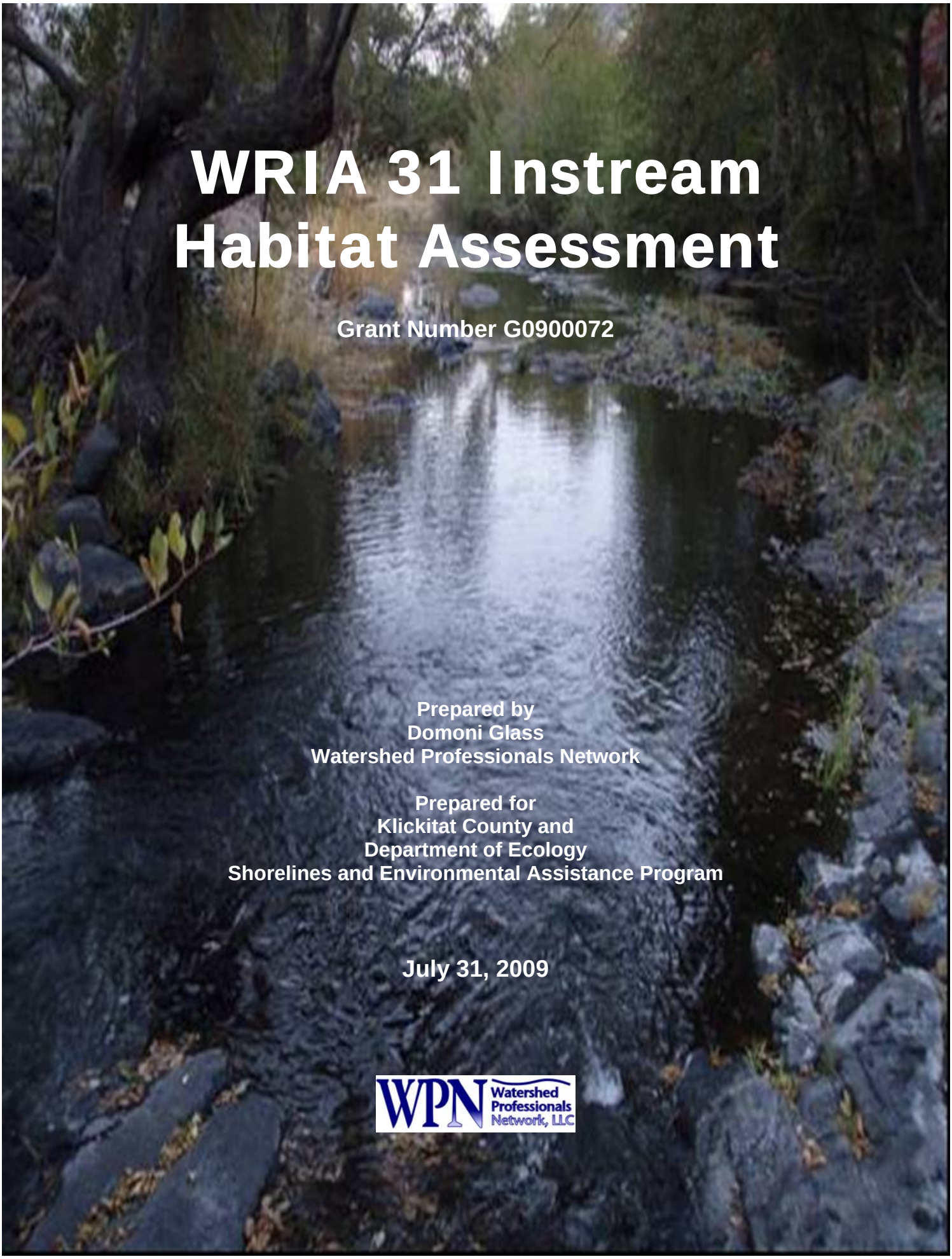


WRIA 31 Instream Habitat Assessment

Grant Number G0900072

Prepared by
Domoni Glass
Watershed Professionals Network

Prepared for
Klickitat County and
Department of Ecology
Shorelines and Environmental Assistance Program

July 31, 2009

WPN Watershed Professionals Network, LLC

WRIA 31 Instream Habitat Assessment

Grant Number G0900072

Prepared by
Domoni Glass
Watershed Professionals Network

Prepared for
Klickitat County and
Department of Ecology
Shorelines and Environmental Assistance Program

July 31, 2009

Table of Contents

Abstract 1
1.0 Introduction 1
2.0 Background 1
2.1 Current Condition 1
2.1.1 Physical Setting 3
2.2 Prior Data Collection Efforts and Assessments 4
3.0 Methods 6
3.1 Study Area 6
3.2 Sampling Process Design (Experimental Design) 7
3.3 Sampling Procedures 7
3.3.1 Habitat Characteristics 7
3.3.2 Fish Presence/Absence 12
3.3.3 Spawning Surveys 12
3.4 Data Analysis 12
3.5 sediment Source Modeling 13
3.5.1 Data Sources 13
3.5.2 Soil Creep and Stream Bank Erosion 14
3.5.3 Agricultural Lands 14
3.5.4 Cultivated Land 14
3.5.5 Grazing 16
3.5.6 Road Surface Erosion 18
3.5.7 Data and Study Limitations 18
4.0 Results 19
4.1 Habitat 19
4.1.1 Pools 24
4.1.2 Spawning Area and Substrate Condition 27
4.1.3 Riparian Characteristics 32
4.1.4 Instream Woody Debris 32
4.2 Fish Surveys 38
4.2.1 Snorkel Surveys 38
4.2.2 Spawning Surveys 40
4.3 Barriers 41
4.4 Hydromodifications 42
4.5 Reconnaissance of Old Lady Canyon 43
4.6 Sediment Source Modeling 45
4.6.1 Soil Creep and Stream bank Erosion 45
4.6.2 Agricultural Lands 45
4.6.3 Cultivated Land 45
4.6.4 Grazing 47
4.6.5 Road Surface Erosion 48
5.0 Discussion 49
5.1 Spawning Habitat 49
5.2 Habitat Supporting Egg Incubation 51

5.3 Rearing Habitat 52
5.4 Hydromodifications 54
5.5 Fish Distribution 55
5.6 Sediment Source Modeling 55
5.7 Limiting Factors 57
6.0 References 57

Appendix A - Maps
Appendix B - Photo Review of Study Reaches

List of Figures

Figure 1. Study area 2

Figure 2. Monthly Exceedance flows for Rock Creek and Alder Creek (USGS gage stations: http://waterdata.usgs.gov/nwis/current; Ecology gage: https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070). 5

Figure 3. Daily maximum water temperature at four stations in Rock Creek based on 1999 to 2004 data (Aspect 2005). (RC-09 is located near the mouth of Rock Creek, RC-8 is located just downstream of the confluence with Squaw Creek, RC-7 is located in Squaw Creek near the confluence with the mainstem Rock Creek, and RC-6 is located upstream in the basin near the confluence with Badger Gulch.) 6

Figure 4. Major streams in WRIA 31. 8

Figure 5. Fish distribution within WRIA 31 from the WDFW SaSI Report (WDFW 2002, http://wdfw.wa.gov/fish/sasi/)..... 9

Figure 6. Percent of the sampled length of each basin that was dry. 23

Figure 7. Percent of sampled channel units that were riffles, pools, and glides for each basin. 24

Figure 8. The frequency of occurrence of pools at various depths, by basin. 25

Figure 9. Average substrate composition for riffle and non-riffle channel units for each basin in the study area. 30

Figure 10. Frequency of occurrence of spawning areas with indicated percent fines in the substrate. 33

Figure 11. Frequency of occurrence of embeddedness within riffles by basin. 34

Figure 12. One of a set of four waterfalls located in Reach 3 of Wood Gulch..... 41

Figure 13. Photo of the series of weirs in Wood Gulch. 43

Figure 14. Bridge footing in Wood Gulch, Reach 2, near segment 11. Note the scoured pool adjacent to the structure. 44

Figure 15. Photo of Old Lady Canyon culvert under Highway 14 (left) and photo of Old Lady Canyon culvert under the railroad (right). Piles of debris running down the center of the culvert on the right are piles of bird droppings..... 44

Figure 16. 1992 Landsat land cover and land use (from Aspect 2004) 46

Figure 17. Land within 1,000 feet of streams used in WEPP analysis of cultivated land. 47

Figure 18. Stream flow, water temperature, and air temperature for water year 2008 (from Washington Department of Ecology website: https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070)..... 50

List of Tables

Table 1. Data collected in the field at the segment scale (100 meters) (left 2 columns)

and at the individual channel unit scale (right 2 columns). 10

Table 2. Summary of methods used to estimate sediment inputs. 13

Table 3. WEPP estimates of erosion from various cultivated land uses (average tons/acre/year). 15

Table 4. WEPP erosion estimates used in analysis (average tons/acre/year). 16

Table 5. Land use within 1,000 feet of streams in the Rock, Wood, Pine, and Glade subbasins. 17

Table 6. Road conditions used for SEMODL2 calculations. 18

Table 7. Sample reaches, total reach length, sampled reach length and percent of reach sampled. 19

Table 8. Average stream gradient of sampled basins. 21

Table 9. Number and type of channel units sampled and portion of stream length that was dry. 22

Table 10. Pool Volume in each reach. 26

Table 11. Total estimated volume of pools (m^3) by basin and stream. 27

Table 12. Spawning area in each reach. 28

Table 13. Total estimated spawning area (m^2) by basin and stream. 29

Table 14. Substrate composition of spawning areas by basin, stream, and reach. 31

Table 15. Average canopy cover, inner riparian zone width, and typical vegetation for each reach sampled. 35

Table 16. Average abundance of large woody debris in the stream segments (segments had an average length of 110 meters). 37

Table 17. Number of fish observed in each basin by species. 39

Table 18. Number of *Oncorhynchus Mykiss* observed in each basin by size class. 39

Table 19. Location and number of steelhead redds observed in lower Rock Creek. 40

Table 20. Estimated average annual sediment input from soil creep. 45

Table 21. Estimated average annual sediment input to streams from cultivated land. 47

Table 22. Estimated percent of stream length with livestock damage. 48

Table 23. Length of road hydrologically connected to streams and estimated average annual sediment input (tons/yr). 49

Table 24. Estimated average annual sediment input to streams (tons/yr). 56

We wish to thank the Nature Conservancy and the landowners in the study area that cooperated with the project.

ABSTRACT

1.0 INTRODUCTION

The WRIA 31 Watershed Assessment (Aspect and WPN 2004) and the WRIA 31 Watershed Management Plan (WRIA 31 Planning Unit 2009) identified a need for quantitative information on fish habitat across the WRIA. Habitat data were collected in fall and early winter of 2008 and spring of 2009 in five of the subbasins across the WRIA. The project is focused on spawning and rearing habitat for steelhead (*Oncorhynchus mykiss*). Streams were also snorkeled to identify the distribution of various fish species present in the study area and to provide an index of density throughout the subbasins. Estimates of sediment delivery to streams were also estimated through a modeling effort. This information will be used to help identify actions that can be taken to improve fish habitat and water quality.

This report summarizes the results of those efforts The project was funded by the Washington Department of Ecology (Ecology) through Grant No. G0900072.

2.0 BACKGROUND

WRIA 31 is located in eastern Klickitat County, southeastern Yakima County, and western Benton County, Washington. The streams in the WRIA drain to the Columbia River. Major streams include Rock Creek, Chapman Creek, Wood Gulch, Pine Creek, Glade Creek, and Alder Creek (Figure 1). Several minor streams also drain to the Columbia. The streams in the WRIA are seasonally intermittent for at least portions of their length.

2.1 CURRENT CONDITION

The WRIA 31 Limiting Factors Analysis (Lautz 2000) identified several factors potentially limiting fish production in Rock Creek. These included water access, widening of the channel from livestock grazing and flooding, and water quality affected by degraded riparian areas. Technically, some of these factors are not limiting factors but processes affecting habitat quality. There is very little publicly available information regarding fish habitat in the WRIA. The Limiting Factors Analysis recognized that conclusions were largely speculative and recommended that "*More detailed information should be collected to more precisely define these factors, and to identify specific areas where restoration activities will best address them.*" The WRIA 31 Watershed Assessment (Aspect and WPN 2004) and the WRIA 31 Watershed Management Plan (WRIA 31 Planning Unit 2009) also recognized the shortcomings of the data and recommended that additional data be collected to support the more accurate identification of limiting factors and to support the identification of actions which have the greatest probability of improving habitat.

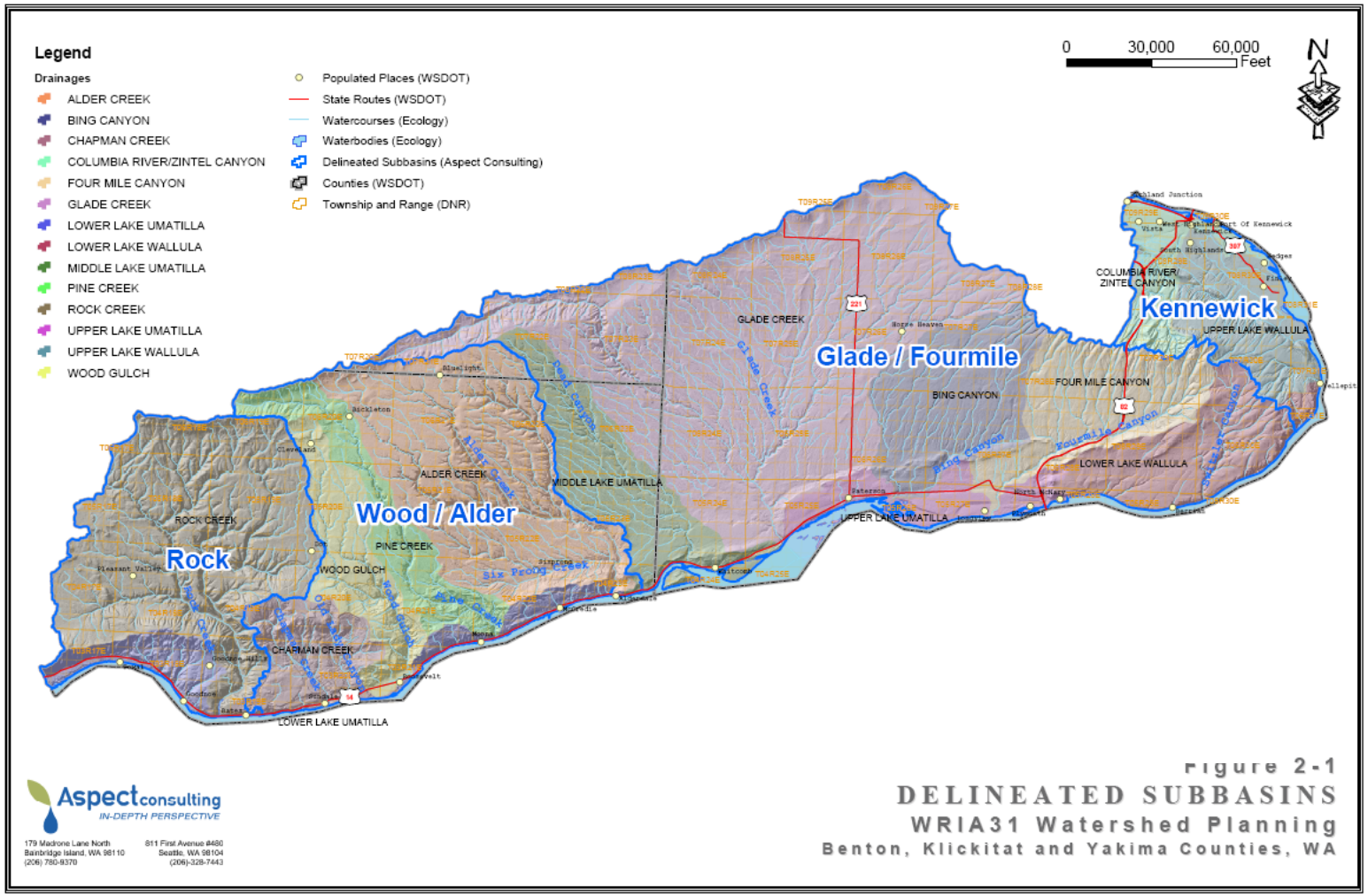


Figure 1. Study area

The Rock Creek steelhead population is part of the Middle Columbia Steelhead Distinct Population Segment, which is listed as threatened under the Federal Endangered Species Act. Prior to this study, steelhead use of other subbasins within the WRIA was unknown; however, use of some of the other subbasins by steelhead was suspected. In August 2005, NOAA Fisheries designated portions of Rock Creek, Chapman Creek, Wood Gulch, Pine Creek, Alder Creek, and Glade Creek as critical habitat (NOAA 2005).

2.1.1 Physical Setting

WRIA 31 drains south from the Horse Heaven Hills into the Columbia River. Elevations range from nearly 4,800 feet in the northern part of the Rock Creek subbasin to 266 feet at the Columbia River, and generally decrease from west to east and from north to south.

The entire WRIA is underlain by the Miocene Columbia River Basalt, including the Grande Ronde, Wanapum, and Saddle Mountain Basalt members (WDNR 2000). The Wanapum Basalt is the dominant geologic formation in Rock Creek, with the younger Saddle Mountain Basalt dominating the Wood Gulch and Pine Creek subbasins. The volcanic bedrock forms the steep canyon walls of many of the larger streams as they have cut down into the basalt, and provides gravel- and cobble-sized particles to these streams as well as forming bedrock chutes and falls in a few locations.

Quaternary flood deposits and loess overlie the basalt in the Eastern part of the WRIA, and cover most of the Glade Creek subbasin. The flood deposits were left behind during Pleistocene outburst floods from glacial Lake Missoula and include gravel along the Columbia River grading to sand and silt deposits as far as 17 miles inland from the river in the Glade Creek subbasin. Quaternary loess deposits, wind-blown silt and fine sand, cover the northern part of Glade Creek. The fine-grained flood deposits and loess are easily eroded by running water; the major channels in the Glade Creek subbasin have eroded down to the basalt bedrock. Chapman Creek is also dominated by the Quaternary flood deposits. Loess overlays most of the subbasin.

Shrub land and grassland dominate WRIA 31 (Aspect and WPN 2004). Rock Creek is the only subbasin in the WRIA with a substantial amount of timber land (25.8%), which is located in the headwaters of the subbasin (Aspect and WPN 2004). Less than 10 percent of the land in Rock Creek basin is cultivated. Larger portions of the subbasin lands are cultivated in the smaller eastern basins (Glade and Alder Creek basins) (IRZ 2004). There is little urban/residential development in WRIA 31, except near Kennewick at the eastern end of the WRIA (Aspect and WPN 2004).

Two recent forest/range fires have affected the study area. The Cleveland fire burned 18,500 acres in the headwaters of Rock Creek in 1998 and the Wood Gulch fire burned 11,640 acres in that basin in 2007 (www.wsp.wa.gov/fire/docs/mobilization/mobe_history_for_2008.pdf).

Precipitation decreases from west to east across the WRIA and also decreases from north to south (Aspect and WPN 2004). Specifically, mean annual precipitation ranges from

around 24 inches along the western border of the Rock Creek subbasin to less than 8 inches near Kennewick on the east end of the WRIA. The majority of precipitation occurs between October and April, with some precipitation occurring as snow, particularly at higher elevations in the Horse Heaven Hills (Aspect and WPN 2004).

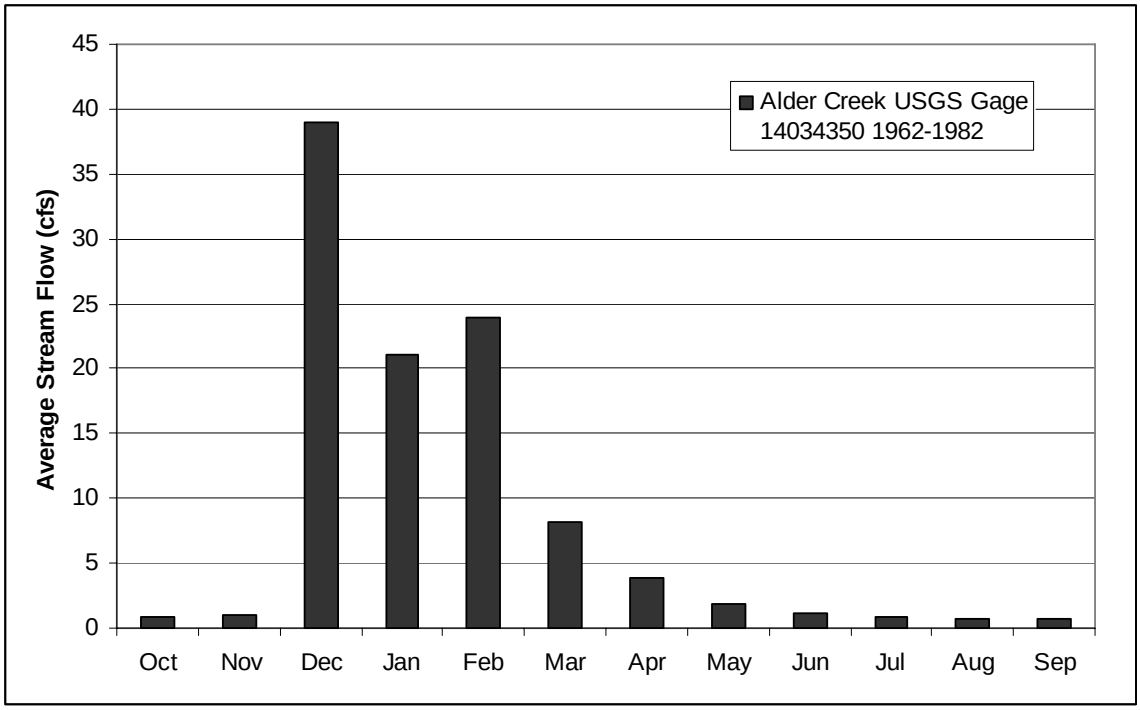
Stream flow data are available for Rock Creek and Alder Creek. Stream flows at both these locations peak in winter and early spring and are generally low throughout the summer, fall, and into early winter (Figure 2) (USGS stream gages, http://waterdata.usgs.gov/nwis/current; Ecology stream gage website https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070). Many of the streams in the WRIA go dry during summer, although isolated pools may persist (Aspect and WPN 2004). Summer flow in eastern streams is augmented by irrigation return flows.

