figure 14. Sediment Concentration and Yield.

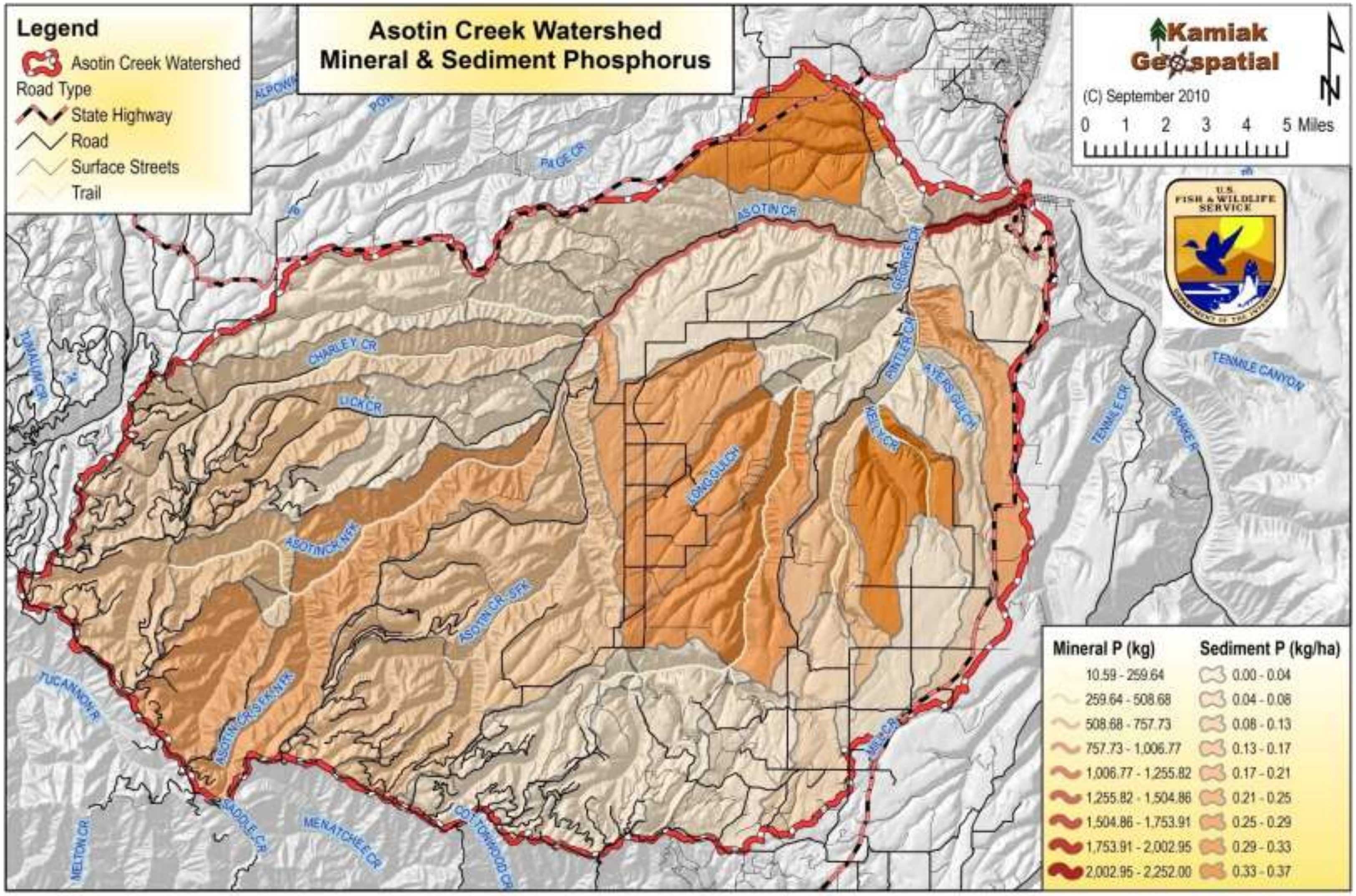


Figure 15. Mineral and Sediment Phosphorus contributions and conveyance.

