Wenatchee River Instream Flow Studies
Appendix B

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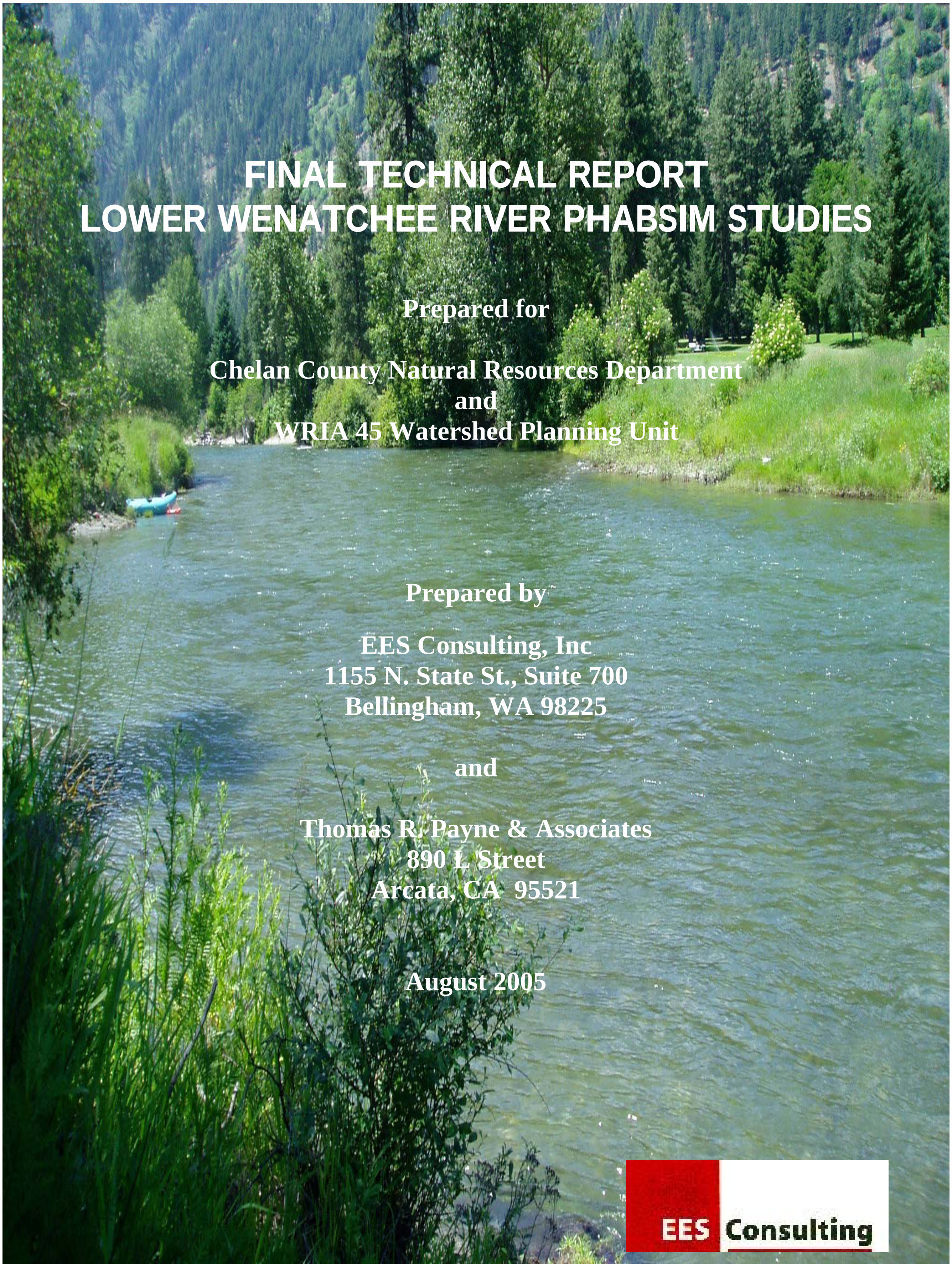

FINAL TECHNICAL REPORT
LOWER WENATCHEE RIVER PHABSIM STUDIES

Prepared for

Chelan County Natural Resources Department
and
WRIA 45 Watershed Planning Unit

Prepared by

EES Consulting, Inc
1155 N. State St., Suite 700
Bellingham, WA 98225

and

Thomas R. Payne & Associates
890 L Street
Arcata, CA 95521

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EES Consulting

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Special thanks are due to the people who assisted in various ways on this study. Local landowners were very cooperative in allowing field teams access to their property for study purposes. The staff at Chelan County Department of Natural Resources has been extremely helpful in many ways, particularly with landowner approvals, field and technical support, and coordinating communication with committees and involved parties.

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EXECUTIVE SUMMARY

The Lower Wenatchee River PHABSIM study focuses on the habitat, hydrologic, and instream flow needs of anadromous salmonids. Fisheries resources of primary concern in the Lower Wenatchee River are commercial and game fish including Chinook salmon, steelhead trout, and bull trout.

The study area is subdivided into the Main Wenatchee River Instream Flow Study Area and the Peshastin Creek Study Area. The Main Lower Wenatchee River Study Area encompasses the mainstem river from RM 0.0 at the mouth of the Wenatchee River at the Columbia River, to River Mile (RM) 27 at the lower end of Tumwater Canyon near Leavenworth. The Lower Wenatchee River was segmented into 4 distinct reaches, based on river morphology and hydrology. Thirty-five transects were selected for intensive study in the mainstem Wenatchee River.

The Peshastin Creek Study Area extends from its mouth at RM 17.9 on the Wenatchee River, upstream to RM 5. Peshastin Creek was not segmented due to the homogeneous nature of the stream. Habitat in Peshastin Creek was represented by 9 transects located near RM 2.2.

The Lower Wenatchee River Instream Flow Study was conducted using the Physical Habitat Simulation (PHABSIM) modeling approach, which is commonly referred to as the U.S. Fish and Wildlife Service Instream Flow Incremental Method (IFIM).

A principal product of PHABSIM is the Weighted Usable Area (WUA) chart, which is a quantifiable index of habitat value, relative to flow. The modeled flow range in the mainstem Wenatchee River is from 220 cfs to 10,000 cfs. The modeled flow range for Peshastin Creek is 11 cfs to 425 cfs. This document reports WUA results for rearing salmonids including chinook salmon, steelhead trout, and bull trout. WUA results for spawning salmonids are reported for Chinook salmon, and steelhead trout. This report is organized into five main sections, 1.0 Introduction, 2.0 Methodology, 3.0 Results, 4.0 Hydrology, and 5.0 References. The methodology, results, and hydrology are contained in the main body of the text and supporting technical data is located in the appendices.

PHABSIM ASSESSMENT
GLOSSARY OF TERMS

Anadromous	Going upstream to spawn, usually from salt to fresh water.
Calibration flow	Measured flow used to evaluate model (RHABSIM, PHABSIM) performance.
EESC	EES Consulting, Inc. Primary consultant for Wenatchee River PHABSIM study
Freshet	A sudden rise in the level of a stream, or a flood due to heavy rains or the rapid melting of snow and ice.
HABSIM	The Weighted Usable Area Habitat Simulation in RHABSIM.
HSC	Habitat Suitability Criteria- Values for depth, velocity, substrate and cover that reflect the likelihood that fish will use a particular range for each factor. HSC unique for each species and life stage of concern.
HYDSIM	The hydraulic model in RHABSIM.
IFIM	Instream Flow Incremental Methodology
PHABSIM	Physical Habitat Simulation System
RCW	Revised Code of Washington
Redd	Most salmonids deposit their eggs in nests called redds. Redds are dug in the streambed substrate by the female. Most redds occur in predictable areas and are easily identified by an experienced observer by their shape, size, and color (lighter than surrounding areas because rocks have been overturned and biofilm and silt have been cleaned away).
RHABSIM	Analysis and integration of physical stream measurements and habitat preference criteria require the use of a group of computer programs developed by the US Fish and Wildlife Service. DTA uses RHABSIM, developed by Tom Payne and Associates of Arcata, CA.
Stream Reach	A subset of the study area that is distinguished from other reaches for stated reasons.
Study Area	The portion of a river or stream that will be addressed in the study.
Study Site	A particular area within a Reach where transects are grouped.
VAF	Velocity Adjustment Factors (VAF) are a measure of how well the model simulates velocities using a three velocity set regression data set. A VAF between 0.90 and 1.10 is considered good. A VAF between 0.85 and 0.90 or between 1.10 and 1.15 is considered to be fair. A VAF between .80 and .85 or 1.15 and 1.20 is marginal, while a VAF below 0.80 or above 1.20 is considered poor.
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WSE	Water surface elevation
WUA	Habitat quantification is expressed as an index called Weighted Useable Area (WUA), and is given in habitat per 1,000 linear ft of stream.

1.0 INTRODUCTION

1.1 Authority

EES Consulting, Inc. (EESC) and Thomas R. Payne and Associates (TRPA) are conducting this study under contract to Chelan County, for the WRIA 45 Planning Unit. This study is undertaken as part of the WRIA 45 Watershed planning process administered by the Washington Department of Ecology (RCW 90.82).

This report is organized into five main sections; 1.0 Introduction, 2.0 Methodology and Approach, 3.0 Results, 4.0 Hydrology, and 5.0 References. The methodology, results, and hydrology are contained in the main body of the text and supporting technical data is located in the appendices.

1.2 Background

The primary purposes of the WRIA 45 watershed planning are to:

- Facilitate the establishment of instream flows to protect aquatic resources
- Provide a mechanism for coordinated water resources management for out-of-stream needs.

This report presents the study methodology and results for discussion of instream needs for the Lower Wenatchee River and Peshastin Creek.

1.3 Study Objectives

Study objectives for the Lower Wenatchee River PHABSIM Study are:

- Quantify the relationship between stream flow and available aquatic habitat for appropriate salmonid species and life stages for the Lower Wenatchee River.
- Quantify the relationship between stream flow and available aquatic habitat for appropriate salmonid species and life stages for Peshastin Creek.
- Provide a well-documented, scientific basis to serve as a decision-making tool for instream flow evaluations. Specifically, the areas of interest are the mainstem Wenatchee River from its mouth at the Columbia River, upstream to Tumwater Canyon at River Mile (RM) 27 and Peshastin Creek from its mouth at the Wenatchee River, upstream to RM 5.0 (Figure 1.3-1).

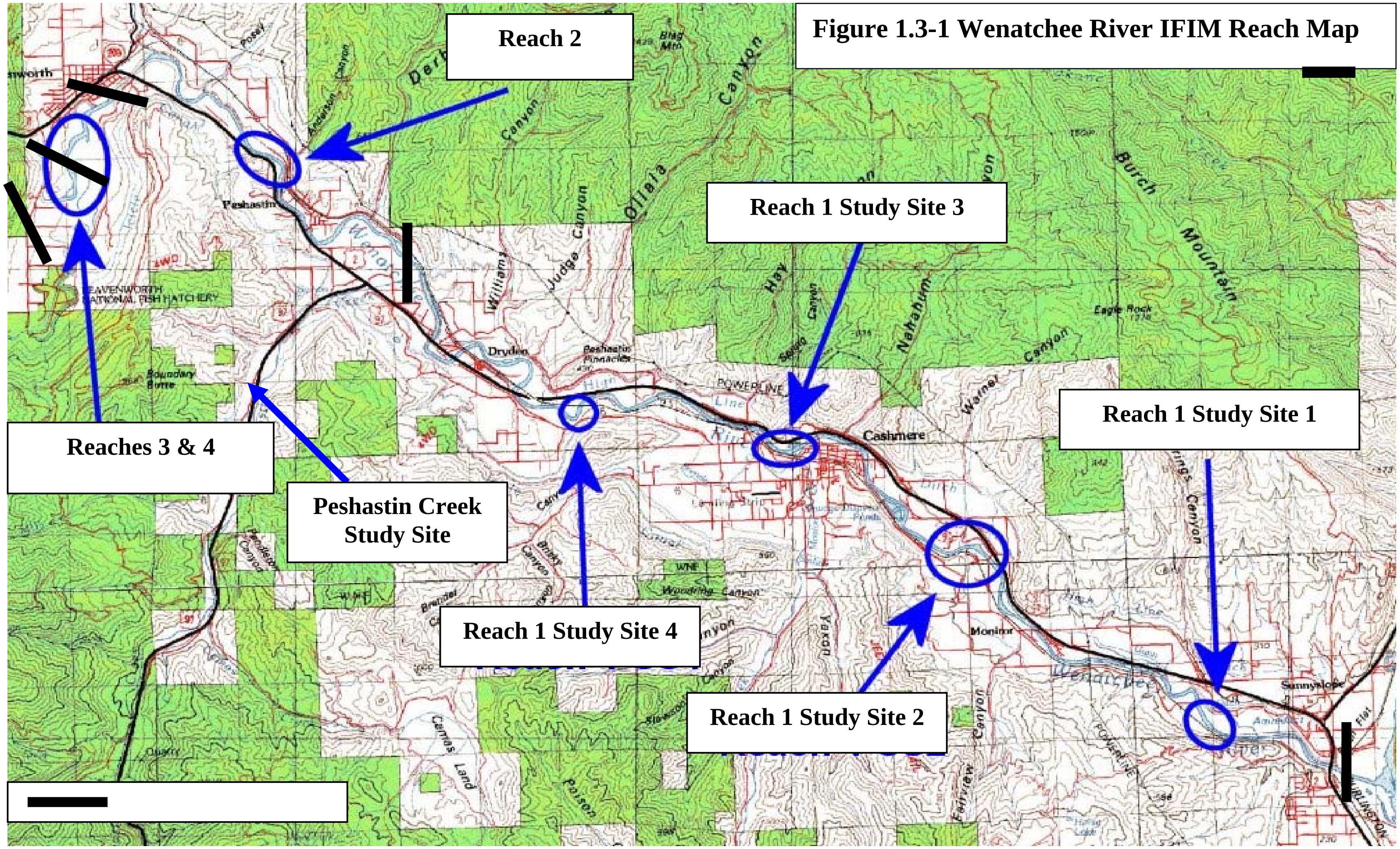


Figure 1.3-1 Wenatchee River IFIM Reach Map
Reach 2
Reach 1 Study Site 3
Reach 1 Study Site 1
Reaches 3 & 4
Peshastin Creek Study Site
Reach 1 Study Site 4
Reach 1 Study Site 2
Peshastin
Dryden
Cashmere
Monitor
Sunnyslope
LEAVENWORTH NATIONAL FISH HATCHERY

1.4 Wenatchee River Watershed

Originating as rainfall and snowmelt on the eastern flank of the Cascade Mountains in North Central Washington, the Wenatchee River flows 54 miles to the southeast from Lake Wenatchee to the Columbia River in Chelan County, Washington. The drainage area of the Wenatchee River and its tributaries is approximately 1,371 square miles. The Wenatchee River Basin study area extends from RM 27, near the town of Leavenworth, downstream to the confluence with the Columbia River. The two largest tributaries in this reach are the Icicle River and Peshastin Creek, which join the Wenatchee River at RM 25.6 and RM 17.9, respectively. The gradient of the Wenatchee River within the study area is moderate to low, averaging about 0.36% from Tumwater Canyon downstream to the confluence with the Columbia. Although the overall gradient is somewhat moderate, several high-gradient rapids can be found within this river segment.

The topography, hydrology, and land use in the Wenatchee watershed are diverse. In the mountainous headwaters, much of the area is managed park and forest land with glaciers and snow fields on the higher peaks and dense coniferous forests covering the mid-elevation slopes. The headwater streams are generally steep, continuous cascades with boulder and cobble substrate. The mid and upper river segments generally wind through constricted valley floors and flow over cobble and gravel riffles interspersed with short, boulder strewn cascades. The Lower Wenatchee River flows through a valley of fertile orchards, with occasional small towns along the river. The banks of the river are mainly covered with boulders and cobble, and in some areas, riprap has been constructed.

2.0 METHODOLOGY AND APPROACH

2.1 Overview of PHABSIM Methodology

Unless otherwise noted, PHABSIM study procedures follow the WDFW/WDOE Updated Instream Flow Guidelines (April, 2004). The PHABSIM methodology is based on the premise that stream-dwelling fish are more often found in a certain range of depths, velocities, substrates, and cover types, depending upon the species and life stage, and that the availability of these preferred habitat conditions varies with stream flow. PHABSIM is designed to quantify potential physical habitat available for each life stage of interest, for a target fish species, at various levels of stream discharge, using a series of modeling programs initially developed by the U.S. Fish and Wildlife Service. Major components of the methodology include: (1) study site and transect selection; (2) transect weighting; (3) field collection of hydraulic data; (4) hydraulic simulation to determine the spatial distribution of combinations of depths and velocities with respect to substrate and cover under a variety of discharges; and (5) habitat simulation, using habitat suitability criteria, to generate an index of change in habitat relative to change in discharge. The product of the habitat simulation is expressed as Weighted Usable Area (WUA) for a range of simulated stream discharges.

It is important to recognize that the product of a PHABSIM analysis is not a set value but a range of values to be used as a tool for discussing and determining a range of stream flows that will meet the needs of all affected resources.

2.2 Stream Description

The Mainstem Wenatchee River Study Area extends from the confluence of the Wenatchee River at the Columbia River (RM 0.0), upstream to the lower end of Tumwater Canyon (RM 27.0). Chinook, sockeye, and coho salmon, as well as steelhead and bull trout utilize this area as a transportation corridor for upstream and downstream movement, migration, and juvenile rearing. Spawning and incubation of chinook and steelhead also occur in this reach

The Mainstem Wenatchee River Study Area includes only the Wenatchee River and its associated habitats (i.e., edge and mid-channel); it does not encompass any of the tributaries downstream of RM 27.0 or their associated habitats.

Within the Mainstem Wenatchee River Study Area, the river is primarily contained within a single channel. For short distances, the channel may split around islands or gravel bars and form distinct geomorphic features that exhibit habitat variations distinct from the main channel. In places river banks have been modified with riprap positioned along one or both banks to protect property and infrastructure from flood damage.

Differences in morphology and hydrology in the Wenatchee River are addressed by segmenting the river into four distinct reaches. Study reaches within the 27-mile study area of the Wenatchee River are differentiated by changes in hydrology, slope, and habitat type.

The Peshastin Creek Study Area extends from its mouth to RM 5. Species of concern that utilize Peshastin Creek include chinook salmon, steelhead and bull trout. Segmenting was not required in Peshastin Creek due to the homogenous nature of the habitat.

2.3 Stream Reach Description

Reach 1: Columbia River to Peshastin Creek (RM 0.0 – 17.7). The majority of Reach 1 is characterized by moderate gradient and long, wide glides with short sections of riffles, rapids and pools. Side and split channel areas comprise approximately 25% of the river length. The upper end of this reach, downstream of Dryden Dam, is steeper, with more rapids and intermittent large pools. Peshastin Creek, at the upstream boundary of this segment, contributes significant inflow.

Reach 2: Peshastin Creek to Leavenworth (RM 17.7 – 24.3). A majority of Reach 2 is moderate gradient, with well-defined banks and fewer meanders and point bars than found in Reach 1. Long glides are the predominant habitat feature, with pools, riffles and rapids interspersed throughout the reach. The upper end of this reach (downstream of Leavenworth) is steeper with more rapids and runs than the lower portion. Although many small tributaries enter the mainstem in this reach, cumulative inflow is small relative to the flow in the river.

Reach 3: Leavenworth Park to Icicle Creek (RM 24.3 – 25.6). Reach 3 is differentiated from Reach 2 by a dramatically lower gradient and a wider, unconfined channel. Reach 3 has smaller substrate and more gravel bars and gravel banks than Reach 2. The habitat is predominantly very wide glides, riffles, and pools.

Reach 4: Icicle Creek to Tumwater Canyon (RM 25.6 – 27.0). The majority of the habitat in Reach 4 is similar to the glide, pool, and riffle habitat in Reach 3. The major feature that distinguishes the two reaches is that Reach 4 lies upstream of the significant additional stream flow contributed by the Icicle River. Upstream of RM 26.3, the river narrows and steepens, with the habitat changing to fast glides, deep runs, and minor rapids.

2.4 Physical Habitat Surveys

Physical habitat surveys were conducted with a low elevation, aerial video survey of the Wenatchee River from the mouth to Tumwater Canyon and in Peshastin Creek from the mouth to Ingalls Creek. The purpose of the video was to obtain an overview of the river and determine the frequency of various types of fish habitat found within the study area.

The aerial video was used to characterize habitat types throughout the Lower Wenatchee River and Peshastin Creek. Areas with a variety of habitat types located in a relatively short distance were noted as possible locations for transect placement. With the habitat types in hand, the entire length of the Wenatchee River from the Icicle Road bridge to the Columbia River was surveyed on foot or via raft to ground truth the initial habitat typing from the video. Where appropriate, habitat types were changed to match what was observed on the ground. A frequency distribution of habitat types forms the basis for transect selection and transect weighting. Details of the habitat frequency analysis are described in Section 2.6.

This information in conjunction with ground-truthing surveys, hydrology, and topographic considerations, was used to segment the Wenatchee River into study reaches and aid in the selection and placement of transects.

2.5 Transect Selection

Study sites and transects were selected to best represent the variety of habitat types within the Lower Wenatchee River. EESC selected 35 transects within the four study reaches between RM 0.0 and RM 27.0 on the mainstem Wenatchee River. Nine transects in one study reach were selected on Peshastin Creek. The study sites and transects were approved by representatives of the WDOE and WDFW during site visits on April 9 and 21, 2004. Figures 2.5-1 through 2.5-7 show locations of study sites and transect locations throughout the Lower Wenatchee River Study area and Peshastin Creek.