Stream temperatures in Rock Creek regularly exceed state water quality standards (Figure 3) (Aspect 2005; Ecology stream gage website https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070). One segment of Rock Creek is currently listed as a category 5 on the 303(d) list (Ecology 2008). A study of trends in riparian condition through time found that floodplain vegetation has been increasing since 1938 (Aspect Consulting 2005).

2.2 PRIOR DATA COLLECTION EFFORTS AND ASSESSMENTS

Previous studies related to the project are limited. The Limiting Factors Analysis (Lautz 2000), the WRIA 31 Watershed Analysis (Aspect and WPN 2004), and the WRIA 30 Watershed Management Plan (WRIA 31 Planning Unit 2009) all identified a need to collect additional information regarding aquatic habitat to fill the numerous data gaps. Data collected in the WRIA prior to this study has included the following:

- Stream temperature monitoring by the Conservation District (Aspect 2005; some of the data unpublished, contact Central Klickitat Conservation District)
- A review of the historic GLO notes from the late 1800s for portions of the basins (Aspect and WPN 2004),
- Study of temperature, nitrates, and fecal coliform abundance in the WRIA (Aspect 2005)
- An evaluation of water temperature conditions completed by Ecology (Ehinger 1996)
- An evaluation of trends in riparian vegetation from 1938 to early this century (Aspect 2005)
- A study of nitrate concentrations in Glade Creek basin (Aspect 2005)
- Stream gaging in Rock and Alder Creeks for a short period, discontinued by the USGS in 1968 (http://waterdata.usgs.gov/nwis/nwisman/?site_no=14036600&agency_cd=USGS)
- Recent stream gaging in Rock Creek by Ecology (https://fortress.wa.gov/ecy/wrs/wrs/flows/station.asp?wria=31),
- Periodic (unpublished) spawning surveys conducted by the Yakama Nation Fisheries



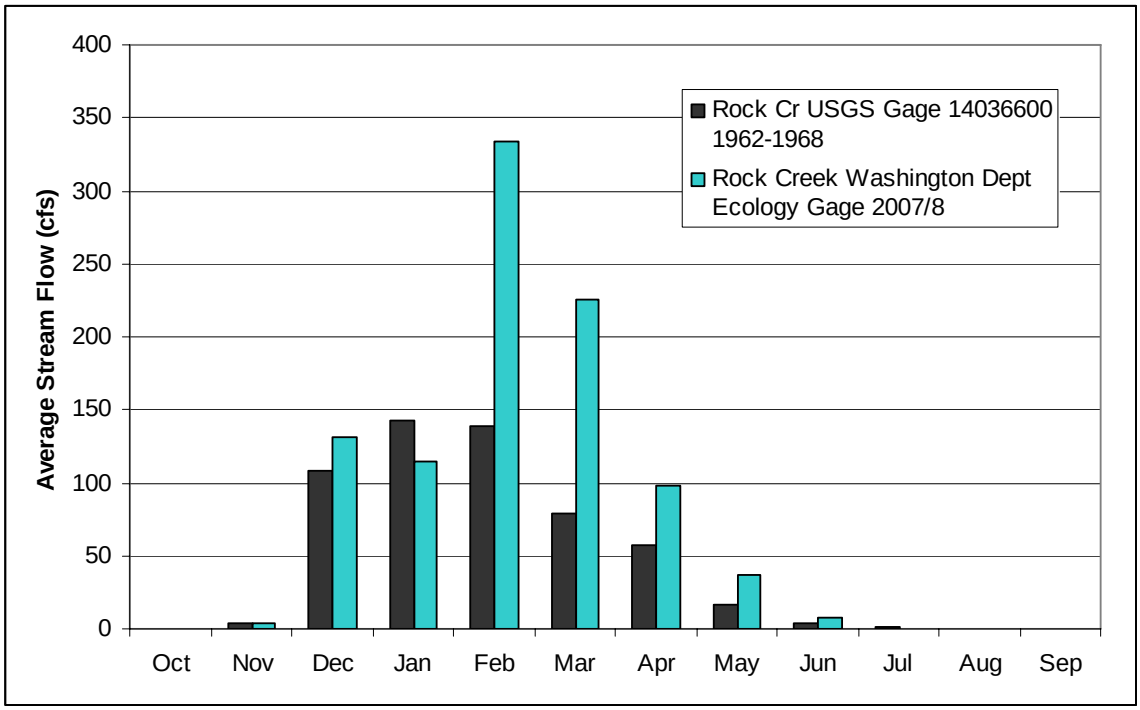


Figure 2. Monthly Exceedance flows for Rock Creek and Alder Creek (USGS gage stations: http://waterdata.usgs.gov/nwis/current; Ecology gage: https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070).

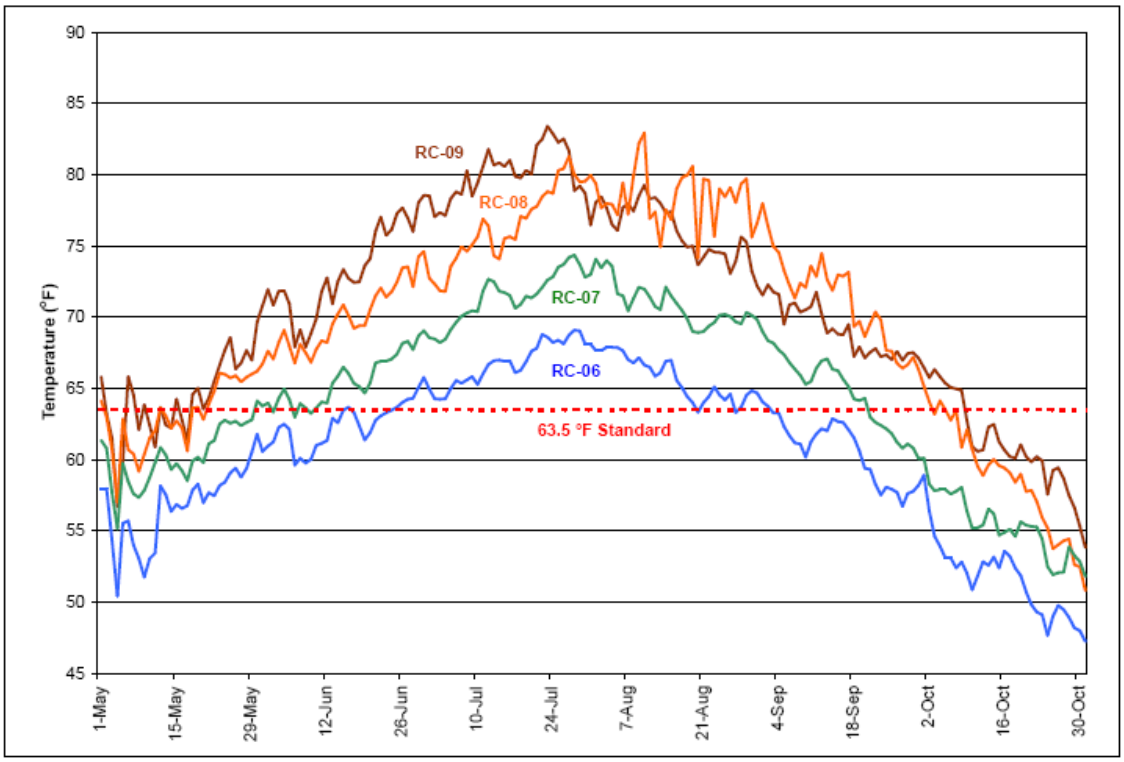


Figure 3. Daily maximum water temperature at four stations in Rock Creek based on 1999 to 2004 data (Aspect 2005). (RC-09 is located near the mouth of Rock Creek, RC-8 is located just downstream of the confluence with Squaw Creek, RC-7 is located in Squaw Creek near the confluence with the mainstem Rock Creek, and RC-6 is located upstream in the basin near the confluence with Badger Gulch.)

3.0 METHODS

3.1 STUDY AREA

The study area is located in Water Resources Inventory Area (WRIA) 31, which covers portions of Klickitat County, Yakima County, and Benton Counties, Washington (Figure 4). The study area does not include the Columbia River. The City of Kennewick lies on the eastern edge of the WRIA. Specific study areas included the streams in the Rock Creek, Wood Gulch, Chapman Creek, Pine Creek, and Glade Creek subbasins.

Within the subbasins, the study included all suspected anadromous waters in Rock Creek, Chapman Creek, Wood Gulch, Pine Creek, and Glade Creek. The WDFW Salmonid Stock Inventory (2002; http://wdfw.wa.gov/fish/sasi/) identifies steelhead in Rock Creek and two of its tributaries, (Quartz and Squaw Creeks) (Figure 5). No fish are indicated in that report in the other Subbasins. The Limiting Factors Analysis indicates that fish are also found in the lower 0.3 mi of Chapman Creek and near the mouth of Wood Gulch. The Draft Recovery Plan (NMFS 2008) depicts the potential distribution of *Oncorhynchus mykiss* (steelhead and rainbow trout) far into many of the subbasins. The study area included the full extent of the potential distribution of steelhead identified in the Draft Recovery Plan.

3.2 SAMPLING PROCESS DESIGN (EXPERIMENTAL DESIGN)

The various subbasins were stratified into stream reaches. Reach boundaries were defined at major tributaries in each subbasin using the DNR stream GIS coverage. The resulting reaches were evaluated using aerial photos and topographic maps to determine where major changes in gradient or stream size occurred. Additional reach boundaries were defined at these locations.

Within each of the reaches, stream segments were defined every 100 meters. Data were collected at a minimum of 3 stream segments in each reach. A target of at least 10% of the total habitat was set, recognizing that the target may not be met in some areas if sufficient landowner participation could not be attained. Microsoft Excel's RANDBETWEEN function was used to select random numbers within the range of segment numbers present in each reach. In cases where a randomly selected segment was found to be inaccessible due to terrain or permission to sample was not granted by the landowner, another sample reach was selected randomly.

3.3 SAMPLING PROCEDURES

3.3.1 Habitat Characteristics

In each stream segment, the number, area, and wetted and residual depth of pools, the area of spawning habitat, the quality of spawning gravel, the abundance of instream wood, riparian condition, bank condition, cover, and any hydromodifications were documented. Passage barriers were also identified. Between the randomly selected segments, crews documented any passage barriers encountered.

Measurement procedures were selected from the list of recommended procedures provided by the Washington Department of Fish and Wildlife (Johnson et al. 2001). The majority of the field sampling procedures used in this study followed the U.S. Forest Service Region 6 Stream Inventory Handbook (USFS 2006), with some modifications.

Modifications included:

- No temperature measurements were taken; the program relied on existing data for temperature
- The USFS procedures collect measurements in 10 randomly selected "slow" reaches and 10 randomly selected "fast" reaches. Most other commonly used procedures, including the TFW procedures (Pleuss and Shuett-Hames 1998), collect data within a selected stream segment. The methods were modified to sample specified segments rather than individual slow and fast segments. However, all individual channel units (e.g. riffle, pool, glide) were measured and documented within each randomly selected stream segment.

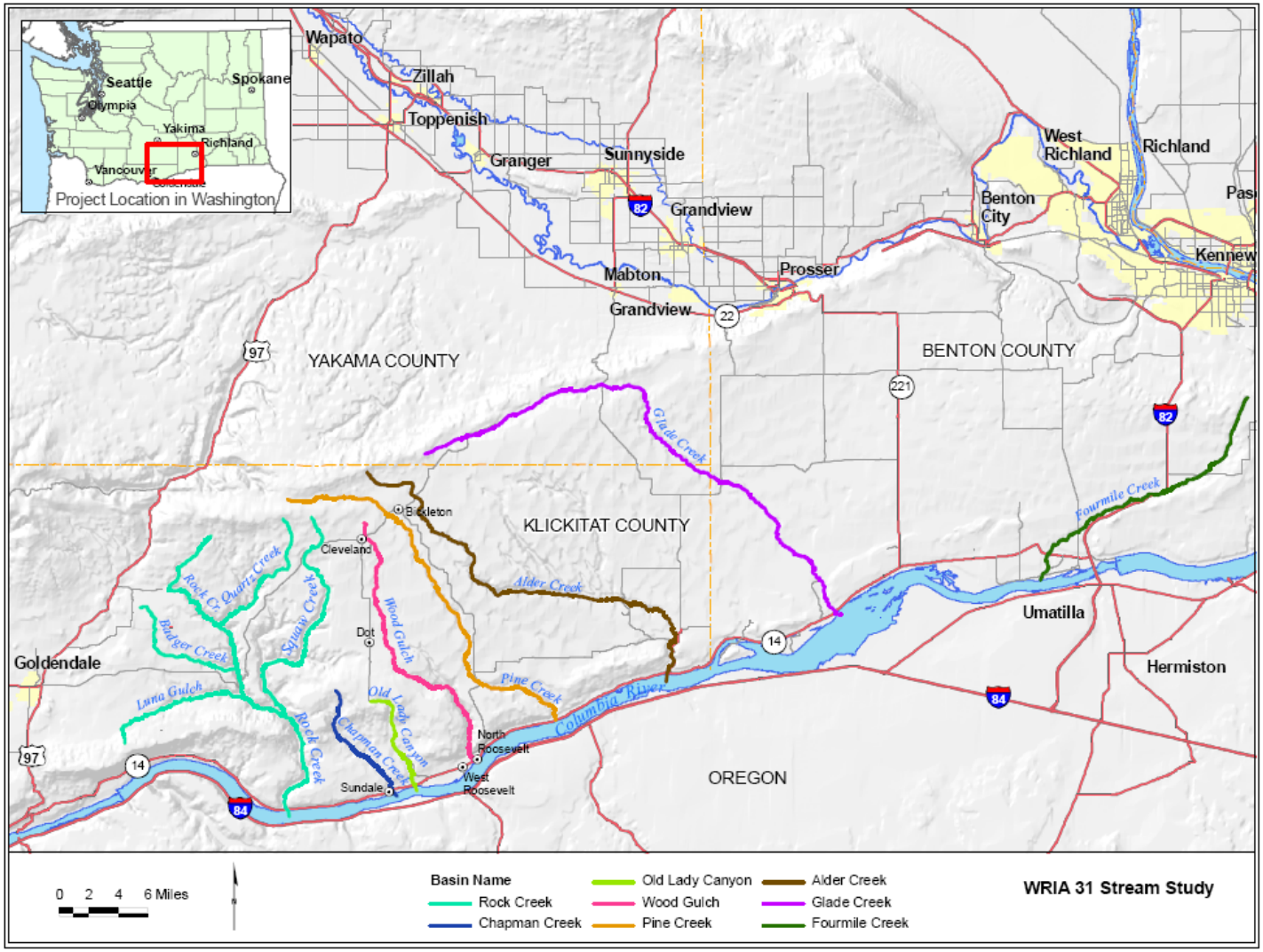


Figure 4. Major streams in WRIA 31.

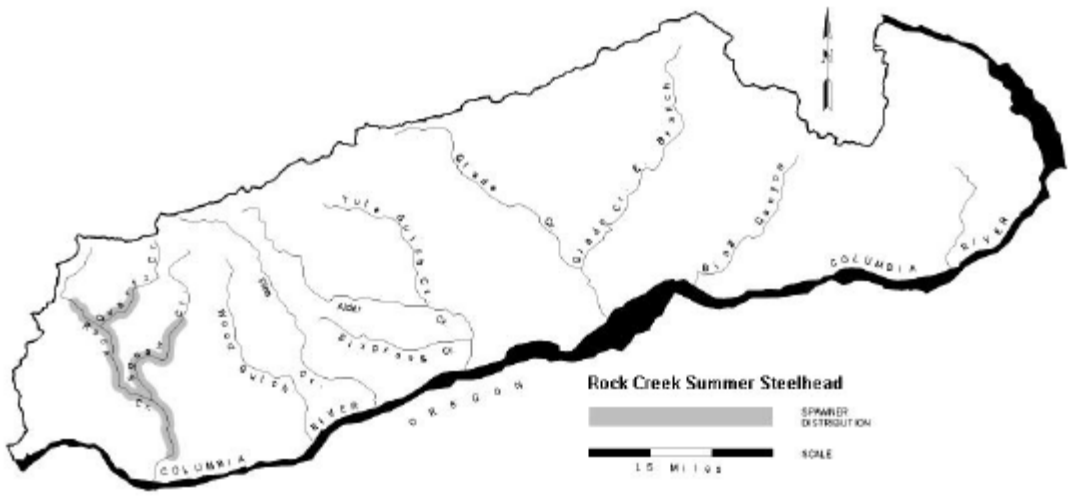


Figure 5. Fish distribution within WRIA 31 from the WDFW SaSI Report (WDFW 2002, http://wdfw.wa.gov/fish/sasi/)

- The Forest Service manual codes for the field forms were modified – the Forest Service manual uses some difficult to remember coding; more memorable codes were used for this project.
- Walnut was added as a tree species potentially occurring in the project area (walnut is common in riparian areas of portions of Rock Creek and Chapman Creek).

At each randomly selected segment, individual channel units were identified (a channel unit was defined as a pool, riffle, glide, braid, or dry segment; side channels were documented separately from main channel units). Data collected for each stream segment and each channel unit included the GPS location for the top and bottom of the segment, bankfull width, maximum bankfull depth, three separate estimates of average bankfull depth (calculated as the average depth across a transect), width of the inner riparian zone (defined as extending from the stream to a point where vegetation changes to a more upslope character), dominant and subdominant plant species within the inner riparian zone, average overstory height, average understory height, canopy closure, stream gradient, and dominant and subdominant plant species in the outer riparian zone (defined as the area between the inner riparian zone and a point 75 feet from the bankfull location), and the presence or absence of unstable banks, hydromodifications, barriers, and factors affecting riparian condition (such as cattle or roads) (Table 1). Photos of each transect were taken to document sites.

Table 1. Data collected in the field at the segment scale (100 meters) (left 2 columns) and at the individual channel unit scale (right 2 columns).

Segment Information		Channel Unit Information	
Measurement	**Unit of Measure**	**Measurement**	**Unit of Measure**
GPS location at start of segment	UTM NAD27	Channel Unit	Sequential numbering
GPS location at end of segment	UTM NAD27	Channel Unit Type	Alphanumeric Codes
Date	mm/dd/yy	Length	feet
Surveyor's initials		Width	feet
Bankfull width	To nearest 0.1 foot	Maximum depth	Feet to nearest 0.1 foot
Maximum bankfull depth	To nearest 0.1 foot	Average depth	Feet to nearest 0.1 foot; averaged across transects
Average bankfull depth	Measurements taken across three transects, measured to the nearest 0.1 foot and averaged for each transect	Pool tail crest height	Feet to nearest 0.1 foot
Width of inner riparian zone	Feet – The inner zone extends from bankfull perpendicular to the creek to a point where the vegetation changes to a more upslope character.	Aspect taken upstream	degrees
Vegetation class in the inner riparian zone	Alphanumeric codes for none, grass, small and large shrubs, saplings and poles, and small, medium, and large trees	Small (6-12 inch dia) instream wood	Number of pieces
Dominant plant species in the inner riparian zone	Alphanumeric codes	Medium (12 to 20 inch dia) instream wood	Number of pieces
Sub-dominant plant species in the inner riparian zone	Alphanumeric codes	Large (>20 inch dia.) instream wood	Number of pieces
Average understory height in the inner zone	Feet, ocular estimate	Wood jams	Number of jams
Canopy Closure	Ocular estimate of the percent of the stream segment with overhanging	Root wads	Number of root wads

Segment Information	
Measurement	**Unit of Measure**
	vegetation
Vegetation class in the outer riparian zone, which extends from the outer edge of the inner zone to a point 75 feet from the stream.	Alphanumeric codes – the same used for the inner zone
Dominant plant species in the outer riparian zone	Alphanumeric codes
Sub-dominant plant species in the outer riparian zone	Alphanumeric codes
Average understory height in the outer zone	Feet, ocular estimate
Factors affecting riparian vegetation	Notes on observations
Presence or absence of unstable banks	Y/N
Presence or absence of hydromodifications (man-made features which affect streamflow, bankfull width, floodplone width, or habitat quality)	Y/N
Presence or absence of barriers	Y/N
Stream gradient	Percent
Comments	Text

Channel Unit Information	
Measurement	**Unit of Measure**
Substrate composition	% bedrock (>4096 mm) % boulder (256 to 4096 mm) % cobble (64 to 256 mm) % gravel (16 to 64 mm) % pebble (2 to 16 mm) % sand (0.06 to 2 mm) % silt and clay (<0.60 mm)
Embeddedness	Numeric codes corresponding to <5%, 5-25%, 25-50%, 50-75%, and >75% of substrate covered with fines
% spawning gravel (% of unit suitable for spawning)	percent
Length of unstable banks	Feet on right and left sides of channel
GPS locations of unstable banks	UTM NAD27
Notes	

Hydromodifications were noted within the sample segments and at any other location where they were encountered. Documentation of hydromodifications included the GPS location, type, length of affected stream (ft), percent of width of the channel affected, wetted width of stream bankfull width of stream, floodprone width of stream, and notes. Barriers were also documented within the sample segments and any other location where they were encountered. Documentation of barriers included GPS location, length of culvert, drop, falls, or chute, height of culvert, drop or chute above stream bottom, water depth, plunge pool length, width, and depth, bankfull width and depth, and notes and photos.