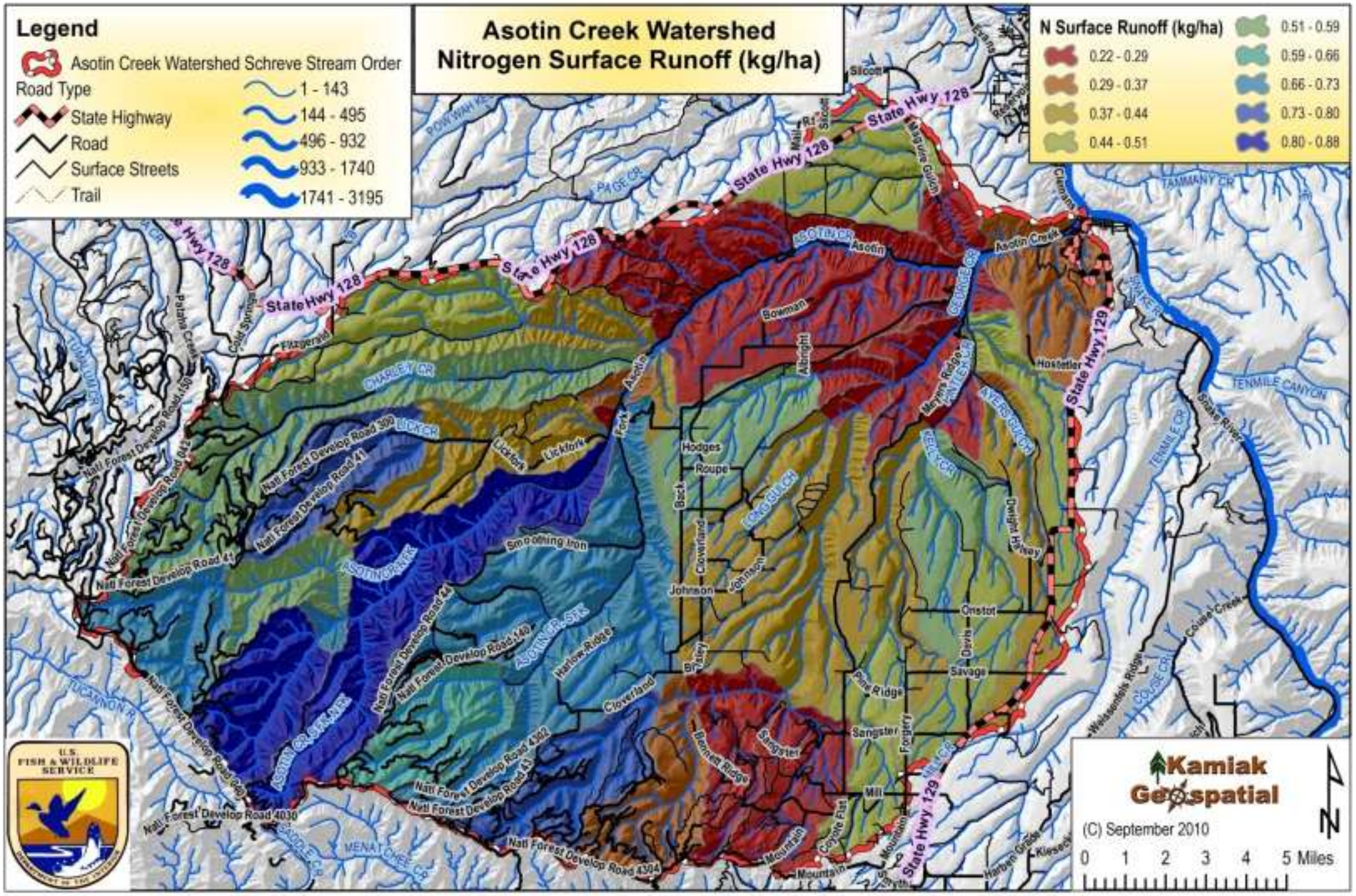


Figure 16. Nitrogen Surface Runoff.