Table 2.5 -1 Transect locations on the Wenatchee River and Peshastin Creek

System	Reach No.	Reach Locations	No. Transects	Transect Locations
Wenatchee River	1	RM 0.0 - 17.7	4	RM 3.0 – 3.2
			6	RM 7.3 – 7.5
			7	RM10.2 – 10.5
			3	RM 13.8 – 13.9
	2	RM 17.7 – 24.3	6	RM 21.1 – 21.6
	3	RM 24.3 – 25.6	4	RM 24.9 – 25.3
	4	RM 25.6 – 27.0	5	RM 25.9 – 26.2
Peshastin Creek	1	RM 0.0 – 5.0	9	RM 2.1 – 2.2

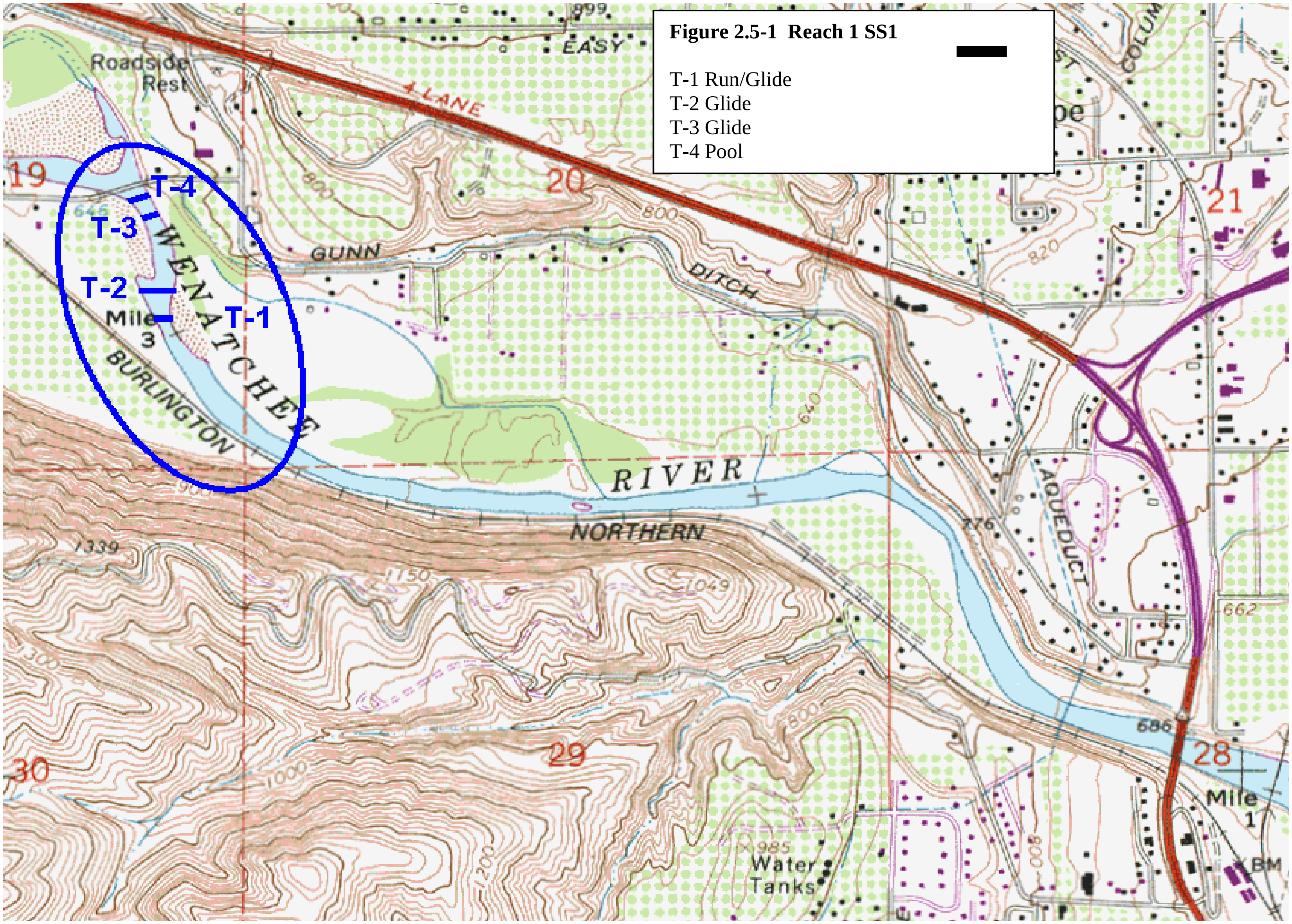


Figure 2.5-1 Reach 1 SS1

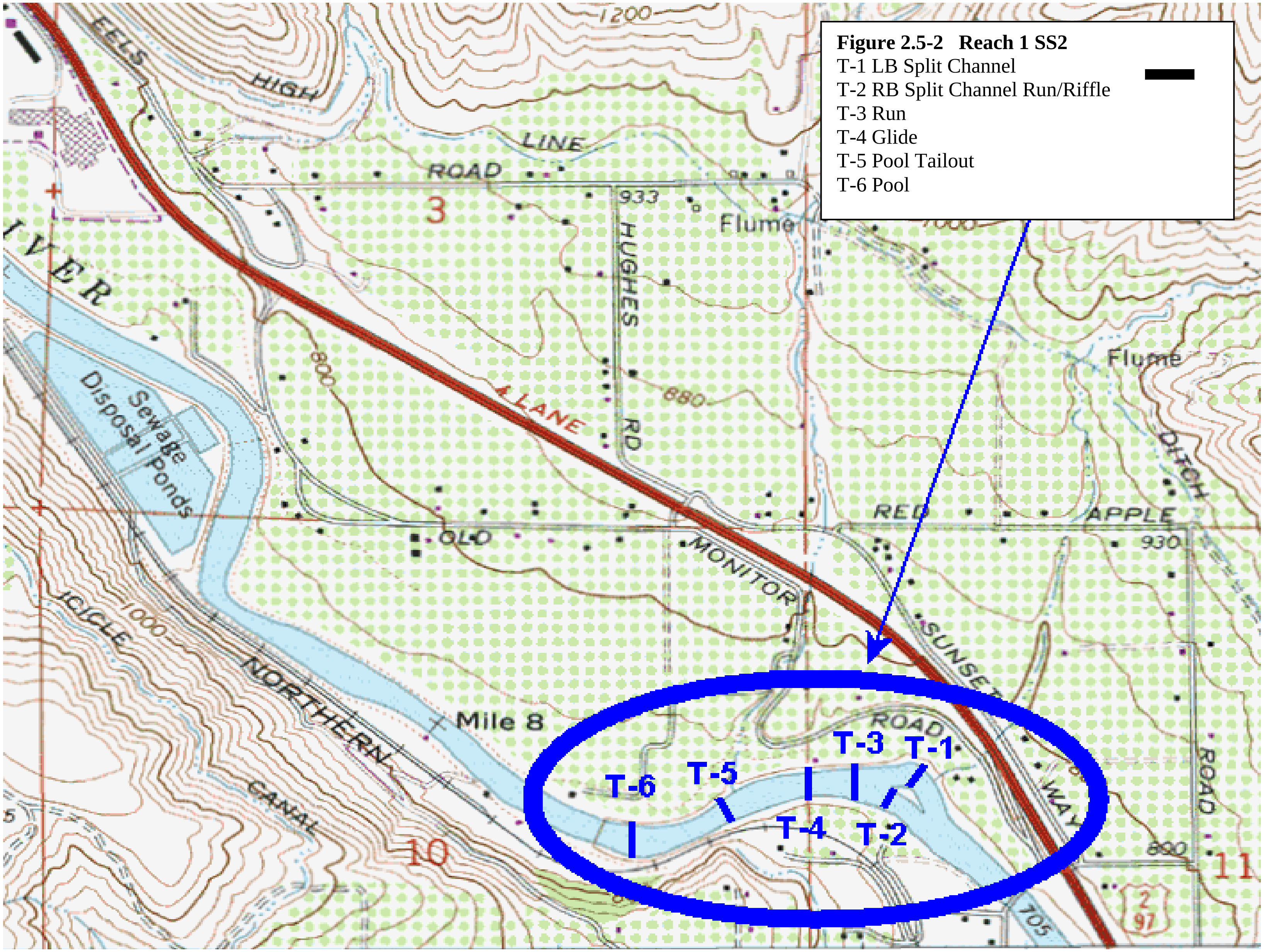


Figure 2.5-2 Reach 1 SS2
T-1 LB Split Channel
T-2 RB Split Channel Run/Riffle
T-3 Run
T-4 Glide
T-5 Pool Tailout
T-6 Pool

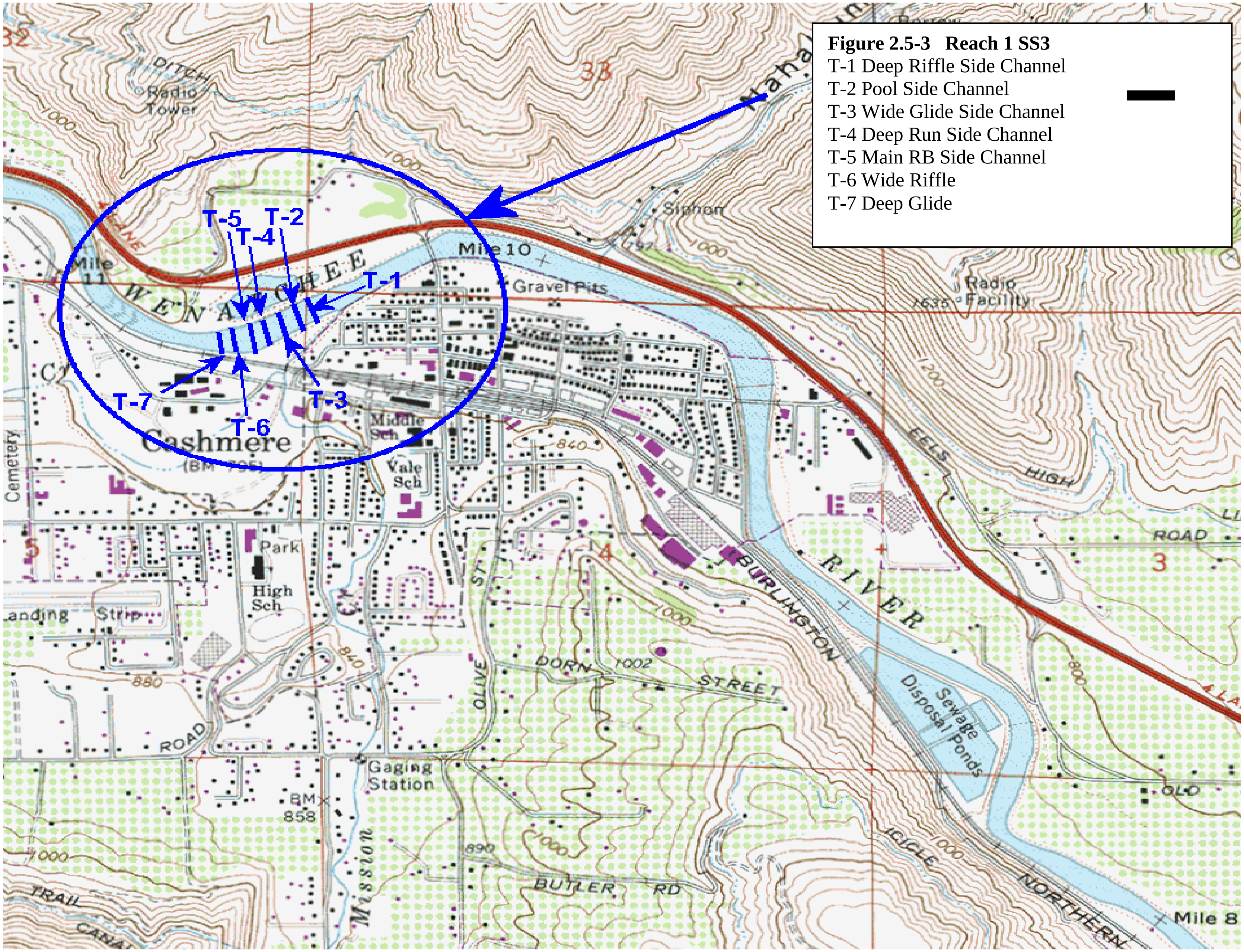


Figure 2.5-3 Reach 1 SS3
T-1 Deep Riffle Side Channel
T-2 Pool Side Channel
T-3 Wide Glide Side Channel
T-4 Deep Run Side Channel
T-5 Main RB Side Channel
T-6 Wide Riffle
T-7 Deep Glide

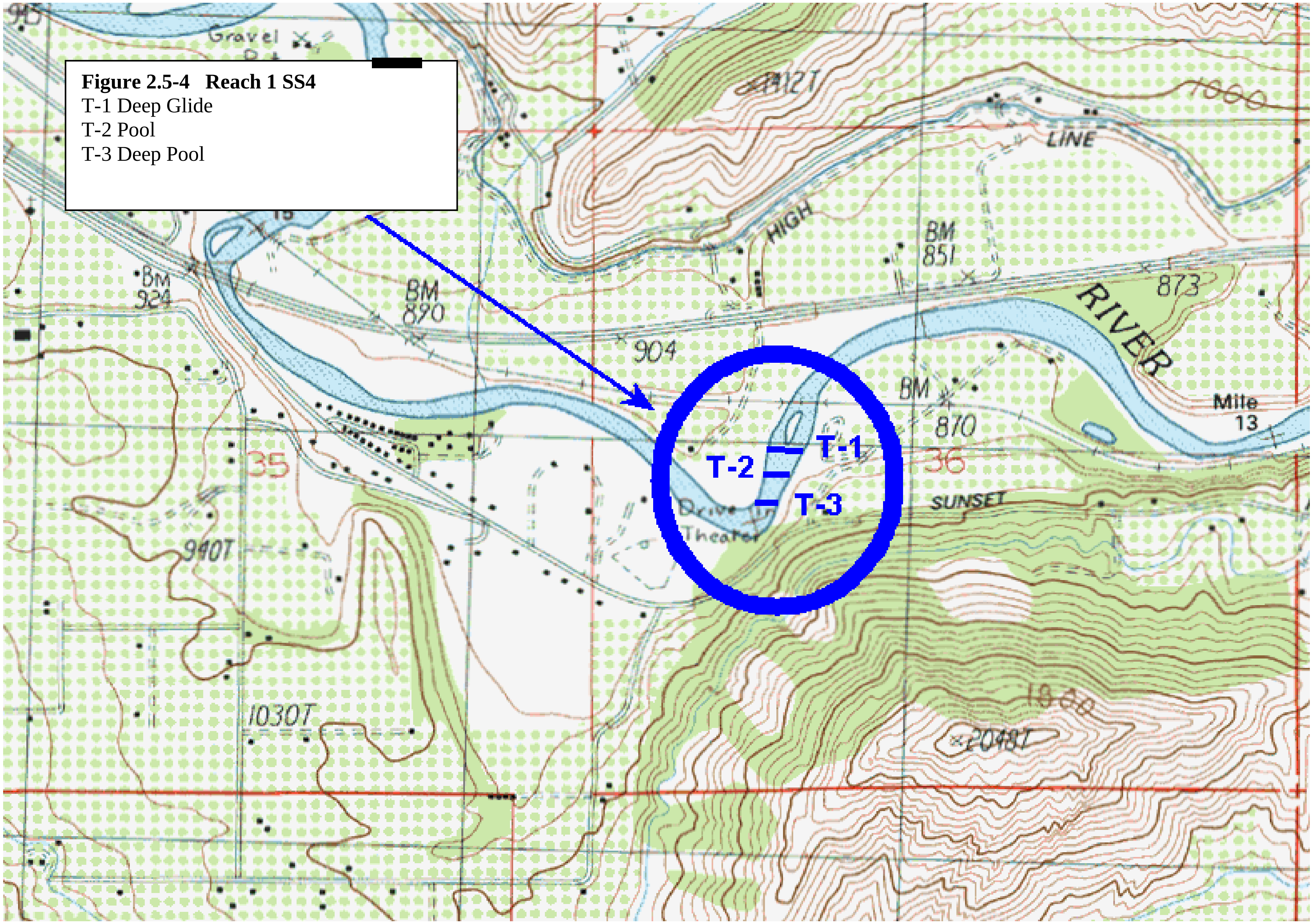


Figure 2.5-4 Reach 1 SS4
T-1 Deep Glide
T-2 Pool
T-3 Deep Pool
T-1
T-2
T-3
RIVER
HIGH
LINE
SUNSET
Drive In
Theater
Mile
13
BM
851
BM
890
BM
870
BM
924
904
873
940T
1030T
2048T
1412T
35
36
Gravel

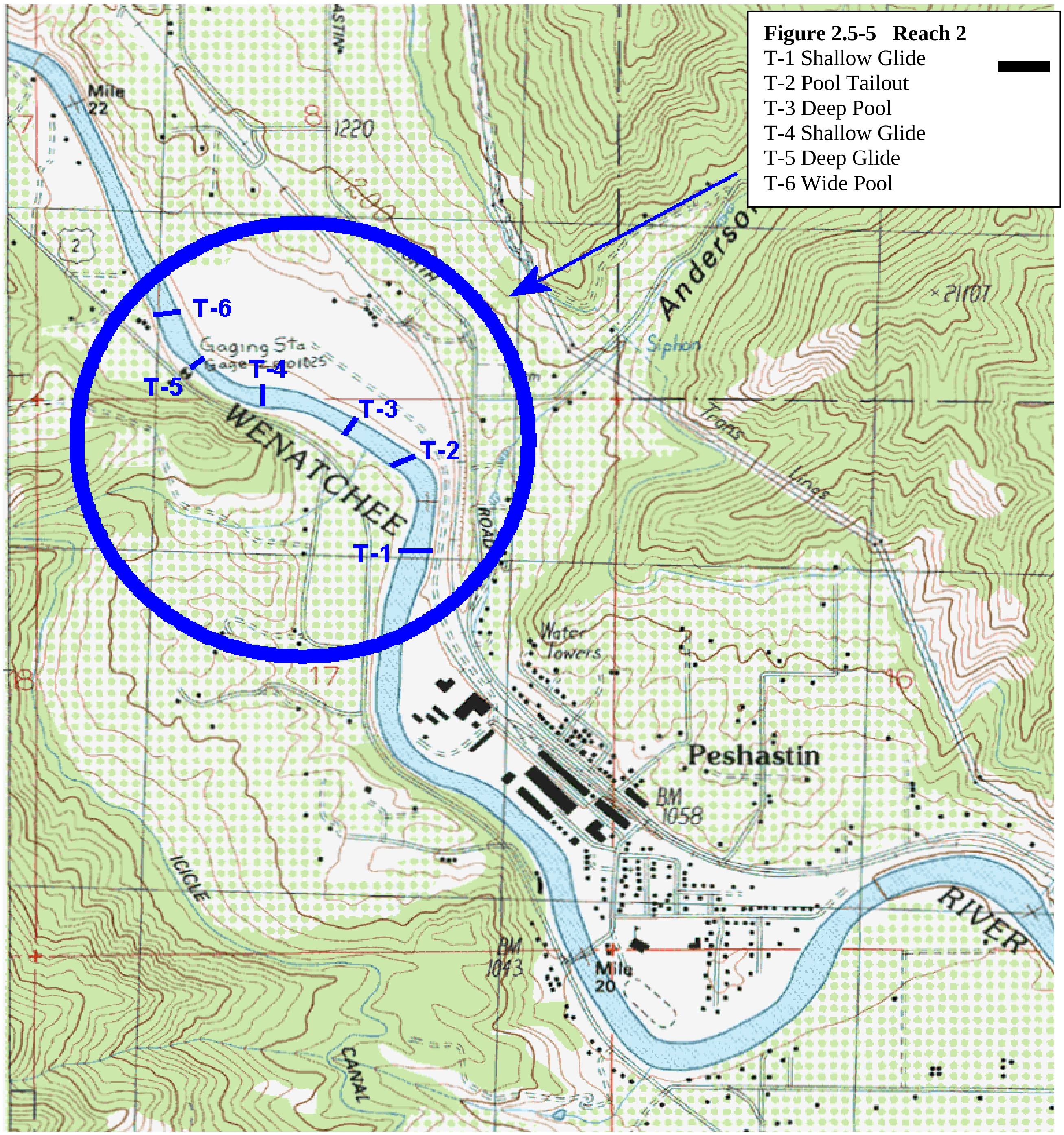
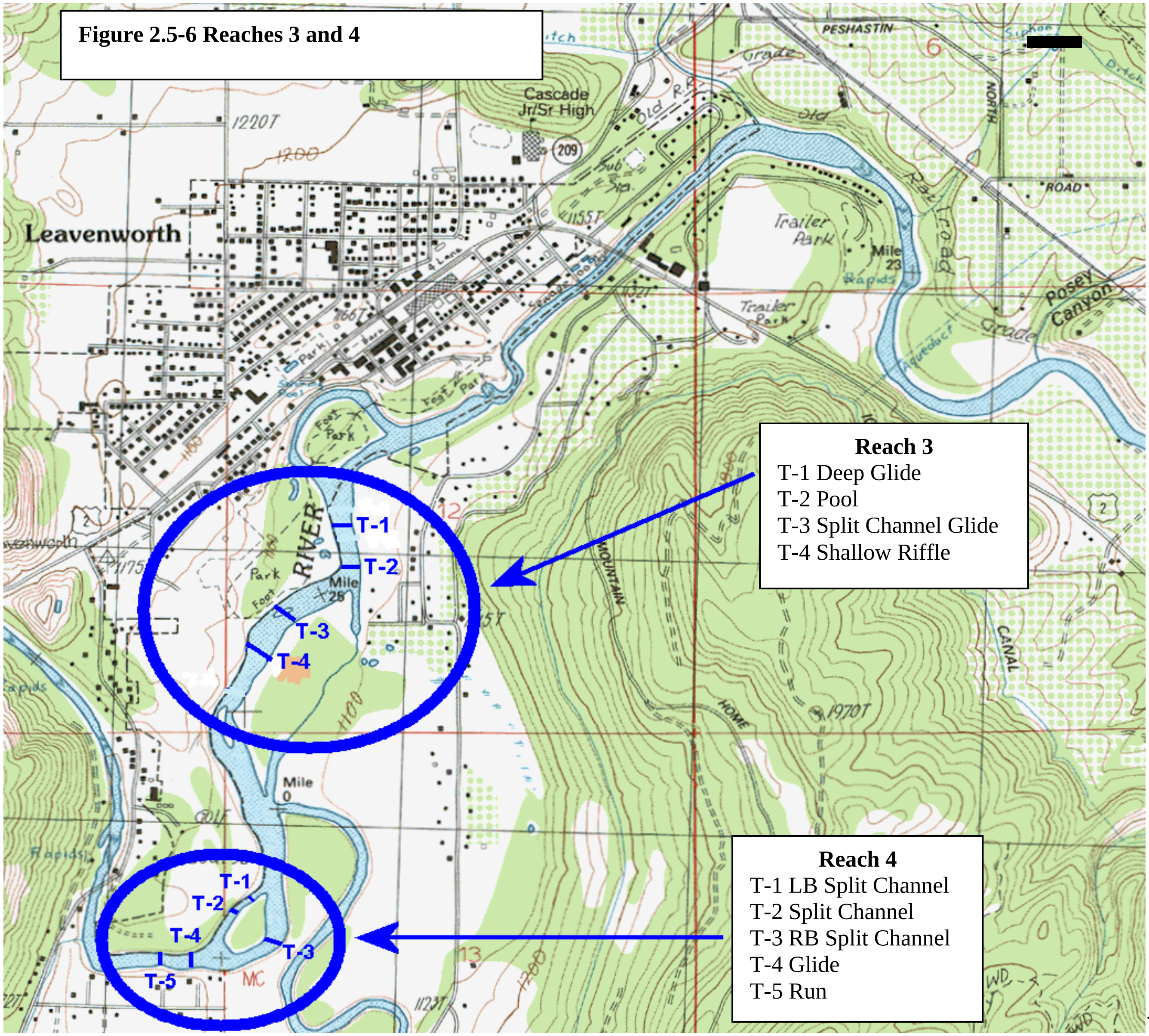