Details regarding field data collection procedures and can be found in the Quality Assurance Project Plan (QAPP) developed for this study (Glass 2008) and the Forest Service Stream Inventory Handbook (USFS 2006).

3.3.2 Fish Presence/Absence

Fish presence was determined in each of the sample segments where habitat data were collected. The segments were snorkeled in one pass and the numbers of fish observed was recorded by species and size class. Size classes were defined as <100mm, 100-200 mm, 200-300 mm, and 300-400 mm. No fish were observed during the snorkel surveys that were greater than 400 mm (15.7 inches) in length. Lengths were visually estimated by the snorkeler. In addition to the sample segments, a few other locations of interest were also snorkeled (a few large pools lying outside of the sample segments and a major wetland in Glade Creek).

3.3.3 Spawning Surveys

Spawning surveys were conducted in Rock Creek on May 12-13, 2009. Surveys were conducted by walking along either bank or in the stream as bank conditions and stream velocity allowed. Using polarized glasses, visual surveys were conducted to determine the presence of steelhead or redds. All mainstem habitats were surveyed. Side channel habitats with sufficient flow were also surveyed. Walk through surveys were conducted in Reaches 1 and 2, with no data other than detection data recorded. From the beginning of Reach 4, through the end of the survey, all habitat types were recorded and numbered sequentially. Reach segments, in which physical surveys were conducted in the fall of 2008, were recorded when they could be identified. UTM coordinates were collected at all detection locations. UTM coordinates were recorded in NAD27 CONUS.

3.4 DATA ANALYSIS

Data were reviewed for inconsistencies, extremes, outliers, and obvious errors using Microsoft Excel. SYSTAT and Microsoft Excel were used for to support the data analysis. Averages of measurements taken in the sampled segments were used to represent habitat quality throughout each reach. The total area of spawning habitat and the total volume of rearing habitat was calculated for each segment. Area and volume per unit measure was expanded across the entire reach to estimate total area of spawning habitat and total volume of rearing habitat for the entire reach.

The sampled stream segments were assumed to be representative of the entire stream reach. The information collected was used to support the estimation of the quantity and quality of spawning and rearing habitat throughout the basin. Data analysis relative to stream temperature relied on stream temperature data collected by the Central Klickitat Conservation District and reported by Aspect (2005) and temperature data gathered by the Washington Department of Ecology at the flow gage (https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070).

3.5 SEDIMENT SOURCE MODELING

Sediment input was estimated based on observations made during a 1-day site reconnaissance, viewing orthophotographs to help identify land uses and sediment sources, and GIS modeling of sediment inputs (Table 2).

Table 2. Summary of methods used to estimate sediment inputs.

Sediment Source	Method
Soil creep/stream bank erosion	A combined estimate was based on SEDMODL2 calculations
Agricultural land	The WEPP model was used to estimate erosion and delivery rates from representative field/buffer/slope combinations. These sediment input rates were extrapolated to croplands within 1,000 feet of streams. Erosion from grazing of streamside vegetation was evaluated based on percent of stream length observed to be damaged by grazing during the stream inventory, extrapolated to rest of stream areas utilized for grazing.
Road surface erosion	Observations of road conditions/lengths/delivery were made during a 1-day site visit. Erosion/delivery estimates were based on SEDMODL2 calculations on all roads in GIS database

3.5.1 Data Sources

The following GIS coverages and data were used in the analysis:

- Topography – USGS 10 meter Digital Elevation Model
- Streams – Washington State Department of Natural Resources Watercourse (WC) Hydrography (WDNR Jan. 2009)
- Roads – State Transportation coverage (WDNR Jan. 2009)
- Geology – WDNR 1:100,000 scale geology (WDNR 2000)
- Soils – NRCS soils, combined WA DNR coverage for Klickitat county and SSURGO for Benton and Yakima counties. Acquired from Aspect Consulting
- Land Use – US National Land Cover Data (NLCD) from1992 Landsat data. Acquired WRIA31 subset of data from Aspect Consulting (USGS 1992)
- Data from the crop analysis completed in 2004 (IRZ 2004) and a crop database provided by the Washington Department of Agriculture (2009) which provides information on crops and irrigation in the project area

- Existing traffic count data for portions of gravel-surfaced roads in Klickitat County obtained from the County (personal communication, Seth Scarola, Project Engineer, Klickitat County Pubic Works, June 1, 2009)

In addition, observations on the types of land uses/sediment sources in the subbasins and average road conditions across the subbasins were made during a site visit on May 14, 2009. The objective of the reconnaissance-level site visit was to observe existing conditions and sediment-producing activities in the subbasins. Observations of croplands, road drainage connectivity, unpaved road conditions, potential sediment delivery pathways, and presence/absence of defined channels at road crossings were made. Approximately 200 miles of road within the four subbasins were driven.

Based on field observations, type N and U (non-fish bearing) streams in areas underlain by loess and fine-grained flood deposits (Ql and Qfs geologic units) and were not included as streams in the analysis of sediment delivery in the Glade Creek subbasin. During the field checking, there were swales, but very few actual channels were found in locations that were mapped as type N or U on Ql and Qfs geologic units. It is possible that mapped streams in parts of other subbasins, particularly lower Rock Creek, are not actually streams on the ground, but we did not have adequate field data to verify stream presence/absence in other subbasins. Since sediment delivery estimates were based on mapped streams, a higher number of mapped streams will result in an overestimate of sediment delivery to streams.

3.5.2 Soil Creep and Stream Bank Erosion

Soil creep and stream bank erosion are natural processes that occur along all streams and provide a background level of sediment input to streams. Soil creep is the slow downward motion of the soil column due to gravity and provides sediment to stream banks where it enters the stream. In some locations in larger, alluvial sections of streams, the flow has enough energy to erode the stream banks, providing sediment from this mechanism. In general, soil creep is considered the input mechanism in smaller headwater channels, while stream bank erosion is often the input mechanism in larger channels. Based on observations by the stream inventory crew, stream bank erosion does not appear to be widespread in WRIA31. For this reason, the estimate of soil creep from the SEDMODL2 application was used to estimate sediment input from both these sources. A soil depth of 60 inches was used based on depths reported for soils in the watershed by the NRCS (http://websoilsurvey.nrcs.usda.gov/app/). The lowest creep rates in SEDMODL2 (0.03/0.07 mm/yr for slopes greater and less than 30 percent, respectively) were used due to the low rainfall in the area.

3.5.3 Agricultural Lands

An assessment of erosion and delivery from agricultural lands was made using the WEPP model (http://www.ars.usda.gov/Research/docs.htm?docid=10621) and existing GIS coverages showing land use.

3.5.4 Cultivated Land

The primary plowed/planted agricultural lands are within the Glade Creek subbasin and include rotations of winter wheat and fallow land, row crops, and wine grapes. Primary row crops include corn, peas, beans, and potatoes (personal communications, June 5, 1009, Troy Grimes, ConAgra farm and dairy operations manager; and WA Dept. of Agriculture database 2006). Land in the northern portion of the subbasin is not irrigated. Center pivot irrigation is used on row crops in the southern portion of the basin, generally from March through October. Some row crops have multiple rotations within the year, and a cover crop is generally planted to provide erosion control over winter. There are also limited plowed/planted lands within the other study subbasins.

Cover crops between grape vines reduce surface erosion

Since there is no detailed GIS information on specific crops, and rotations change through time, the WEPP model was used to calculate erosion and delivery to streams from several representative scenarios (Table 3). For all runs, the Richland WA climate and the Shano silt loam soil was used. Slopes of 2, 5, 10, 20, 30, 40, and 50% with 1,000 foot lengths were modeled. Management files included the standard WEPP-provided winter wheat mulch tilled, winter wheat conventional tilled, winter wheat no till, fallow tilled, to represent the range of dryland farming methods in the northern part of the basin. Several WEPP runs were made to determine the range of predicted erosion from irrigated land, including: corn spring chisel plow (with and without irrigation), corn no till winter wheat cover crop (no irrigation), and three different no till, irrigation, with winter wheat cover crop scenarios (sweet corn, peas, and potatoes).

Table 3. WEPP estimates of erosion from various cultivated land uses (average tons/acre/year).

Hill Slope Gradient (%)	Winter wheat, continuous no till	Winter wheat, conventional till	Winter wheat, mulch till	Winter wheat, continuous no till, stationary depletion irrigation (Mar-0ct)	Winter wheat, conventional till, stationary depletion irrigation (Mar-Oct)	Corn, spring chisel plow (no irrigation)	Corn, no till, winter wheat cover crop (no irrigation)	Corn, spring chisel plow, stationary depletion irrigation (Mar-Oct)	Sweet corn, no till, winter wheat cover crop, stationary depletion irrigation (Mar-Oct)	Peas, no till, winter wheat cover crop, stationary depletion irrigation (Mar-Oct)	Potatoes, no till, winter wheat cover crop, stationary depletion irrigation (Mar-Oct)
2	0	0	0	0	0.01	0	0	0	0	0	0
5	0	0.1	0	0	0.1	0	0	0.3	0	0.1	0.1
10	0	0.3	0.2	0	0.7	0.2	0.1	1.3	0.4	0.3	0.2
20	0.1	1.2	0.8	0.1	4.9	0.7	0.3	4	1	0.7	0.9
30	0.2	2.1	1.5	0.4	10.1	1.3	0.6	7.6	1.6	1.1	1.1
40	0.3	3.1	2.3	0.9	15	1.9	0.8	10.9	2.2	1.5	2
50	0.4	4.4	2.9	1.1	19.7	2.5	1.3	14.4	3.2	1.9	3

The WEPP results were compiled into three average rates that were used for the three cultivated land use categories available in the GIS coverage: Cultivated irrigated;

Cultivated small grains; and Cultivated fallow (Table 4).

Table 4. WEPP erosion estimates used in analysis (average tons/acre/year).

Hill Slope Gradient (%)	Cultivated irrigated (average winter wheat and row crop, no till, irrigated)	Cultivated small grains (winter wheat, mulch till)	Cultivated fallow (Winter wheat continuous, no till)
2	0.0	0.0	0.0
5	0.1	0.0	0.0
10	0.2	0.2	0.0
20	0.7	0.8	0.1
30	1.1	1.5	0.2
40	1.7	2.3	0.3
50	2.3	2.9	0.4

These average erosion rates (tons/acre/yr) were applied to acres of land within 1,000 feet of streams mapped as Cultivated – Fallow, Cultivated - Irrigated Land, and Cultivated - Small Grains management scenarios in the GIS database derived from Landsat imagery (USGS 1992). It is assumed that the majority of sediment eroded from land farther than 1,000 feet from a stream channel will be re-deposited before it enters a stream channel. The acreages used in this analysis are shown in italics in Table 5.

3.5.5 Grazing

Livestock grazing occurs within the Rock Creek, Wood Gulch, and Pine Creek subbasins. Observations during the site reconnaissance suggested that in most locations, grazing was not intense enough to contribute substantial amounts of sediment to streams. However, in a few locations, grazing was observed to be concentrated near streams and trampling of banks was observed to be a localized sediment source. An assessment of the degree of livestock damage to riparian areas was included as part of the WRIA 31 stream study. Inventory crews noted if livestock damage was evident at each study site, but no quantitative measurements were made. These notes were compiled and a relative ranking was given to each site (no livestock damage, minor livestock damage, some livestock damage, and heavy livestock damage). These data were extrapolated to un-inventoried stream reaches that are used for grazing and do not have riparian fencing.

The WEPP model was used to estimate erosion from grazing by modeling the cow paths as a narrow skid trail with 10% ground cover, silty loam soils, and 5 % slope. A modified climate was generated using the included CLIGEN PRISM routine based on the Richland WA climate, with a location of 120.333° W and 45.8667°N to represent the areas within Wood Gulch that were noted to have the heaviest cattle use along streams.

Table 5. Land use within 1,000 feet of streams in the Rock, Wood, Pine, and Glade subbasins.

Subbasin	Reported Land Use[1]	Acres
Rock Creek	BARREN - Various	17
	CULTIVATED - Fallow	*1,658*
	CULTIVATED - Irrigated Land	*581*
	CULTIVATED - Small Grains	*2,563*
	DEVELOPED - Various	136
	FORESTED UPLANDS - Various	25,800
	GRASSLANDS / HERBACEOUS	7,808
	SHRUBLAND	30,360
	WETLAND - Various	111
	Unknown	79
Rock Creek Total		69,111
Wood Gulch	BARREN - Various	1
	CULTIVATED - Fallow	*205*
	CULTIVATED - Irrigated Land	*3*
	CULTIVATED - Small Grains	*468*
	DEVELOPED - Various	61
	FORESTED UPLANDS - Various	817
	GRASSLANDS / HERBACEOUS	4,001
	SHRUBLAND	8,875
	WETLAND - Various	20
	Unknown	1
Wood Gulch Total		14,451
Pine Creek	BARREN - Various	0
	CULTIVATED - Fallow	*213*
	CULTIVATED - Small Grains	*140*
	DEVELOPED - Various	107
	FORESTED UPLANDS - Various	3,277
	GRASSLANDS / HERBACEOUS	2,827
	SHRUBLAND	9,541
	WETLAND - Various	36
	Unknown	15
Pine Creek Total		16,157
Glade Creek	BARREN - Various	1
	CULTIVATED - Fallow	*46,253*
	CULTIVATED - Irrigated Land	*8,844*
	CULTIVATED - Small Grains	*17,953*
	DEVELOPED - Various	334
	FORESTED UPLANDS - Various	46
	GRASSLANDS / HERBACEOUS	5,118
	SHRUBLAND	27,422
	WETLAND - Various	1
	Unknown	50
Glade Creek Total		106,023

Note: italicized rows were used in cultivated land analysis

1/ Land use data is based on a 1972 dataset and is likely out of date.

3.5.6 Road Surface Erosion

SEDMODL2 was used to estimate road surface erosion from roads in the subbasins. SEDMODL2 is an empirical road surface erosion model that estimates surface erosion and delivery to streams based on road conditions such as road width, gradient, surfacing, traffic, ditch width, cutslope height, and cover. Information on the model calculations can be found in the technical documentation (http://www.ncasi.org/support/downloads/Detail.aspx?id=5).

Current road conditions on representative roads in the subbasins were observed during a site visit on May 14, 2009. Road data collected during the site visit included: length of road that drains to a stream at each crossing, tread width, ditch width, tread gradient, tread configuration, tread surfacing, cutslope height, and cover density. These data were compiled by road class and used to provide input data to SEDMODL2 based on mapped road class. Traffic count data were available for some of the gravel-surfaced roads and obtained from Klickitat County (personal communication, Seth Scarola, Project Engineer, Klickitat County Pubic Works, June 1, 2009). If traffic count data were available for specific roads, the data were used to determine traffic level based on SEDMODL2 traffic classes.

Runoff from unsurfaced roads can deliver sediment to streams

SEDMODL2 was run for all roads included on the DNR road coverage in the four subbasins. Table 6 summarizes conditions that were used as model input.

Table 6. Road conditions used for SEMODL2 calculations.

DNR Road Class	Tread width (ft)	Ditch Width (ft)	Surfacing	Traffic	Cutslope Cover Density	Road Configuration
1 – Highway 2 – Secondary 3 – All Season	30	10	Asphalt	Moderate	70%	Insloped
4 - Unpaved	12	3	Gravel	Light*	70%	Insloped
5 (trail), Railroad	Not modeled (not roads)					

* Actual traffic count data were used if available for gravel surfaced roads.

3.5.7 Data and Study Limitations

Constraints on the erosion assessment include: a) limited spatial information on crops grown and irrigation methods within the study area; and b) limitation of the amount of time that could be spent in the field to collect validation data.

4.0 RESULTS

4.1 HABITAT

The study area included the public and private lands of Rock Creek, Chapman Creek, Pine Creek, Wood Gulch, Old Lady Canyon, and Glade Creek. Data were collected in all reaches between October 29, 2008 and December 12, 2008 with the exception of Glade Creek. Data collection in Glade Creek occurred between May 28 and May 30, 2009. All of the reaches except Glade Creek were sampled during low flow periods. Glade Creek was sampled in May during the spring freshets; therefore, the Glade Creek data do not represent the low flow condition. Tribal trust lands were excluded from the data collection effort since they are not included within the WRIA 31 planning area. Base maps for the project areas depicting the sample locations are provided in Appendix A, Maps 1 through 8. Photos of the sample reaches are provided in Appendix B. A total of 19,703 meters (57,432 feet) of stream were sampled which represented 15.7 percent of the total habitat in the identified reaches throughout the study area (Table 7).

Average gradient in the sampled reaches ranged from 0 to 5.29 percent (Table 8). Reach 3 in Wood Gulch had the steepest gradient. Other steep reaches included Reach 2 in Pine Creek and the upper reaches of Rock and Squaw Creeks.

Overall, 20.1 percent of the length of the sampled stream segments was dry (Table 9; Figure 6). Within the Rock Creek subbasin, the dry sections were concentrated in Reaches 6, 7, and 8; continuous flow was observed in the canyon reaches upstream of Reach 8. Dry reaches were scattered throughout the other subbasins.

Pools comprised 32% (Chapman Creek) to 54% (Pine Creek) of the channel units sampled (Figure 7) and riffles covered between 15% (Glade Creek) and 57% (Chapman Creek) of the total channel units sampled (Figure 7).

Table 7. Sample reaches, total reach length, sampled reach length and percent of reach sampled.

Basin	Stream	Reach	Total sample length (ft)	Total Sample Length (m)	Reach Length (ft)	Reach Length (m)	Percent Sampled
Chapman Creek	CHAPMAN CREEK	1	1,109	338	1,312	400	84.5%
Chapman Creek	CHAPMAN CREEK	2	3,174	967	12,139	3,700	26.1%
Chapman Creek	CHAPMAN CREEK	3	2,069	631	6,234	1,900	33.2%
Chapman Creek Total			***5,906***	***1,800***	***19,685***	***6,000***	***30.0%***
Pine Creek	PINE CREEK	1	2,417	737	21,325	6,500	11.3%
Pine Creek	PINE CREEK	2	1,275	389	12,139	3,700	10.5%
Pine Creek	PINE CREEK	3	1,847	563	10,171	3,100	18.2%
Pine Creek	PINE CREEK	4	1,375	419	14,436	4,400	9.5%

Basin	Stream	Reach	Total sample length (ft)	Total Sample Length (m)	Reach Length (ft)	Reach Length (m)	Percent Sampled
Pine Creek Total			***6,562***	***2,000***	***58,071***	***17,700***	***11.3%***
Rock Creek	LUNA GULCH	1	1,014	309	4,265	1,300	23.8%
Rock Creek	LUNA GULCH	2	1,134	346	6,234	1,900	18.2%
Rock Creek	LUNA GULCH	3	332	101	6,562	2,000	5.1%
Rock Creek	QUARTZ CREEK	1	1,019	311	6,890	2,100	14.8%
Rock Creek	ROCK CREEK	1	1,842	561	4,921	1,500	37.4%
Rock Creek	ROCK CREEK	2	1,119	341	6,890	2,100	16.2%
Rock Creek	ROCK CREEK	4	1,471	448	13,123	4,000	11.2%
Rock Creek	ROCK CREEK	5	1,384	422	9,843	3,000	14.1%
Rock Creek	ROCK CREEK	6	1,259	384	3,281	1,000	38.4%
Rock Creek	ROCK CREEK	7	1,201	366	3,937	1,200	30.5%
Rock Creek	ROCK CREEK	8	1,118	341	3,609	1,100	31.0%
Rock Creek	ROCK CREEK	9	1,125	343	6,890	2,100	16.3%
Rock Creek	ROCK CREEK	10	1,011	308	5,906	1,800	17.1%
Rock Creek	ROCK CREEK	11	1,969	600	14,108	4,300	14.0%
Rock Creek	ROCK CREEK	12	1,075	328	7,218	2,200	14.9%
Rock Creek	ROCK CREEK	13	1,580	482	12,467	3,800	12.7%
Rock Creek	SQUAW CREEK	1	1,043	318	6,890	2,100	15.1%
Rock Creek	SQUAW CREEK	2	1,084	330	7,218	2,200	15.0%
Rock Creek	SQUAW CREEK	3	1,158	353	6,562	2,000	17.6%
Rock Creek	SQUAW CREEK	4	377	115	10,499	3,200	3.6%
Rock Creek	SQUAW CREEK	5	984	300	3,937	1,200	25.0%
Rock Creek	SQUAW CREEK	6	991	302	3,937	1,200	25.2%
Rock Creek	SQUAW CREEK	7	4,063	1,238	31,824	9,700	12.8%
Rock Creek Total			***38,386***	***11,700***	***264,764***	***80,700***	***14.5%***
Wood Gulch	WOOD GULCH	1	1,147	350	3,281	1,000	35.0%
Wood Gulch	WOOD GULCH	2	3,343	1,019	27,559	8,400	12.1%
Wood Gulch	WOOD GULCH	3	2,401	732	22,638	6,900	10.6%
Wood Gulch	WOOD GULCH	4	1,517	462	11,811	3,600	12.8%
Wood Gulch	WOOD GULCH	5	2,460	750	20,341	6,200	12.1%
Wood Gulch Total			***9,843***	***3,000***	***85,630***	***26,100***	***11.5%***
Glade Creek	GLADE CREEK	1	684	208	1,987	606	34.4%
Glade Creek	GLADE CREEK	2	1,160	353	5,034	1534	23.0%
Glade Creek	GLADE CREEK	3	2,102	641	9,159	2792	23.0%
Glade Creek Total			***3,945***	***1,203***	***16,180***	***4,926***	***24.4%***
TOTAL			**64,642**	**19,703**	**444,330**	**135,426**	
Percent sampled across all reaches						**15.7%**	

Table 8. Average stream gradient of sampled basins.