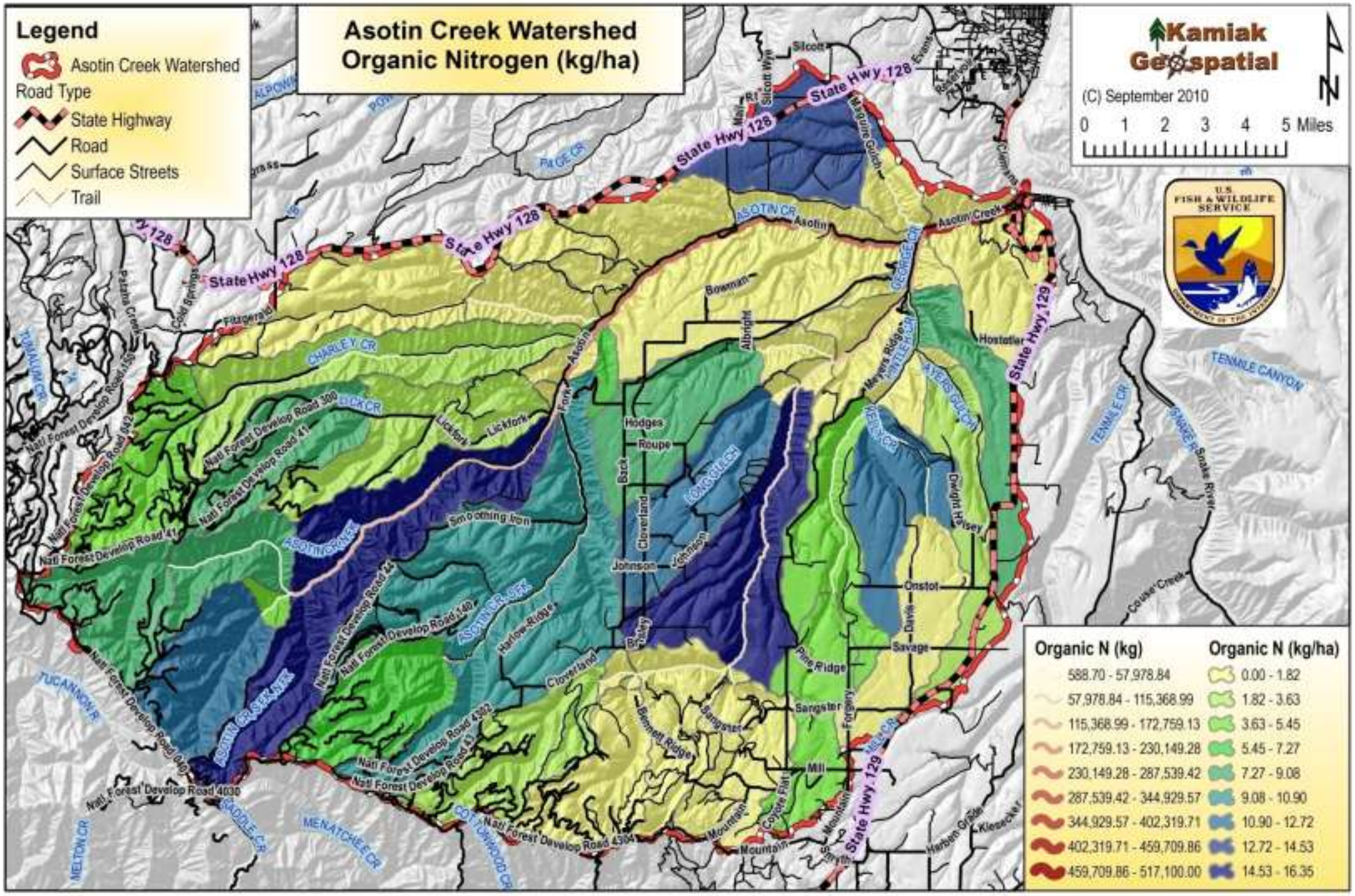


Figure 17. Sub-Basin Organic Nitrogen.