Figure 2.5-5 Reach 2
T-1 Shallow Glide
T-2 Pool Tailout
T-3 Deep Pool
T-4 Shallow Glide
T-5 Deep Glide
T-6 Wide Pool
T-1
T-2
T-3
T-4
T-5
T-6
WENATCHEE
RIVER
Peshastin
Anderson
Mile 22
Mile 20
Water Towers
BM 1058
BM 1043
ICICLE
CANAL

Figure 2.5-6 Reaches 3 and 4



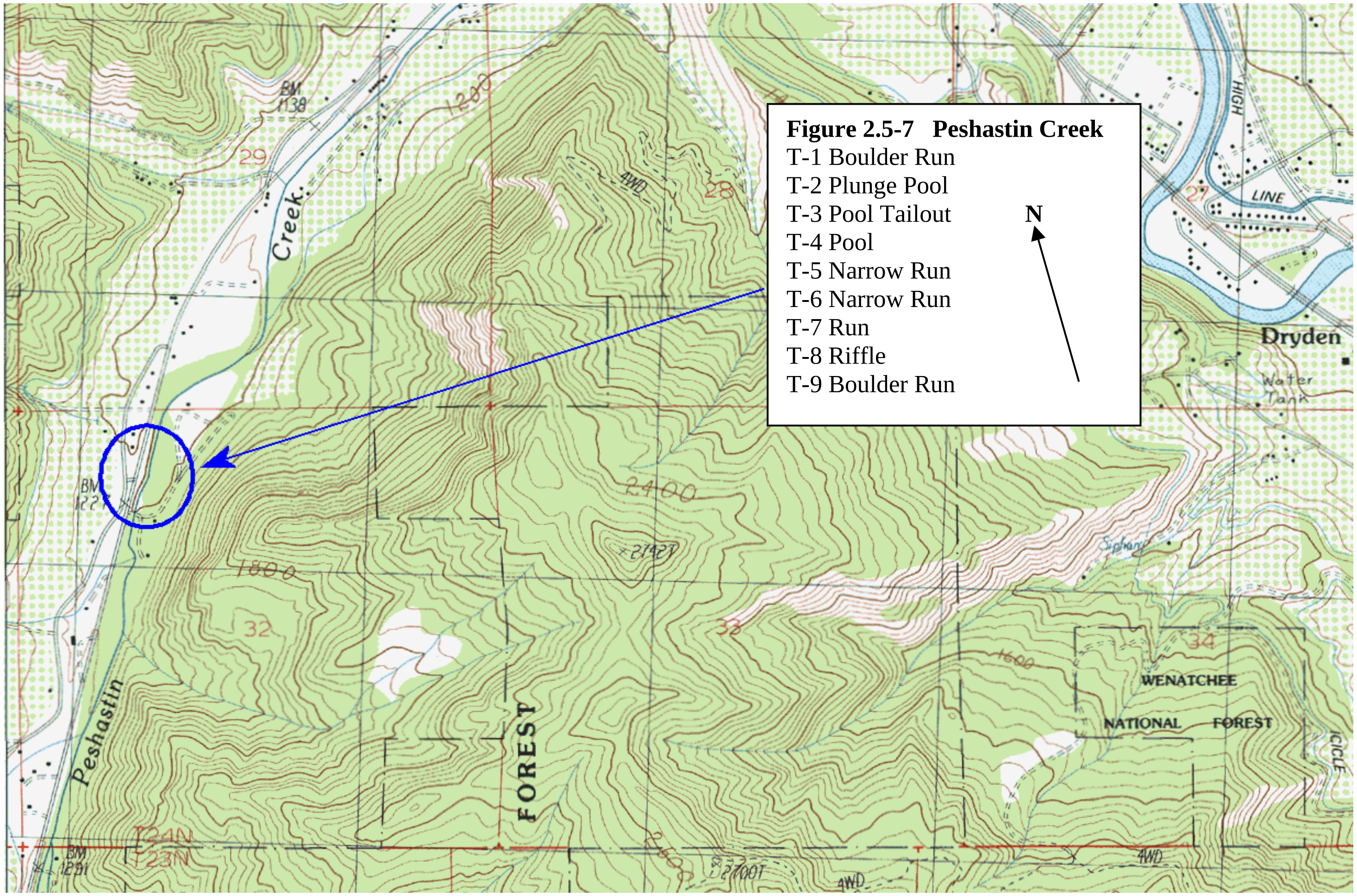


Figure 2.5-7 Peshastin Creek
T-1 Boulder Run
T-2 Plunge Pool
T-3 Pool Tailout
T-4 Pool
T-5 Narrow Run
T-6 Narrow Run
T-7 Run
T-8 Riffle
T-9 Boulder Run
N
Creek
Peshastin
Dryden
FOREST
WENATCHEE
NATIONAL
FOREST

2.6 Transect Weighting

Weighting for each transect was accomplished in two steps. The first involved classification of the various habitat types present in the study reach. These classifications were derived from study of the low altitude aerial video, river inspection, and ground truthing.

The second step involved a frequency analysis to determine the proportion of each habitat type in each study reach. Frequencies of habitat types for the Lower Wenatchee River and Peshastin Creek were calculated from the low-elevation aerial video. EESC analyzed the low-altitude videotape using the following procedures. The video was viewed in an upstream direction and the tape image was "frozen" on the screen at exactly 5-second intervals according to a screen-generated stop watch. The habitat type that lined up with an index marker drawn horizontally across the center of the monitor screen was tallied according to the established habitat classifications shown in Table 2.6-1. A total of 518 observation points were made on the Lower Wenatchee River from the video tape.

Transect weighting (Table 2.6-2) is based on the frequency of habitat types in the Lower Wenatchee River that are represented by the selected transects. Transects were weighted empirically, using results from the habitat frequency analysis and professional judgment. Transect weighting for Peshastin Creek was accomplished using the same methodology as the Mainstem Wenatchee River. A total of 145 observations were made from the videotape for Peshastin Creek. Table 2.6-3 shows transect weighting for the 9 transects on Peshastin Creek.

Table 2.6-1 Macrohabitat Type Coding and Descriptions		
Code	**Habitat Name**	**Habitat Description**
1	Backwater/Eddy Pool	Upstream of flow obstruction or on channel margins where flow decelerates. Slower velocity and deeper, non-turbulent flow with a strong hydraulic control. Often fine particles due to reduced shear stress. Water surface slope <1%.
2	Lateral pool	Pool formed on the margin of the stream as a result of a structural element, substrate composition, or thalweg location. (Generally at least 2 of the pool perimeter interfaces with adjacent habitat units.)
3	Plunge pool	Flow at head is vertical passing over an obstruction; fast, turbulent often with a bubble plume down the center
4	Glide	Smooth generally unbroken surface, generally laminar flow, moderate to shallow depth, often smaller substrates. Often doubles as a pool tailout
5	Riffle	Topographic cross-over between pool and bar in pool-riffle morphology; spans the channel; particles are usually fairly well-sorted; water surface slope 1-4%
6	Depositional riffle	Shallow with moderate velocities (less than run), lateral bottom profile is usually uniform, surface is broken but not turbulent like a run, gradient ≤ 4%. Poorly sorted substrate upstream of obstructions.
7	Boulder garden	Coarse planar bed in which the largest particles (boulder size) rise well above bankfull water depth creating flow irregularities; insufficient flow convergence to create pools or riffle; water surface slope 1-4% but mostly less then 2.5% Note that boulder gardens have some overlap and are a subset of riffle habitats
8	Chute	All the flow is concentrated in a narrow area. Flow is fast to very fast.
9	Rapid	Water (rough, turbulent surface, usually with standing wave at the hydraulic jump that occurs at the bottom as the flow rapidly decelerates into a pool, though it could merge into a riffle; water surface slope 2.5-4%.
10	Cascade	Tumbling, turbulent flow with pronounced vertical drops causing a stepped gradient, substrate often boulders and cobble. Gradient is 8-20% and total vertical drop within unit is at least 2 ft.
11	Braided channel	One or more divisions of the stream channel separated by islands of substrate not well vegetated
12	Split channel	Flow is approximately evenly split between islands; height of the islands exceeds bankfull elevation; water slope varies dependent upon the type of mesohabitat occupying each of the splits.
13	Side channel	Small channel relative to main channel; may or may not have flow at time of survey; includes remnant flood terrace side channels that can often be vegetated.

Table 2.6-2 Wenatchee River Transect Weighting					
Reach	**Study Site**	**Transect No.**	**Transect Description**	**Transect Weight**	**River Mile**
1	1	1	Run/glide 400’ DS of T-2	7.40%	3.0
		2	Wide, shallow, faster glide	9.45%	3.1
		3	Glide 200’-300’ below T-4	7.10%	3.1
		4	Pool just below Sleepy Hollow Br.	2.37%	3.2
	2	1	LB split channel US Old Monitor Bridge	1.98%	7.3
		2	RB split channel glide/run	1.97%	7.3
		3	Faster glide/run above diversion on RB	7.41%	7.4
		4	Wide glide w/spawning bar on RB	7.10%	7.4
		5	Glide/pool tailout, 200’ DS of T-6	7.10%	7.5
		6	Large Pool	2.37%	7.5
	3	1	LB side channel, deep riffle	2.59%	10.2
		2	LB side channel, pool	2.59%	10.3
		3	LB side channel, wide glide	2.59%	10.4
		4	LB side channel, deep run	2.59%	10.5
		5	Main RB side channel, DS of T-6	10.34%	10.5
		6	Wide, shallow riffle with large substrate	7.70%	10.5
		7	Narrow, deep glide, large substrate	5.51%	10.6
	4	1	Deep glide above complex split channel	7.10%	13.8
		2	Mid pool, gravel bar on RB	2.37%	13.8
		3	Deep pool, back water on both sides	2.37%	13.9
			Total transect Weight for Reach 1	100%	
2	1	1	Shallow glide 500’ downstream of T-2	20.83%	21.1
		2	Pool tail out	20.83%	21.2
		3	Deeper pool, center fast, eddies in sides	5.56%	21.3
		4	Shallow glide above run	18.76%	21.4
		5	Deep glide under USGS cableway	20.83%	21.5
		6	Wide Pool 400’ above T-5	13.19%	21.6
			Total transect Weight for Reach 2	100%	
3	1	1	Wide, glide, 300’ downstream of T-2	28.00%	24.9
		2	Wide pool 300’ downstream of T-3	24.00%	24.9
		3	Split channel glide, 300’ DS of T-3	16.00%	25.0
		4	Wide shallow glide/riffle	32.00%	25.2
			Total transect Weight for Reach 3	100%	
4	1	1	LB split channel – glide	8.00%	25.9
		2	LB split channel – glide/run	8.00%	25.9
		3	Large RB split channel – glide	16.00%	25.9
		4	Glide above channel split	43.00%	26.1
		5	Run/glide 300’ upstream of T-4	25.00%	26.2
			Total transect Weight for Reach 4	100%	

Table 2.6-3 Peshastin Creek Transect Weighting			
Transect No.	**Description**	**Transect Weight**	**River Mile**
1	Boulder Run	21.4%	2.1
2	Plunge Pool in center 1/3	12.7%	2.1
3	Tailout of Pool	0.7%	2.1
4	Pool	12.7%	2.2
5	Narrow Run	8.6%	2.2
6	Narrow Run	8.6%	2.2
7	Medium-width Run	8.6%	2.2
8	Riffle	5.4%	2.2
9	Wide Boulder Run	21.3%	2.2
	Total Transect Weight	100%	

2.7 Field Methods

2.7.1 Mainstem Wenatchee River

The field methods and hydraulic analysis for the mainstem Wenatchee River followed the 1-velocity method as described in Payne (2003). This method uses one set of velocity measurements and a water surface elevation (WSE), usually at the high flow, and two additional stage discharge points as input to the PHABSIM model to generate hydraulic simulations for the desired range of flows. The EESC/TRPA field team obtained a high flow set of hydraulic calibration measurements at each transect. Measurements included depths and velocities at close intervals across the transect and water surface elevations at each transect at each of the three flows.

Mid-channel depth and velocity distributions at the calibration flow were measured using an acoustic doppler current profiler (ADCP) mounted on a small trimaran boat and side tied to an inflatable raft. The ADCP uses acoustic pulses to measure water velocities and depths across the channel. According to an extensive evaluation conducted by the U.S. Geological Survey (USGS), “ADCP’s can be used successfully for data collection under a variety field conditions” (USGS 1996). ADCP hydraulic measurements are made from a boat by moving the ADCP across the channel while it collects vertical-velocity profile and channel-depth data. The ADCP tracks the distance traveled from the point of origin so each depth and velocity measurement is coordinated with a horizontal distance on the transect. Measurements are taken at close intervals across the transect and at multiple levels in the water column. The ADCP is connected by cable to a power source and a radio modem that is linked to a laptop computer on shore. The computer is used to program the instrument, monitor its operation, and collect and store the data.

Because the ADCP will not measure in depths less than approximately 1.5 feet, shallow depth measurements near shore and other locations were taken manually using either a Price AA meter or a Swoffer brand, propeller-type velocity meter mounted on a standard top-set USGS wading rod. Manually measured velocities were taken at sixth tenths of the depth when depths were less than 2.5 feet and at two tenths and eight tenths of the depth when depths equaled or exceeded 2.5 feet or when the expected velocity profile was altered by an obstruction immediately upstream.

An auto level was used to measure headpin elevations, water surface elevations (WSE), hydraulic controls and above water bed elevations along each transect. All measurements were referenced relative to a temporary benchmark. Bed elevations below the water surface were obtained by subtracting measured depths taken during velocity calibration from the water surface elevations for that particular transect. Except when surveying the bed profile, the surveyor attempted to measure elevations to the nearest .01 feet.

Substrate and cover were measured visually during a low-flow period in September. In the deeper portions of pool, transects substrate was measured with the aid of a mask and snorkel. Cover and substrate codes are shown in Appendix A and are according to the revised Washington State Resource Agency Instream Flow Guidelines (WDFW/WDOE, 2004).

2.7.2 Peshastin Creek

Field data was collected at all Peshastin Creek transects at a high, middle, and low flow for model calibration purposes. Generally all field data was taken using the standard procedures described in Trihey and Wegner (1981) and Bovee (1982). Not all transects used the same benchmark. Head pin elevations, hydraulic slopes, stage of zero flow, water surface elevations (WSE) and above-water channel cross-sections were measured using a Topcon auto level and stadia rod, using standard survey techniques. The surveyor tied these features to the transect benchmark to the nearest 0.01 feet. Below water channel cross-sections were determined by subtracting measured depths from the WSE at the middle flow. Depths at high flow measurement locations that were not present at the middle flow measurement were subtracted from the high flow WSE.

Depth and velocity distributions at the three calibration flows was measured using a digital, Swoffer brand, propeller-type velocity meter mounted on a standard top-set wading rod. Velocity was measured at sixth tenths of the depth when depth was less than 2.5 feet and at two tenths and eight tenths of the depth where depths equaled or exceeded 2.5 feet, or when flow was influenced by an upstream obstruction. The rules for placement of verticals along the transect were closely followed. If there was uncertainty about whether a vertical was warranted, the vertical was usually placed at that point. In addition to stationing, notes were taken regarding the position of the top-set rod base plate relative to the substrate it was touching so that the meter could be placed in the exact position at succeeding calibration flows. These notes on substrate also revealed if bed shift had occurred since the previous calibration measurement; comparison of bed elevations during discharge measurements also indicated whether substantial sediment had been added or removed. Temporary staff gage levels and the time of day were recorded at the beginning and end of each transect measurement to note changes in stage.

Substrate was classified using a three-digit code representing the most abundant particle size, the second-most abundant particle size, and the percentage of the most abundant particle size. For example, a code of 73.7 would mean that the most abundant substrate was large cobble (6 to 12-inch diameter), that small gravel (0.5 to 1.5-inch diameter) was the second-most abundant substrate, and that large cobble represented 70 percent of the cell area.

2.8 Affected Species and Life Stages

Fisheries resources of primary concern in the Lower Wenatchee River and Peshastin Creek are commercial and game fish that include chinook salmon, steelhead trout, and bull trout. All of these species utilize the study area during some part of their life cycle. Figures 2.8-1 and 2.8-2 present the life-stage timing of salmonids in the Lower Wenatchee River and Peshastin Creek, respectively.

Anadromous fish use the Wenatchee River in a variety of ways. Adults of all species use the lower river as an upstream migration corridor to the spawning grounds in the upper Wenatchee. Salmonid fry and smolts use the river as a downstream migration corridor on their journey towards the sea. Migration of salmonids was not addressed in this study.

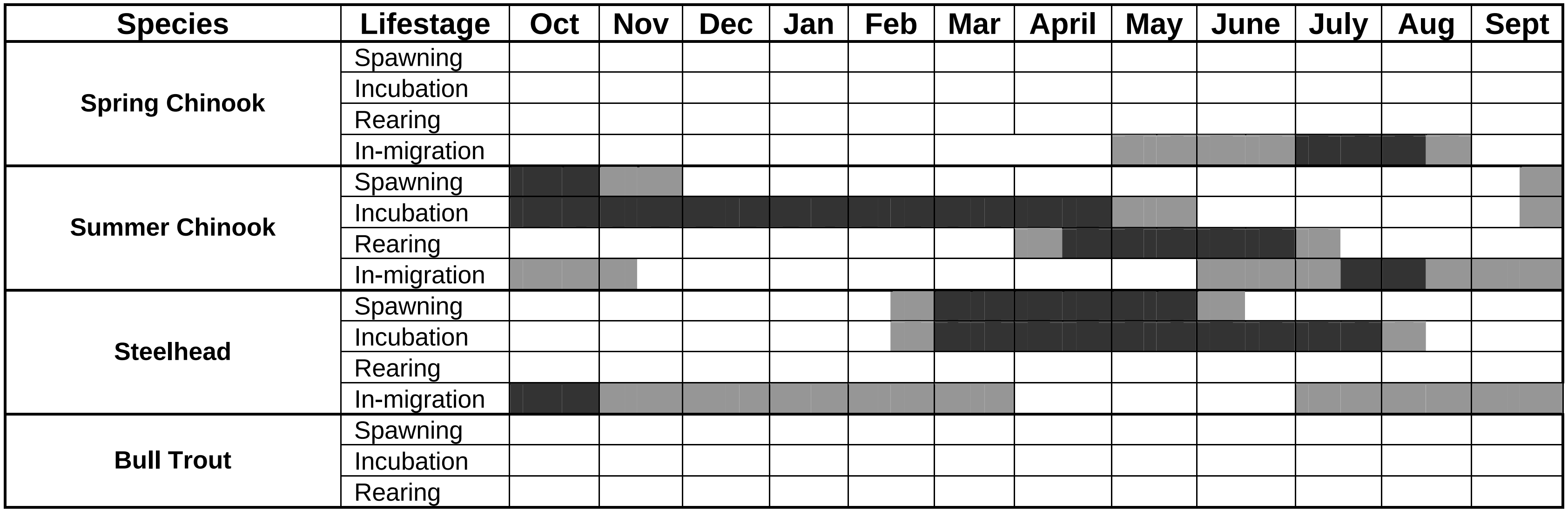
The Wenatchee River and Peshastin Creek provide spawning and rearing habitat important to the fresh water survival of the affected salmonids. Spawning steelhead trout and chinook salmon can often be found in reaches that offer good habitat. Analysis of spawning habitat in this study targeted steelhead trout and chinook salmon. Rearing salmonid species include steelhead trout, bull trout and chinook salmon. All of these species can be found year round in both the Lower Wenatchee River and Peshastin Creek.

2.9 Habitat Suitability Criteria

Salmonid species are not found randomly in streams and rivers, but rather have an affinity for particular ranges of depth, velocity, cover and substrate. Occurrence of fish due to these habitat parameters varies with species and life stage. In PHABSIM studies the range of each of these parameters are commonly referred to as fish preference criteria or a Habitat Suitability Criteria (HSC).

HSC for the Lower Wenatchee PHABSIM study for chinook salmon and steelhead were recommended by the Washington Department of Ecology and Washington Department of Fish and Wildlife (WDFW/WDOE, 2004). In the case of chinook and steelhead, Washington state data from many studies across the state have been combined to form a robust data set. In the absence of site-specific data for each PHABSIM study, this Washington "standard" criteria is recommended.