Basin	Stream	Reach #	Average Gradient (%)
Chapman Creek	Chapman Creek	1	1.83
		2	1.94
		3	1.79
Pine Creek	Pine Creek	1	1.43
		2	2.75
		3	1.00
		4	1.13
Rock Creek	Luna Gulch	1	1.00
		2	1.00
		3	1.00
	Quartz Creek	1	3.00
	Rock Creek	1	0.75
		2	1.50
		4	0.75
		5	0.33
		6	1.33
		7	0.33
		8	0.67
		9	1.00
		10	1.00
		11	2.00
		12	3.33
		13	3.50
	Squaw Creek	1	1.00
		2	0.00
		3	0.67
		4	1.00
		5	1.00
		6	1.00
		7	3.00
Wood Gulch	Wood Gulch	1	1.00
		2	1.22
		3	5.29
		4	1.08
		5	1.00
Glade	Glade	1	1.00
		2	1.38
		3	0.71

Table 9. Number and type of channel units sampled and portion of stream length that was dry.

Basin	Stream	Reach	Number of Channel Units Measured	Number of Riffles Sampled	Number of Pools Sampled	Number of Glides Sampled	Percent of Length That was Dry
Chapman Creek	CHAPMAN CREEK	1	13	7	6	0	35.5%
Chapman Creek	CHAPMAN CREEK	2	38	20	9	9	4.3%
Chapman Creek	CHAPMAN CREEK	3	37	18	13	5	19.3%
Chapman Creek total			***88***	***45***	***28***	***14***	***14.5%***
Pine Creek	PINE CREEK	1	34	12	16	0	63.4%
Pine Creek	PINE CREEK	2	27	8	14	1	41.5%
Pine Creek	PINE CREEK	3	26	6	11	2	10.7%
Pine Creek	PINE CREEK	4	24	11	10	2	0.9%
Pine Creek Total			***111***	***37***	***51***	***5***	***41.6%***
Rock Creek	LUNA GULCH	1	7	1	1	2	67.7%
Rock Creek	LUNA GULCH	2	15	6	7	2	0.0%
Rock Creek	LUNA GULCH	3	8	2	5	1	0.0%
Rock Creek	QUARTZ CREEK	1	14	7	7	0	0.0%
Rock Creek	ROCK CREEK	1	16	6	8	2	0.0%
Rock Creek	ROCK CREEK	2	3	1	1	1	0.0%
Rock Creek	ROCK CREEK	4	16	5	6	5	0.0%
Rock Creek	ROCK CREEK	5	8	4	2	2	0.0%
Rock Creek	ROCK CREEK	6	14	6	6	1	46.3%
Rock Creek	ROCK CREEK	7	9	2	4	2	29.3%
Rock Creek	ROCK CREEK	8	10	3	4	1	36.1%
Rock Creek	ROCK CREEK	9	13	5	6	2	0.0%
Rock Creek	ROCK CREEK	10	11	5	2	4	0.0%
Rock Creek	ROCK CREEK	11	40	17	16	7	0.0%
Rock Creek	ROCK CREEK	12	22	10	12	0	0.0%
Rock Creek	ROCK CREEK	13	33	16	16	1	0.0%
Rock Creek	SQUAW CREEK	1	17	7	8	1	2.7%
Rock Creek	SQUAW CREEK	2	5	0	1	1	70.4%
Rock Creek	SQUAW CREEK	3	13	4	6	1	26.8%
Rock Creek	SQUAW CREEK	4	4	2	2	0	0.0%
Rock Creek	SQUAW CREEK	5	3	0	0	0	100.0%
Rock Creek	SQUAW CREEK	6	3	0	0	0	100.0%
Rock Creek	SQUAW CREEK	7	66	29	34	1	16.3%
Rock Creek Total			***549***	***220***	***233***	***56***	***13.9%***
Wood Gulch	WOOD GULCH	1	7	1	2	0	58.4%
Wood Gulch	WOOD GULCH	2	40	17	20	1	0.0%
Wood Gulch	WOOD GULCH	3	65	30	33	2	0.0%

Basin	Stream	Reach	Number of Channel Units Measured	Number of Riffles Sampled	Number of Pools Sampled	Number of Glides Sampled	Percent of Length That was Dry
Wood Gulch	WOOD GULCH	4	15	5	8	2	0.0%
Wood Gulch	WOOD GULCH	5	16	0	5	4	68.7%
Wood Gulch Total			***143***	***53***	***68***	***9***	***24.0%***
Glade Creek	GLADE CREEK	1	10	1	5	4	0.0%
Glade Creek	GLADE CREEK	2	10	4	5	2	0.0%
Glade Creek	GLADE CREEK	3	15	0	6	6	7.6%
Glade Creek Total			***35***	***5***	***16***	***12***	***4.1%***
Totals for sampled areas			**727**	**278**	**317**	**77**	**20.1%**

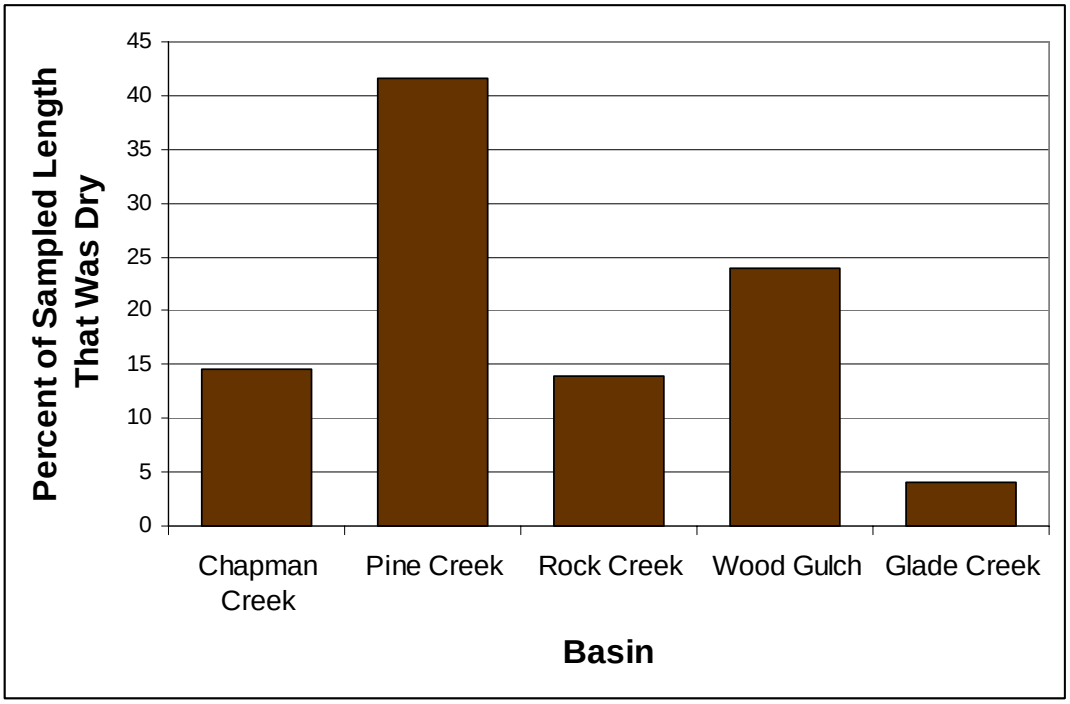


Figure 6. Percent of the sampled length of each basin that was dry.

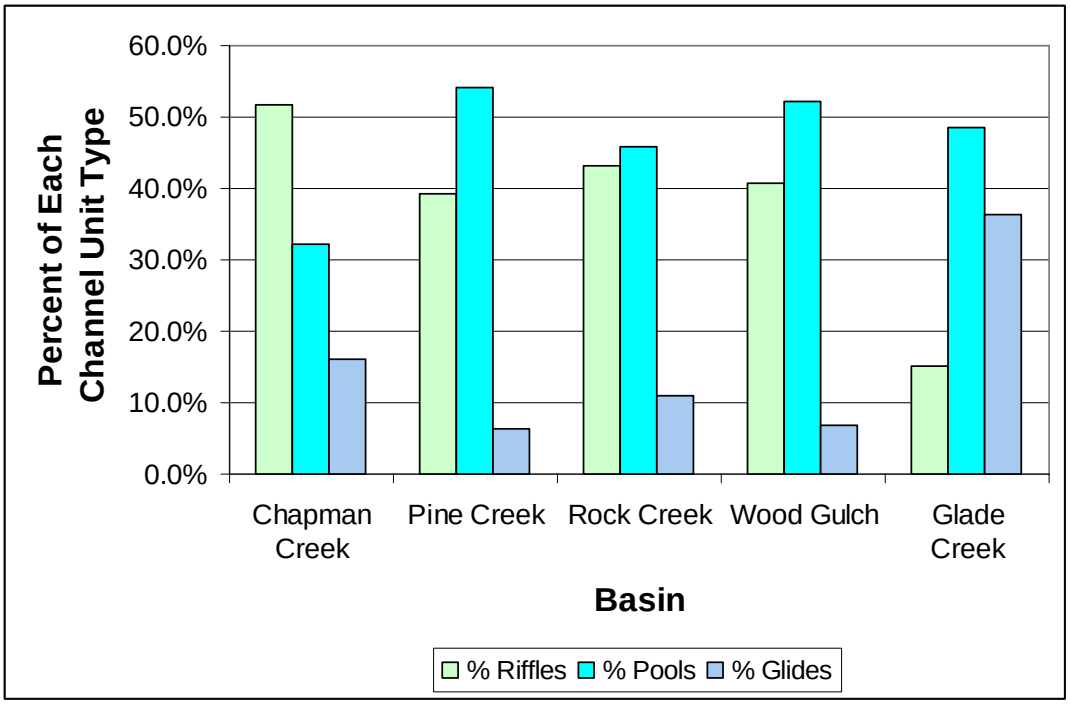


Figure 7. Percent of sampled channel units that were riffles, pools, and glides for each basin.

4.1.1 Pools

Average pool depth ranged from 0.061 to 0.853 meters (0.2 to 2.8 feet) and maximum pool depth ranged from 0.122 to 2.13 meters (0.4 to 7.0 feet). The distribution of average and maximum pool depths were similar for all the basins except Glade Creek which had much deeper pools on average (Figure 8). With the exception of Glade Creek, pools were generally less than 0.6 meters (2 feet) deep.

Pool volume was estimated for each pool sampled in the study area and the average pool volume per 100 meters was estimated for each stream segment. The average and standard deviation of pool volume was estimated for each reach (Zar 1974). Pool volume per 100 meters ranged from 0.13 to 77.89 m^3 per 100m and averaged 6.6 m^3 per 100m (Table 10; Appendix A, Maps 9 through 16). Expanding the mean density of pool volume/m^3 over the total length of each reach, the total estimated volume of pools in the study area is estimated at 5,408 m^3 (7,073 square yards), 78 percent of which is located in the Rock Creek basin (Tables 10 and 11).

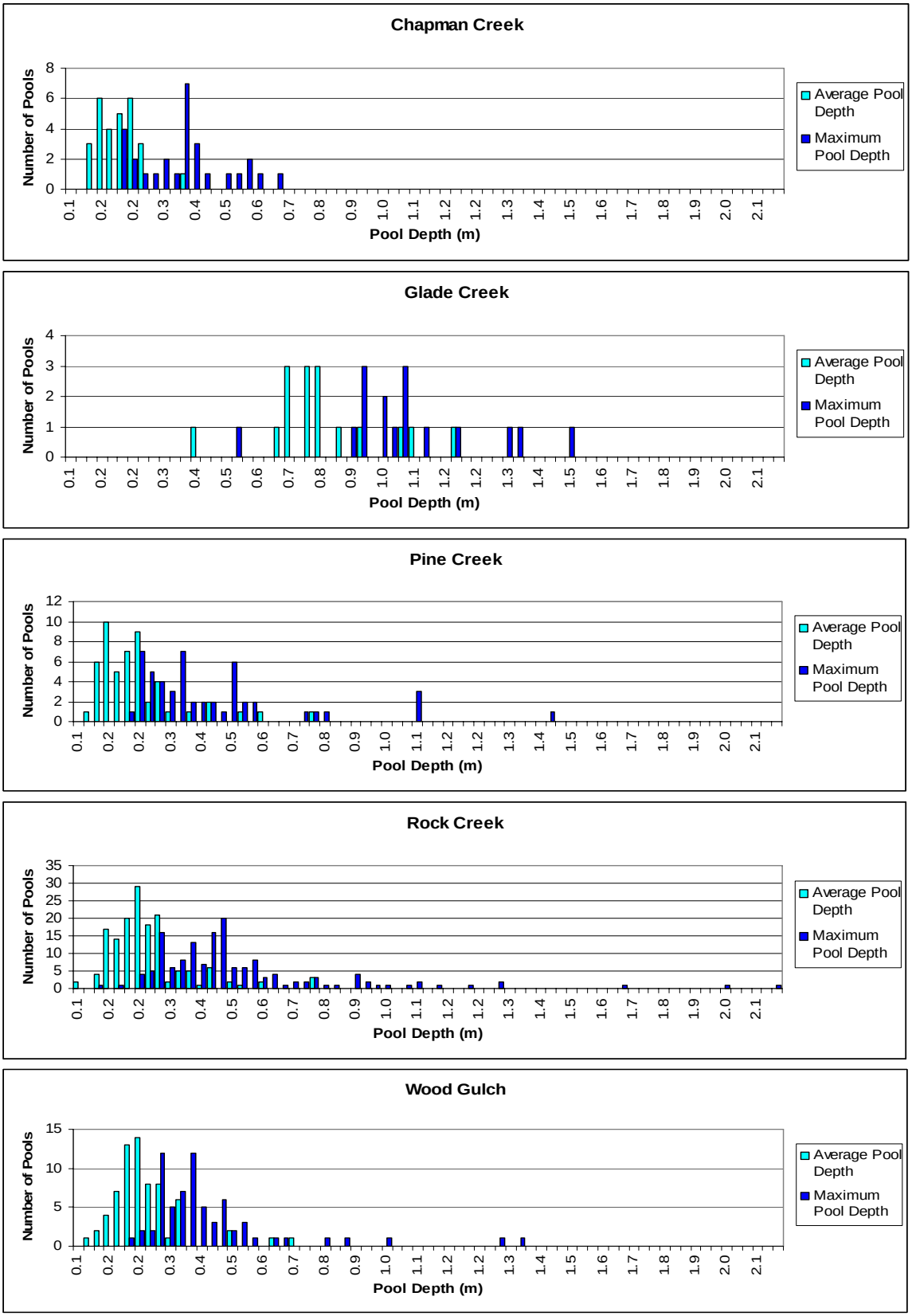


Figure 8. The frequency of occurrence of pools at various depths, by basin.

Table 10. Pool Volume in each reach.

Basin	Stream	Reach	Average Pool Volume (m^3)/ 100m	Standard Deviation Pool Volume (m^3)/ 100m	Total Estimated Pool Volume (m^3) in Reach	Standard Deviation of Total Estimated Pool Volume (m^3) in Reach
Chapman Creek	Chapman Creek	1	2.37	27.02	9.5	108.1
		2	0.13	6.91	4.8	255.7
		3	0.16	7.58	3.1	144.1
Pine Creek	Pine Creek	1	0.75	41.08	48.6	2670.5
		2	0.77	22.14	28.5	819.1
		3	0.87	46.09	27.0	1428.9
		4	1.77	21.24	78.0	934.7
Rock Creek	Luna Gulch	1	0.20	2.55	2.7	33.2
		2	2.87	12.59	54.5	239.2
		3	2.70	N/A*	54.0	N/A*
	Quartz Creek	1	3.61	46.33	75.9	973.0
	Rock Creek	1	29.62	110.51	444.3	1657.7
		2	77.89	392.09	1635.6	8233.9
		4	8.44	136.06	337.5	5442.3
		5	7.10	42.65	213.1	1279.4
		6	1.40	28.71	14.0	287.1
		7	8.73	102.11	104.7	1225.4
		8	3.62	41.64	39.8	458.0
		9	3.93	40.97	82.5	860.3
		10	1.13	22.04	20.3	396.8
		11	1.19	41.62	51.1	1789.7
		12	1.26	9.87	27.8	217.1
		13	0.29	6.10	10.9	232.0
	Squaw Creek	1	2.34	14.79	49.1	310.7
		2	2.41	17.72	52.9	389.8
		3	3.30	36.66	66.0	733.1
		4	26.73	N/A*	855.2	N/A*
		5	DRY	DRY	0.0	0.0
		6	DRY	DRY	0.0	0.0
		7	0.38	28.84	37.2	2797.8
Wood Gulch	Wood Gulch	1	0.37	5.69	3.7	56.9
		2	1.06	27.28	89.3	2291.8
		3	0.45	14.53	30.8	1002.4
		4	8.16	113.04	293.7	4069.3
		5	0.13	5.73	8.1	355.1
Glade Creek	Glade Creek	1	24.99	87.07	151.3	527.3
		2	10.55	79.54	161.8	1220.4
		3	8.63	117.21	240.8	3272.2

* Not enough samples to calculate a standard deviation

Table 11. Total estimated volume of pools (m^3) by basin and stream.

BASIN / STREAM		TOTAL
Chapman Creek		17
Glade Creek		554
Pine Creek		182
Rock Creek	Luna Gulch	111
	Quartz Creek	76
	Rock Creek Mainstem	2,982
	Squaw Creek	1,060
Rock Creek Total		4,229
Wood Gulch		426
Grand Total		**5,408**

4.1.2 Spawning Area and Substrate Condition

The area of spawning habitat was estimated for each channel unit containing spawning habitat (including riffles, glides, and the tails out of many pools), and the average spawning area per 100 meters was estimated for each segment. The mean and standard deviation of spawning area was calculated for the portions of each reach that were included in the study by averaging the values for each segment and completing the calculations for standard deviation (Zar 1974). Spawning area per 100 meters ranged from 0.0 to 314.5 m^2 per 100m and averaged 77.7 m^2 per 100m (Table 12; Appendix A, Maps 17 through 24). Expanding the average spawning area per m^2 over the total length of each reach, including portions not directly sampled, the total estimated area of spawning habitat in the study area is estimated at 5,408 m^2, 78 percent of which is located in the Rock Creek basin (Tables 12 and 13).

The substrate composition was documented for each channel unit in each sample segment (Table 14). Two methods were used to document substrate condition. The modified Wentworth procedure visually estimates the percent of the substrate that falls into a range of categories. This measure is focused on the composition of the materials *within* the substrate. In addition, a visual estimate of embeddedness was documented. This measure focuses on the amount of fine sediment overlying the substrate.

In general, substrate materials tended to be slightly coarser in riffles than in other channel unit types (pools, glides, marshes) (Figure 9). Chapman Creek and Glade Creek basins tended to have a much higher percentage of fines than were observed in Rock Creek, Wood Gulch, and Pine Creek. As will be discussed later, this is related to the underlying geology of the basins. Glade and Chapman Creek have much less spawning material (gravel/cobble) than is found in the other basins.