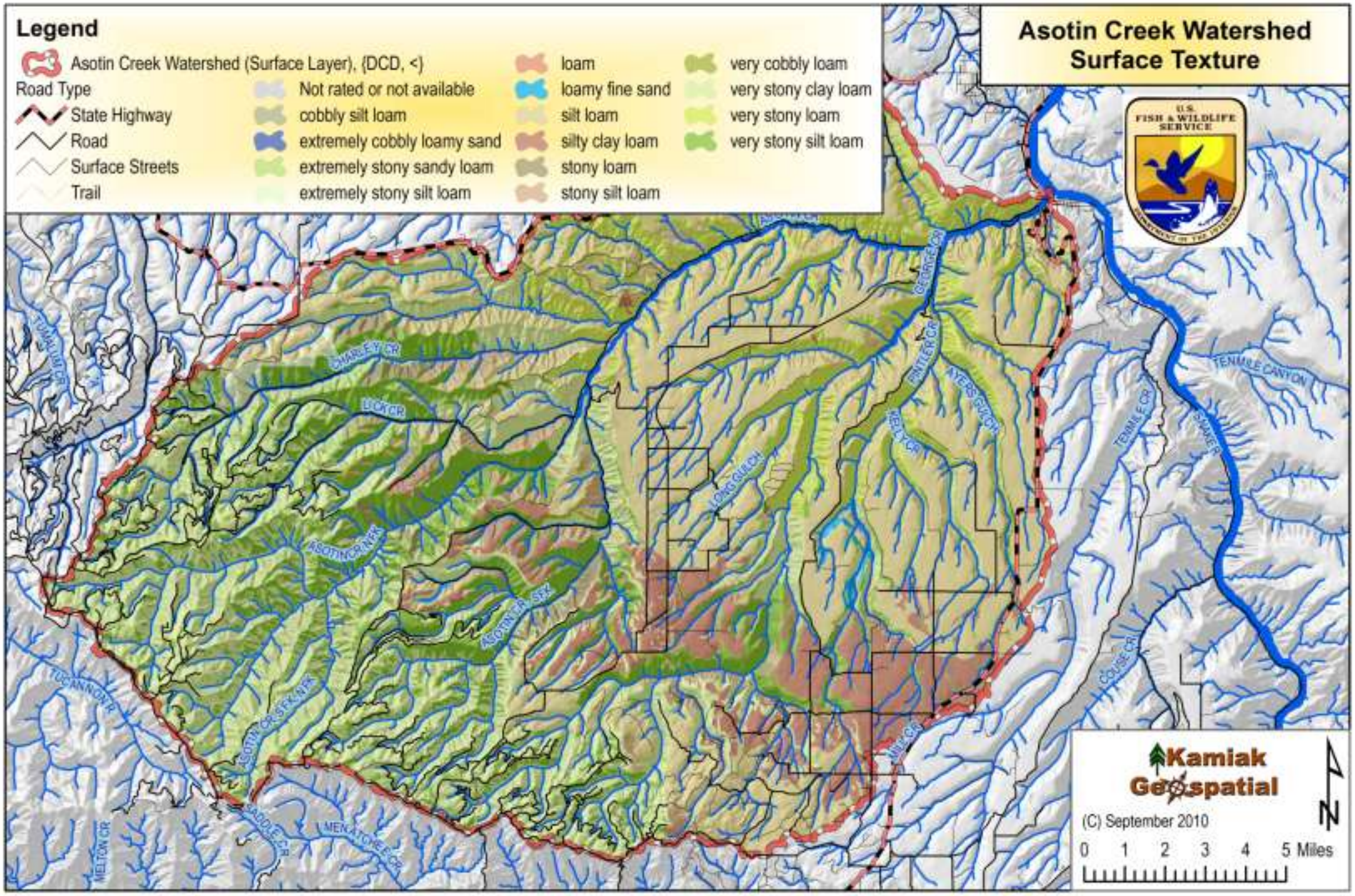


Figure 18. Stream Segment Surface texture for Spawning Habitat.