Figure 2.8-1
Lower Mainstem Wenatchee River
RM 0.0 to RM 25.6 (Tumwater Canyon)



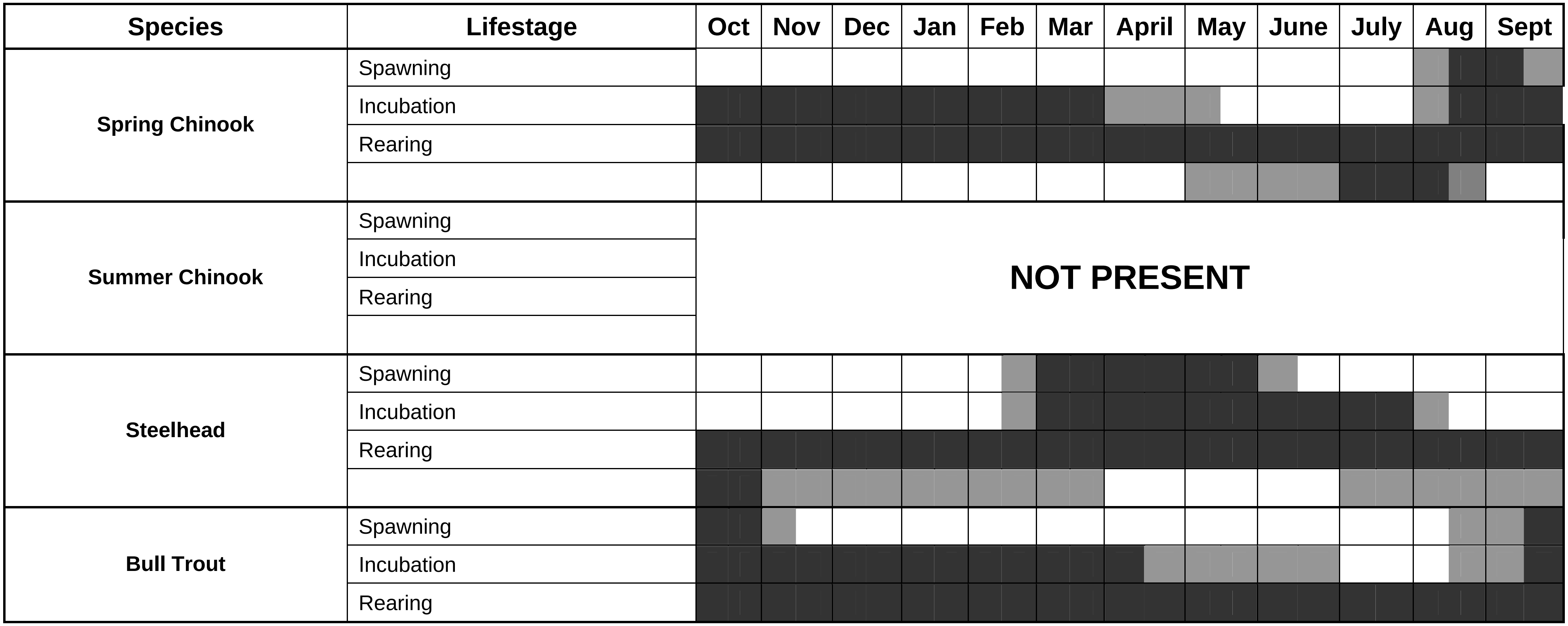
<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key:
Black indicates periods of heaviest use
Grey indicates periods of moderate use
Blank areas indicate periods of little or no use

Figure 2.8-2. Peshastin Creek Fish Periodicity



<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key:

Black indicates periods of heaviest use

Grey indicates periods of moderate use

Blank areas indicate periods of little or no use

Prior to the current study, the bull trout HSC base data contained relatively fewer observations. Confidence in the Washington "standard" criteria for bull trout was not as strong as for other species. As an adjunct study to the Lower Wenatchee PHABSIM study; EESC, WDFW, and WDOE embarked on a cooperative study to collect bull trout spawning and rearing data in the Chiwawa drainage, a tributary to the upper Wenatchee River basin. The data was collected from September through November 2004 and significantly increased the number of bull trout observations used for Washington criteria. Based on the analysis of the data gathered for this study, and additional spawning data gathered on the Mad River, Washington HSC were revised for both spawning and rearing bull trout. The revised Washington bull trout rearing criteria was used to generate the WUA information for the Lower Wenatchee PHABSIM study.

The HSC tables used for the Lower Wenatchee PHABSIM study are contained in Appendix A to this report.

2.10 Data Compilation Methods

The ADCP interfaces directly with a laptop computer when collecting data. Software provided by the manufacturer of the ADCP is used to record and display the data as it is being collected. This same program is used to output a text file containing all the detail of a transect including the depth, velocity, distance, and error checking values for each vertical and bin along the transect. Verticals are columns looking straight down from the water surface to the river bottom. Velocity data taken at incremental depths are called bins.

A conversion utility from RHABSIM (Riverine Habitat Simulation) reads the text file from the ADCP software and converts it into a format that was imported into a spreadsheet. This utility screens out errors and converts bins of velocities into mean column velocities (average velocity for the one vertical). Three summary columns are created; distance, depth, and velocity.

Since the ADCP and the boat were incapable of taking readings in very shallow depths, manual depth and velocity data were manually entered into the spreadsheet. The summary ADCP data were integrated between the left and right banks of the manual data. The substrate and cover codes were entered alongside the depth and velocity data. Using a true water surface elevation entered by the user, depths were converted into elevations. A total discharge for the transect is generated. At this point, the data for each transect was subjected to a final check for errors and corrected. The corrected data files were then converted into a format readable by RHABSIM. RHABSIM read the file, and the completed data deck was ready for hydraulic modeling.

2.11 Data Analysis

2.11.1 Hydraulic Modeling

Analysis and integration of physical stream measurements and habitat preference criteria require the use of a group of the PHABSIM computer programs. There are two main programs in the RHABSIM library: the hydraulic model (called IFG-4) and the habitat model (called HABTAT). The IFG-4 hydraulic simulation model predicts depth of flow and mean column velocities across the stream transect as a function of discharge. A log-log regression analysis is used to develop stage-discharge relationships at each transect and to predict velocity/discharge relationships at each habitat cell. Interpolation and extrapolation with the regression equations allows modeling of flows between and beyond the measured discharges. The resulting simulated hydraulic information is then input to the HABTAT program.

The HABTAT program integrates the simulated hydraulic information from IFG-4 with habitat suitability criteria (i.e., preference curves) and quantifies habitat availability over a range of flows for the specified target species and life stages. Habitat quantification is expressed as an index called Weighted Useable Area (WUA), and is given in units of habitat per 1,000 linear ft of stream.

Riverine Habitat Simulation (RHABSIM), a series of programs developed by Thomas R. Payne and Associates of Arcata, California, allows direct input of Acoustic Doppler Current Profiler (ADCP) data, and is an extensive conversion of the PHABSIM hydraulic and habitat simulation system developed by the USFWS. RHABSIM was used by EESC and Payne and Associates for the Lower Wenatchee River modeling.

2.11.2 Hydraulic Modeling Procedures

The Lower Wenatchee River PHABSIM data input files (decks) were compiled by Payne and Associates and calibrated using methods described in Payne (2003). All of the input decks were initially processed using the Problem Report subroutine of the Field Data Entry Module of RHABSIM. This program looks for errors in data placement and produces hard copy of the pertinent information needed to run the model, including transect weighting factors, slopes, stage of zero flow and Water Surface Elevation (WSE). EESC collected one set of velocity calibration measurements at each transect. In addition to the high flow calibration flow, WSE and discharges measured at two lower flows were used to generate the stage-discharge relationship.

In Washington State, a standard "three velocity set" regression model is normally used on all transects except where special circumstances required the use of alternate modeling methods. The three-velocity set models require that “verticals” (i.e., stations) be placed in exactly the same locations along the stream bed and that velocity measurements be taken at these stations at all the calibration flows.

It is not possible to do this when using the ADCP, since the placement of “verticals” is determined by boat speed, boat direction, and beginning point along the transect. As a result, “one velocity set” models were used. The “one velocity set” models use the velocities from one of the calibration flows for velocity modeling and employ the WSEs from the other calibration flows to develop the stage/discharge relationship.

After discussions on PHABSIM analysis with representatives from WDFW and WDOE, all parties agreed that a standard “three velocity set” methodology would be appropriate for Peshastin Creek and a “one velocity set” approach would be appropriate for Wenatchee River.

One of the goals of the hydraulic simulation is to have the model accurately reflect measured velocities and depths at calibration flows, while minimizing changes to the data. In this regard, only minor changes were made to the IFIM decks in order for the model to more accurately predict cell velocities at the simulated flow. When calibrating one velocity set data decks, normally, two types of corrections can be made directly or indirectly to velocity data: 1) changes in the measured velocity; and, 2) changes in the Manning's N (roughness coefficient) for given cells. Changes were kept to a minimum and the decks were revised only when specific changes improved model performance.

One type of data change was a minor velocity adjustment (0.01 - 0.10 ft/sec) in some cells where there was depth but no measured velocity. The model "sees" a measured zero velocity as a blank and will attempt to fill that cell with a velocity based on a mass balance equation for the transect, taking into consideration slope, adjacent velocities, and calculated Manning's N values. Replacing a measured 0.00 with a velocity of 0.01 or 0.1 often corrects this problem. In addition, edge cells are often assigned high Manning's N values (i.e., the roughness coefficient) by the model. The high N values slow the velocity through these cells, giving an unrealistic simulation of velocities. In these instances the N values were manually reduced.

The range of extrapolation for simulated depths and velocities depends on the hydraulics of the channel and the accuracy of the velocity simulation, slope and Manning's N values in the case of one velocity set calibrations. Flows of interest were within the limits of acceptable extrapolation.

The range of extrapolation for simulated depths and velocities depends on the hydraulics of the channel and the spread between calibration flows. Velocity Adjustment Factors (VAF) are a measure of how well a three-flow regression model simulates velocities. A VAF between 0.90 and 1.10 is considered good. A VAF between 0.85 and 0.90 or between 1.10 and 1.15 is considered to be fair. A VAF between .80 and .85 or 1.15 and 1.20 is marginal, while a VAF below 0.80 or above 1.20 is considered poor. In the case of one velocity set models, the VAFs are actually adjustment factors of discharge, not velocities, and a wider range of values (between 0.10 and 10.0) is acceptable. A summary of VAFs and calibration details are presented in Tables 2 and 4 of Appendix B.

2.11.3 Measured Flows for Lower Wenatchee River

A single set of calibration flow data was developed from the field measurements. Actual measured flows for the Lower Wenatchee River and Peshastin Creek are shown in Table 2.11-1.

Table 2.11-1 Calibration Flows (cfs), Lower Wenatchee River and Peshastin Creek

	Low Flow	Medium Flow	High Flow And Velocity Calibration
Wenatchee River	670	1,400	3,700-4,200
Peshastin Creek	23	71	215

2.11.4 Model Performance

Only minor changes were made to the original input decks. Most revisions fell into three categories:

- Replacing a measured velocity of 0.0 ft/second with a velocity of 0.1 ft/second
- Changing the Manning's N value to either reduce or increase the velocities in the given cell
- Adjusting the bed elevations the stream margin cells slightly

Appendix B presents the summary of calibration details for the transects. Mean error (for both given and predicted discharges), ratio of measured vs. predicted discharges, and B coefficients were all within the acceptable limits for PHABSIM calibration.

Output from the hydraulic models was then used to determine changes in the Lower Wenatchee River water depths, velocities, surface area, and fish habitat throughout a range of flows from 220 cfs to 10,000 cfs.

After the hydraulic models were calibrated, transect weighting and lengths to simulate a 1,000 foot reach were added as shown in Table 2.6-1 and 2.6-2 for the rearing and spawning life stages. Final hydraulic model runs were made to produce input for the HABTAT habitat model.

3.0 RESULTS

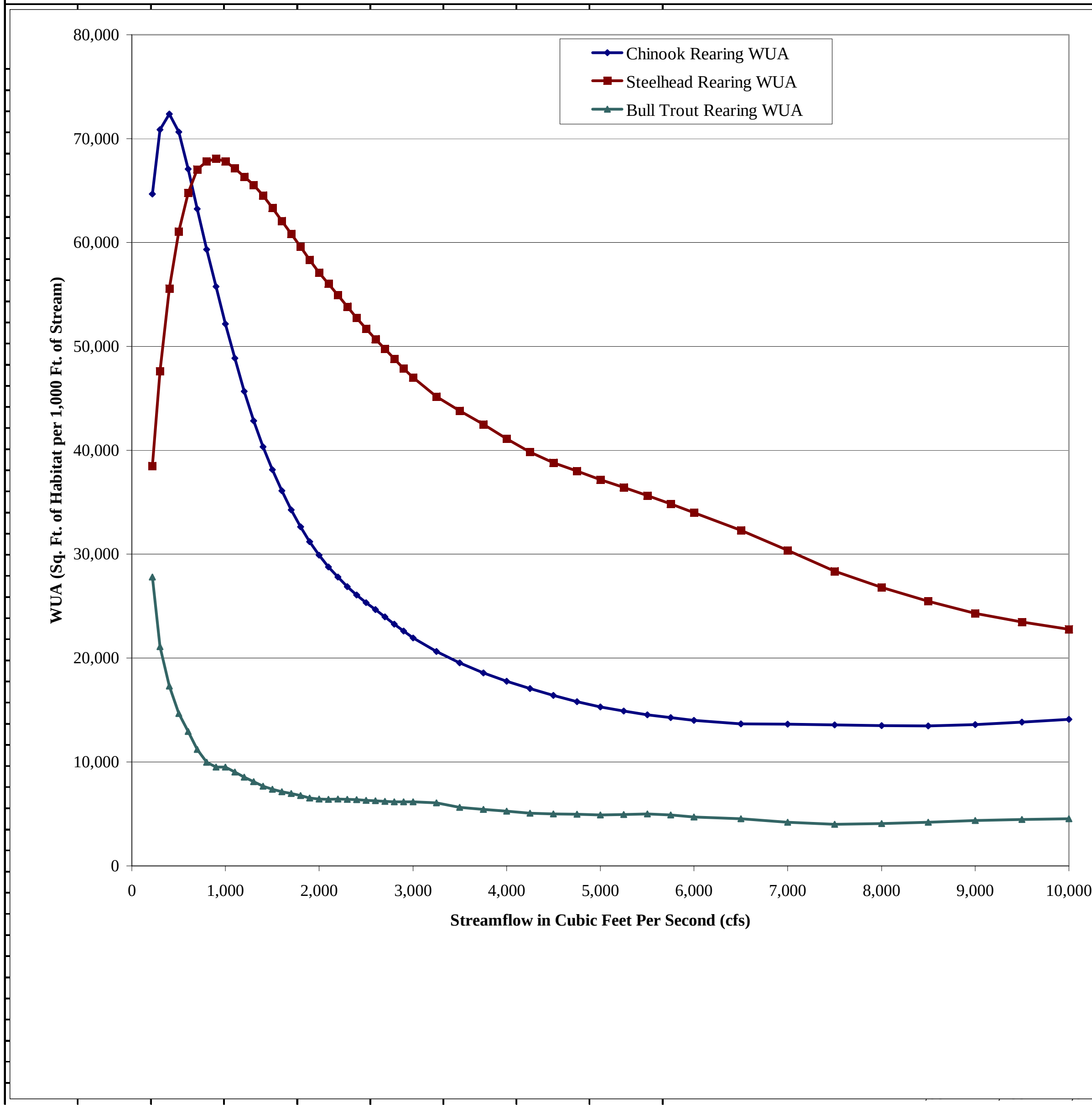
3.1 Weighted Usable Area Results

Within the HABTAT program, output from the hydraulic modeling is combined with habitat suitability criteria for depth, velocity, and substrate/cover for the target species life stages. The output from this model is expressed as Flow (Q) v, Weighted Usable Area (WUA), which is an index of available habitat per 1,000 lineal ft of stream for each species and life stage of concern.

Figures 3.1-1 to 3.1-8 show Wenatchee River Flow v WUA graphs for Reach 1 through 4 for rearing and spawning life stages. Tables 3.1-1 to 3.1-4 give tabular results of the Wenatchee River, Reach 1 to 4 WUA data.

Figures 3.1-9 and 3.1-10 show Peshastin Creek Flow v WUA graphs for rearing and spawning life stages. Peshastin Creek WUA results are also shown in Table 3.1-5.

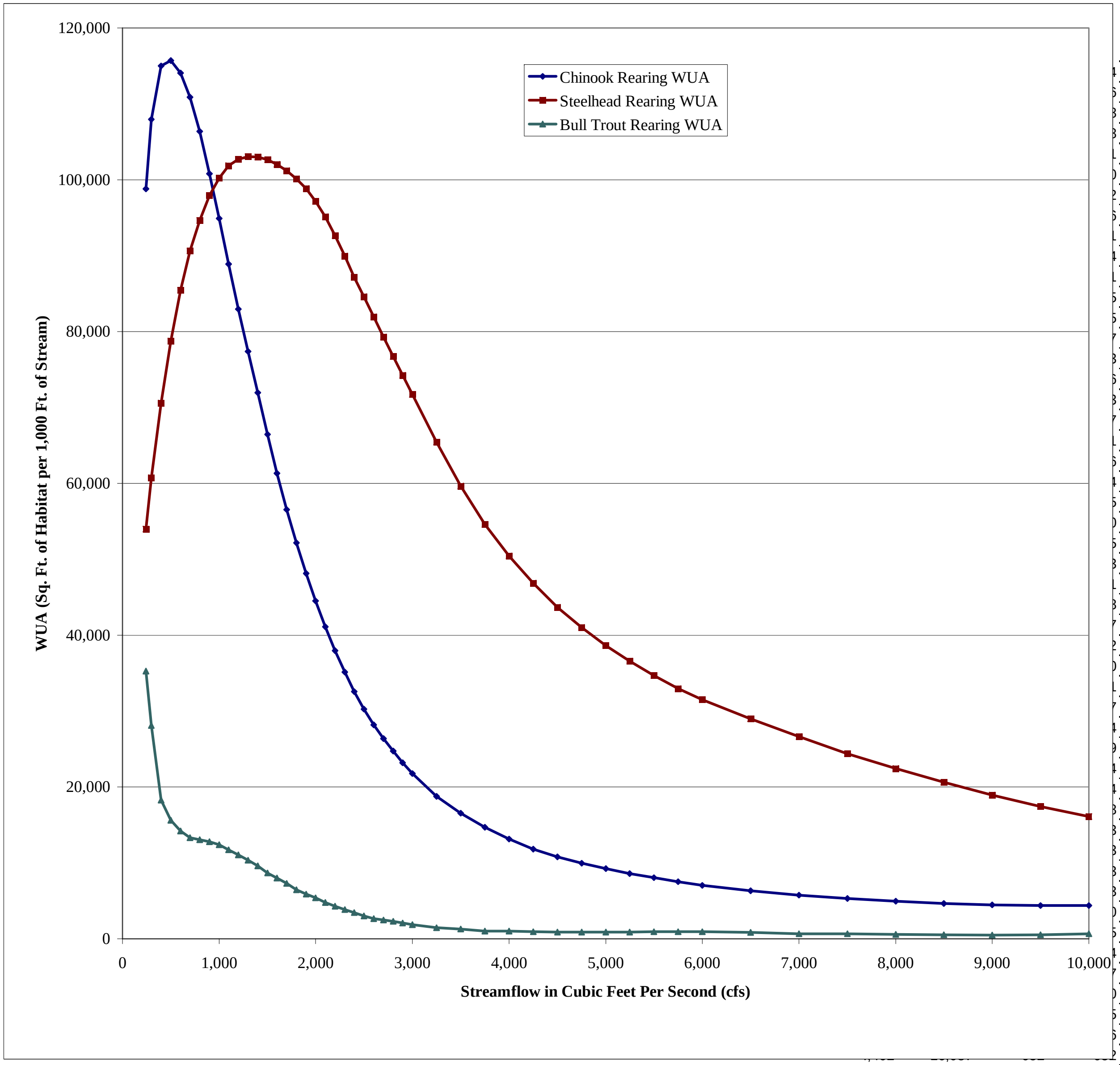
Figure 3.1-1 Wenatchee River Reach 1: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

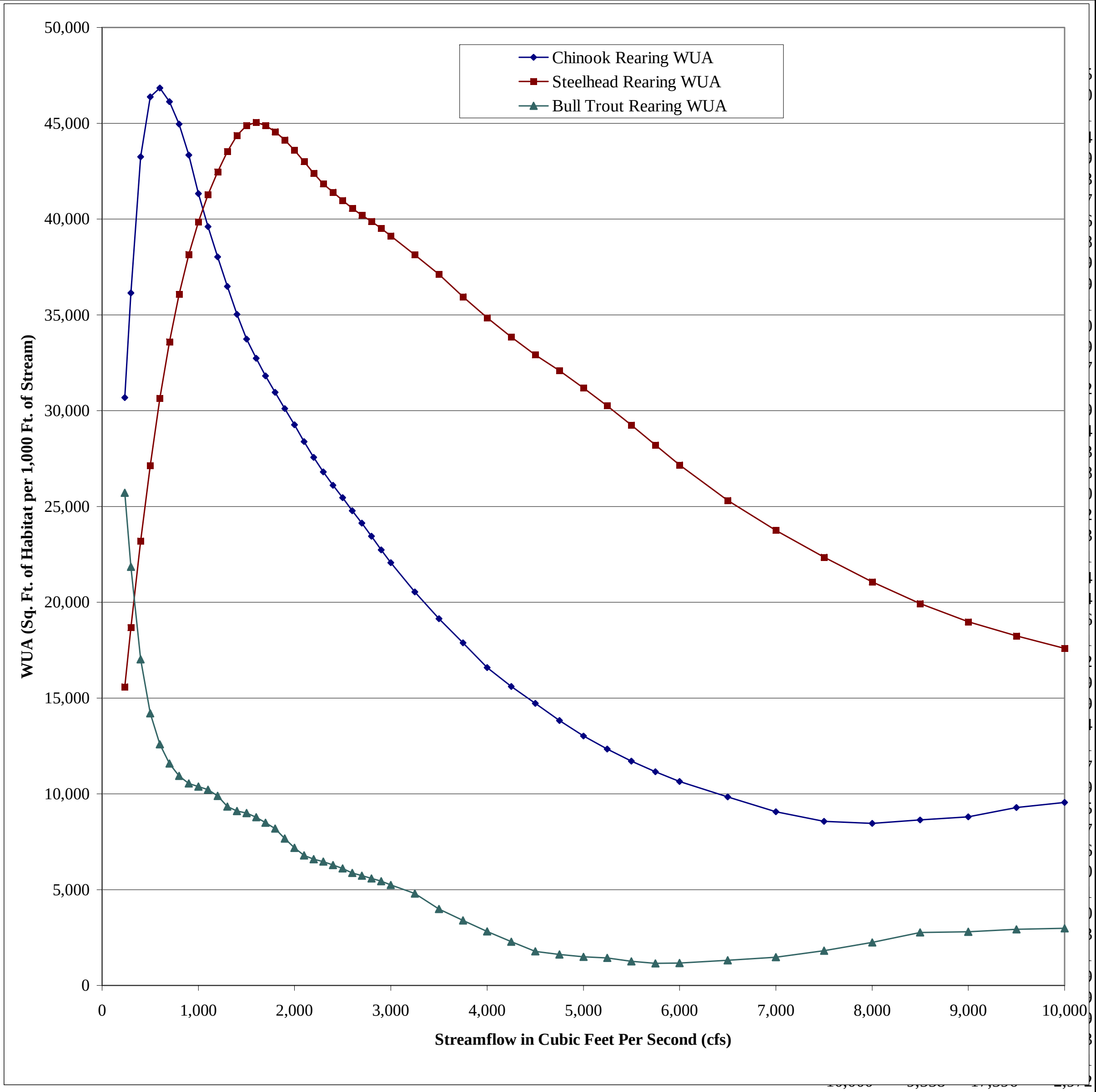
Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
220	89%	57%	**100%**
300	98%	70%	76%
400	**100%**	82%	62%
500	98%	90%	53%
600	93%	95%	47%
700	87%	99%	40%
800	82%	**100%**	36%
900	77%	**100%**	34%
1,000	72%	**100%**	34%
1,100	68%	99%	32%
1,200	63%	97%	31%
1,300	59%	96%	29%
1,400	56%	95%	28%
1,500	53%	93%	27%
1,600	50%	91%	26%
1,700	47%	89%	25%
1,800	45%	88%	24%
1,900	43%	86%	24%
2,000	41%	84%	23%
2,100	40%	82%	23%
2,200	38%	81%	23%
2,300	37%	79%	23%
2,400	36%	78%	23%
2,500	35%	76%	23%
2,600	34%	75%	23%
2,700	33%	73%	22%
2,800	32%	72%	22%
2,900	31%	70%	22%
3,000	30%	69%	22%
3,250	29%	66%	22%
3,500	27%	64%	20%
3,750	26%	62%	19%
4,000	25%	60%	19%
4,250	24%	59%	18%
4,500	23%	57%	18%
4,750	22%	56%	18%
5,000	21%	55%	18%
5,250	21%	54%	18%
5,500	20%	52%	18%
5,750	20%	51%	18%
6,000	19%	50%	17%
6,500	19%	47%	16%
7,000	19%	45%	15%
7,500	19%	42%	14%
8,000	19%	39%	15%
8,500	19%	37%	15%
9,000	19%	36%	16%
9,500	19%	34%	16%
10,000	19%	33%	16%