Table 12. Spawning area in each reach.

Basin	Stream	Reach	Ave Spawning area (m^2) /100 m	Standard Deviation Spawning Area (m^2) /100 m	Total Estimated Spawning Area (m^2) in Reach	Standard Deviation Total Estimated Spawning Area
Chapman Creek	Chapman Creek	1	0.0	0.00	0.00	0.00
		2	0.0	0.00	0.00	0.00
		3	0.3	0.79	1697.40	15.01
Pine Creek	Pine Creek	1	26.1	35.55	677.16	2310.61
		2	18.3	8.94	2004.83	330.63
		3	64.7	32.98	4966.35	1022.47
		4	112.9	71.45	51.93	3143.76
Rock Creek	Luna Gulch	1	4.0	3.65	871.43	47.43
		2	45.9	39.80	203.63	756.19
		3	10.2	N/A*	3158.10	N/A*
	Quartz Creek	1	150.4	94.48	3814.16	1984.14
	Rock Creek	1	254.3	103.43	6603.49	1551.40
		2	314.5	488.99	10526.51	10268.86
		4	263.2	105.08	5137.75	4203.37
		5	171.3	9.33	1484.28	279.83
		6	148.4	146.94	1659.06	1469.36
		7	138.3	161.76	958.30	1941.16
		8	87.1	99.53	2029.11	1094.88
		9	96.6	87.23	2650.00	1831.74
		10	147.2	30.24	4742.63	544.35
		11	110.3	36.39	1081.28	1564.68
		12	49.1	42.57	724.42	936.60
		13	19.1	10.75	5422.16	408.51
	Squaw Creek	1	258.2	122.70	876.30	2576.65
		2	39.8	68.99	1830.75	1517.80
		3	91.5	94.68	865.41	1893.63
		4	27.0	N/A*	0.00	N/A*
		5	DRY	DRY	0.00	0.00
		6	DRY	DRY	4913.30	0.00
		7	50.7	53.36	1174.03	5176.40
Wood Gulch	Wood Gulch	1	117.4	145.07	8751.62	1450.73
		2	104.2	55.30	766.24	4645.12
		3	11.1	7.49	559.52	516.50
		4	15.5	20.77	285.02	747.73
		5	4.6	11.87	1697.40	2310.61
Glade Creek	Glade Creek	1	0.0	0.00	0.00	0.00
		2	0.0	0.00	0.00	0.00
		3	0.0	0.00	0.00	0.00

* Not enough samples to calculate a standard deviation

Table 13. Total estimated spawning area (m^2) by basin and stream.

BASIN / STREAM		TOTAL
Chapman Creek		6
Glade Creek		0
Pine Creek		9,346
Rock Creek	Luna Gulch	1,127
	Quartz Creek	3,158
	Rock Creek Mainstem	41,411
	Squaw Creek	13,908
Rock Creek Total		59,604
Wood Gulch		11,536
Grand Total		**80,492**

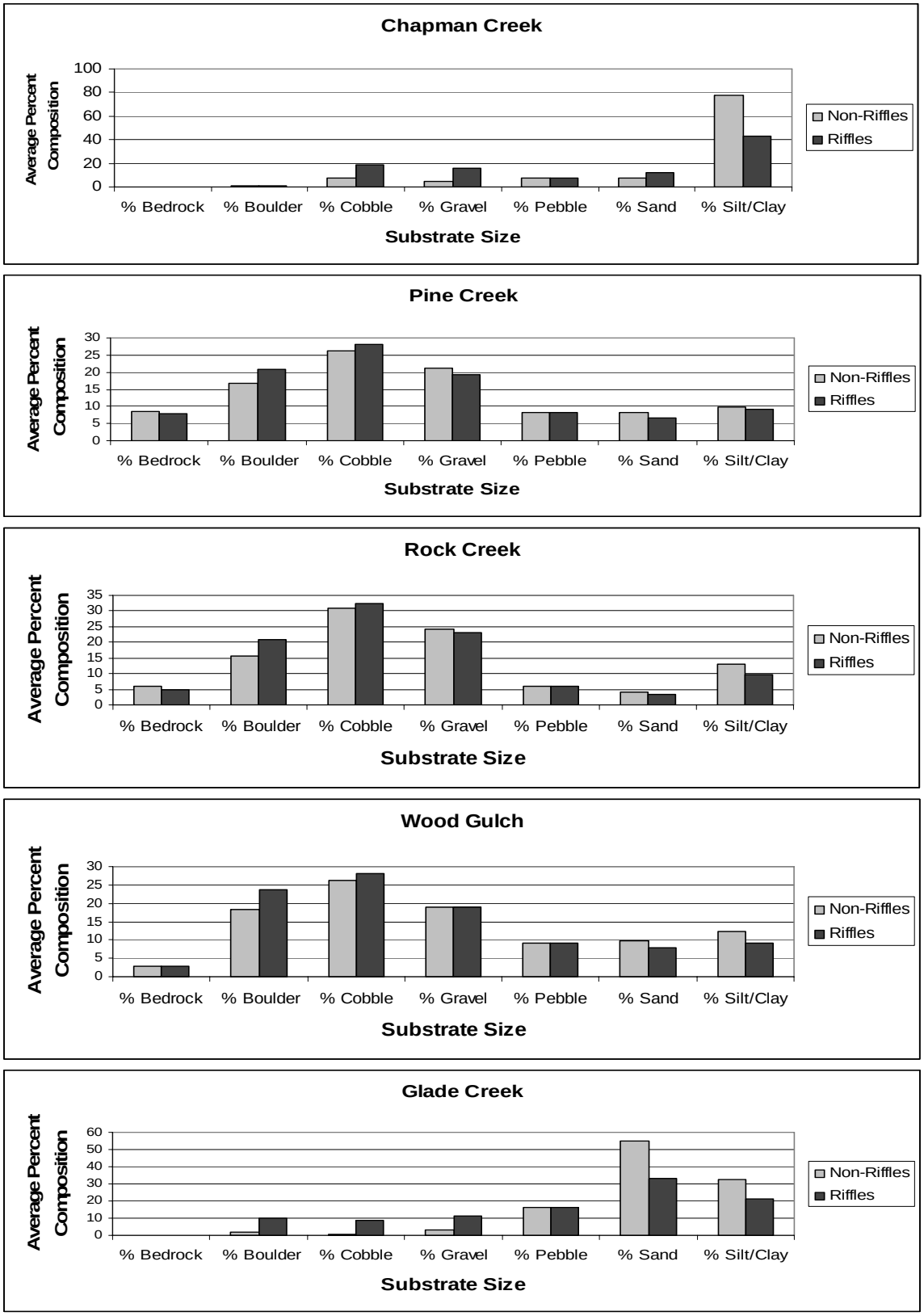


Figure 9. Average substrate composition for riffle and non-riffle channel units for each basin in the study area.

Table 14. Substrate composition of spawning areas by basin, stream, and reach.

Basin	Stream	Reach	% Bedrock	% Boulder	% Cobble	% Gravel	% Pebble	% Sand	% Silt & Clay
Chapman Creek	Chapman Creek	1	0.0	3.3	19.2	15.0	4.2	9.2	49.2
		2	0.0	1.3	15.3	17.3	10.3	14.0	42.0
		3	0.0	0.9	23.2	15.3	6.5	11.2	42.9
Chapman Creek Total			0.0	1.4	19.0	16.2	7.9	12.2	43.4
Pine Creek	Pine Creek	1	8.8	22.9	27.1	14.6	8.8	7.9	10.0
		2	23.8	29.4	18.1	11.9	2.5	3.8	10.6
		3	0.0	13.3	35.8	26.7	10.8	6.7	6.7
		4	0.0	16.8	31.8	25.5	10.5	7.3	8.2
Pine Creek Total			8.0	20.9	28.0	19.2	8.2	6.6	9.1
Rock Creek	Luna Gulch	1	0.0	30.0	35.0	15.0	5.0	5.0	10.0
		2	0.0	18.3	37.5	22.5	5.8	2.5	13.3
		3	2.5	20.0	37.5	15.0	7.5	0.0	17.5
	Luna Gulch Total		0.6	20.0	37.2	20.0	6.1	2.2	13.9
	Quartz Creek	1	0.7	24.3	30.0	24.3	10.7	5.0	5.0
	Mainstem Rock Creek	1	0.0	10.0	40.0	36.7	5.0	0.0	8.3
		2	15.0	30.0	35.0	15.0	0.0	0.0	5.0
		4	15.0	12.0	24.0	24.0	11.0	6.0	8.0
		5	5.0	15.0	33.3	28.3	5.0	3.3	10.0
		6	0.0	21.0	42.0	22.0	0.0	0.0	15.0
		7	5.0	15.0	35.0	30.0	0.0	0.0	15.0
		8	0.0	15.0	38.3	35.0	0.0	1.7	10.0
		9	0.0	12.0	39.0	35.0	3.0	4.0	7.0
		10	0.0	19.0	33.0	24.0	7.0	2.0	15.0
		11	0.0	25.0	36.5	21.5	5.0	2.1	10.0
		12	3.0	32.5	28.5	19.0	5.5	4.5	7.0
		13	6.0	23.0	28.7	19.7	8.0	2.7	12.0
	Mainstem Total		3.2	21.6	33.3	23.6	5.3	2.6	10.3
	Squaw Creek	1	0.0	11.4	42.1	31.4	3.6	4.3	7.1
		2							
		3	0.0	26.3	33.8	25.0	2.5	6.3	6.3
		4	0.0	30.0	30.0	15.0	2.5	7.5	15.0
		7	13.9	19.8	25.7	20.4	8.1	3.5	8.5
	Squaw Creek Total		9.4	19.5	29.6	22.5	6.5	4.1	8.4
Rock Creek Total			4.8	21.0	32.3	23.1	6.0	3.2	9.7
Wood Gulch	Wood Gulch	1	0.0	25.0	25.0	30.0	10.0	10.0	0.0
		2	1.2	21.5	32.1	22.9	7.9	6.2	8.2
		3	4.1	26.7	25.0	15.0	9.8	9.0	10.3
		4	0.0	12.5	35.0	26.3	11.3	6.3	8.8
		5							
Wood Gulch Total			2.7	23.8	28.1	18.8	9.3	7.8	9.3
Glade Creek	Glade Creek	1	0.0	0.0	10.0	10.0	30.0	40.0	10.0
		2	0.0	12.5	8.8	11.3	12.5	31.3	23.8
		3							
Glade Creek Total			0.0	10.0	9.0	11.0	16.0	33.0	21.0

The percent fines in spawning areas is an important factor in assessing the quality of

spawning habitats. Spawning areas are predominately located in riffles where flows reduce the quantity of fine sediments and also provide oxygen within the substrate (Bjornn and Reiser, 1991). Fine substrate materials that accumulate in gravel can cause asphyxiation of rearing eggs and alevins. The modified Wentworth method employed in this study identified the smaller substrate sizes as silt and clay (< 0.59 mm) and sand (0.60 to 1.00 mm).

Figure 10 and Appendix A, maps 25 through 32 depict the average percent composition of both the finer material (silt and clay) and the sum of the composition of sand and silt/clay. Rock Creek had the lowest composition of fine materials in the substrate; the percent composition of fine materials was less than 20 percent in all but a couple of cases and was less than 15 percent in the majority of the locations. The higher values were collected in backwater areas of side channels. Pine Creek and Wood Gulch also tended to have low levels of fine materials in riffles, though a larger number of riffles had higher levels of fine sediments. Chapman Creek tended to have a very fine substrate and Glade Creek has an abundance of sand.

Embeddedness (Figure 11) was similar in Rock Creek, Pine Creek, and Wood Gulch. Embeddedness tended to be much higher in Glade Creek and Chapman Creek. As will be discussed later, these differences are likely related to variations in the local geology.

4.1.3 Riparian Characteristics

The documented characteristics of riparian zones included a measure of the depth of the "inner" riparian zone, defined as the point where the vegetation changes to a more upslope character, dominant and subdominant species, and an ocular estimate of canopy closure. The study was conducted after leaf fall, so the estimates of canopy closure are highly subjective. Estimates of canopy closure ranged from 0 to 46.7 percent, averaging 20.8 percent (Table 15; Appendix A, Maps 33 through 40). The width of the inner riparian zone ranged from 0 to 15.7 meters, with an average of 4.7 meters.

The most common species in the riparian zones included alder, willow, walnut, and white oak. Walnut is not a native species.

4.1.4 Instream Woody Debris

The abundance of large woody debris in the sample area was generally low (Table 16). The average total number of pieces in the sample reaches ranged from 0 to 4.8 pieces per stream segment (segments averaged 110 meters). The majority of these pieces were small (6 to 12 inch diameter) to medium (12 to 20 inch diameter) in size.

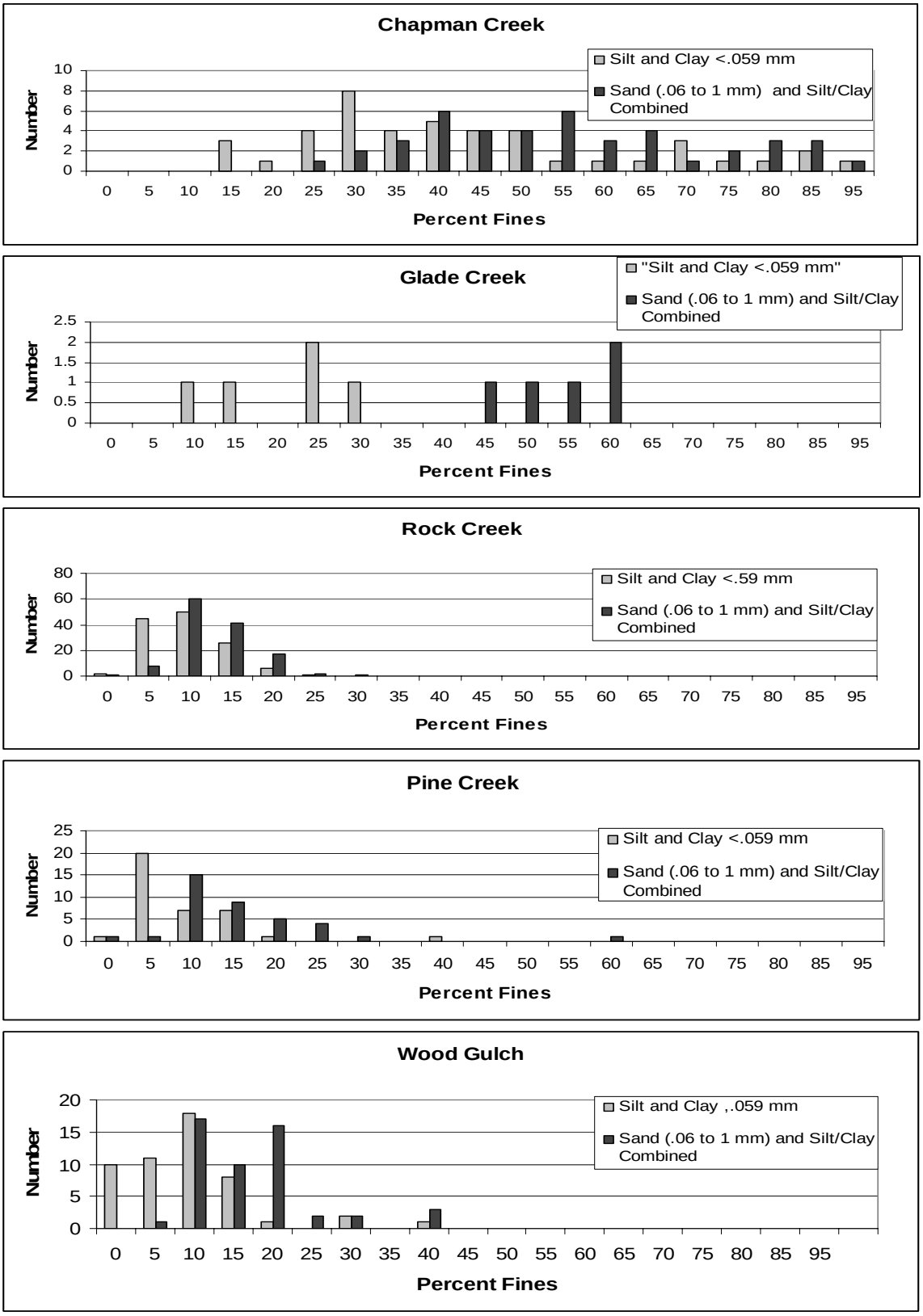


Figure 10. Frequency of occurrence of spawning areas with indicated percent fines in the substrate.

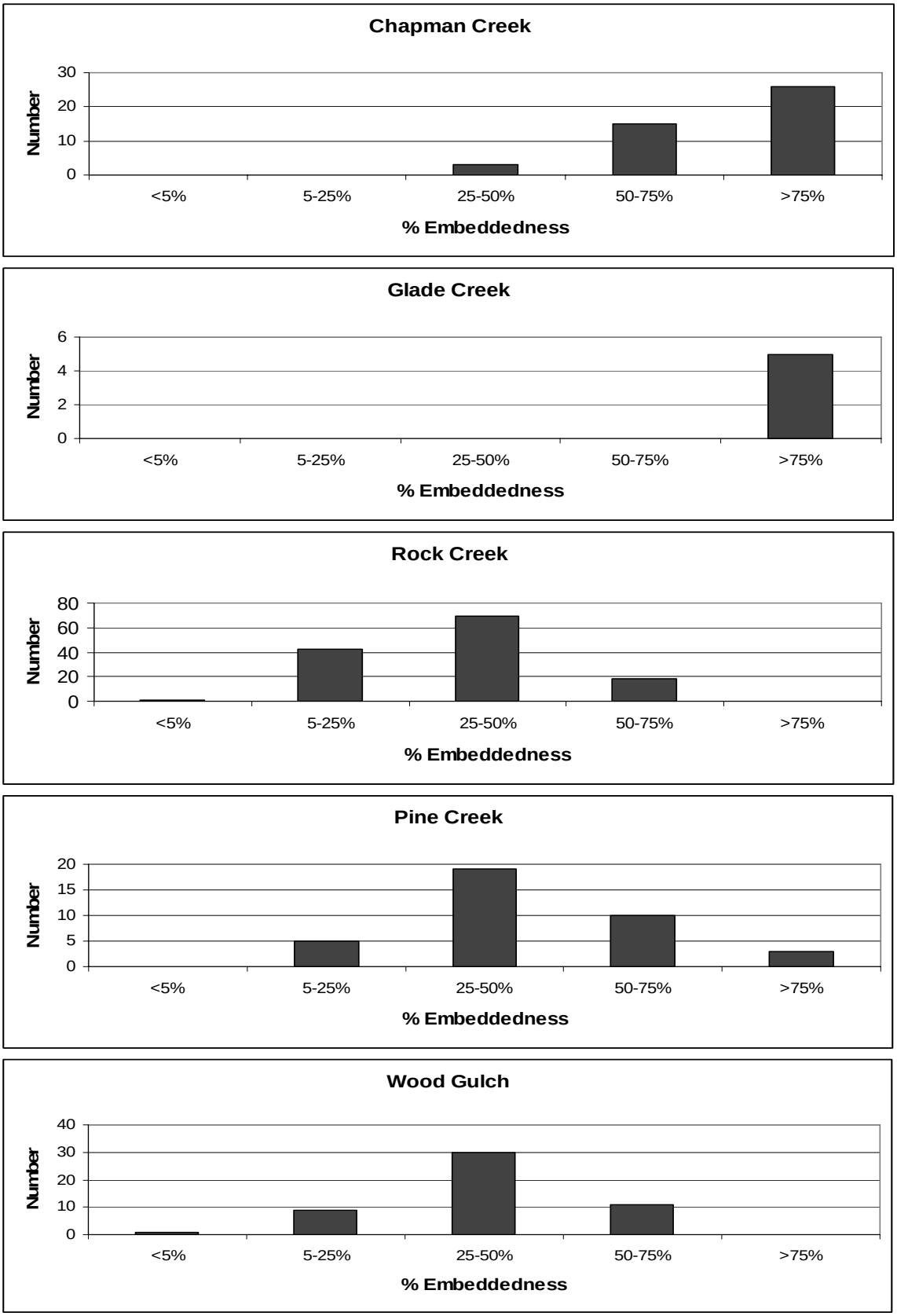


Figure 11. Frequency of occurrence of embeddedness within riffles by basin.

Table 15. Average canopy cover, inner riparian zone width, and typical vegetation for each reach sampled.