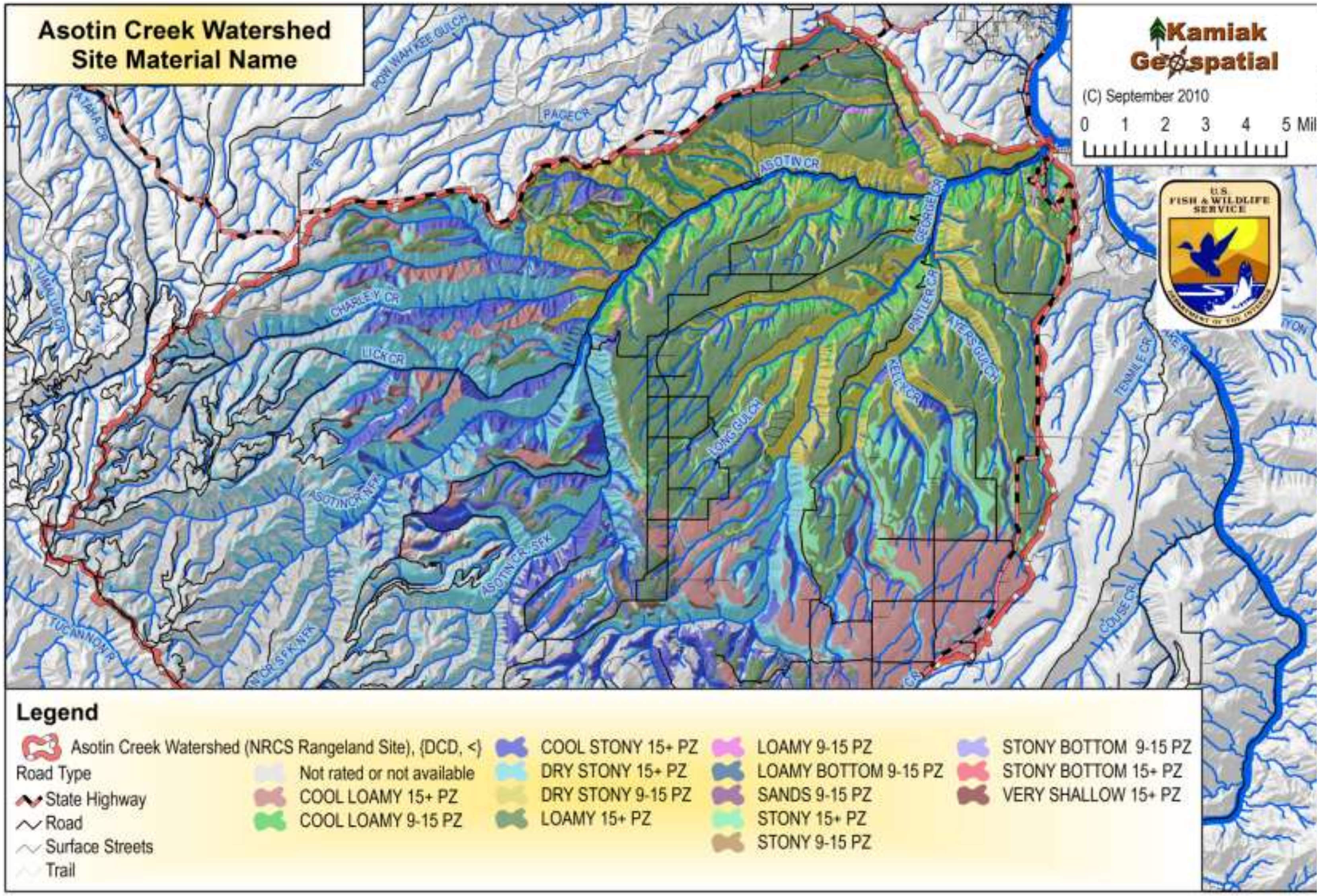


Figure 19. Stream Segment Site Material Name for Spawning Habitat Suitability.

Table 5. Dewatering Events from 1994-2009 by Stream Segment.

Stream Reach	Ratio of Days Dewatered vs. Watered	Maximum Consecutive Days Dewatered	Most Frequently Dewatered Month	Days of Dewatered Condition in the 15 year period											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2	5.37%	17	July	12	15	24	22	24	49	77	43	12	1	0	0
4	0.29%	5	January	8	0	0	8	0	0	0	0	0	0	0	0
6	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
8	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
9	0.09%	5	January	5	0	0	0	0	0	0	0	0	0	0	0
11	0.94%	10	April	7	7	15	20	2	0	0	0	0	0	0	0
12	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
13	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
14	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
16	0.38%	6	July	0	0	0	0	0	3	17	1	0	0	0	0
17	0.42%	5	July	7	1	0	5	0	0	10	0	0	0	0	0
19	0.27%	5	January	13	2	0	0	0	0	0	0	0	0	0	0
21	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
23	0.07%	4	January	4	0	0	0	0	0	0	0	0	0	0	0
24	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
25	3.05%	17	July	10	17	24	23	18	23	33	12	2	0	0	0
27	0.00%	0	--	0	0	0	0	0	0	0	0	0	0	0	0
28	0.26%	3	March	0	2	7	5	0	0	0	0	0	0	0	0
30	1.86%	11	July	0	0	5	20	8	24	31	12	0	0	0	0
31	1.37%	17	July	1	0	9	19	2	13	26	3	1	0	0	0
33	27.86%	46	July	8	43	63	157	173	168	216	182	154	30	0	0
35	4.12%	9	July	0	1	0	10	18	31	81	36	37	3	0	0
36	8.32%	23	May	0	0	7	57	114	81	89	43	27	3	0	0
38	0.77%	7	April	0	14	13	15	0	0	0	0	0	0	0	0

Table 5. Dewatering Events from 1994-2009 by Stream Segment.

Stream Reach	Ratio of Days Dewatered vs. Watered	Maximum Consecutive Days Dewatered	Most Frequently Dewatered Month	Days of Dewatered Condition in the 15 year period											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
39	0.90%	10	July	0	0	2	2	1	17	24	3	0	0	0	0
40	0.44%	2	June	0	0	0	0	5	9	7	2	1	0	0	0
41	0.13%	3	July	1	0	0	0	0	0	6	0	0	0	0	0
43	2.80%	7	May	0	0	0	15	37	29	26	19	23	0	0	0
44	0.55%	6	July	3	1	0	5	0	0	18	3	0	0	0	0
Total Number of Dewatering Events by Month				**79**	**103**	**169**	**383**	**402**	**447**	**661**	**359**	**257**	**37**	**0**	**0**

Table 6. Asotin Creek Stream Segment Attributes: SWAT Model (highlighted fields show favorable conditions). See Figure 10 for segment locations.