Figure 3.1-2 Wenatchee River Reach 2: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow			
Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
245	85%	52%	**100%**
300	93%	59%	80%
400	99%	68%	52%
500	**100%**	76%	44%
600	99%	83%	40%
700	96%	88%	38%
800	92%	92%	37%
900	87%	95%	36%
1,000	82%	97%	35%
1,100	77%	99%	33%
1,200	72%	**100%**	31%
1,300	67%	**100%**	29%
1,400	62%	**100%**	27%
1,500	57%	**100%**	25%
1,600	53%	99%	23%
1,700	49%	98%	21%
1,800	45%	97%	18%
1,900	42%	96%	17%
2,000	38%	94%	15%
2,100	36%	92%	14%
2,200	33%	90%	12%
2,300	30%	87%	11%
2,400	28%	85%	10%
2,500	26%	82%	8%
2,600	24%	80%	8%
2,700	23%	77%	7%
2,800	21%	74%	7%
2,900	20%	72%	6%
3,000	19%	70%	5%
3,250	16%	64%	4%
3,500	14%	58%	4%
3,750	13%	53%	3%
4,000	11%	49%	3%
4,250	10%	45%	3%
4,500	9%	42%	3%
4,750	9%	40%	2%
5,000	8%	38%	2%
5,250	7%	35%	3%
5,500	7%	34%	3%
5,750	7%	32%	3%
6,000	6%	31%	3%
6,500	5%	28%	2%
7,000	5%	26%	2%
7,500	5%	24%	2%
8,000	4%	22%	2%
8,500	4%	20%	2%
9,000	4%	18%	1%
9,500	4%	17%	2%
10,000	4%	16%	2%

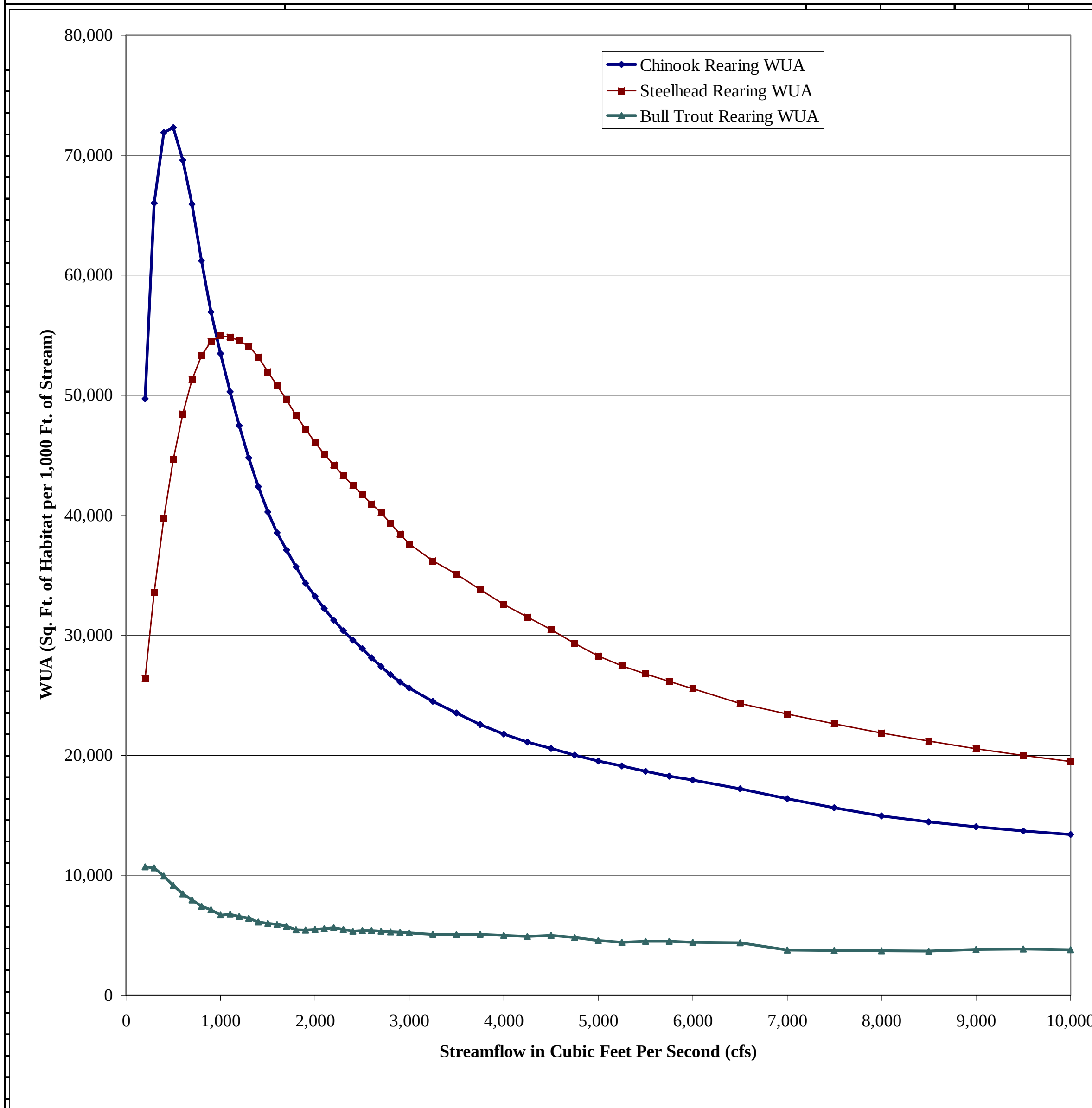
Figure 3.1-3 Wenatchee River Reach 3: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
235	65%	35%	**100%**
300	77%	41%	85%
400	92%	52%	66%
500	99%	60%	55%
600	**100%**	68%	49%
700	98%	75%	45%
800	96%	80%	43%
900	93%	85%	41%
1,000	88%	88%	40%
1,100	85%	92%	40%
1,200	81%	94%	38%
1,300	78%	97%	36%
1,400	75%	98%	35%
1,500	72%	**100%**	35%
1,600	70%	**100%**	34%
1,700	68%	**100%**	33%
1,800	66%	99%	32%
1,900	64%	98%	30%
2,000	62%	97%	28%
2,100	61%	95%	26%
2,200	59%	94%	26%
2,300	57%	93%	25%
2,400	56%	92%	24%
2,500	54%	91%	24%
2,600	53%	90%	23%
2,700	52%	89%	22%
2,800	50%	89%	22%
2,900	49%	88%	21%
3,000	47%	87%	20%
3,250	44%	85%	19%
3,500	41%	82%	16%
3,750	38%	80%	13%
4,000	35%	77%	11%
4,250	33%	75%	9%
4,500	31%	73%	7%
4,750	30%	71%	6%
5,000	28%	69%	6%
5,250	26%	67%	6%
5,500	25%	65%	5%
5,750	24%	63%	4%
6,000	23%	60%	5%
6,500	21%	56%	5%
7,000	19%	53%	6%
7,500	18%	50%	7%
8,000	18%	47%	9%
8,500	18%	44%	11%
9,000	19%	42%	11%
9,500	20%	40%	11%
10,000	20%	39%	12%

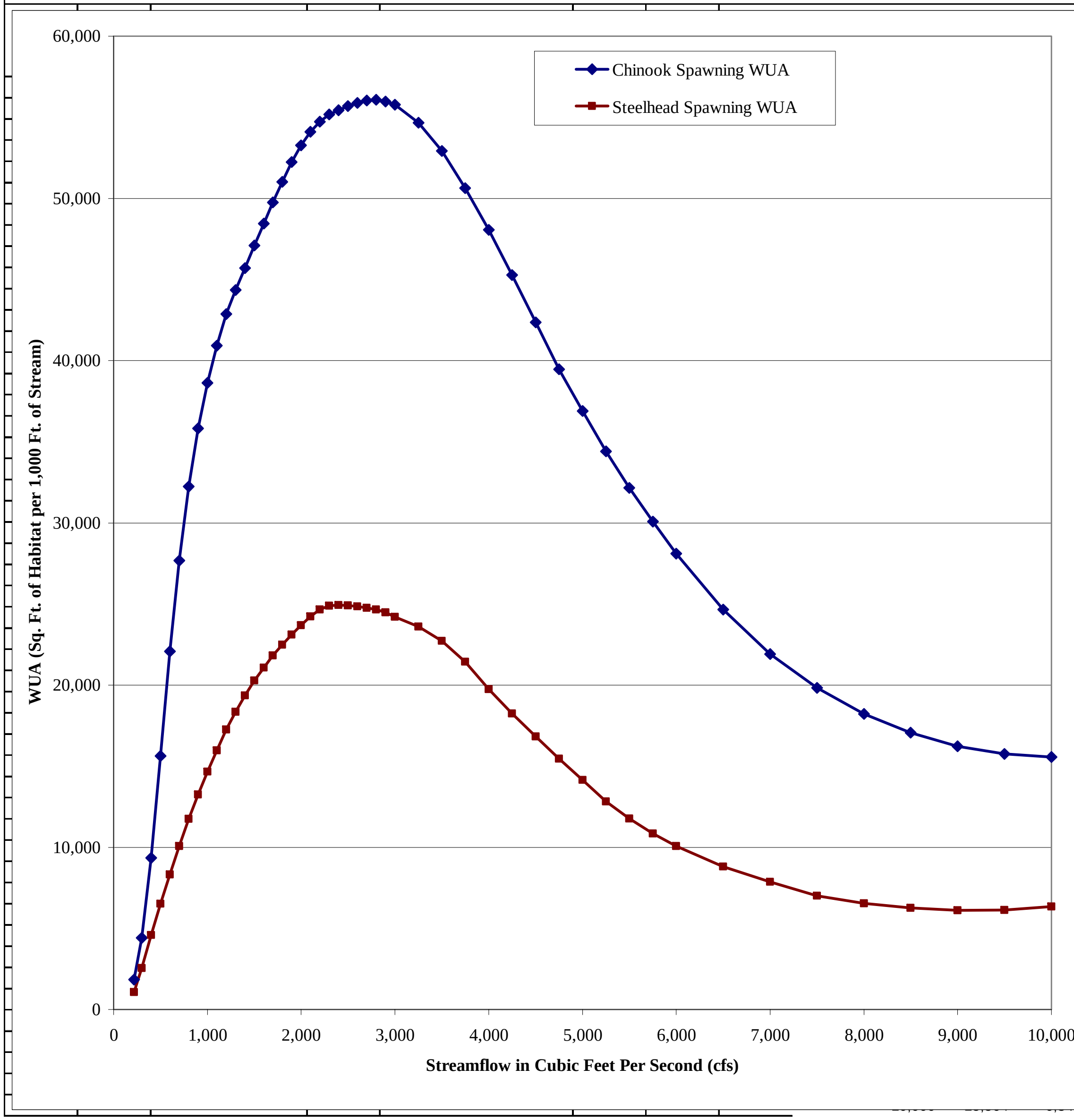
Figure 3.1-4 Wenatchee River Reach 4: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
200	69%	48%	**100%**
300	91%	61%	99%
400	99%	72%	93%
500	**100%**	81%	85%
600	96%	88%	79%
700	91%	93%	74%
800	85%	97%	69%
900	79%	99%	67%
1000	74%	**100%**	62%
1100	70%	**100%**	63%
1200	66%	99%	61%
1300	62%	98%	60%
1400	59%	97%	57%
1500	56%	95%	56%
1600	53%	92%	55%
1700	51%	90%	54%
1800	49%	88%	51%
1900	47%	86%	51%
2000	46%	84%	51%
2100	45%	82%	52%
2200	43%	80%	53%
2300	42%	79%	51%
2400	41%	77%	50%
2500	40%	76%	51%
2600	39%	75%	51%
2700	38%	73%	50%
2800	37%	72%	49%
2900	36%	70%	49%
3000	35%	68%	49%
3250	34%	66%	48%
3500	33%	64%	47%
3750	31%	62%	47%
4000	30%	59%	47%
4250	29%	57%	46%
4500	28%	55%	47%
4750	28%	53%	45%
5000	27%	51%	43%
5250	26%	50%	41%
5500	26%	49%	42%
5750	25%	48%	42%
6000	25%	46%	41%
6500	24%	44%	41%
7000	23%	43%	35%
7500	22%	41%	35%
8000	21%	40%	35%
8500	20%	39%	34%
9000	19%	37%	36%
9500	19%	36%	36%
10000	19%	35%	35%

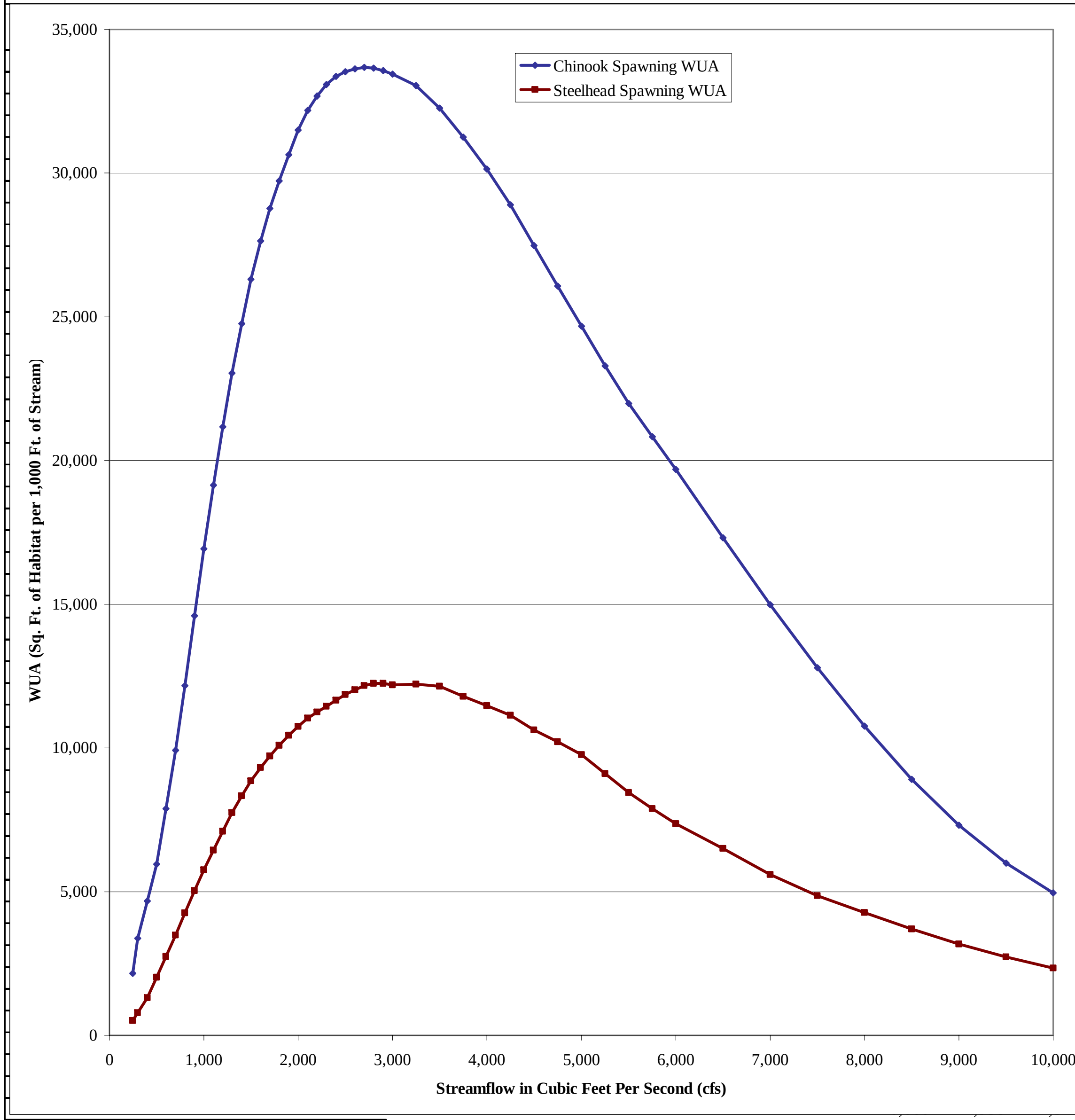
Figure 3.1-5 Wenatchee River Reach 1: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Spawning WUA	Steelhead Spawning WUA
220	3%	4%
300	8%	10%
400	17%	18%
500	28%	26%
600	39%	33%
700	49%	40%
800	57%	47%
900	64%	53%
1,000	69%	59%
1,100	73%	64%
1,200	76%	69%
1,300	79%	74%
1,400	82%	78%
1,500	84%	81%
1,600	86%	85%
1,700	89%	88%
1,800	91%	90%
1,900	93%	93%
2,000	95%	95%
2,100	96%	97%
2,200	98%	99%
2,300	98%	**100%**
2,400	99%	**100%**
2,500	99%	**100%**
2,600	**100%**	**100%**
2,700	**100%**	99%
2,800	**100%**	99%
2,900	**100%**	98%
3,000	99%	97%
3,250	97%	95%
3,500	94%	91%
3,750	90%	86%
4,000	86%	79%
4,250	81%	73%
4,500	76%	68%
4,750	70%	62%
5,000	66%	57%
5,250	61%	51%
5,500	57%	47%
5,750	54%	43%
6,000	50%	40%
6,500	44%	35%
7,000	39%	32%
7,500	35%	28%
8,000	33%	26%
8,500	30%	25%
9,000	29%	25%
9,500	28%	25%
10,000	28%	25%

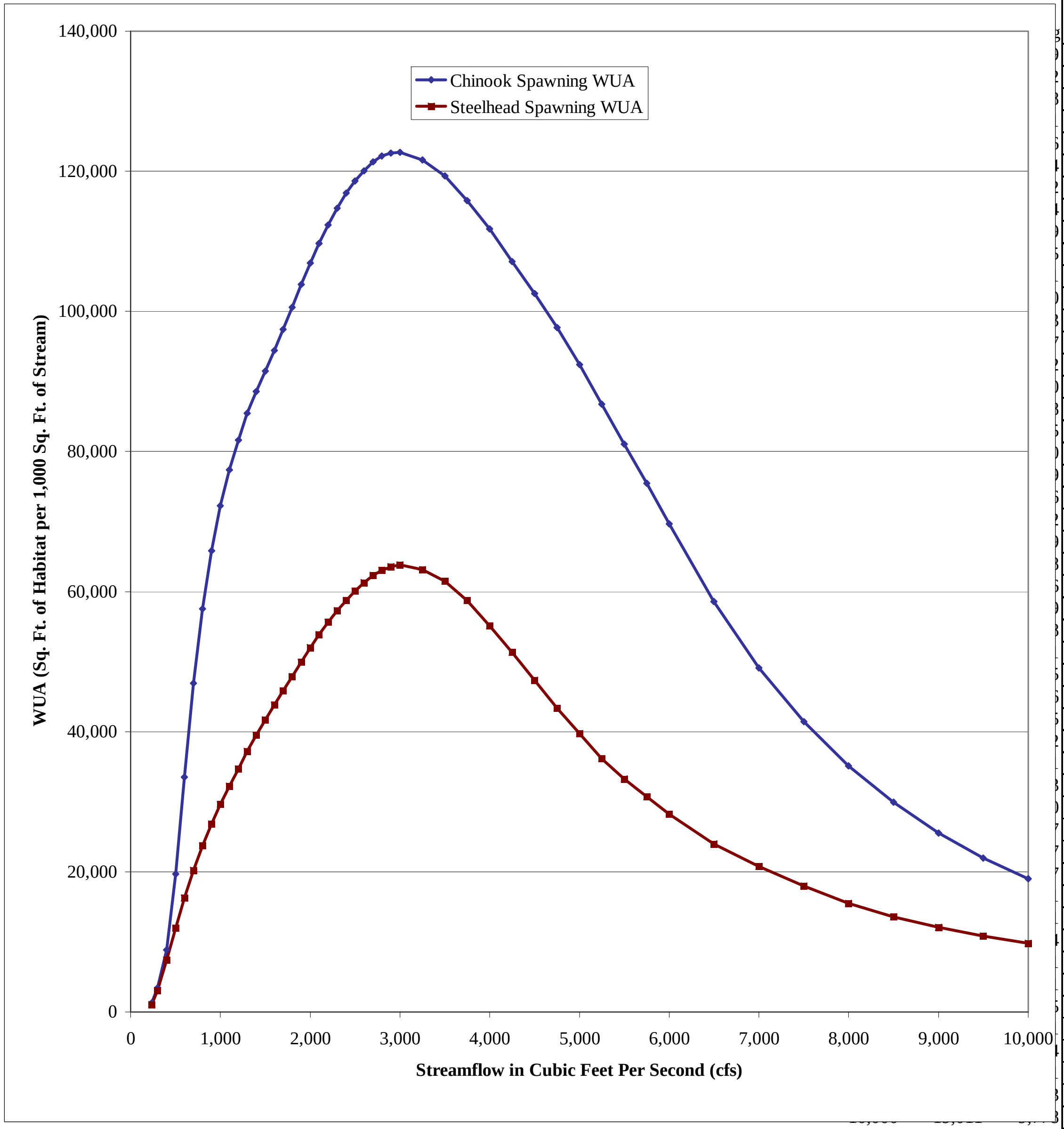
Figure 3.1-6 Wenatchee River Reach 2: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Spawning WUA	Steelhead Spawning WUA
245	6%	4%
300	10%	6%
400	14%	11%
500	18%	16%
600	23%	22%
700	29%	28%
800	36%	35%
900	43%	41%
1,000	50%	47%
1,100	57%	53%
1,200	63%	58%
1,300	68%	63%
1,400	74%	68%
1,500	78%	72%
1,600	82%	76%
1,700	85%	79%
1,800	88%	82%
1,900	91%	85%
2,000	94%	88%
2,100	96%	90%
2,200	97%	92%
2,300	98%	93%
2,400	99%	95%
2,500	**100%**	97%
2,600	**100%**	98%
2,700	**100%**	99%
2,800	**100%**	**100%**
2,900	**100%**	**100%**
3,000	99%	**100%**
3,250	98%	**100%**
3,500	96%	99%
3,750	93%	96%
4,000	89%	94%
4,250	86%	91%
4,500	82%	87%
4,750	77%	83%
5,000	73%	80%
5,250	69%	74%
5,500	65%	69%
5,750	62%	64%
6,000	58%	60%
6,500	51%	53%
7,000	45%	46%
7,500	38%	40%
8,000	32%	35%
8,500	26%	30%
9,000	22%	26%
9,500	18%	22%
10,000	15%	19%