Basin	Stream	Reach	Canopy Cover (%)	Average Width of Inner Riparian Zone (m)	Typical Vegetation Class in Inner Riparian Zone	Most Common Dominant Species in Inner Riparian Zone	Most Common Sub-dominant Species in Inner Riparian Zone
Chapman Creek	Chapman Creek	1	45.0	10.7	Grasslands and Forbs	Cottonwood and Alder	Cottonwood and Alder
		2	37.2	5.8	Small Trees	Alder	Willow, Walnut, None
		3	39.2	4.6	Grasslands and Forbs	Alder	None, Elderberry
Pine Creek	Pine Creek	1	11.4	3.3	Shrub and seedlings, samplings and poles, small trees	Alder and Willow	Willow
		2	21.3	5.7	Shrub and seedlings, samplings and poles	Alder	Willow
		3	16.0	4.0	Shrub and seedlings, small tree	Alder and Willow	Willow and Alder
		4	26.3	5.3	Small tree	Alder	Willow
Rock Creek	Luna Gulch	1	6.0	5.6	Grasslands and Forbs, small tree	White oak, Alder	White oak, Ponderosa Pine, and none
		2	41.7	4.6	Small tree	Alder	White oak
		3	60.0	4.6	Small tree	Alder	Willow
	Quartz Creek	1	46.7	3.0	Small tree	Alder	White oak
	Rock Creek	1	18.3	6.5	Saplings and poles	Alder	Walnut
		2	28.3	6.4	Saplings and poles	Alder	None
		4	17.5	5.7	Small tree	Alder	Walnut
		5	13.3	7.1	Small tree	Alder	White oak, Walnut, Big leaf maple
		6	13.3	6.1	Saplings and poles	Alder	None
		7	10.7	3.0	Small tree	Alder	None
		8	3.3	2.5	Grasslands and forbs to saplings and poles	Cottonwood, Willow	Willow, Alder
		9	11.7	4.6	Saplings and poles	Alder	None

Basin	Stream	Reach	Canopy Cover (%)	Average Width of Inner Riparian Zone (m)	Typical Vegetation Class in Inner Riparian Zone	Most Common Dominant Species in Inner Riparian Zone	Most Common Sub-dominant Species in Inner Riparian Zone
		10	18.3	3.0	Small tree	Alder	None
		11	19.0	3.4	Shrubs to small tree	Willow and Alder	None, Alder
		12	56.7	3.6	Small tree	Alder	None
		13	16.3	5.0	Small tree	White oak	Willow, Walnut, White oak, Quaking Aspen
	Squaw Creek	1	26.7	3.6	Small tree	Alder	None, Walnut
		2	5.0	1.5	Small tree	Alder	Willow
		3	10.0	3.0	Small tree	Alder	None, Big leaf maple, Alder
		4	15.0	3.0	Small tree	Alder	White oak
		5	0.0	0.0	Grasslands and Forbs	Willow, Juniper, None	None
		6	0.0	0.0	Grasslands and Forbs	Juniper, Willow	Alder, Willow, None
		7	12.0	2.9	Shrubs to Small Trees	Alder, Willow	None, Willow
Wood Gulch	Wood Gulch	1	0.0	0.0	Grasses to small trees	Alder, Willow, None	None
		2	17.2	3.0	Shrubs to small trees	Alder	Willow, None, Alder
		3	31.4	4.1	Small tree	Alder, White oak	None, Alder
		4	18.3	4.9	Small tree	Alder	Walnut
		5	17.9	4.4	Shrubs and seedlings	Willow	None, Ponderosa Pine
Glade Creek	Glade Creek	1	13.3	15.7	Grasslands and Forbs	Grasslands and Forbs	None
		2	8.8	6.5	Grasslands and Forbs	Grasslands and Forbs	None
		3	37.1	11.8	Grasslands and Forbs	Grasslands and Forbs	None

Table 16. Average abundance of large woody debris in the stream segments (segments had an average length of 110 meters).

Basin	Stream	Reach	Number of large woody debris pieces averaged over the stream segments in each reach					
			Small	Med-ium	Large	Jams	Root wads	Total
Chapman Creek	Chapman Creek	1	1.2	0.6	0.4	0.1	0.0	2.3
		2	0.9	0.4	0.0	0.0	0.0	1.3
		3	0.6	0.5	0.0	0.1	0.1	1.3
Pine Creek	Pine Creek	1	1.1	0.1	0.0	0.0	0.0	1.2
		2	0.3	0.1	0.0	0.0	0.0	0.4
		3	1.0	0.3	0.0	0.1	0.0	1.5
		4	0.8	0.1	0.0	0.0	0.0	1.0
Rock Creek	Luna Gulch	1	1.3	1.0	0.0	0.0	0.1	2.4
		2	0.1	0.0	0.0	0.0	0.0	0.1
		3	0.0	0.1	0.0	0.0	0.0	0.1
	Quartz Creek	1	1.4	0.1	0.1	0.0	0.0	1.5
	Rock Creek	1	1.6	0.2	0.0	0.3	0.0	2.1
		2	1.0	0.7	0.0	0.0	0.0	1.7
		4	0.1	0.0	0.0	0.0	0.0	0.1
		5	3.8	1.0	0.0	0.0	0.0	4.8
		6	2.1	0.3	0.0	0.0	0.0	2.4
		7	2.9	1.3	0.0	0.0	0.0	4.2
		8	0.1	0.2	0.1	0.0	0.0	0.4
		9	1.5	0.2	0.1	0.0	0.0	1.8
		10	3.0	0.3	0.0	0.0	0.0	3.3
		11	0.1	0.1	0.0	0.0	0.0	0.2
		12	0.6	0.4	0.3	0.0	0.0	1.4
		13	0.9	0.2	0.1	0.1	0.0	1.3
	Squaw Creek	1	1.7	0.2	0.0	0.0	0.0	1.9
		2	2.4	0.2	0.0	0.0	0.0	2.6
		3	0.1	0.0	0.0	0.0	0.0	0.1
		4	0.0	0.0	0.0	0.0	0.0	0.0
		5	0.0	0.0	0.0	0.0	0.0	0.0
		6	0.0	0.0	0.0	0.0	0.0	0.0
		7	0.5	0.2	0.1	0.0	0.0	0.7
Wood Gulch	Wood Gulch	1	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.7	0.2	0.0	0.0	0.0	0.9
		3	0.4	0.2	0.0	0.0	0.0	0.7
		4	0.5	0.1	0.0	0.0	0.0	0.6
		5	0.6	0.5	0.1	0.0	0.0	1.2
Glade Creek	Glade Creek	1	0.0	0.0	0.0	0.0	0.0	0.0
		2	0.0	0.0	0.0	0.0	0.0	0.0
		3	0.0	0.1	0.0	0.0	0.0	0.1

4.2 FISH SURVEYS

4.2.1 Snorkel Surveys

Snorkel surveys were conducted in 799 stream segments within 33 larger reaches in the Rock Creek, Chapman Creek, Wood Gulch, and Pine Creek basins. No fish were found in 53 percent of the stream segments (Appendix A, Maps 41 through 48). The following species were encountered:

Oncorhynchus kisutch	Coho Salmon
Oncorhynchus mykiss	Steelhead, rainbow, redband trout
Rhinichthys cataractae	Longnose dace
Rhinichthys Osculus	Speckled dace
Rhinichthys sp.	Unknown dace
Richardsonius balteatus	Redside Shiners

According to the principal at the Bickleton School and a local resident, the students at the school often place coho into the stream; hence, the coho that were found were likely planted by the students. Chapman Creek contained only speckled dace (Table 17). The other basins had a greater diversity of species. The highest concentration of steelhead/rainbows was found in Rock Creek.

Eighty-nine (89) percent of the *O. Mykiss* observed were less than 100mm in length (Table 18). These fish could be either anadromous or resident fish. The remaining fish were larger than smolts and smaller than kelts or adults; hence, the larger fish were likely all resident fish.

The *O. Mykiss* observed in Pine Creek were all resident fish. Passage is blocked at Highway 14. We also found a natural barrier in Reach 2, which would limit the upstream extent of anadromous fish once the barrier at the highway is replaced. No other impassible barriers were found in Rock Creek, Pine Creek, Glade Creek, or Wood Gulch within the sampled segments. Additional barriers may exist outside of the sampled areas.

O. Mykiss was found in Wood Gulch up to the confluence with Big Horn Canyon. We did not sample Big Horn Canyon, but did continue up Wood Gulch beyond the confluence for several more miles.

The highest concentrations of *O. mykiss* in Rock Creek were found downstream of Luna Gulch in reaches 4 through 7. The total number of fish observed in these reaches constituted 90 percent of the *O. mykiss* observed in the mainstem of Rock Creek and 71 percent of the *O. mykiss* observed throughout the subbasin. Two of these reaches, reaches 6 and 7, were intermittently dry, trapping the fish within the reach. These two reaches contained 60 percent of the *O. mykiss* observed in the mainstem of Rock Creek and 47 percent of the *O. mykiss* observed throughout the subbasin. Only 8.2 percent of the *O. mykiss* in the subbasin were found upstream of the Bickleton Bridge, suggesting that movement into the headwaters to rear during the warm summer months is not a common life history strategy. The majority of the *O. Mykiss* observed in Squaw Creek were located downstream of the confluence with Harrison Creek. Squaw Creek supported 16% of the total fish observed in the Rock Creek basin.

Table 17. Number of fish observed in each basin by species.

Basin	Coho	Steehead/ Rainbow Trout	Longnose Dace	Speckled Dace	Unknown Dace	Redside Shiners	Unknown	Grand Total
Chapman Creek				1194			1	1195
Pine Creek		69		2510	4609			7188
Rock Creek	2	4016	30	3607	455	583	1	8694
Wood Gulch	35	434	111		2540		2	3122
Glade Creek					51			51
Grand Total	37	4519	141	7311	7655	583	4	20250

Table 18. Number of *Oncorhynchus Mykiss* observed in each basin by size class.

			Size Class (mm)				
Basin	**Stream**	**Reach**	**<100**	**100-200**	**200-300**	**300-400**	**Grand Total**
Pine Creek		1	17	20	3		40
		2	2	3	1		6
		4	21	2			23
Pine Creek Total			40	25	4		69
Rock Creek	Luna Gulch	2	160	15	5		180
		3	21				21
	Rock Creek	4	528	48	14		590
		5	364	32			396
		6	605	40	1		646
		7	1155	33	2		1190
		8	10				10
		9	102	15			117
		10	58	3			61
		11	129	5			134
		12	3				3
		13	2				2
	Squaw Creek	1	37	1			38
		2	80	5	3		88
		3	382	55	5		442
		4	62	20	1		83
		7	12	3			15
Rock Creek Total			3710	275	31		4016
Wood Gulch		2	233	17	2		252
		3	20	35	3		58
		4	48	40	35	1	124
Wood Gulch Total			301	92	40	1	434
Glade Creek							
Glade Creek Total							
Grand Total			4051	392	75	1	4519

4.2.2 Spawning Surveys

Spawning surveys were conducted in from the mouth of Rock Creek to the Bickleton Bridge on May 12 and 13, 2009. This portion of Rock Creek contained the greatest number of juvenile *O. Mykiss* observed during the snorkel surveys. Surveys were not conducted upstream of the Bickleton Bridge due to restrictions on access. Surveys were also not conducted in Reach 3 since those lands are tribal lands and are not included in the WRIA 31 management area.

The stream flow was at approximately 31 to 32 cfs at the time of survey, which was low enough to support reasonably good visibility. The weather at the time of survey was sunny which also facilitated detection of steelhead and redds. Visibility of the habitat was limited. The majority of the stream had to be surveyed from the bank due to flow conditions. Bank visibility was limited by access; one bank or the other was inaccessible due to the presence of steep slopes through Reach 7. Visibility from the bank was occasionally limited by vegetation. Surveys were also limited by water depth. Observations of steelhead were only made where the stream was less than approximately 2 feet deep. Overall visibility of the habitat is estimated at 60-70%. Approximately 30-40% of the habitat was not adequately surveyed.

A total of 20 redds were positively identified (Table 19; Appendix A, Map 49). Six additional observations identified possible redds which could not be confirmed. Seven spawning steelhead were observed. Field crews were not able to determine if any of these fish were fin clipped. Crews noted an abundance of high quality spawning gravel that did not contain any redds.

Table 19. Location and number of steelhead redds observed in lower Rock Creek.

UTM NAD27	# Adult Steelhead	# Confirmed Steelhead Redds	# Questionable Redds
698530/5072596	1	4	
697962/5073659			2
697515/5073985	2	2	
697285/5074062			1
696386/5074489			2
695981/507489		3	
695720/5074783	2	1	
695431/5074884		1	
695015/5074899	2	2	
693624/5075271		1	
693558/5075525		2	
692983/5075936		4	
692474/5076544			1
TOTAL	7	20	6

4.3 BARRIERS

Field crews looked for potential barriers within the survey area and at all other locations that they passed as they moved from one sample area to another. The following is a discussion regarding identified barriers;

Pine Creek Mouth: A group of 3 culverts are placed on the left bank (downstream orientation) of Pine Creek about 200 feet from the main channel. A 4th culvert is about 150 feet from the main channel on the right bank. These culverts pass under highway 14 and rail tracks near the mouth of Pine Creek. The culverts are not clogged; however, a large pile of alder (possibly a beaver dam) 100 ft upstream of the culverts seems to prevent water from flowing to the culverts. The old streambed is overgrown, suggesting that flow has been diverted for a long time. The height from the streambed to the culvert lip is 3.2 feet. This is likely a barrier to fish passage due to the lack of flow through the culvert. At extremely high flow/flood conditions, water may overflow the beaver dam and pass through the culvert, allowing fish to pass. The culverts open directly into the Columbia River with no jump height. The right bank culvert has no stream bed upstream of culvert, indicating very infrequent flow through the culvert. A culvert which passes stream flow could potentially exist below the water level which was present at the time of the survey (12/7/08) and below the water level of the pond at the mouth of Pine Creek.

A natural waterfall which blocks fish passage has previously been identified on Pine Creek. The falls is located roughly ½ to ¾ miles upstream of the lower East Road Bridge, which blocks upstream passage of fish (Jim Wright, personal communication, June 2004). The field crews did not find this waterfall during the study. It is possible the location was reported incorrectly. Field crews did document a waterfall in Reach 2 which was not passable at the time that data were collected due to a lack of flow, but would be easily passable at higher flows.

Wood Gulch: There is a series of waterfalls in Reach 3 of Wood Gulch (Figure 12). Each of the falls was determined to be passable, but passage would be difficult in places.

Figure 12. One of a set of four waterfalls located in Reach 3 of Wood Gulch.

Old Lady Canyon: A reconnaissance survey was completed in lower Old Lady Canyon. Two "waterfalls" (vertical drops, no water) are present in the first reach of the basin. One is 17 feet high and the second is 16 feet high. There is a 21 foot interval between the two drops where a

small depression 0.5 foot deep is present. Both would be upstream barriers to fish movement if flow was present in the canyon (see section 4.6 below).

4.4 HYDROMODIFICATIONS

Hydromodifications are man-made features which affect streamflow, bankfull, width, floodprone width, or habitat quality. They can include ditches, dikes, road fills, culverts, bridges, and other structures which affect the stream. They do not include land uses causing erosion.

Field crews documented hydromodifications within the sample segments and at any location where such features were encountered while moving between sample segments. The following is a description of the hydromodifications encountered during the study. The list should not be considered to include all hydromodifications in the basins.

CHAPMAN CREEK
Culverts under Highway 14 and the railroad: the passage under the railroad tracks is an open box/bridge about 60 feet wide with zero gradient. This feature is not a barrier to fish passage. There are two box culverts under Highway 14, each of which is about 10 feet wide by an average of 7 feet high. Gradient within the culverts is 2.5 to 3 percent. The culvert passes stream flows without a drop in elevation. The culverts are not migration barriers.

ROCK CREEK
Private Bridge on the mainstem of Rock Creek, a little upstream of the confluence with Squaw Creek: The private bridge engages both bankfull and floodprone flows. Bankfull flows are confined on the left bank by bridge footing. Floodprone flows are confined by the footings on both banks. The channel is braided immediately upstream of the bridge. The channel on the right bank (facing downstream) flows against the road/bridge prism which is armored by large boulders. The channel is constricted by the road/bridge construction and remains confined for a long distance downstream. A beaver dam/pool is located immediately downstream and under the bridge. The wetted flow is confined on the left bank by riprap. The right bank of the wetted and bankfull channel is not confined by the bridge.

Bickleton Bridge: The bridge footings are nearly engaged by the wetted flow at low flow. Bankfull flows are confined on both banks by the footings, as are floodprone flows. The bridge is scheduled to be replaced with a wider bridge that spans the floodplain.

Old Highway 8 Bridge across Rock Creek: The stream is scoured to a depth of about 5 feet along the right bank footing. The stream is confined beneath the bridge and is significantly wider upstream. There is a wetted secondary channel along the upstream abutment on the left bank. The bridge confines the channel at low flow, bankfull flow, and floodprone flow.

WOOD GULCH
Weirs in Reach 2: A series of 4 weirs have been place at UTM, NAD 27 715449/5077355 (Figure 13). This structure is located just downstream of the gas pipeline. Each of the weirs spans the channel to bankfull and is about 25 feet wide, on average. The total distance from the top of the downstream weir to the top of the 4th upstream weir is 75 feet. A 25 foot pool is present between the weirs. The pools have a maximum depth of 1.2 feet. Boulders have been

placed along each bank above floodplain. The stream gradient through this area is 2 degrees (~4.5 %). The area is rich with noxious/invasive weeds including Himalayan blackberry, fullers teasel, common mullein, Canada thistle, bull thistle, curly dock, and Queen Anne's lace.

Figure 13. Photo of the series of weirs in Wood Gulch.

Remnants of a concrete bridge: Bridge footings were observed in Reach 2 near segment 11. The bridge was either not completed or has been partially demolished. There is no deck on the footings (Figure 14). The stream is scoured against the right bank footing. A pool with a maximum depth of 2.3 feet was observed there. The footing on the left bank is above flood prone width.

4.5 RECONNAISSANCE OF OLD LADY CANYON

A brief reconnaissance of Old Lady Canyon was completed on 12/16/08, four days after a period of heavy rain. The basin has several emergent wetlands. Several inches of snow were present on the ground, so the ability to observe channel conditions was limited. The stream was not flowing. The culvert under Highway 14 near the mouth of the basin is well positioned to carry any flow. The culvert had no sediment deposits in it; only dry, clean concrete was present, suggesting a general lack of flow since installation (Figure 15). The culvert under the railroad, located just downstream of Highway 14, had numerous piles of bird droppings and nest debris which have accumulated under each of the mud-swallow nests which are constructed on metal fittings attached to the top of the culvert (Figure 15). The presence of the abundance of droppings and nest debris suggests flow through the culvert has not occurred since summer. The culvert under the railroad did have some sediment deposits, suggesting occasional flows. Overall, flow in Old Lady Canyon does not appear to be common. It clearly did not flow during

the heavy rainstorms which occurred 4 days prior to conducting the reconnaissance of the basin. As was mentioned above, the canyon has 2 steep drops, 17 and 16 feet high, separated by a 21 foot span. If flow was present in the canyon, these waterfalls would serve as a block to upstream migration of fish.

Figure 14. Bridge footing in Wood Gulch, Reach 2, near segment 11. Note the scoured pool adjacent to the structure.

Figure 15. Photo of Old Lady Canyon culvert under Highway 14 (left) and photo of Old Lady Canyon culvert under the railroad (right). Piles of debris running down the center of the culvert on the right are piles of bird droppings.

4.6 SEDIMENT SOURCE MODELING

A screening-level assessment of sediment sources and input rates to streams in the Rock Creek, Wood Gulch, Glade Creek, and Pine Creek subbasins was completed using existing data and GIS coverages to determine if anthropogenic sediment inputs appear to be great enough to cause concern for aquatic habitat and water quality in the subbasins.

4.6.1 Soil Creep and Stream bank Erosion

Soil creep and stream bank erosion are two natural processes that provide sediment to streams. Since the processes overlap, an estimate of soil creep was used to represent sediment inputs from both sources. Based on observations by the stream inventory field crews, stream bank erosion is not widespread in any of the main channels inventoried, and few instances of anthropogenic bank erosion (e.g., grazing, road fillslope erosion) were noted by the stream inventory crews.

The SEDMODL2 calculated average annual soil creep estimates ranged from 580-5,950 tons/year (Table 20). Sediment inputs from soil creep or bank erosion include material from the entire depth of the soil column, a mix of fine- and coarse-grained sediment.

Table 20. Estimated average annual sediment input from soil creep.

Subbasin	Estimated input (average tons/year)
Rock Creek	5,950
Wood Gulch	840
Pine Creek	4,700
Glade Creek	580

4.6.2 Agricultural Lands

Much of the land within the Glade Creek subbasin, and portions of the land within the other three subbasins is managed for agriculture, either cultivated land or livestock grazing (Figure 16).

4.6.3 Cultivated Land

The northern part of the Glade Creek basin is used primarily for dryland wheat production, while center-pivot irrigated row crops dominate the southern part of the subbasin. Row crops are dominated by wheat, but include potato, sweet corn, grass seed, onions, alfalfa, peas, grapes, mint, field corn, carrots, beans, and sugar beets (WA Dept. of Agriculture 2009). In many locations, the row crops are planted with minimal tillage and a cover crop is planted for erosion control. Irrigation rates are monitored to minimize runoff (personal communication, Troy Grimes, June 5 2009). A hybrid poplar farm is located along lower Glade Creek.

Erosion from cultivated land was estimated using the WEPP model and applied to land within 1,000 feet of a stream (Figure 17). Note that some areas mapped as streams in upper Glade Creek were not found to have stream channels during the field reconnaissance. These were not included in the analysis.