Sequence Number	Channel Number	Area (M^2)	Cumulative Area (m^2)	Cumulative Area (ha)	Average Slope	Width (meters)	Depth (meters)	Water Yield (mm)	Channel Runoff (m^3/day)	Channel Runoff (ft^3/ second)	Sediment Yield (tons/yr)	Sediment Concentration (mg/kg)	Organic Nitrogen (kg/yr)	Organic Phosphorus (kg/yr)	Nitrates (kg/yr)	Mineral Phosphorus (kg/yr)
1	2	32,657,900	58,234,900	5,823	3.26%	4.84	0.35	141	22,420.80	9.16	1,569.0	9.00	24,730	3,432	3,042	179
2	4	82,593,200	104,714,000	10,471	3.07%	5.48	0.39	173	49,645.44	20.29	4,780.0	17.82	95,070	13,330	7,433	416
3	6	2,046,700	25,157,800	2,516	5.00%	4.10	0.29	483	33,315.84	13.62	1,981.0	15.44	27,960	3,846	2,044	62
4	8	14,540,900	35,583,500	3,558	4.28%	4.30	0.31	341	33,220.80	13.58	1,979.0	13.28	26,660	3,655	2,295	74
5	9	53,108,000	113,849,300	11,385	2.37%	6.03	0.43	313	97,718.40	39.94	6,630.0	16.96	132,200	18,510	9,118	371
6	11	28,046,300	49,851,000	4,985	3.50%	4.62	0.33	97	13,296.96	5.43	1,268.0	10.03	25,650	3,617	2,677	180
7	12	918,200	164,618,500	16,462	2.23%	7.29	0.53	246	111,024.00	45.38	7,899.0	16.83	157,900	22,130	11,820	553
8	13	3,425,700	272,758,200	27,276	1.72%	8.47	0.62	215	160,876.80	65.76	12,690.0	18.35	253,100	35,480	19,370	976
9	14	3,128,200	334,121,300	33,412	1.47%	9.01	0.66	200	183,427.20	74.97	14,290.0	17.73	279,700	39,200	22,530	1,164
10	16	10,412,500	39,603,800	3,960	3.61%	4.56	0.33	44	4,809.02	1.97	406.3	3.85	5,219	748	1,372	92
11	17	75,067,700	448,792,800	44,879	1.33%	9.60	0.70	159	195,091.20	79.74	15,450.0	17.21	290,600	40,840	26,050	1,416
12	19	463,000	21,825,900	2,183	5.46%	3.96	0.28	28	1,663.20	0.68	42.3	1.13	589	79	375	11
13	21	384,100	21,375,100	2,138	4.11%	3.94	0.28	44	2,579.04	1.05	115.3	2.18	957	129	509	15
14	23	1,557,300	26,185,900	2,619	5.04%	4.16	0.30	204	14,636.16	5.98	518.8	6.00	7,261	973	1,742	47
15	24	18,197,000	65,758,000	6,576	2.88%	5.30	0.38	102	18,334.08	7.49	703.8	5.23	8,716	1,170	2,656	72
16	25	36,281,200	123,865,100	12,387	2.27%	6.39	0.46	75	25,444.80	10.40	1,847.0	8.24	68,450	9,587	4,445	183
17	27	1,152,800	26,567,700	2,657	5.54%	4.19	0.30	41	2,976.48	1.22	303.3	6.67	28,170	4,190	778	73
18	28	1,859,100	152,291,900	15,229	2.42%	7.11	0.52	68	28,460.16	11.63	2,151.0	8.55	96,640	13,780	5,265	259
19	30	4,149,600	29,105,100	2,911	4.55%	4.24	0.30	46	3,653.86	1.49	354.8	6.41	19,610	3,061	1,041	75
20	31	11,465,400	192,862,400	19,286	2.10%	7.58	0.55	62	32,590.08	13.32	2,536.0	8.61	116,500	16,880	6,605	355
21	33	22,038,800	43,001,500	4,300	3.92%	4.46	0.32	42	4,938.62	2.02	447.6	4.71	20,970	3,115	1,475	78
22	35	21,796,700	43,110,400	4,311	4.66%	4.47	0.32	48	5,718.82	2.34	531.1	7.31	29,700	4,630	1,769	114
23	36	5,808,000	91,919,900	9,192	3.10%	6.06	0.44	44	10,955.52	4.48	1,012.0	6.58	51,060	7,805	3,386	204
24	38	1,266,500	22,824,700	2,282	5.42%	4.00	0.28	30	1,867.10	0.76	67.8	1.30	5,189	765	628	27
25	39	19,232,300	133,976,900	13,398	2.67%	6.70	0.48	39	14,411.52	5.89	1,203.0	6.00	72,680	11,150	4,840	282
26	40	4,880,000	331,719,300	33,172	1.85%	8.98	0.66	52	47,165.76	19.28	3,745.0	8.29	189,300	28,040	11,590	647
27	41	101,600	780,613,700	78,061	0.36%	11.63	0.86	113	242,265.60	99.02	19,200.0	16.37	479,900	68,880	37,640	2,063
28	43	6,292,100	32,999,400	3,300	2.89%	4.37	0.31	40	3,655.58	1.49	387.3	5.99	34,300	5,416	1,056	125
29	44	24,864,200	838,477,300	83,848	1.05%	11.83	0.87	108	248,400.00	101.53	19,970.0	16.35	517,100	74,750	39,490	2,252

Table 7. Asotin Creek Watershed Sub-Basin Watershed Attributes: SWAT Model (highlighted fields show favorable conditions). See Figure 4 for Watershed locations.