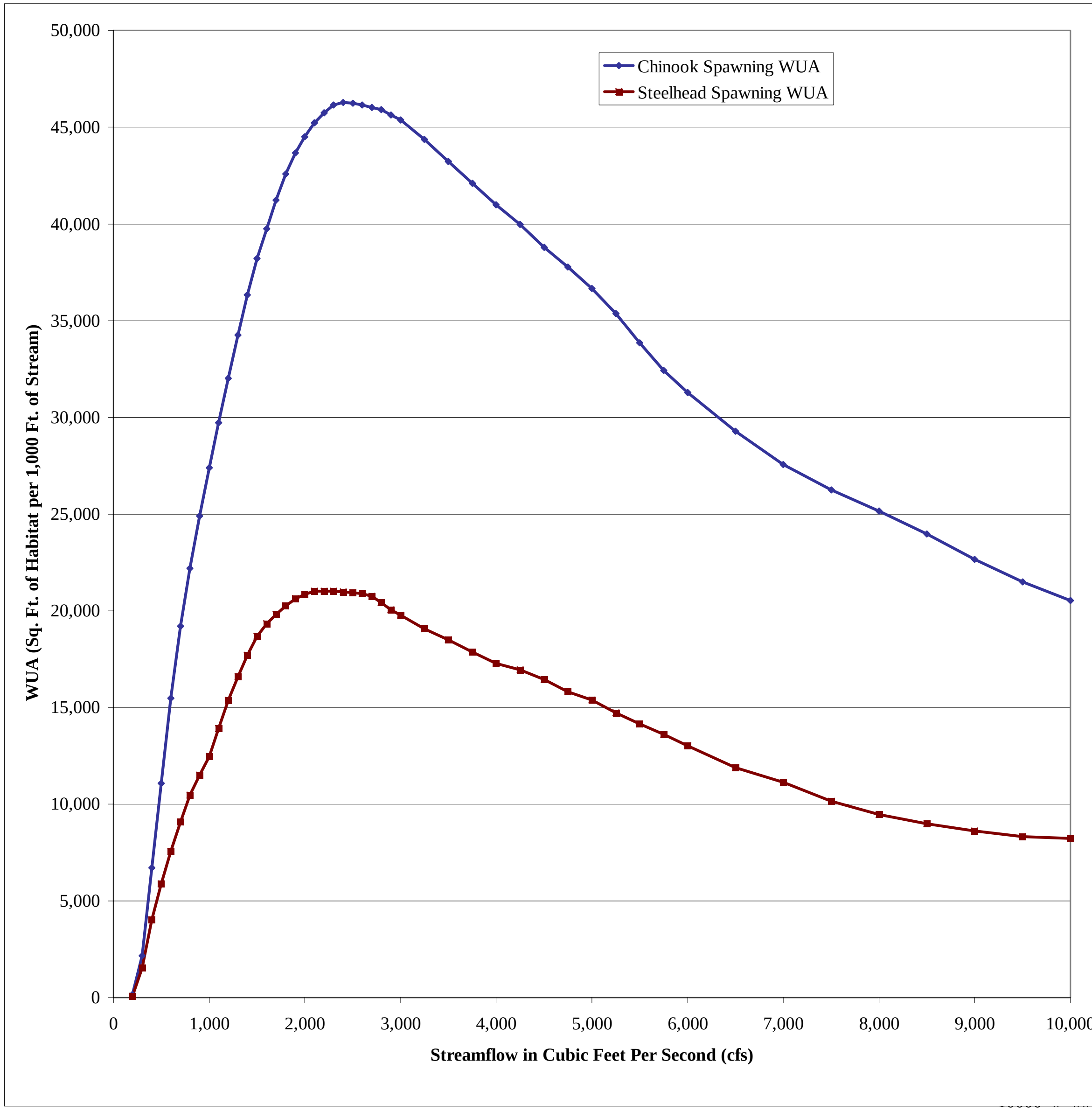
Figure 3.1-7 Wenatchee River Reach 3: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Spawning WUA	Steelhead Spawning WUA
235	1%	2%
300	3%	5%
400	7%	12%
500	16%	19%
600	27%	25%
700	38%	32%
800	47%	37%
900	54%	42%
1,000	59%	46%
1,100	63%	51%
1,200	67%	54%
1,300	70%	58%
1,400	72%	62%
1,500	75%	65%
1,600	77%	69%
1,700	79%	72%
1,800	82%	75%
1,900	85%	78%
2,000	87%	82%
2,100	89%	84%
2,200	92%	87%
2,300	93%	90%
2,400	95%	92%
2,500	97%	94%
2,600	98%	96%
2,700	99%	98%
2,800	100%	99%
2,900	100%	100%
3,000	100%	100%
3,250	99%	99%
3,500	97%	96%
3,750	94%	92%
4,000	91%	86%
4,250	87%	80%
4,500	84%	74%
4,750	80%	68%
5,000	75%	62%
5,250	71%	57%
5,500	66%	52%
5,750	62%	48%
6,000	57%	44%
6,500	48%	38%
7,000	40%	33%
7,500	34%	28%
8,000	29%	24%
8,500	24%	21%
9,000	21%	19%
9,500	18%	17%
10,000	15%	15%

Figure 3.1-8 Wenatchee River Reach 4: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Spawning WUA	Steelhead Spawning WUA
200	0%	0%
300	5%	7%
400	14%	19%
500	24%	28%
600	33%	36%
700	41%	43%
800	48%	50%
900	54%	55%
1,000	59%	59%
1,100	64%	66%
1,200	69%	73%
1,300	74%	79%
1,400	78%	84%
1,500	83%	89%
1,600	86%	92%
1,700	89%	94%
1,800	92%	96%
1,900	94%	98%
2,000	96%	99%
2,100	98%	**100%**
2,200	99%	**100%**
2,300	**100%**	**100%**
2,400	**100%**	**100%**
2,500	**100%**	**100%**
2,600	**100%**	99%
2,700	99%	99%
2,800	99%	97%
2,900	99%	95%
3,000	98%	94%
3,250	96%	91%
3,500	93%	88%
3,750	91%	85%
4,000	89%	82%
4,250	86%	81%
4,500	84%	78%
4,750	82%	75%
5,000	79%	73%
5,250	76%	70%
5,500	73%	67%
5,750	70%	65%
6,000	68%	62%
6,500	63%	57%
7,000	60%	53%
7,500	57%	48%
8,000	54%	45%
8,500	52%	43%
9,000	49%	41%
9,500	46%	40%
10,000	44%	39%

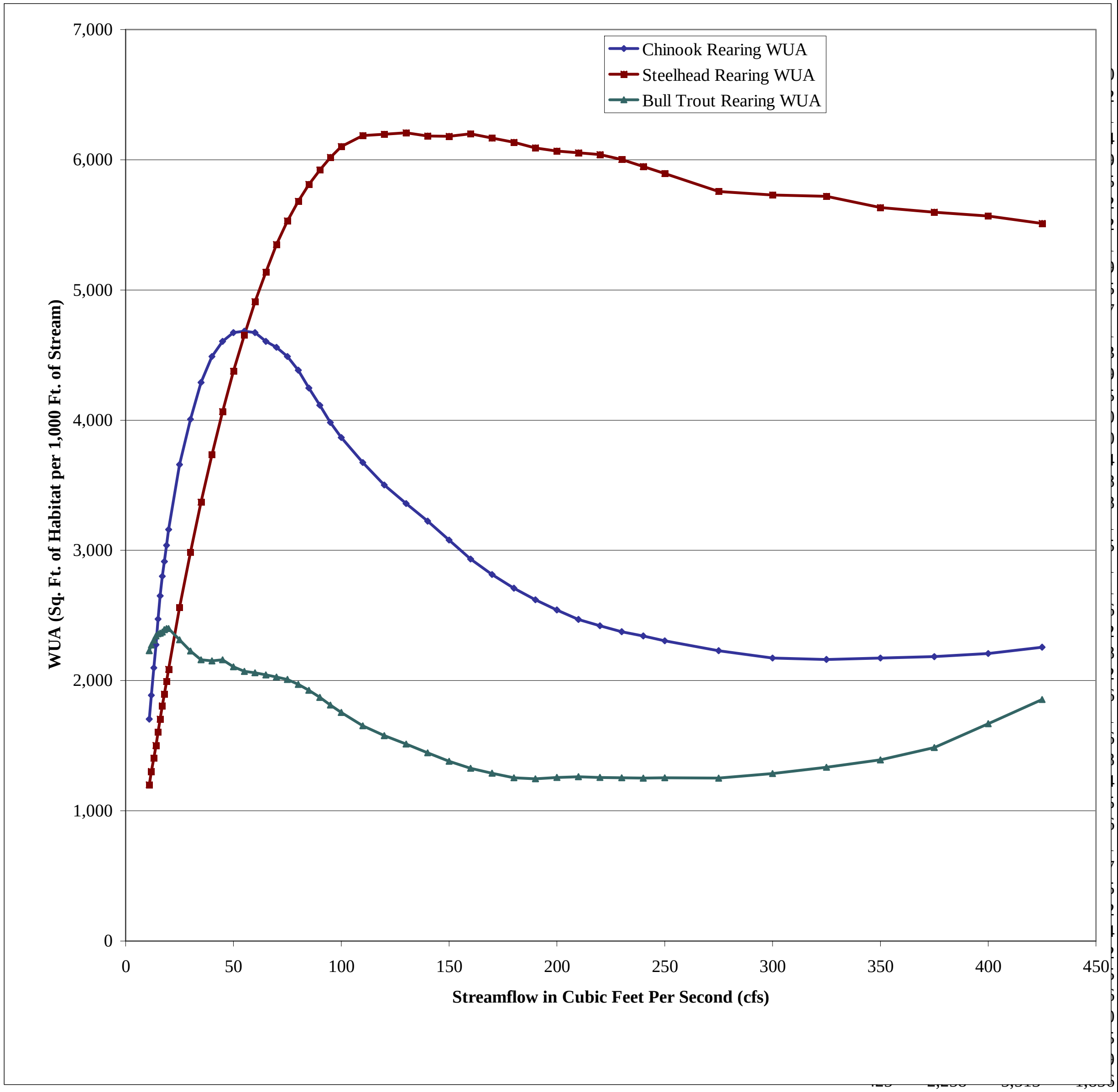
TABLE 3.1-1 WENATCHEE RIVER REACH 1 WEIGHTED USABLE AREA (WUA)										
	Chinook				**Steelhead**				**Bull Trout**	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
220	64,675	89.38%	1,839	3.28%	38,502	56.57%	1,081	4.34%	27,790	100.00%
300	70,868	97.94%	4,421	7.88%	47,599	69.94%	2,555	10.25%	21,102	75.94%
400	72,356	100.00%	9,337	16.65%	55,561	81.64%	4,578	18.36%	17,306	62.27%
500	70,620	97.60%	15,631	27.88%	61,052	89.71%	6,508	26.10%	14,673	52.80%
600	67,082	92.71%	22,084	39.38%	64,763	95.16%	8,327	33.39%	12,929	46.53%
700	63,246	87.41%	27,663	49.33%	67,044	98.51%	10,084	40.44%	11,186	40.25%
800	59,317	81.98%	32,242	57.50%	67,803	99.63%	11,751	47.13%	9,974	35.89%
900	55,770	77.08%	35,813	63.87%	68,056	100.00%	13,257	53.17%	9,494	34.16%
1,000	52,180	72.12%	38,630	68.89%	67,803	99.63%	14,654	58.77%	9,491	34.15%
1,100	48,872	67.54%	40,917	72.97%	67,134	98.65%	15,962	64.02%	9,025	32.48%
1,200	45,676	63.13%	42,871	76.45%	66,346	97.49%	17,266	69.24%	8,534	30.71%
1,300	42,847	59.22%	44,358	79.11%	65,520	96.27%	18,360	73.63%	8,089	29.11%
1,400	40,341	55.75%	45,712	81.52%	64,538	94.83%	19,357	77.63%	7,679	27.63%
1,500	38,117	52.68%	47,097	83.99%	63,334	93.06%	20,286	81.36%	7,365	26.50%
1,600	36,084	49.87%	48,451	86.40%	62,072	91.21%	21,079	84.54%	7,141	25.70%
1,700	34,262	47.35%	49,745	88.71%	60,826	89.38%	21,829	87.54%	6,965	25.07%
1,800	32,641	45.11%	51,008	90.96%	59,610	87.59%	22,488	90.19%	6,768	24.36%
1,900	31,200	43.12%	52,240	93.16%	58,335	85.72%	23,104	92.66%	6,543	23.54%
2,000	29,912	41.34%	53,272	95.00%	57,108	83.91%	23,691	95.01%	6,425	23.12%
2,100	28,772	39.77%	54,111	96.50%	56,045	82.35%	24,221	97.14%	6,400	23.03%
2,200	27,788	38.40%	54,736	97.61%	54,919	80.70%	24,656	98.88%	6,417	23.09%
2,300	26,874	37.14%	55,173	98.39%	53,830	79.10%	24,896	99.85%	6,399	23.03%
2,400	26,076	36.04%	55,439	98.87%	52,743	77.50%	24,935	100.00%	6,360	22.89%
2,500	25,348	35.03%	55,691	99.32%	51,715	75.99%	24,909	99.90%	6,315	22.72%
2,600	24,653	34.07%	55,888	99.67%	50,707	74.51%	24,847	99.65%	6,260	22.53%
2,700	23,978	33.14%	56,025	99.91%	49,773	73.14%	24,759	99.29%	6,212	22.35%
2,800	23,264	32.15%	56,075	100.00%	48,790	71.69%	24,645	98.84%	6,173	22.21%
2,900	22,583	31.21%	55,963	99.80%	47,857	70.32%	24,475	98.15%	6,171	22.21%
3,000	21,923	30.30%	55,780	99.47%	46,993	69.05%	24,204	97.07%	6,164	22.18%
3,250	20,633	28.52%	54,660	97.48%	45,166	66.37%	23,610	94.69%	6,053	21.78%
3,500	19,549	27.02%	52,935	94.40%	43,786	64.34%	22,723	91.13%	5,639	20.29%
3,750	18,562	25.65%	50,627	90.29%	42,497	62.44%	21,432	85.95%	5,418	19.50%
4,000	17,767	24.56%	48,070	85.73%	41,100	60.39%	19,749	79.20%	5,277	18.99%
4,250	17,064	23.58%	45,275	80.74%	39,848	58.55%	18,249	73.19%	5,051	18.17%
4,500	16,412	22.68%	42,354	75.53%	38,814	57.03%	16,837	67.53%	5,001	17.99%
4,750	15,814	21.86%	39,470	70.39%	37,990	55.82%	15,460	62.00%	4,966	17.87%
5,000	15,304	21.15%	36,888	65.78%	37,183	54.64%	14,141	56.71%	4,883	17.57%
5,250	14,908	20.60%	34,410	61.37%	36,449	53.56%	12,827	51.44%	4,937	17.77%
5,500	14,549	20.11%	32,152	57.34%	35,641	52.37%	11,765	47.18%	4,990	17.96%
5,750	14,257	19.70%	30,076	53.64%	34,820	51.16%	10,838	43.47%	4,900	17.63%
6,000	13,992	19.34%	28,093	50.10%	33,998	49.96%	10,067	40.37%	4,705	16.93%
6,250	13,773	19.03%	26,304	46.91%	33,186	48.76%	9,399	37.69%	4,551	16.38%
6,500	13,663	18.88%	24,649	43.96%	32,296	47.46%	8,821	35.38%	4,532	16.31%
6,750	13,657	18.87%	23,198	41.37%	31,354	46.07%	8,325	33.39%	4,397	15.82%
7,000	13,647	18.86%	21,904	39.06%	30,355	44.60%	7,858	31.51%	4,200	15.11%
7,250	13,583	18.77%	20,786	37.07%	29,325	43.09%	7,400	29.68%	4,037	14.53%
7,500	13,577	18.76%	19,827	35.36%	28,378	41.70%	7,006	28.10%	4,003	14.40%
7,750	13,549	18.73%	18,968	33.83%	27,552	40.48%	6,722	26.96%	4,095	14.74%
8,000	13,498	18.66%	18,229	32.51%	26,794	39.37%	6,539	26.23%	4,061	14.61%
8,250	13,461	18.60%	17,598	31.38%	26,096	38.35%	6,389	25.62%	4,148	14.93%
8,500	13,474	18.62%	17,066	30.43%	25,459	37.41%	6,265	25.13%	4,215	15.17%
8,750	13,516	18.68%	16,613	29.63%	24,857	36.52%	6,177	24.77%	4,311	15.51%
9,000	13,598	18.79%	16,223	28.93%	24,301	35.71%	6,112	24.51%	4,353	15.67%
9,250	13,696	18.93%	15,934	28.42%	23,843	35.03%	6,096	24.45%	4,440	15.98%
9,500	13,822	19.10%	15,764	28.11%	23,453	34.46%	6,123	24.56%	4,455	16.03%
9,750	13,947	19.28%	15,649	27.91%	23,107	33.95%	6,213	24.92%	4,510	16.23%
10,000	14,084	19.46%	15,564	27.76%	22,753	33.43%	6,341	25.43%	4,520	16.27%

TABLE 3.1-2 WENATCHEE RIVER REACH 2 WEIGHTED USABLE AREA (WUA)										
	Chinook				Steelhead				Bull Trout	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
245	98,823	85.40%	2,159	6.41%	53,988	52.39%	516	4.22%	35,244	100.00%
300	107,948	93.28%	3,377	10.03%	60,744	58.94%	789	6.45%	28,086	79.69%
400	114,996	99.37%	4,666	13.86%	70,582	68.49%	1,303	10.64%	18,268	51.83%
500	115,720	100.00%	5,956	17.69%	78,770	76.43%	2,015	16.46%	15,638	44.37%
600	114,085	98.59%	7,889	23.43%	85,443	82.91%	2,741	22.38%	14,211	40.32%
700	110,904	95.84%	9,913	29.44%	90,603	87.91%	3,482	28.44%	13,330	37.82%
800	106,360	91.91%	12,166	36.13%	94,660	91.85%	4,261	34.80%	13,032	36.98%
900	100,790	87.10%	14,594	43.34%	97,902	95.00%	5,030	41.08%	12,796	36.31%
1,000	94,930	82.03%	16,929	50.27%	100,205	97.23%	5,759	47.03%	12,411	35.22%
1,100	88,912	76.83%	19,146	56.86%	101,845	98.82%	6,442	52.61%	11,734	33.29%
1,200	82,950	71.68%	21,174	62.88%	102,719	99.67%	7,099	57.98%	11,061	31.38%
1,300	77,371	66.86%	23,047	68.44%	103,059	100.00%	7,742	63.23%	10,355	29.38%
1,400	71,927	62.16%	24,767	73.55%	102,993	99.94%	8,334	68.06%	9,595	27.22%
1,500	66,468	57.44%	26,305	78.12%	102,651	99.60%	8,853	72.30%	8,657	24.56%
1,600	61,328	53.00%	27,636	82.07%	102,031	99.00%	9,311	76.04%	8,003	22.71%
1,700	56,547	48.87%	28,771	85.44%	101,190	98.19%	9,712	79.32%	7,286	20.67%
1,800	52,160	45.07%	29,733	88.30%	100,132	97.16%	10,093	82.43%	6,473	18.37%
1,900	48,141	41.60%	30,644	91.00%	98,839	95.91%	10,440	85.27%	5,887	16.70%
2,000	44,516	38.47%	31,499	93.54%	97,154	94.27%	10,753	87.82%	5,391	15.29%
2,100	41,108	35.52%	32,182	95.57%	95,123	92.30%	11,035	90.12%	4,786	13.58%
2,200	37,961	32.80%	32,678	97.04%	92,670	89.92%	11,247	91.86%	4,294	12.18%
2,300	35,146	30.37%	33,087	98.26%	89,977	87.31%	11,445	93.47%	3,845	10.91%
2,400	32,572	28.15%	33,364	99.08%	87,186	84.60%	11,654	95.18%	3,430	9.73%
2,500	30,255	26.14%	33,536	99.59%	84,586	82.08%	11,852	96.80%	2,995	8.50%
2,600	28,208	24.38%	33,635	99.89%	81,943	79.51%	12,014	98.12%	2,673	7.59%
2,700	26,373	22.79%	33,674	100.00%	79,303	76.95%	12,174	99.43%	2,471	7.01%
2,800	24,732	21.37%	33,653	99.94%	76,720	74.44%	12,241	99.97%	2,298	6.52%
2,900	23,196	20.05%	33,565	99.68%	74,239	72.04%	12,244	100.00%	2,087	5.92%
3,000	21,777	18.82%	33,446	99.32%	71,722	69.59%	12,198	99.62%	1,872	5.31%
3,250	18,775	16.22%	33,044	98.13%	65,450	63.51%	12,214	99.75%	1,460	4.14%
3,500	16,537	14.29%	32,266	95.82%	59,652	57.88%	12,143	99.17%	1,301	3.69%
3,750	14,685	12.69%	31,253	92.81%	54,586	52.97%	11,795	96.33%	1,027	2.91%
4,000	13,134	11.35%	30,137	89.50%	50,441	48.94%	11,472	93.69%	1,014	2.88%
4,250	11,819	10.21%	28,894	85.80%	46,878	45.49%	11,136	90.95%	939	2.66%
4,500	10,777	9.31%	27,474	81.59%	43,694	42.40%	10,627	86.79%	894	2.54%
4,750	9,939	8.59%	26,070	77.42%	41,000	39.78%	10,216	83.44%	864	2.45%
5,000	9,238	7.98%	24,679	73.29%	38,650	37.50%	9,765	79.75%	878	2.49%
5,250	8,563	7.40%	23,288	69.16%	36,577	35.49%	9,101	74.33%	903	2.56%
5,500	8,058	6.96%	21,983	65.28%	34,690	33.66%	8,450	69.02%	943	2.68%
5,750	7,540	6.52%	20,821	61.83%	32,948	31.97%	7,888	64.42%	943	2.68%
6,000	7,047	6.09%	19,696	58.49%	31,490	30.56%	7,360	60.11%	933	2.65%
6,250	6,669	5.76%	18,500	54.94%	30,226	29.33%	6,914	56.46%	916	2.60%
6,500	6,329	5.47%	17,311	51.41%	28,978	28.12%	6,500	53.09%	820	2.33%
6,750	6,024	5.21%	16,141	47.93%	27,789	26.96%	6,033	49.27%	730	2.07%
7,000	5,754	4.97%	14,987	44.51%	26,621	25.83%	5,589	45.64%	685	1.94%
7,250	5,498	4.75%	13,869	41.19%	25,462	24.71%	5,202	42.49%	673	1.91%
7,500	5,298	4.58%	12,791	37.99%	24,360	23.64%	4,862	39.71%	664	1.88%
7,750	5,117	4.42%	11,752	34.90%	23,381	22.69%	4,556	37.21%	614	1.74%
8,000	4,941	4.27%	10,756	31.94%	22,449	21.78%	4,271	34.88%	587	1.66%
8,250	4,793	4.14%	9,798	29.10%	21,503	20.87%	3,993	32.61%	564	1.60%
8,500	4,655	4.02%	8,905	26.44%	20,606	19.99%	3,705	30.26%	540	1.53%
8,750	4,550	3.93%	8,079	23.99%	19,758	19.17%	3,428	28.00%	519	1.47%
9,000	4,474	3.87%	7,314	21.72%	18,935	18.37%	3,171	25.89%	475	1.35%
9,250	4,445	3.84%	6,599	19.60%	18,152	17.61%	2,936	23.98%	503	1.43%
9,500	4,393	3.80%	5,994	17.80%	17,426	16.91%	2,726	22.26%	536	1.52%
9,750	4,399	3.80%	5,462	16.22%	16,750	16.25%	2,532	20.68%	592	1.68%
10,000	4,402	3.80%	4,958	14.72%	16,087	15.61%	2,347	19.17%	652	1.85%