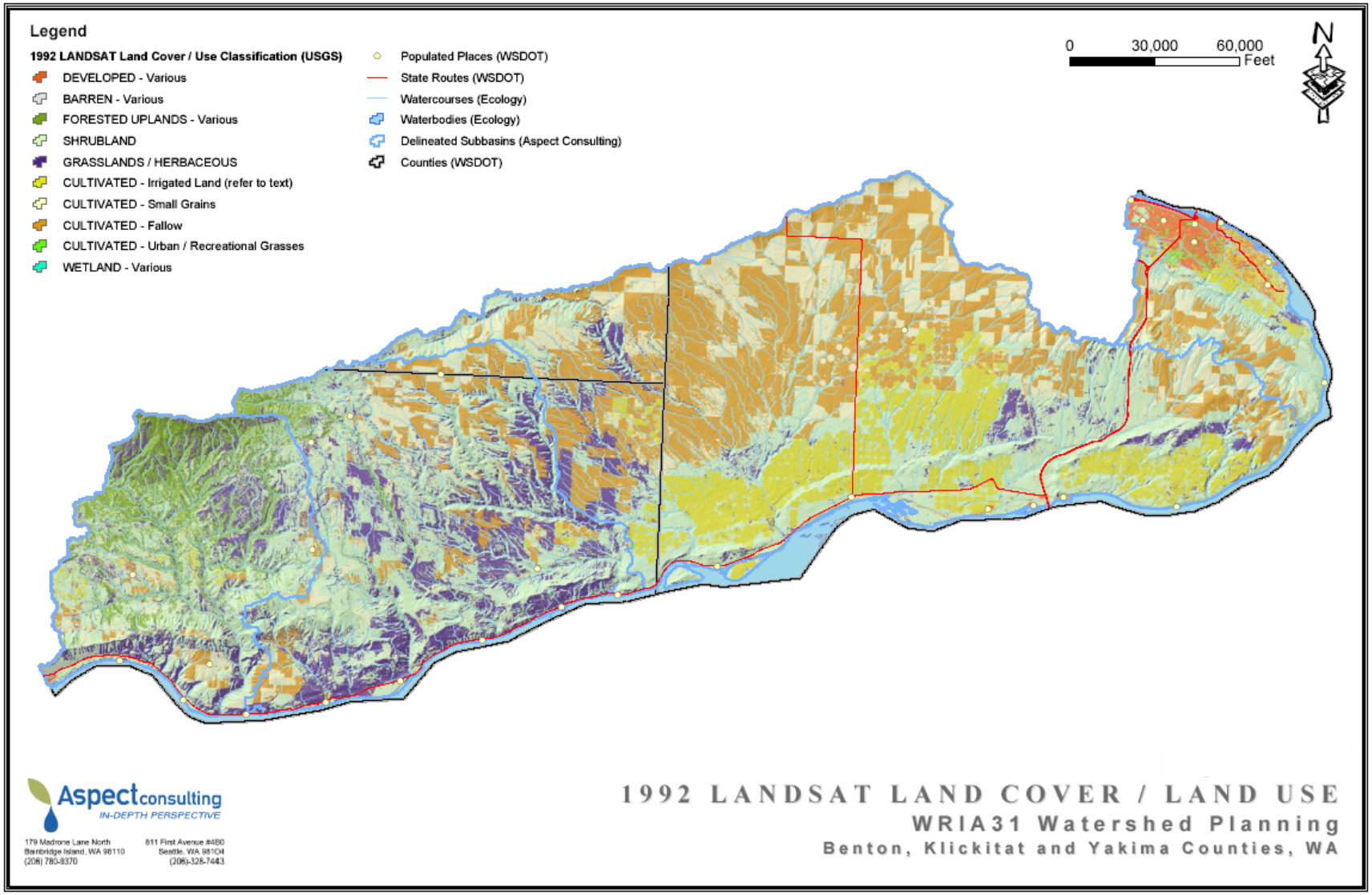


Figure 16. 1992 Landsat land cover and land use (from Aspect 2004)

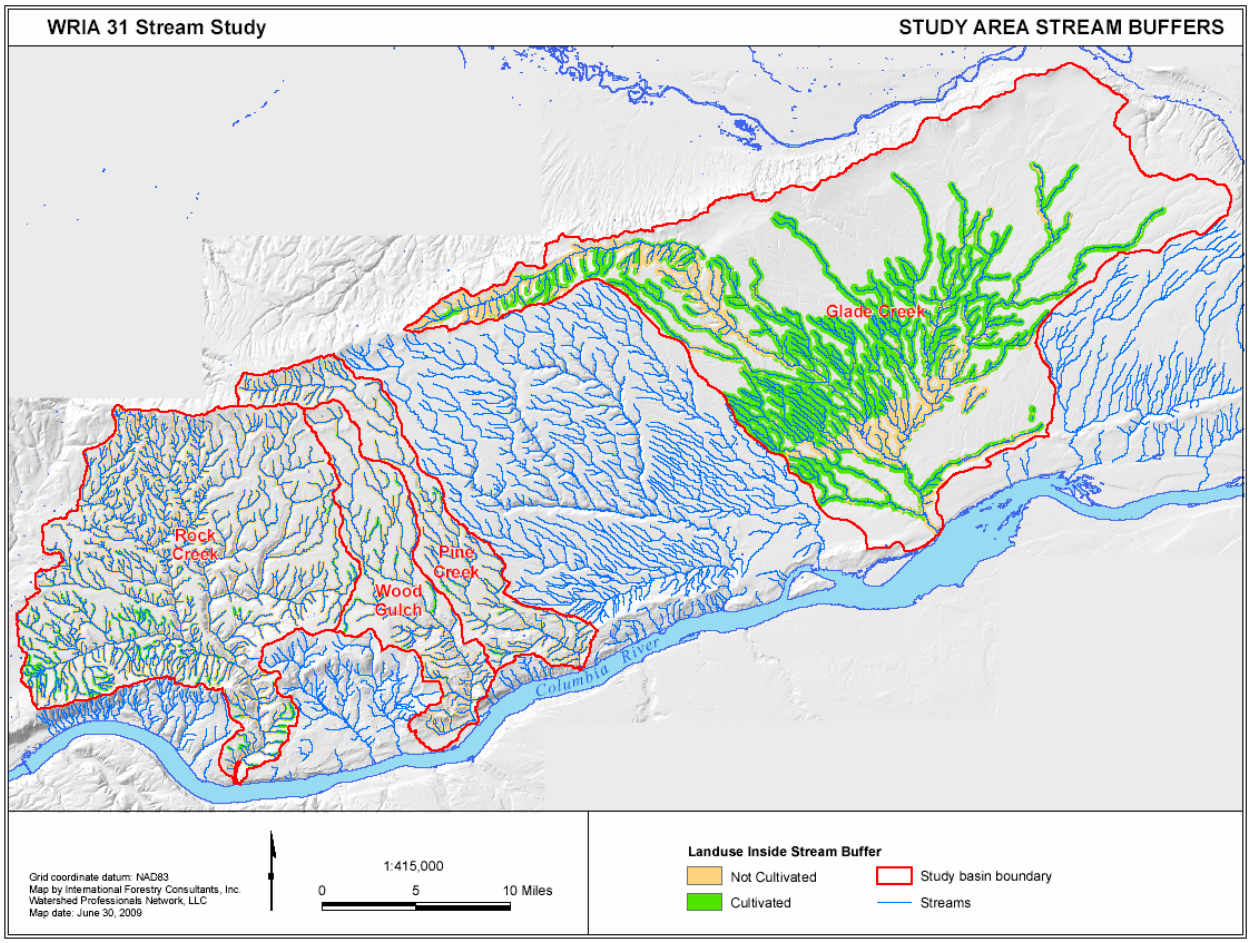


Figure 17. Land within 1,000 feet of streams used in WEPP analysis of cultivated land.

Estimated average annual sediment input from cultivated land ranged from 50 tons/year in Pine Creek to 6,400 tons/year in Glade Creek (Table 21). These numbers should be regarded as rough estimates because actual crops and irrigation rates vary through time in each of the fields, so general estimates were made using the WEPP model based on assumed average conditions. Sediment entering streams from cultivated land is transported by surface runoff and would be primarily fine-grained sediment.

Table 21. Estimated average annual sediment input to streams from cultivated land.

Subbasin	Estimated sediment input (tons/yr)
Rock Creek	1,000
Wood Gulch	110
Pine Creek	50
Glade Creek	6,400

4.6.4 Grazing

Parts of the Rock Creek, Wood Gulch, and Pine Creek subbasins are managed for grazing. Cattle and horses are the primary livestock grazing in the basins. In some

locations, the livestock have free access to streams; in other areas landowners rotate the livestock or have fenced riparian areas. The extent of stream bank damage by grazing was estimated from data collected during the stream inventories, and a relative ranking was given to each site (no livestock damage, minor livestock damage, some livestock damage, and heavy livestock damage) and extrapolated to un-inventoried stream reaches.

The percent of stream length estimated to be affected by livestock grazing ranged from 0% in Glade Creek to 8% in Rock Creek, Wood Gulch, and Pine Creek (Table 22). The degree of damage in affected reaches ranged from light to moderate, with two sample sites noting heavy damage from grazing. The photographs of all the stream reaches inventoried were reviewed to assess the extent of trampling and potential sediment sources from grazing. Effects noted included trampling of streamside vegetation and a few access pathways with areas of bare soil. The WEPP model was used to estimate erosion from the bare pathways, but due to the low precipitation in the area, no runoff, and therefore no surface erosion, was predicted by the model. It is likely that livestock use of the streams and banks is a local source of fine-grained sediment; however it does not appear to be a major source in the subbasins inventoried.

Table 22. Estimated percent of stream length with livestock damage.

Subbasin	Estimated percent of total stream length with livestock damage	Relative degree of disturbance
Rock Creek total	8%	(see below by tributary)
Luna Gulch	0%	None
Quartz Creek	5%	Moderate
Squaw Creek	12%	Light
Mainstem	4%	Light to moderate
Wood Gulch	8%	Moderate (heavy in one location)
Pine Creek	8%	Moderate (heavy in one location)
Glade Creek	0%	None

4.6.5 Road Surface Erosion

Unpaved roads can be a source of fine-grained sediment. Traffic on gravel and unsurfaced roads disturbs and breaks down the road tread into small particles that can be easily transported by surface runoff. The road surface is also compacted by the traffic, which reduces the infiltration rates and results in more runoff than undisturbed ground. If the road drains to a stream, eroded sediment can enter the stream.

Surface erosion from roads in the four subbasins was estimated using SEDMODL2, a GIS model that determines which portions of the road network have the potential to drain to streams and then estimates erosion and delivery from those segments of road. Based on the topography, roads, and streams in the GIS database, SEDMODL2 predicted between 16 and 154 miles of roads are hydrologically connected to streams (e.g., drain to streams) in the four subbasins (Table 23). Based on average road characteristics, between 17 and 370 tons/yr of sediment were predicted to enter streams from these roads. Note that the sediment production rates are predicted to be higher in Rock Creek than the other subbasins. This is caused by the high traffic levels measured on many of the roads

in this area. Roads without traffic counts were assumed to have lighter traffic use, and therefore are assumed to produce less sediment.

Table 23. Length of road hydrologically connected to streams and estimated average annual sediment input (tons/yr).

Subbasin	Length of road hydrologically connected (mi)	Estimated average annual sediment input (tons/yr)
Rock Creek	93	370
Wood Gulch	16	38
Pine Creek	21	17
Glade Creek	154	73

5.0 DISCUSSION

5.1 SPAWNING HABITAT

Substrate composition, water quantity, water quality, and cover are important elements of spawning habitat for salmonids. The number of spawners that a stream can support is a function of the area of suitable spawning habitat (substrate, water depth, and water velocity) and the availability of cover for holding adult spawners.

The spawning area reported in this study was an estimate of the quantity of suitable spawning habitat defined by the presence of suitable substrate material. Suitable substrate material includes gravel and cobble in the range of 13 to 102 mm (Bjornn and Reiser, 1991). Based on substrate material alone, Rock Creek contained 75 percent of the available spawning habitat in the WRIA, Wood Gulch contained 14 percent of the spawning habitat, and Pine Creek contained 11.6 percent of the habitat.

Spawning habitat in Glade Creek and Chapman Creek was negligible to non-existent. Substrate of suitable size to support spawning was rare in these streams. The lack of spawning habitat in these creeks is influenced by the underlying geology of the basins. In contrast to the streams containing spawning habitat, the geology in Chapman and Glade Creeks is dominated by fine-grained Quaternary deposits, including loess and large, valley-scale Quaternary landslide deposits. There is relatively little basalt exposed in the subbasins. As a result, the majority of sediment provided to the channel is fine-grained. Hence, accumulations of spawning size material do not form in these creeks.

Anadromous salmonids generally require 15 to 35 cm of water depth (enough to cover the fish during spawning (Bjornn and Reiser, 1991). Anadromous species also prefer to spawn where water velocities range from 1 to 7 feet per second (Bjornn and Reiser 1991). At the time the surveys were completed, much of the suitable spawning substrate did not have sufficient water depth to support spawning. Surveys were completed during the low flow period and steelhead were not spawning. Steelhead spawn in the spring, at which time flows are generally much higher in Rock Creek (Figure 18). Therefore, water depth and velocity is expected to be suitable to support spawning in most, if not all, of the area

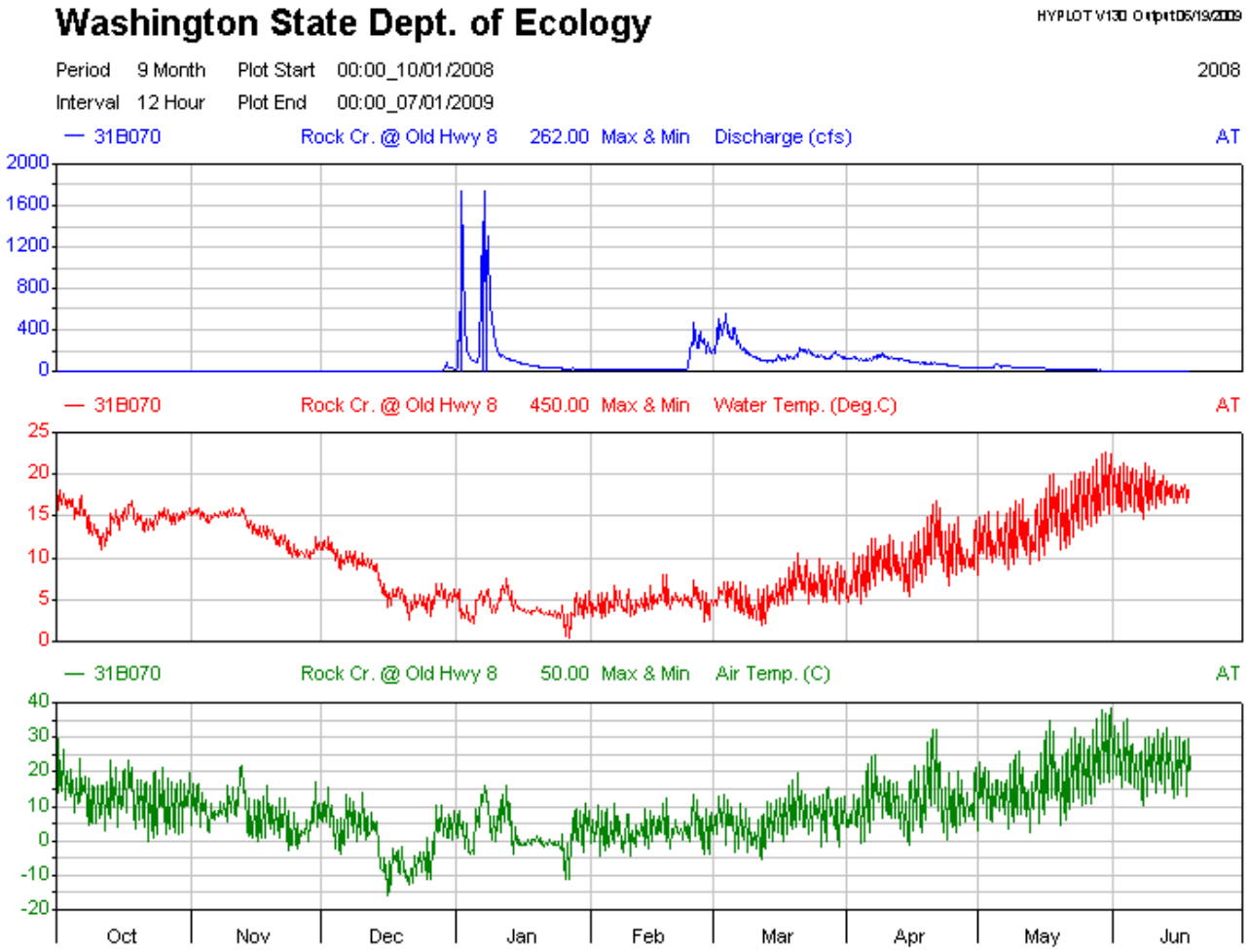


Figure 18. Stream flow, water temperature, and air temperature for water year 2008 (from Washington Department of Ecology website: https://fortress.wa.gov/ecy/wrx/wrx/flows/station.asp?sta=31B070)

where suitable substrate is present in the Rock Creek basin. Stream flows are not monitored in Wood Gulch or Pine Creek; therefore, the availability of suitable water depth and velocity during the spawning period is unknown for those basins.

Bjornn and Reiser (1991) provide data regarding average area of steelhead redds. They indicated that both Reiser and White (1981) and Hunter (1973) report an average area of redds at 4.4 m^2. Based on this number, Rock Creek should be able to support up to 13,500 spawning pairs of steelhead, Wood Gulch may be able to support up to 2,600 spawning pairs, and Pine Creek would be able to support up to 2,100 spawning pairs (assuming access to habitat becomes available).

5.2 HABITAT SUPPORTING EGG INCUBATION

The primary habitat characteristics affecting survival of eggs to emergence as fry are substrate condition and dissolved oxygen concentrations (Bjornn and Reiser 1991; Silver et al. 1963; Coble 1961). Temperature also influences survival, in that the time from egg deposition to emergence as fry is affected by stream temperature (Alderdice and Velsen 1978). Minimum and maximum temperatures can also affect survival (Bell 1986).

The amount of fines in the substrate where redds are located and the amount of fine materials that settle on redds during incubation can affect the rate of water interchange between the stream and the redd (Wickett 1954; Reiser and White 1988), although some studies have found no effect (Fudge et al. 2008). If the rate of interchange is low, the amount of oxygen reaching the eggs may not be sufficient to support the development of the embryos (Coble 1961; Silver et al. 1963).

The relationship between the amount of fine sediment in redds and subsequent survival of eggs has been the subject of many studies. Most of the studies have been conducted in the laboratory, which often inadequately duplicate the structure and composition of natural redds (Chapman 1988). Additionally, the methods and sizes of material evaluated have not been consistent, making it difficult to compare results (Chapman 1988; Kondolf 2000).

Reiser and White (1988) completed of the better studies which evaluated survival of steelhead eggs in relation to sediment concentrations in spawning gravels constructed in artificial spawning channels. They found that sediment less than 0.84 mm in diameter was the most detrimental to incubating eggs. This size class of concern was also reported by McNeil and Ahnell (1964), Cloern (1976), Tagart (1976), although none of these other studies evaluated any size other than 0.84 mm. Reiser and White (1988) found differential survival in eggs at early stages of development and eggs which were partially developed. Survival of early stage eggs dropped rapidly as fine sediments (<0.84 mm) increased, dropping to 30 percent survival inn gravels containing 10 percent fines. The more developed eggs had good survival in gravels containing up to 20 percent fine sediments. The Authors noted that redd-building activity cleans and flushes fine sediments from the gravels and the initial development of sensitive eggs generally occurs in relatively clean gravel. Sediment may increase over time in the redds, but the later developmental stages appear to be more tolerant of sediment deposition. Therefore, the

mortality reported at various sediment concentrations for the more developed eggs are the more applicable study results.

The amount of fine sediment in spawning areas documented in this study was less than 20% for all but a few of the spawning areas in Rock Creek. The two sites which had higher fine sediment concentrations were both backwater areas in side channels. The majority of the spawning areas in Pine Creek and Wood Gulch also contained less than 20 percent fines; six of the spawning areas in each of those basins exceeded 20 percent fines. The substrate in riffles in Chapman and Glade Creeks contained an abundance of fines and generally was not suitable to support the development of eggs. Hence, viable spawning habitat is rare to non-existent in those basins. As was explained earlier, the underlying geology in these basins is a major factor influencing the quality of the substrate. Actual fine sediment levels within redds would be expected to be

Oxygen concentrations in the water column were not documented in this study. Aspect (2005) collected dissolved oxygen data throughout the Rock Creek basin in 2004. All their measurements exceeded 10 mg/l. Davis (1975) indicated that freshwater salmonid populations function without impairment at dissolved oxygen levels between 7.75 mg/l and saturation. Therefore, dissolved oxygen levels in Rock Creek are not likely impairing productivity. Dissolved oxygen levels in the other basins are unknown. In general, oxygen concentrations in flowing streams with rough substrates tend to approach saturation (Coble 1961). Hence, it is reasonable to assume that oxygen levels will be high enough to support embryo development in Pine Creek, and Wood Gulch. The substrate in Chapman Creek and Glade Creek is not rough; therefore, assumptions regarding oxygen concentration are not advised.