Watershed	Mean Elevation (meters)	Average Slope Percent	Curve Number (average of sub-basin)	Annual Precipi-tation (mm)	Annual Evapotran-spiration (mm)	Percolation (mm)	Surface Runoff (mm)	Trans-mission Loss (mm)	Water Yield (mm)	Sediment Yield (tons/ha)	Organic Nitrogen (kg/ha)	Organic Phosphorus (kg/ha)	Mineral Phosphorus (kg/ha)	NO3 Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Acres	Hect-ares
10	511.21	25.4%	81.62	601.80	461.42	41.79	94.82	60.89	36.70	0.40	1.18	0.15	0.03	0.31	0.02	6,144	2,486
20	481.75	25.7%	82.12	575.37	449.33	35.70	86.74	72.60	16.64	0.07	0.30	0.04	0.01	0.29	0.02	1,555	629
21	563.19	8.7%	83.42	575.36	445.50	2.82	123.97	78.29	46.29	12.88	12.97	1.71	0.37	0.46	0.01	6,600	2,671
30	651.47	26.1%	82.08	564.08	446.76	31.28	82.54	50.41	34.49	0.17	0.77	0.10	0.02	0.28	0.02	18,550	7,507
40	308.11	29.5%	79.74	599.67	463.95	47.89	83.48	82.94	3.93	-	-	-	0.00	0.27	0.02	25	10
50	507.02	30.9%	81.46	579.97	454.34	36.52	84.98	75.26	12.77	0.05	0.19	0.02	0.01	0.28	0.02	1,206	488
60	618.33	32.0%	81.79	547.28	441.27	27.61	74.50	61.59	15.68	0.05	0.21	0.03	0.01	0.26	0.02	2,833	1,147
70	723.74	15.7%	84.20	593.29	452.22	1.96	135.56	106.49	30.18	7.73	8.56	1.13	0.24	0.51	0.01	4,752	1,923
80	793.30	45.1%	81.54	592.76	453.52	27.39	108.52	83.25	27.50	0.14	0.98	0.13	0.02	0.37	0.02	2,573	1,041
81	1,080.81	29.4%	81.31	643.55	465.52	41.84	133.41	84.60	50.64	0.28	1.45	0.19	0.03	0.45	0.02	7,213	2,919
90	774.03	24.4%	83.60	566.98	405.29	41.10	117.26	104.38	15.31	4.20	5.89	0.76	0.17	0.37	0.01	773	313
100	1,039.24	48.5%	79.23	754.16	489.29	74.50	185.41	127.83	60.98	0.48	3.37	0.44	0.05	0.55	0.03	8,070	3,266
101	1,442.89	30.4%	73.01	1,095.49	583.15	275.57	228.51	111.48	244.39	0.81	5.41	0.66	0.08	0.56	0.02	6,320	2,558
110	708.23	47.1%	81.14	569.45	449.67	20.97	95.52	82.97	14.81	0.06	0.39	0.05	0.01	0.33	0.02	847	343
120	653.72	35.6%	81.51	546.60	441.51	28.14	72.70	65.66	10.14	0.03	0.11	0.01	0.00	0.25	0.02	1,025	415
121	847.32	10.6%	84.94	563.40	418.35	1.21	141.08	89.77	51.91	4.46	7.96	1.04	0.23	0.51	0.01	6,167	2,496
130	651.44	35.9%	80.90	583.60	456.69	38.77	83.42	67.52	19.53	0.16	0.68	0.09	0.02	0.28	0.02	1,435	581
140	582.49	44.8%	81.85	602.22	460.70	39.67	96.17	90.87	10.03	0.07	0.23	0.03	0.01	0.32	0.02	313	127
141	853.72	14.3%	84.35	584.81	420.68	25.06	136.96	106.30	31.05	0.69	2.42	0.31	0.05	0.43	0.01	5,327	2,156
150	615.15	48.7%	79.87	546.60	443.90	32.14	64.97	60.81	8.59	0.03	0.10	0.01	0.00	0.22	0.02	459	186
160	686.95	48.2%	79.64	566.98	453.10	23.47	87.01	80.85	8.53	0.02	0.12	0.02	0.00	0.29	0.02	227	92
170	1,162.05	36.2%	77.57	889.67	533.11	106.56	244.55	117.40	132.90	1.85	9.75	1.27	0.13	0.73	0.03	20,409	8,259
171	1,492.31	37.2%	72.62	1,206.02	615.46	312.19	264.51	130.81	325.19	3.11	6.57	0.81	0.11	0.61	0.01	5,466	2,212

Table 7. Asotin Creek Watershed Sub-Basin Watershed Attributes: SWAT Model (highlighted fields show favorable conditions). See Figure 4 for Watershed locations.