TABLE 3.1-3 WENATCHEE RIVER REACH 3 WEIGHTED USABLE AREA (WUA)										
	Chinook				Steelhead				Bull Trout	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
235	30,676	65.48%	1,280	1.04%	15,592	34.61%	1,059	1.66%	25,705	100.00%
300	36,141	77.15%	3,406	2.78%	18,669	41.44%	3,052	4.79%	21,850	85.01%
400	43,241	92.30%	8,882	7.24%	23,200	51.50%	7,408	11.61%	17,021	66.22%
500	46,377	99.00%	19,663	16.03%	27,132	60.23%	11,981	18.78%	14,194	55.22%
600	46,847	100.00%	33,531	27.33%	30,650	68.04%	16,256	25.49%	12,589	48.97%
700	46,120	98.45%	46,921	38.25%	33,596	74.58%	20,184	31.64%	11,583	45.06%
800	44,947	95.94%	57,518	46.88%	36,068	80.07%	23,702	37.16%	10,937	42.55%
900	43,340	92.51%	65,835	53.66%	38,151	84.69%	26,804	42.02%	10,536	40.99%
1,000	41,324	88.21%	72,253	58.89%	39,848	88.46%	29,619	46.43%	10,378	40.37%
1,100	39,610	84.55%	77,366	63.06%	41,275	91.63%	32,225	50.52%	10,219	39.76%
1,200	38,016	81.15%	81,630	66.54%	42,461	94.26%	34,711	54.42%	9,889	38.47%
1,300	36,483	77.88%	85,448	69.65%	43,518	96.61%	37,180	58.29%	9,341	36.34%
1,400	35,028	74.77%	88,559	72.19%	44,367	98.49%	39,533	61.98%	9,110	35.44%
1,500	33,726	71.99%	91,492	74.58%	44,889	99.65%	41,677	65.34%	8,999	35.01%
1,600	32,738	69.88%	94,420	76.96%	45,047	100.00%	43,802	68.67%	8,777	34.15%
1,700	31,812	67.91%	97,413	79.40%	44,891	99.65%	45,840	71.87%	8,492	33.04%
1,800	30,945	66.05%	100,568	81.97%	44,554	98.91%	47,868	75.04%	8,179	31.82%
1,900	30,117	64.29%	103,862	84.66%	44,125	97.95%	49,915	78.25%	7,664	29.81%
2,000	29,271	62.48%	106,899	87.13%	43,591	96.77%	52,010	81.54%	7,173	27.91%
2,100	28,392	60.60%	109,724	89.44%	43,003	95.46%	53,879	84.47%	6,778	26.37%
2,200	27,560	58.83%	112,321	91.55%	42,383	94.09%	55,636	87.22%	6,580	25.60%
2,300	26,801	57.21%	114,705	93.50%	41,836	92.87%	57,302	89.84%	6,462	25.14%
2,400	26,104	55.72%	116,879	95.27%	41,397	91.90%	58,729	92.07%	6,283	24.44%
2,500	25,464	54.35%	118,592	96.67%	40,969	90.95%	60,078	94.19%	6,101	23.74%
2,600	24,783	52.90%	120,050	97.85%	40,562	90.04%	61,276	96.07%	5,874	22.85%
2,700	24,131	51.51%	121,359	98.92%	40,203	89.25%	62,309	97.69%	5,724	22.27%
2,800	23,447	50.05%	122,186	99.60%	39,878	88.53%	63,018	98.80%	5,576	21.69%
2,900	22,728	48.52%	122,599	99.93%	39,508	87.70%	63,551	99.63%	5,441	21.17%
3,000	22,070	47.11%	122,683	100.00%	39,119	86.84%	63,785	100.00%	5,242	20.39%
3,250	20,540	43.84%	121,633	99.14%	38,134	84.65%	63,126	98.97%	4,789	18.63%
3,500	19,129	40.83%	119,333	97.27%	37,103	82.37%	61,475	96.38%	3,989	15.52%
3,750	17,879	38.16%	115,812	94.40%	35,950	79.81%	58,742	92.09%	3,384	13.17%
4,000	16,595	35.42%	111,748	91.09%	34,843	77.35%	55,111	86.40%	2,821	10.97%
4,250	15,597	33.29%	107,096	87.29%	33,850	75.14%	51,323	80.46%	2,287	8.90%
4,500	14,727	31.44%	102,535	83.58%	32,914	73.07%	47,340	74.22%	1,769	6.88%
4,750	13,820	29.50%	97,661	79.60%	32,090	71.24%	43,337	67.94%	1,615	6.28%
5,000	13,013	27.78%	92,413	75.33%	31,190	69.24%	39,747	62.31%	1,487	5.78%
5,250	12,336	26.33%	86,758	70.72%	30,245	67.14%	36,157	56.69%	1,436	5.59%
5,500	11,709	24.99%	81,048	66.06%	29,240	64.91%	33,231	52.10%	1,260	4.90%
5,750	11,146	23.79%	75,468	61.51%	28,200	62.60%	30,711	48.15%	1,141	4.44%
6,000	10,648	22.73%	69,666	56.78%	27,159	60.29%	28,234	44.26%	1,170	4.55%
6,250	10,240	21.86%	63,934	52.11%	26,185	58.13%	25,960	40.70%	1,247	4.85%
6,500	9,845	21.01%	58,601	47.77%	25,306	56.18%	23,981	37.60%	1,313	5.11%
6,750	9,445	20.16%	53,665	43.74%	24,500	54.39%	22,281	34.93%	1,356	5.28%
7,000	9,071	19.36%	49,093	40.02%	23,755	52.73%	20,761	32.55%	1,481	5.76%
7,250	8,784	18.75%	45,012	36.69%	23,037	51.14%	19,320	30.29%	1,611	6.27%
7,500	8,569	18.29%	41,430	33.77%	22,356	49.63%	17,975	28.18%	1,819	7.07%
7,750	8,470	18.08%	38,129	31.08%	21,715	48.21%	16,676	26.14%	2,070	8.05%
8,000	8,463	18.07%	35,129	28.63%	21,067	46.77%	15,491	24.29%	2,239	8.71%
8,250	8,515	18.18%	32,418	26.42%	20,461	45.42%	14,440	22.64%	2,548	9.91%
8,500	8,635	18.43%	29,932	24.40%	19,931	44.24%	13,564	21.26%	2,769	10.77%
8,750	8,679	18.53%	27,677	22.56%	19,426	43.12%	12,766	20.01%	2,792	10.86%
9,000	8,801	18.79%	25,559	20.83%	18,973	42.12%	12,051	18.89%	2,803	10.90%
9,250	8,997	19.20%	23,648	19.28%	18,578	41.24%	11,402	17.88%	2,900	11.28%
9,500	9,289	19.83%	21,937	17.88%	18,234	40.48%	10,823	16.97%	2,931	11.40%
9,750	9,451	20.17%	20,412	16.64%	17,894	39.72%	10,285	16.12%	3,019	11.74%
10,000	9,558	20.40%	19,011	15.50%	17,596	39.06%	9,778	15.33%	2,972	11.56%

TABLE 3.1-4 WENATCHEE RIVER REACH 4 WEIGHTED USABLE AREA (WUA)										
	Chinook				Steelhead				Bull Trout	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
200	49,691	68.72%	163	0.35%	26,397	48.04%	78	0.37%	10,726	100.00%
300	66,016	91.30%	2,163	4.67%	33,566	61.09%	1,544	7.35%	10,628	99.09%
400	71,887	99.42%	6,710	14.50%	39,747	72.34%	4,027	19.16%	9,940	92.67%
500	72,306	100.00%	11,086	23.95%	44,671	81.30%	5,886	28.00%	9,151	85.32%
600	69,587	96.24%	15,477	33.43%	48,449	88.18%	7,564	35.99%	8,471	78.97%
700	65,906	91.15%	19,198	41.47%	51,278	93.32%	9,080	43.20%	7,977	74.37%
800	61,211	84.66%	22,196	47.95%	53,308	97.02%	10,477	49.84%	7,431	69.28%
900	56,936	78.74%	24,899	53.79%	54,461	99.12%	11,502	54.72%	7,148	66.64%
1,000	53,488	73.98%	27,398	59.19%	54,945	100.00%	12,462	59.29%	6,690	62.37%
1,100	50,302	69.57%	29,735	64.24%	54,859	99.84%	13,912	66.19%	6,754	62.97%
1,200	47,473	65.66%	32,014	69.16%	54,523	99.23%	15,367	73.11%	6,588	61.42%
1,300	44,789	61.94%	34,253	74.00%	54,105	98.47%	16,596	78.95%	6,446	60.10%
1,400	42,381	58.61%	36,328	78.48%	53,184	96.79%	17,695	84.18%	6,123	57.08%
1,500	40,285	55.71%	38,218	82.56%	51,963	94.57%	18,675	88.85%	5,999	55.93%
1,600	38,557	53.33%	39,759	85.89%	50,812	92.48%	19,333	91.98%	5,918	55.18%
1,700	37,108	51.32%	41,239	89.09%	49,625	90.32%	19,804	94.21%	5,769	53.79%
1,800	35,715	49.39%	42,585	92.00%	48,334	87.97%	20,249	96.33%	5,467	50.97%
1,900	34,339	47.49%	43,680	94.36%	47,175	85.86%	20,616	98.08%	5,431	50.63%
2,000	33,254	45.99%	44,502	96.14%	46,085	83.87%	20,848	99.18%	5,492	51.21%
2,100	32,232	44.58%	45,220	97.69%	45,110	82.10%	21,020	100.00%	5,563	51.87%
2,200	31,264	43.24%	45,738	98.81%	44,210	80.46%	21,011	99.96%	5,650	52.67%
2,300	30,386	42.02%	46,161	99.72%	43,304	78.81%	21,012	99.96%	5,505	51.33%
2,400	29,598	40.93%	46,290	100.00%	42,507	77.36%	20,969	99.76%	5,362	49.99%
2,500	28,898	39.97%	46,245	99.90%	41,721	75.93%	20,932	99.58%	5,426	50.59%
2,600	28,127	38.90%	46,148	99.69%	40,937	74.51%	20,887	99.37%	5,418	50.51%
2,700	27,396	37.89%	46,026	99.43%	40,213	73.19%	20,748	98.71%	5,352	49.90%
2,800	26,728	36.97%	45,912	99.18%	39,351	71.62%	20,418	97.14%	5,297	49.39%
2,900	26,117	36.12%	45,643	98.60%	38,444	69.97%	20,044	95.36%	5,261	49.05%
3,000	25,624	35.44%	45,375	98.02%	37,625	68.48%	19,771	94.06%	5,210	48.57%
3,250	24,497	33.88%	44,372	95.86%	36,217	65.91%	19,068	90.71%	5,098	47.53%
3,500	23,526	32.54%	43,221	93.37%	35,085	63.85%	18,502	88.02%	5,075	47.31%
3,750	22,570	31.22%	42,109	90.97%	33,801	61.52%	17,870	85.01%	5,083	47.39%
4,000	21,767	30.10%	40,997	88.57%	32,587	59.31%	17,274	82.18%	4,998	46.60%
4,250	21,099	29.18%	39,970	86.35%	31,521	57.37%	16,950	80.64%	4,930	45.96%
4,500	20,580	28.46%	38,791	83.80%	30,466	55.45%	16,442	78.22%	4,991	46.54%
4,750	20,023	27.69%	37,768	81.59%	29,341	53.40%	15,813	75.23%	4,841	45.13%
5,000	19,529	27.01%	36,663	79.20%	28,272	51.45%	15,381	73.17%	4,562	42.53%
5,250	19,105	26.42%	35,370	76.41%	27,445	49.95%	14,725	70.05%	4,414	41.16%
5,500	18,664	25.81%	33,844	73.11%	26,775	48.73%	14,150	67.31%	4,499	41.94%
5,750	18,267	25.26%	32,424	70.05%	26,176	47.64%	13,618	64.79%	4,509	42.03%
6,000	17,950	24.82%	31,285	67.58%	25,544	46.49%	13,031	61.99%	4,421	41.22%
6,250	17,622	24.37%	30,235	65.32%	24,907	45.33%	12,426	59.12%	4,367	40.72%
6,500	17,209	23.80%	29,286	63.27%	24,337	44.29%	11,889	56.56%	4,397	40.99%
6,750	16,765	23.19%	28,407	61.37%	23,935	43.56%	11,488	54.65%	4,182	38.99%
7,000	16,379	22.65%	27,565	59.55%	23,458	42.69%	11,136	52.98%	3,776	35.20%
7,250	16,002	22.13%	26,884	58.08%	23,030	41.91%	10,645	50.64%	3,610	33.66%
7,500	15,642	21.63%	26,256	56.72%	22,621	41.17%	10,158	48.33%	3,756	35.02%
7,750	15,283	21.14%	25,707	55.54%	22,212	40.43%	9,794	46.60%	3,869	36.07%
8,000	14,969	20.70%	25,150	54.33%	21,856	39.78%	9,471	45.06%	3,712	34.60%
8,250	14,694	20.32%	24,573	53.09%	21,514	39.15%	9,235	43.94%	3,594	33.51%
8,500	14,462	20.00%	23,972	51.79%	21,203	38.59%	8,996	42.80%	3,677	34.29%
8,750	14,270	19.74%	23,289	50.31%	20,859	37.96%	8,802	41.87%	3,771	35.16%
9,000	14,058	19.44%	22,656	48.95%	20,554	37.41%	8,615	40.99%	3,842	35.82%
9,250	13,851	19.16%	22,027	47.58%	20,284	36.92%	8,437	40.14%	3,895	36.31%
9,500	13,709	18.96%	21,489	46.42%	19,999	36.40%	8,327	39.62%	3,860	35.99%
9,750	13,568	18.77%	21,005	45.38%	19,747	35.94%	8,265	39.32%	3,753	34.99%
10,000	13,412	18.55%	20,541	44.38%	19,503	35.50%	8,227	39.14%	3,799	35.42%

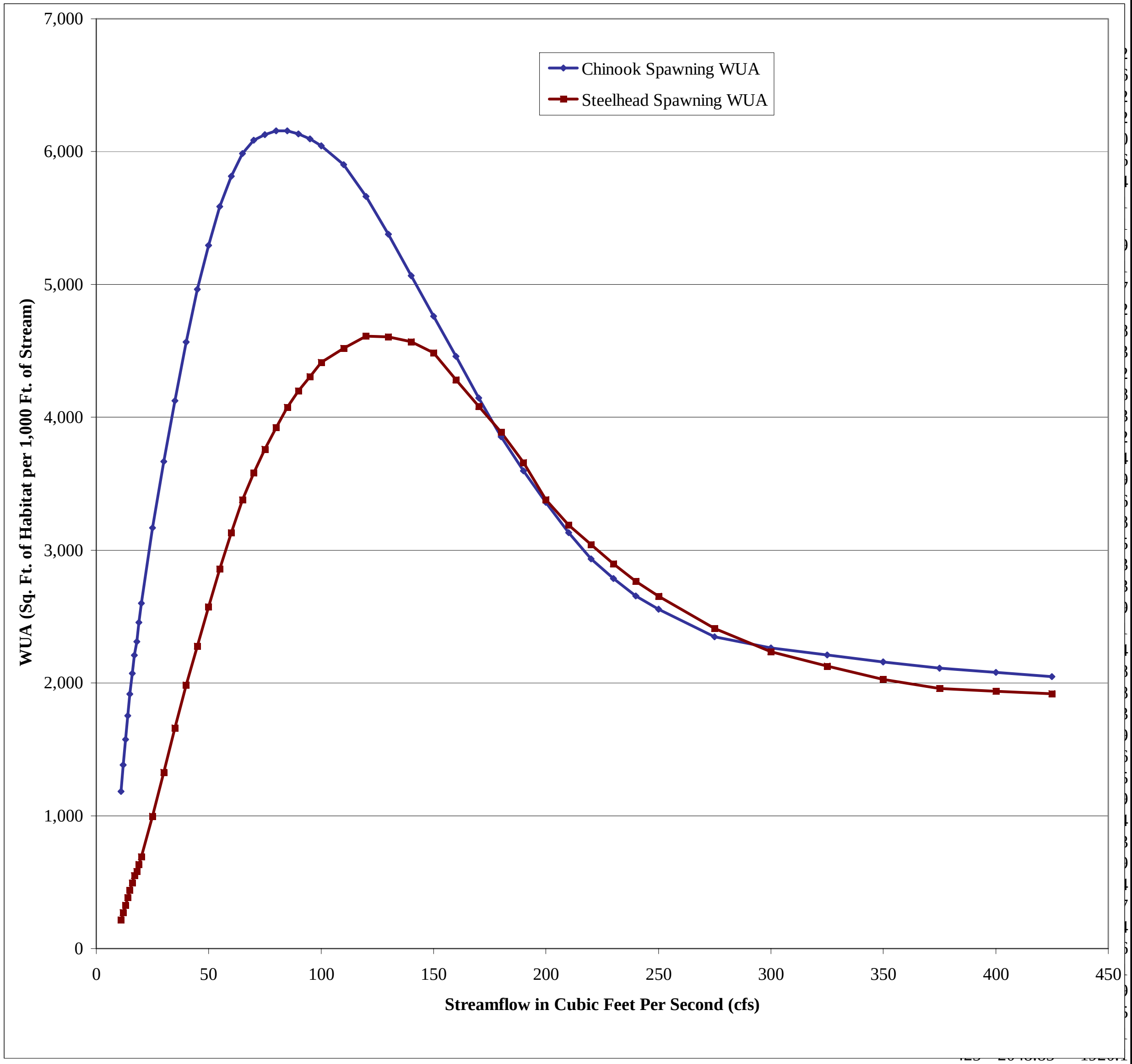
Figure 3.1-9 Peshastin Creek: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Chinook Rearing WUA	Steelhead Rearing WUA	Bull Trout Rearing WUA
11	36%	19%	93%
12	40%	21%	95%
13	45%	23%	96%
14	49%	24%	98%
15	53%	26%	98%
16	57%	27%	99%
17	60%	29%	99%
18	62%	31%	**100%**
19	65%	32%	**100%**
20	67%	34%	**100%**
25	78%	41%	96%
30	86%	48%	93%
35	92%	54%	90%
40	96%	60%	90%
45	98%	66%	90%
50	**100%**	70%	88%
55	**100%**	75%	86%
60	**100%**	79%	86%
65	98%	83%	85%
70	97%	86%	84%
75	96%	89%	84%
80	94%	92%	82%
85	91%	94%	80%
90	88%	95%	78%
95	85%	97%	75%
100	83%	98%	73%
110	78%	**100%**	69%
120	75%	**100%**	66%
130	72%	**100%**	63%
140	69%	**100%**	60%
150	66%	**100%**	58%
160	63%	**100%**	55%
170	60%	99%	54%
180	58%	99%	52%
190	56%	98%	52%
200	54%	98%	52%
210	53%	97%	53%
220	52%	97%	52%
230	51%	97%	52%
240	50%	96%	52%
250	49%	95%	52%
275	48%	93%	52%
300	46%	92%	54%
325	46%	92%	56%
350	46%	91%	58%
375	47%	90%	62%
400	47%	90%	69%
425	48%	89%	77%

Figure 3.1-10 Peshastin Creek: Fish Habitat (WUA) vs. Flow.