There are upper and lower temperature limits for successful incubation of salmonid eggs. Bell (1986) reported a recommended range of temperatures to support incubation of salmonids. The range he reported was between 4.4^{o}C and 14.4^{o}C. During the incubation period in Rock Creek, water temperatures at the Ecology gage ranged between 5 ^{o}C and 22 ^{o}C in 2008. The upper bound of this range exceeds the range recommended by Bell (1986). The authors were unable to find information on lethal water temperatures for incubating eggs. The upper lethal bound on temperature is likely similar to that for fry (likely between 23.9 ^{o}C and 29.4 ^{o}C – see discussion on rearing habitat below).

Overall, the quality of incubating habitat in Rock Creek, Pine Creek, and Wood Gulch appears to be excellent. However, the fish typically spawn later in the season at which time flows are higher. Some unknown proportion may spawn in areas that subsequently become dry as the flows recede. It is unknown what affect this may have on overall survival and productivity. The quality of habitat in Chapman and Glade Creeks is not suitable to support spawning or the development of eggs. The situation in Chapman and Glade Creeks is driven primarily by the underlying geology.

5.3 REARING HABITAT

The factors in the freshwater environment that regulate the number of juvenile salmonids that a stream will support (the carrying capacity) include the amount of suitable habitat in

terms of volume, stream temperature and other water quality parameters, the quality of cover, the amount of food available, and the amount of predation.

Rock Creek contained 78 percent of the total pool volume estimated in WRIA 31. The majority of the Rock Creek pool volume was in the mainstem of the river and in Squaw Creek. Wood Gulch contained 7.8 percent of the total documented pool volume and Pine Creek contained 3.4 percent of the total volume estimated in the WRIA. Glade Creek contained 10 percent of the pool volume in the WRIA, but that habitat will likely not be used due to the paucity of suitable spawning habitat. Note that Glade Creek was sampled in spring during relatively high flows. Actually pool volume in Glade Creek would be substantially lower during the low flow periods. Chapman Creek contained very little pool habitat and also does not have suitable spawning habitat; hence, Chapman Creek does not provide suitable habitat for salmonids.

Summer space requirements of juvenile salmonids during their first year in streams varies with the size of fish and probably ranges from 0.25 to 10 m^2 of stream per fish (Bjornn and Reiser 1991). Actual numbers are highly variable depending upon food availability, habitat quality, etc. Based on these numbers, and excluding other factors affecting survival, Rock Creek should have the capacity to produce between 38,300 and 95,700 age-0 steelhead. Other habitat factors such as temperature and flow likely reduce this potential, as is discussed below.

Total stream flow affects the volume of habitat available. The estimates of habitat volume provided in this report reflect the flows that were present in late fall and early winter of 2008. During that time, Ecology's gage in Rock Creek registered no flow (Figure 18). A large percentage of the stream lengths in all the basins were dry at the time of sampling (Figure 6). Flow is assumed to run subsurface through some of these sections. Hence, the depth of the subsurface flow during the low flow season can affect the volume of rearing habitat. No data is available that can be used to address the inter-annual variability in subsurface flow.

Stream velocity is another important factor in defining rearing habitat. Newly emerged fry require velocities of less than 10 cm/s (Chapman and Bjornn 1969). As the fish mature, they can hold in higher velocities, but will tend to move to lower velocity habitats when flows exceed 15 to 20 cm/s (Bjornn and Reiser 1991). Sufficient data is not available to address the effects of flow on rearing habitat. Flow in summer in all the basins within the study area is very low (except for Glade Creek, which was sampled in spring during high flows). Therefore, it is reasonable to assume that stream flow velocities are within a tolerable range.

Cover is an important aspect of salmonid rearing habitat. It provides places to hide from predation. Cover can take the form of large woody debris, overhanging brush, undercut banks, boulders, turbulent waters, and aquatic vegetation. The quantity of large woody debris is low relative to streams in the Cascade Mountains. The low abundance of instream wood is related to the quantity and type of vegetation in the riparian areas. Many of the riparian areas documented in this study had sparse riparian vegetation. In

some cases, the sparse condition is natural, but in other cases it is affected by current or historical land use. Aspect Consulting (2005) found that vegetation in the valley bottom of Rock Creek has increased by more than 50 percent since 1938. This would suggest that the recruitment of instream wood has or will be increasing. Many of the tree species in the riparian zone are long-lived, so increases in wood recruitment as a result of increases in the abundance of riparian trees may be delayed.

The data collected in this study cannot provide a direct quantification of the amount of cover available in streams. Undercut banks, cover by rocks, overhanging brush, turbulent waters, and aquatic vegetation were not quantified. Hence, the amount of cover available to rearing fish remains unknown.

Temperature is a critical element of rearing habitat. High water temperatures can cause mortality in juvenile salmonids. Bell (1986) reported the upper lethal temperature for steelhead as 23.9 ^{o}C (73.4 ^{o}F). Lee and Rinne (1980) reported an upper lethal temperature of 29.4 ^{o}C (84.9 ^{o}F) for *O. mykiss* and Charlon et al. (1970) reported an upper lethal temperature of 25.0 ^{o}C (77 ^{o}F) for *O. mykiss*.

Water temperature data collected at Ecology's gaging station in Rock Creek approached the lethal temperature reported by Bell (1986). Aspect (2005) reported the average daily maximum temperature for several sample locations in Rock Creek for the period from 1995 to 2008 (Figure 3). The temperatures depicted in Figure 3 increase from upstream to downstream. RC-6 lies at the break between Reaches 9 and 10 in this study, RC-7 lies in Reach 1 of Squaw Creek, RC-8 lies in Reach 4, and RC-9 lies in Reach 1, near the mouth of Rock Creek. Three out of four of the stations had average daily maximum temperatures that exceeded the lethal temperature reported by Bell and the temperature at two of the stations exceeded the lethal temperature reported by Charlon et al. (1970) indicating that stream temperature may be affecting survival of juveniles in Rock Creek. Temperatures exceeding the threshold for mortality effectively reduce the carrying capacity of the basin. Therefore, the potential production numbers estimated above are over-estimates of actual carrying capacity of the rearing habitat. The portion of the habitat affected by excessively high temperatures has not been calculated and likely varies from year to year. Temperature data for the other sampled basins has not been reported.

Other factors affecting survival, such as food availability and predation, have not been assessed and remain unknown.

5.4 HYDROMODIFICATIONS

Within the sampled areas, some hydromodifications were reported. The effects of these features are variable. The culvert at the mouth of Pine Creek is a barrier to upstream migration and effectively prevents access to habitat in that creek. A deep scour pool has developed along the abandoned bridge footing found in Wood Gulch. In this portion of the stream, much of the channel is dry and habitat is concentrated in deep pools where subsurface flow is exposed. Therefore, the presence of this bridge footing may actually improve fish habitat. The set of weirs also found in Wood Gulch may impede movement

of fish up the creek.

With the exception of the barrier at the mouth of Pine Creek, the area affected by hydromodifications in the sampled areas was small and is not significantly affecting the quantity or quality of habitat. Other unidentified hydromodifications are likely present in the basins. The effects of these structures are unknown.

5.5 FISH DISTRIBUTION

Salmonids were present in Rock Creek, Pine Creek, and Wood Gulch. The primary species found in Pine Creek was dace. The *O. Mykiss* found in Pine Creek are presumably resident fish since anadromous access to the creek has likely been blocked at the mouth for many years. The basin supported very few salmonids. All of the salmonids were found in the lower sections of the river, downstream of the falls (see Section 4.3), which were not passable at the time of the surveys but are believed to be passable if sufficient flow was available.

Salmonids in Wood Gulch were concentrated in the upper portions of Reach 3 and in Reach 4. Crews suspected that many of these fish were resident fish and the size distribution of the fish would suggest that a large portion of the fish are resident. The area where fish were found in Wood Gulch is an area where stream flow is more constant. The lower portion of the basin, which supported only dace, has intermittent flow and very little shade over the stream.

Only *O. mykiss* were observed in the upper portions of Rock Creek. Roughly half of the fish in the lower mainstem and lower portions of Squaw Creek were dace and the rest were *O. mykiss*. In terms of total abundance, the majority of the *O. mykiss* in the subbasin (71 percent of the total observed in the Rock Creek subbasin) were concentrated downstream of the Bickleton Bridge and 47 percent of the total number of *O. mykiss* observed in the Rock Creek subbasin were stranded in pools isolated by dry sections. No *O. mykiss* were found in the lower two reaches of Rock Creek. The area where the greatest number of *O. mykiss* were observed corresponds to the area where the greatest volume of spawning habitat was available.

No *O. mykiss* were observed in Glade Creek or Chapman Creek. Neither of these creeks contain salmonid spawning habitat; hence, the absence of salmonids is logical.

5.6 SEDIMENT SOURCE MODELING

A screening-level estimate of sediment delivery to streams in the Rock Creek, Wood Gulch, Pine Creek, and Glade Creek subbasins of WRIA 31 to help determine if sediment inputs were large enough to be a concern for aquatic habitat or water quality. Based on natural processes and land uses within the subbasins, estimates of sediment inputs were made for soil creep/bank erosion, cultivated land, and road surface erosion (Table 24). The extent of grazing along streams was also considered, but modeling of sediment input suggested inputs were low, so this source was not quantified although it is likely a local source of sediment in a few locations. Note that the quantification of sediment sources

was based on a one-day site visit and modeling using existing GIS data. The sediment input numbers generated by the models should be regarded as estimates of the relative magnitude of sediment inputs to the different subbasins. The potential effects of sediment inputs from anthropogenic sources are related to the total anthropogenic effects relative to the natural background inputs.

In the Rock, Wood, and Pine subbasins, sediment inputs from cultivated lands and roads were low in comparison to estimated background (soil creep/streambank erosion) inputs. The Washington DNR Watershed Analysis Methodology (WDNR 1993) indicates that situations where anthropogenic inputs are less than 100 percent of the background inputs are of low concern. The anthropogenic inputs estimated for Rock Creek, Wood Gulch, and Pine Creek are extremely low relative to the background inputs. Sediment inputs arising from anthropogenic sources are not likely having a significant effect on fish habitat or water quality. In the Glade Creek subbasin, sediment input from cultivated land was estimated to be several times greater than background inputs. Keeping in mind that all the sediment inputs are estimates, it is more likely that sediment from anthropogenic sources could noticeably affect water quality or fish habitat in the Glade Creek subbasin.

Table 24. Estimated average annual sediment input to streams (tons/yr).

Subbasin	Soil creep/bank erosion (background)	Cultivated land	Road surface erosion
Rock Creek	5,950	1,000	370
Wood Gulch	840	110	38
Pine Creek	4,700	50	17
Glade Creek	580	6,400	73

The Rock Creek subbasin is the western-most watershed in the WRIA. Most of this area is underlain by the Wanapum Basalt, and receives approximately 20 inches of precipitation/year. Land uses include small amounts of timber harvest in the northern part of the basin, residential and small farm/woodlot use in the central part of the basin, and grazing and cultivated land in the southern part of the basin. Sediment inputs were estimated to be 5,950 tons/yr from soil creep/bank erosion, 1,000 tons/yr from cultivated land, and 370 tons/yr from road surface erosion. Approximately 8% of the stream length was estimated to have light to moderate livestock use.

The Wood Gulch and Pine Creek subbasins are long, narrow, north-south trending watersheds east of Rock Creek. They are primarily underlain by the Saddle Mountain Basalt, with some small scattered areas of finer-grained Quaternary deposits and loess. Average annual precipitation is 12-16 inches/year. The majority of the land is grassland and used for grazing or farming. Estimated sediment inputs in Wood Gulch were 840 tons/yr from soil creep/bank erosion, 110 ton/yr from cultivated lands, and 38 ton/yr from road surface erosion. In Pine Creek, sediment inputs were estimated to be 4,700 tons/yr from soil creep/bank erosion, 560 tons/yr from cultivated land, and 17 tons/yr from road surface erosion. Approximately 8% of the stream length in each of the subbasins was estimated to have moderate livestock use; one segment of relatively high livestock

damage was noted in each stream.

The Glade Creek subbasin is the largest subbasin studied, and its relatively gently sloping ground is blanketed by fine-grained Quaternary flood deposits and loess. Average annual precipitation is 8-10 inches/year. Land in the northern part of the basin is used primarily for dryland wheat production, with irrigated row crops dominant in the southern part of the watershed. The average annual sediment input from soil creep/bank erosion was estimated to be 580 ton/yr, with an estimated 6,400 tons/yr from cultivated lands and 73tons/yr from road surface erosion. The relatively high input from cultivated land is a result of the large amount of irrigated land and WEPP estimates of higher erosion rates from irrigated areas. As noted, these numbers should be regarded as relative estimates since land mangers report that they monitor irrigation rates carefully to minimize runoff, and it was not possible to model this type of detailed management with the information available for this study.

5.7 LIMITING FACTORS

The habitat limiting factors in Rock Creek appear to be related to the quantity and quality of rearing habitat. Low stream flows, which are believed to be a natural condition (Aspect and WPN 2004), greatly limit the total volume of rearing habitat present in the basin. Warm stream temperatures also are likely affecting survival of young steelhead in the basin. Other factors, such as predation, harvest, or food availability, could also be the primary factor limiting the population. These factors were not addressed in this study.

The limiting factor in Pine Creek is the lack of access to available habitats. If this were remedied, the limiting habitat factors in this basin would likely be flow (over 40% of the stream was dry during the surveys) and likely temperature (no temperature data is available for this basin). Similar situations are likely limiting steelhead production in Wood Gulch as well. The primary factor affecting productivity could also be a factor that was not assessed in this study such as harvest, food, and/or predation. The limiting factor in Glade and Chapman Creeks is the lack of spawning habitat, which is driven by the local geology.

6.0 REFERENCES

Alderdice, D.F. and F.P.J. Velsen. 1978. Relation between temperature and incubation time for eggs of chinook salmon (*Oncorhynchus tshawytscha*). J. Fish. Res. Bd. Canada. 35:69-75,

Aspect Consulting, LLC and WPN 2004. *Level 1 Watershed Assessment WRIA 31 (Rock-Glade Watershed)*. November 12, 2004. Aspect Consulting, Seattle, WA.

Aspect Consulting, LLC 2004. Quality *Assurance Project Plan, WRIA 31 Supplemental Water Quality Project.* September 27, 2004. Aspect Consulting, Seattle, WA.

Aspect Consulting, LLC 2005. *Rock Creek Water Quality Report*. Prepared for WRIA 31 Planning Unit. Project No. 030009-003-01. Aspect Consulting, Seattle, WA.

Bell. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers. Office of the Chief Engineers, Fish Passage Development and Evaluation Program. Portland, OR.

Bjornn, T.C. and D.W. Reiser. 1991. *Habitat Requirements of Salmonids in Streams. In*: Meehan (ed*). Influences of Forest and rangeland Management on Salmonid Fishes and Their Habitats.* American Fisheries Society Special Publication 19. AFS. Bethesda MD.

Chapman, D.W. and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176 *in* Northcote, R.G. (ed.). Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Institute of Fisheries, Vancouver, B.C.

Charlon, N., B. Barbier, and L. Bonnet. 1970. Thermal resistance of rainbow trout, *Salmo gairdneri* Richardson, to abrupt temperature variation. Annuals of Hydrobioloty 1: 73-89.

Cloern, J.E. 1976. The survival of coho salmon (*Oncorhynchus kisutch*) eggs in two Wisconsin tributaries of Lake Michigan. American Midland Naturalist 96: 451-461.

Coble, D.W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Tans. Am. Fish. Doc. 90:469-474.

Cooper, A.C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. International Pacific Salmon Fisheries Commission Bulletin no. 18.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. J. Fish. Res. Bd. Can. 32:2295-2332.

Ecology (Washington Department of Ecology). 2008. 2008 Washington State Water Quality Assessment. http://www.ecy.wa.gov/programs/wq/303d/2008/index.html.

Ehinger, W. 1996. *Evaluation of High Temperature in Rock Creek (Klickitat County),* Ecology Report No. 96-308. February 1996.

Glass, D.R. 2008. Quality Assurance Project Plan for WRIA 31 Instream Habitat Assessment. Prepared for Klickitat County and the Washington Department of Ecology.

Hunter, J.W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Report by the Washington State Department of Fame, Fishery Management Division, to the Washington State Department of Ecology, Olympia, Wa.

IRZ. 2004. Letter report from Alan Jackson to Tim Flynn regarding the land use classification and crop rotation study completed for WRIA 31. IRZ. Hermiston, OR.

Johnson, D.H., N. Pittman, E. Wilder, J. Silver, W. Plotnikoff, B. Mason, K. Jones, p. Roger, T. O'Neil, and C. Barrett. 2001. *Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia*. Washington Department of Fish and Wildlife, Olympia, Washington. 212 pp.

Lautz, K. 2000. *Salmon and Steelhead Habitat Limiting Factors, Water Resource Inventory Area 31*. Washington State Conservation Commission. January 30, 2000.

Lee, R.M. and J.N. Rinne. 1980. Critical thermal maxima of five trout species in the southwestern United States. Tans. Am. Fish. Soc. 109:632-635.

McNeil, W.J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report – Fisheries 469.

National Marine Fisheries Service (NMFS). 2008. Draft Recovery Plan for the Rock Creek Population of the Middle Columbia River Steelhead Distinct Population Segment. NMFS. Portland OR. http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Interior-Columbia/Mid-Columbia/Index.cfm.

National Oceanographic and Atmospheric Administration (NOAA). 2005. *Endangered and threatened species; designation of critical habitat for 12 Evolutionarily Significant Units of west coast salmon and steelhead in Washington, Oregon, and Idaho*. Federal Register. Vol 70, No. 170, pp. 52630-52858.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992. An approach to determining stream carrying capacity and limiting habitat for coho salmon (*Oncorhynchus kisutch*). p. 251-260 *In* Proceedings of the coho workshop. *Edited by* L. Berg and P.W. Delaney. Nanaimo, B.C., May 26-28, 1992.

Platts, W.S., R.J. Torquemada, M.S. McHenry, and C.K. Graham. 1989. Changes in salmon spawning and raring habitat from increased delivery of ifne sediment to the Sourth Fork Salmon River, Idaho. Trans. Am. Fish. Soc. 118: 274-283.

Pleus, A. and D.A. Schuett-Hames. 1998. *TFW Monitoring Program Method Manual for the Reference Point Survey*. TFW-AM9-98-002. Northwest Indian Fisheries Commission, Olympia, Washington

Reiser, D.W. and R.G. White. 1981. Effects of flow fluctuation and redd dewatering on salmonid embryo development and fry quality. Idaho Water and Energy Resources Research Institute, Research Technical Completion Report, Contract DE-AC79-79BP10848, Moscow, ID.

Reiser, D.W., and R.G. White. 1988. Effects of two sediment-size classes on steelhead trout and chinook salmon egg incubation and juvenile quality. N. Am. J. Fish. Man. 8:432-437.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92:327-343.

Straher, A.N. 1964. *Quantitative geomorphology of drainage basins and channel networks*. Pages 39-76 In: V.T. Chow (ed). *Handbook of applied hydrology*. McGraw-Hill. New York.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master's thesis, University of Washington, Seattle.

Tappel, P.D., and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. N. Am. J. Fish. Man. 3:123-135.

USFS. 2006. *Stream Inventory Handbook, Level I & II. Version 2.6.* USFS Pacific Northwest Region. http://www.fs.fed.us/r6/water/fhr/sida/handbook/Stream-Inv-2006.pdf.

Zar, J.H. 1974, *Biostatistical Analysis*. Prentice-Hall, Inc. NJ.

US Department of Agriculture, Natural Resources Conservation Service (NRCS) 2000. Soil Survey Geographic (SSURGO) database for Yakima, Klickitat and Benton County Areas Washington. Available on-line at http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/data/wa.html

U.S. Forest Service. 2006. Stream Inventory Handbook, level I & II. Pacific Northwest Region, Region 6. http://www.fs.fed.us/r6/water/fhr/sida/handbook/Stream-Inv-2006.pdf

US Geological Survey (USGS) 1992. National Land Cover Database (NLCD). Available on-line at http://landcover.usgs.gov

WDNR. 2000. Washington State 1:100,000 Geologic GIS data set, available online at http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/gis_data.aspx

WDNR. 1993. Standard methodology for Conducting Watershed Analysis. Washington Forest Practices Board Manual under Chapter 222-22 WAC. Version 2.0.WDNR. Olympia, WA.

Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Bd. Can. 15:933-953.

WRIA 31 Planning Unit. 2009. *Watershed Management Plan. Rock-Glade Watershed (WRIA 31).* http://www.klickitatcounty.org/Planning/fileshtml/wria31/WRIA_31_Watershed_Mgt_Plan_20080919.pdf