Watershed	Mean Elevation (meters)	Average Slope Percent	Curve Number (average of sub-basin)	Annual Precipi-tation (mm)	Annual Evapotran-spiration (mm)	Percolation (mm)	Surface Runoff (mm)	Trans-mission Loss (mm)	Water Yield (mm)	Sediment Yield (tons/ha)	Organic Nitrogen (kg/ha)	Organic Phosphorus (kg/ha)	Mineral Phosphorus (kg/ha)	NO3 Runoff (kg/ha)	Soluble Phosphorus (kg/ha)	Acres	Hect-ares
180	648.59	47.1%	81.04	546.60	442.04	28.91	70.35	67.19	7.29	0.01	0.05	0.01	0.00	0.24	0.02	285	115
181	916.34	16.2%	83.51	565.52	441.30	5.23	116.14	74.85	42.45	5.65	11.22	1.44	0.25	0.39	0.01	6,280	2,541
190	907.47	29.3%	81.86	620.16	418.85	55.29	143.18	88.54	56.11	7.43	16.35	2.07	0.26	0.41	0.01	8,965	3,628
200	872.17	22.9%	82.96	577.96	402.97	50.13	121.55	88.82	34.90	2.69	5.24	0.67	0.15	0.37	0.01	5,446	2,204
201	1,079.81	8.3%	80.94	649.15	459.06	29.21	158.96	108.94	50.24	0.79	4.56	0.58	0.08	0.49	0.01	5,180	2,096
210	838.66	18.4%	83.85	579.73	422.66	2.45	151.14	99.99	52.21	12.53	12.45	1.62	0.36	0.54	0.01	5,386	2,180
211	978.05	5.2%	86.00	594.25	416.21	19.54	156.68	111.85	44.96	0.27	1.30	0.17	0.03	0.50	0.01	5,267	2,131
220	1,033.17	39.8%	79.20	687.45	475.82	62.08	145.50	99.12	48.77	0.35	2.46	0.32	0.04	0.44	0.03	6,930	2,805
221	1,266.45	35.6%	75.54	961.92	542.34	142.19	271.35	148.87	160.57	1.55	8.68	1.13	0.11	0.79	0.03	5,388	2,180
230	1,224.18	55.1%	75.33	1,024.88	544.83	163.18	307.76	171.12	215.23	3.14	14.61	1.92	0.18	0.88	0.02	13,123	5,311
240	1,356.04	56.0%	73.06	1,135.53	627.93	248.72	246.49	150.90	244.25	2.38	7.50	0.92	0.11	0.57	0.01	3,593	1,454
241	1,633.71	33.4%	71.71	1,283.89	610.64	357.45	301.97	123.65	408.04	3.73	7.49	0.93	0.12	0.70	0.01	5,200	2,104
250	1,198.11	66.5%	73.23	1,224.53	635.37	277.02	297.11	222.36	319.88	1.25	5.42	0.67	0.08	0.69	0.01	506	205
251	1,559.29	50.2%	71.58	1,379.86	615.77	392.39	350.99	146.79	498.21	8.67	11.62	1.44	0.18	0.81	0.01	5,711	2,311
260	1,138.48	25.2%	75.05	658.43	553.25	18.78	82.30	61.60	22.70	0.04	0.27	0.03	0.01	0.23	0.01	4,497	1,820
270	936.71	49.8%	77.97	658.43	497.41	35.48	120.61	115.73	8.61	0.01	0.12	0.02	0.00	0.39	0.03	114	46
271	1,153.80	11.8%	75.41	658.43	552.81	18.36	84.23	56.91	28.25	0.04	0.29	0.04	0.00	0.24	0.01	5,279	2,136
280	1,079.15	39.4%	76.34	658.43	500.61	41.28	112.22	102.47	12.88	0.04	0.33	0.04	0.01	0.36	0.03	385	156
281	1,379.76	29.2%	72.94	1,027.31	549.05	194.86	277.38	152.87	216.19	0.55	2.94	0.36	0.04	0.76	0.01	6,086	2,463
290	1,019.42	57.5%	73.24	658.43	492.02	62.77	97.42	92.82	9.78	0.01	0.04	0.01	0.00	0.27	0.01	95	38
291	1,325.80	29.1%	72.74	718.25	502.69	92.51	118.74	77.44	44.70	0.06	0.46	0.06	0.01	0.32	0.01	5,187	2,099
																207,192	83,848

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