Percent of Peak Habitat vs Flow

Flow	Spawning WUA	Steelhead Spawning WUA
11	19%	5%
12	22%	6%
13	26%	7%
14	28%	8%
15	31%	10%
16	34%	11%
17	36%	12%
18	38%	13%
19	40%	14%
20	42%	15%
25	51%	22%
30	60%	29%
35	67%	36%
40	74%	43%
45	81%	49%
50	86%	56%
55	91%	62%
60	94%	68%
65	97%	73%
70	99%	78%
75	**100%**	81%
80	**100%**	85%
85	**100%**	88%
90	**100%**	91%
95	99%	93%
100	98%	96%
110	96%	98%
120	92%	**100%**
130	87%	**100%**
140	82%	99%
150	77%	97%
160	72%	93%
170	67%	89%
180	63%	84%
190	58%	79%
200	55%	73%
210	51%	69%
220	48%	66%
230	45%	63%
240	43%	60%
250	41%	58%
275	38%	52%
300	37%	48%
325	36%	46%
350	35%	44%
375	34%	42%
400	34%	42%
425	33%	42%

TABLE 3.1-5 PESHASTIN CREEK WEIGHTED USABLE AREA (WUA)										
	Chinook				Steelhead				Bull Trout	
Flow (cfs)	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak	Spawning	% of Peak	Rearing	% of Peak
11	1,705	36.40%	1,183	19.21%	1,200	19.33%	217	4.70%	2,230	92.87%
12	1,886	40.27%	1,383	22.47%	1,303	20.99%	271	5.87%	2,272	94.65%
13	2,099	44.81%	1,574	25.56%	1,405	22.63%	326	7.08%	2,311	96.26%
14	2,275	48.57%	1,752	28.46%	1,501	24.19%	384	8.32%	2,344	97.65%
15	2,472	52.76%	1,915	31.11%	1,603	25.83%	440	9.54%	2,359	98.24%
16	2,650	56.57%	2,072	33.66%	1,705	27.46%	494	10.72%	2,365	98.50%
17	2,801	59.79%	2,208	35.85%	1,806	29.08%	550	11.93%	2,372	98.79%
18	2,915	62.23%	2,311	37.53%	1,896	30.54%	580	12.58%	2,392	99.64%
19	3,039	64.87%	2,455	39.87%	1,992	32.10%	634	13.75%	2,401	100.00%
20	3,160	67.46%	2,601	42.24%	2,088	33.63%	691	14.99%	2,399	99.92%
25	3,659	78.12%	3,167	51.43%	2,560	41.24%	996	21.60%	2,315	96.42%
30	4,007	85.54%	3,668	59.57%	2,986	48.10%	1,328	28.80%	2,227	92.75%
35	4,290	91.58%	4,125	66.99%	3,371	54.31%	1,662	36.05%	2,161	89.99%
40	4,490	95.84%	4,567	74.17%	3,734	60.15%	1,985	43.04%	2,153	89.66%
45	4,607	98.34%	4,962	80.59%	4,068	65.52%	2,275	49.34%	2,159	89.92%
50	4,672	99.74%	5,295	85.99%	4,376	70.50%	2,573	55.79%	2,105	87.68%
55	4,685	100.00%	5,585	90.70%	4,655	74.98%	2,858	61.98%	2,070	86.22%
60	4,672	99.73%	5,814	94.43%	4,909	79.08%	3,130	67.89%	2,060	85.81%
65	4,606	98.33%	5,984	97.19%	5,137	82.75%	3,378	73.26%	2,044	85.13%
70	4,559	97.32%	6,086	98.84%	5,351	86.20%	3,580	77.65%	2,028	84.48%
75	4,491	95.86%	6,127	99.51%	5,531	89.10%	3,758	81.49%	2,008	83.65%
80	4,385	93.61%	6,157	100.00%	5,681	91.52%	3,921	85.03%	1,971	82.08%
85	4,247	90.65%	6,155	99.97%	5,810	93.59%	4,073	88.33%	1,925	80.16%
90	4,113	87.81%	6,132	99.59%	5,921	95.37%	4,198	91.03%	1,871	77.93%
95	3,983	85.03%	6,097	99.02%	6,018	96.94%	4,306	93.38%	1,811	75.43%
100	3,867	82.54%	6,043	98.15%	6,101	98.28%	4,414	95.72%	1,756	73.13%
110	3,677	78.48%	5,902	95.85%	6,186	99.64%	4,519	98.00%	1,652	68.83%
120	3,502	74.75%	5,662	91.95%	6,195	99.79%	4,611	100.00%	1,578	65.74%
130	3,360	71.72%	5,379	87.35%	6,208	100.00%	4,606	99.90%	1,512	62.99%
140	3,225	68.85%	5,066	82.28%	6,182	99.59%	4,570	99.10%	1,446	60.23%
150	3,080	65.74%	4,760	77.30%	6,181	99.56%	4,485	97.27%	1,381	57.51%
160	2,934	62.64%	4,458	72.40%	6,199	99.85%	4,281	92.84%	1,326	55.22%
170	2,814	60.07%	4,146	67.34%	6,166	99.32%	4,082	88.53%	1,288	53.64%
180	2,711	57.87%	3,854	62.60%	6,135	98.83%	3,888	84.33%	1,254	52.21%
190	2,621	55.96%	3,596	58.40%	6,091	98.12%	3,659	79.34%	1,245	51.86%
200	2,544	54.30%	3,361	54.58%	6,066	97.72%	3,380	73.30%	1,256	52.32%
210	2,470	52.73%	3,130	50.84%	6,053	97.50%	3,188	69.15%	1,261	52.52%
220	2,422	51.69%	2,934	47.65%	6,039	97.28%	3,042	65.98%	1,257	52.36%
230	2,375	50.70%	2,787	45.26%	6,001	96.67%	2,896	62.80%	1,255	52.26%
240	2,343	50.02%	2,654	43.10%	5,948	95.82%	2,766	59.99%	1,252	52.14%
250	2,306	49.24%	2,554	41.48%	5,894	94.94%	2,653	57.54%	1,254	52.24%
275	2,229	47.58%	2,347	38.12%	5,758	92.76%	2,412	52.30%	1,252	52.17%
300	2,174	46.41%	2,264	36.77%	5,729	92.29%	2,235	48.46%	1,285	53.53%
325	2,163	46.17%	2,211	35.90%	5,719	92.12%	2,126	46.11%	1,336	55.64%
350	2,172	46.37%	2,158	35.05%	5,634	90.76%	2,026	43.94%	1,390	57.90%
375	2,184	46.62%	2,111	34.28%	5,599	90.18%	1,958	42.47%	1,485	61.87%
400	2,208	47.13%	2,078	33.75%	5,569	89.71%	1,937	42.00%	1,669	69.50%
425	2,258	48.19%	2,049	33.28%	5,513	88.80%	1,920	41.64%	1,856	77.32%

4.0 HYDROLOGY

Several long-term gauges in the Wenatchee basin provide a good hydrological picture of the runoff patterns. Two USGS gauging stations, Wenatchee River at Monitor (No. 12462500) and Wenatchee River at Peshastin, (No.12459000) are located within the Wenatchee Study Reach 1 and Reach 2 at RM 7 and RM 21.5, respectively.

The WDOE has recently installed a network of gauging stations in the Wenatchee basin. Peshastin Creek at Green Bridge is one of the stations within the WDOE gauging network. Although the period of record is not long enough to provide useful statistics, these gauges will be of increasing importance as water resource issues are addressed in the coming years.

Streamflow from the mountainous regions of the Wenatchee basin is highest from May through July, averaging 150%-320% of mean annual flow (MAF) as snowmelt fills the streams for an extended period. September is generally the lowest flow month of the year with an average discharge of just 25%-30% of MAF. The timing and duration of the spring runoff is strongly influenced by snowpack, day length, air temperature, and wind. During the fall and winter months streamflow is influenced by fluctuating freezing levels and warm rainfall. Fall and winter flows are generally moderate, averaging approximately 40%-60% of MAF.

The annual hydrograph for the Wenatchee River at Monitor and Wenatchee River at Peshastin are presented in Figures 4-1 and 4-2. Mean monthly flows for Peshastin Creek are presented in Figure 4-3.

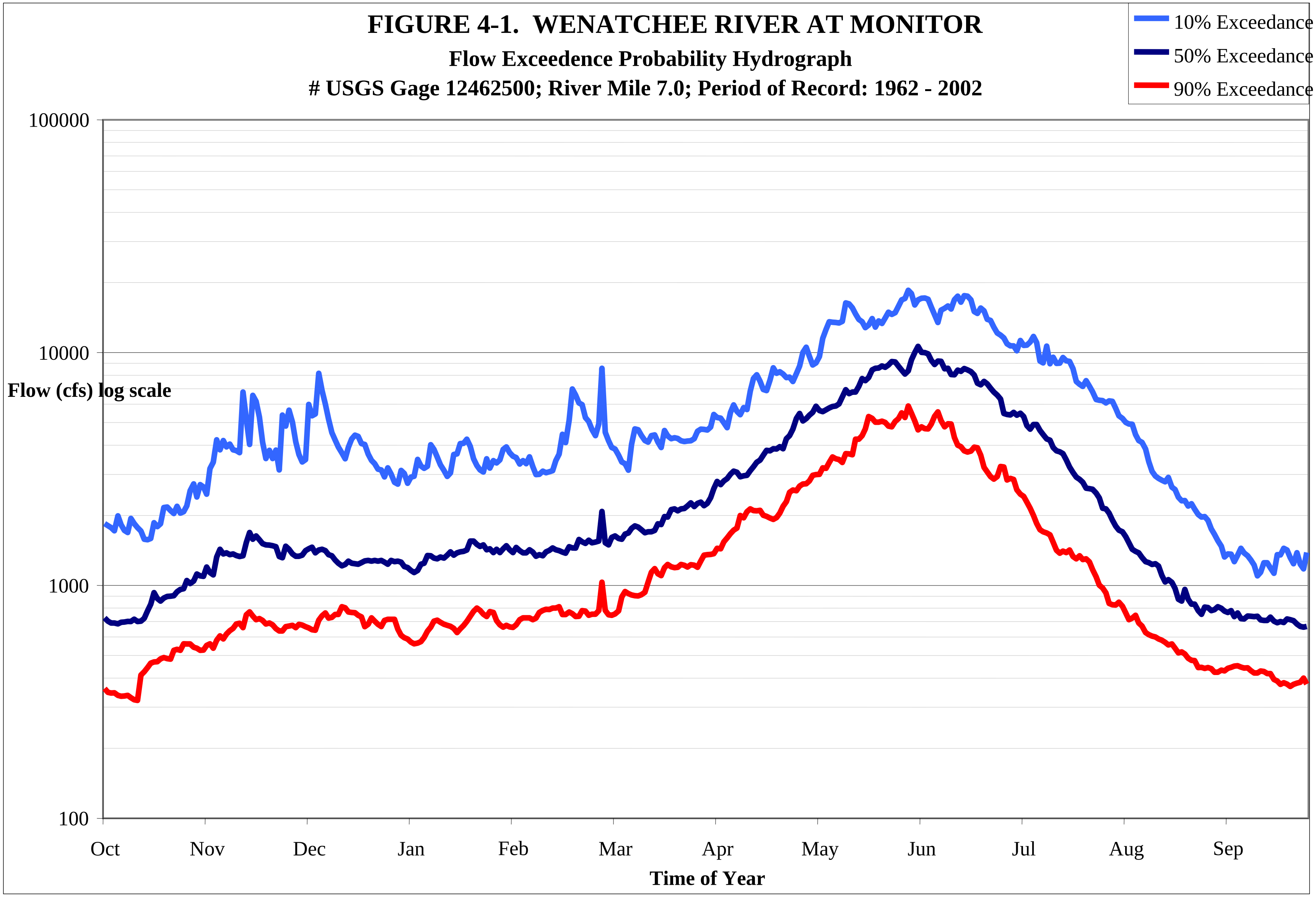


FIGURE 4-1. WENATCHEE RIVER AT MONITOR
Flow Exceedence Probability Hydrograph
USGS Gage 12462500; River Mile 7.0; Period of Record: 1962 - 2002
10% Exceedance
50% Exceedance
90% Exceedance
100000
10000
1000
100
Flow (cfs) log scale
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Time of Year

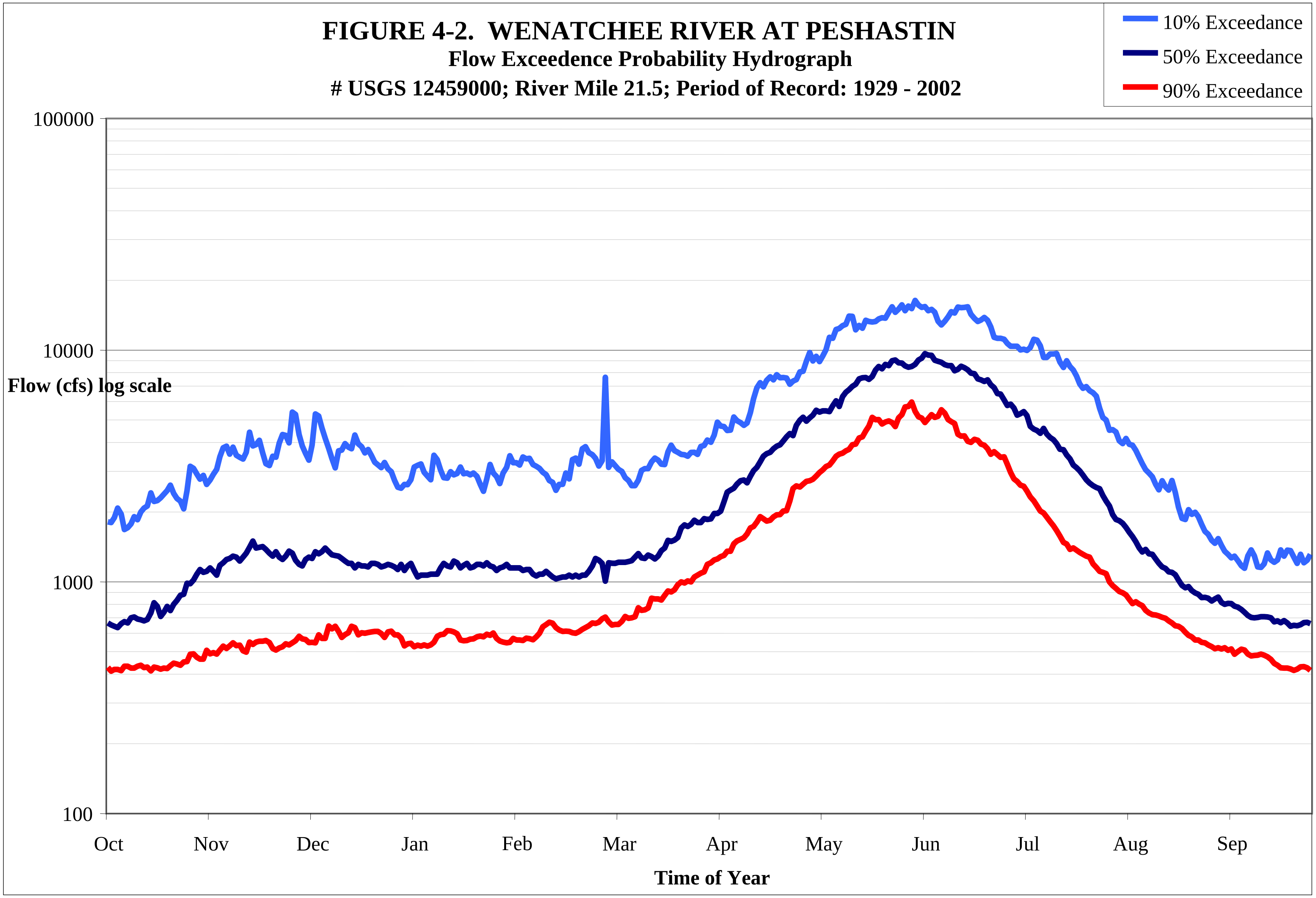


FIGURE 4-2. WENATCHEE RIVER AT PESHASTIN
Flow Exceedence Probability Hydrograph
USGS 12459000; River Mile 21.5; Period of Record: 1929 - 2002
10% Exceedance
50% Exceedance
90% Exceedance
100000
10000
1000
100
Flow (cfs) log scale
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Time of Year

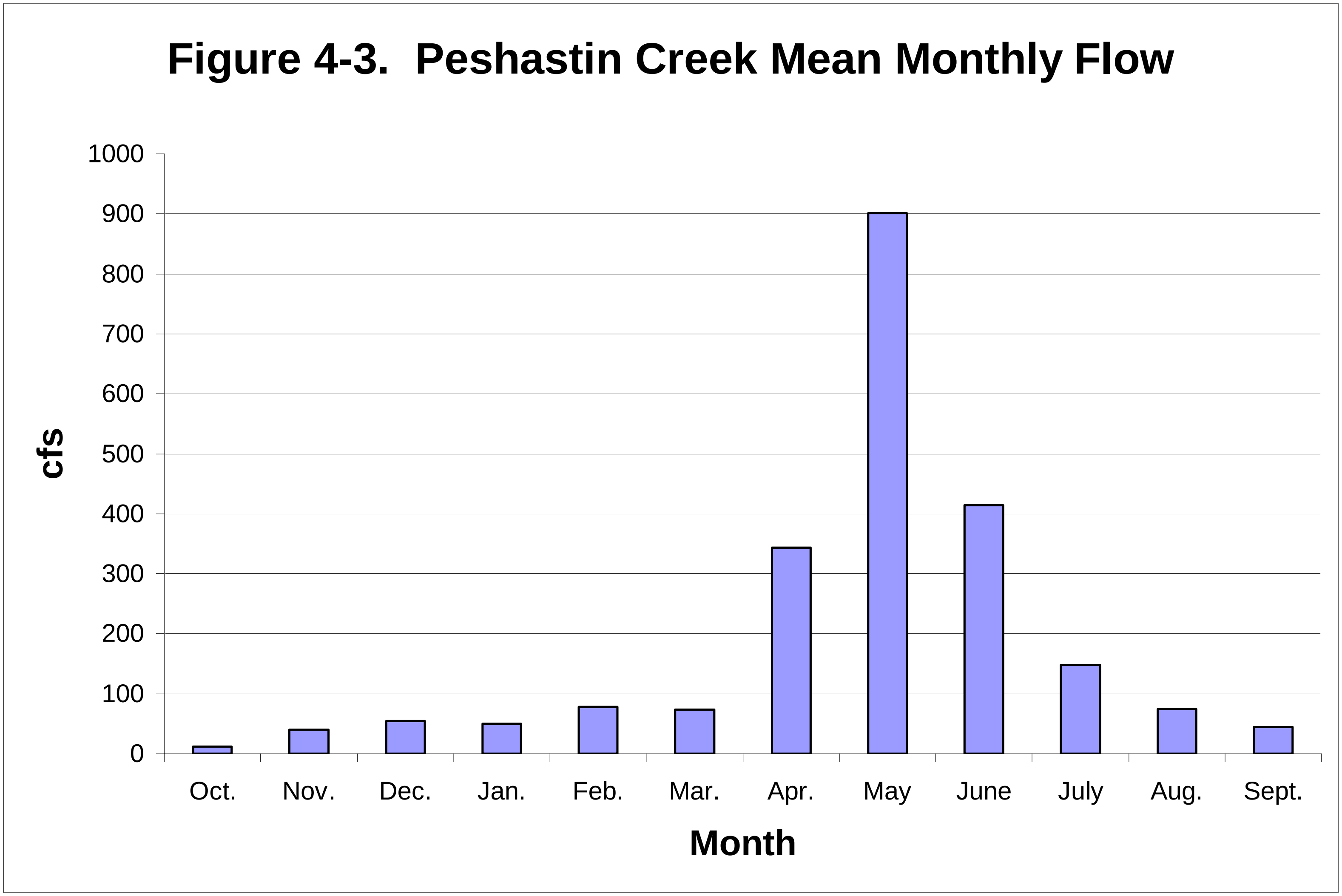


Figure 4-3. Peshastin Creek Mean Monthly Flow
1000
900
800
700
600
500
400
300
200
100
0
cfs
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Month

5.0 REFERENCES

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Washington Department of Fish and Wildlife (WDFW) and Washington Department of Ecology (WDOE), 2004. Instream Flow Guidelines Update. Olympia WA., April 2004

APPENDIX A

SUBSTRATE CODES AND HABITAT SUITABILITY CRITERIA (HSC) FOR THE LOWER WENATCHEE PHABSIM STUDY

APPENDIX B

CALIBRATION DETAILS FOR THE LOWER WENATCHEE AND PESHASTIN PHABSIM MODELS

RECLAMATION

Managing Water in the West

Technical Memorandum

Instream Flow Assessment of Icicle Creek, Washington

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

U.S. Department of the Interior
Bureau of Reclamation

December 2005

Technical Memorandum

Instream Flow Assessment of Icicle Creek, Washington

Prepared by

Ron Sutton
Chelsie Morris

Acknowledgements

We thank the numerous representatives from various organizations who contributed to the success of this project. Steve Kolk of Reclamation contributed to the planning, execution, and funding of the study. Jim Pacheco of WDOE provided guidance on hydraulic calibration criteria and recommended HSCs. MaryJo Sanborn of Chelan County Natural Resource Program provided information on current stage readings in Icicle Creek and useful background information. Personnel from the Chelan County Conservation District, including Sarah Walker, Curt Hosman, Sarah Coffler, and Jeff Hampton assisted with the field sampling. Steve Kolk, Bob Vadas (WDFW), Jim Pacheco, and Pete Rittmueller (EES Consulting) provided valuable comments on the draft report.

Executive Summary

The purpose of this study was to characterize the relationship between stream flow and fish habitat on Icicle Creek, Washington, downstream from the Leavenworth National Fish Hatchery to its mouth at the Wenatchee River. The stream exhibits a very flat slope and is characterized by a meandering pattern. Peak flows occur during late spring and low flows occur during late summer and fall. Flows between 2000 and 2004 ranged from 58 cfs to 3,610 cfs. Chinook salmon, steelhead trout, and bull trout are federally listed species in the Wenatchee basin and were selected by the Wenatchee Watershed Planning Unit as the species of interest for this study. Rearing and spawning life stages of these species were addressed in this study.

The method used was the U.S. Fish and Wildlife Service (USFWS) Physical Habitat Simulation System (PHABSIM) application of the Instream Flow Incremental Methodology (IFIM). The PHABSIM method is based on the premise that stream dwelling fish prefer a certain range of depths, velocities, substrates and cover types, depending on the species and life stage, and that the availability of these preferred habitat conditions varies with flow. Weighted Usable Area (WUA) is the primary product of PHABSIM. Weighted usable area is an index of habitat availability or quantity for the selected species/life stage at each simulated flow. Weighted usable area was calculated for a range of flows between 20 and 800 cfs. Graphs and tables of WUA versus flow are presented for each life stage and species of interest. This technical information can be used by the Planning Unit as the basis for instream flow recommendations in Icicle Creek.

Table of Contents

Introduction

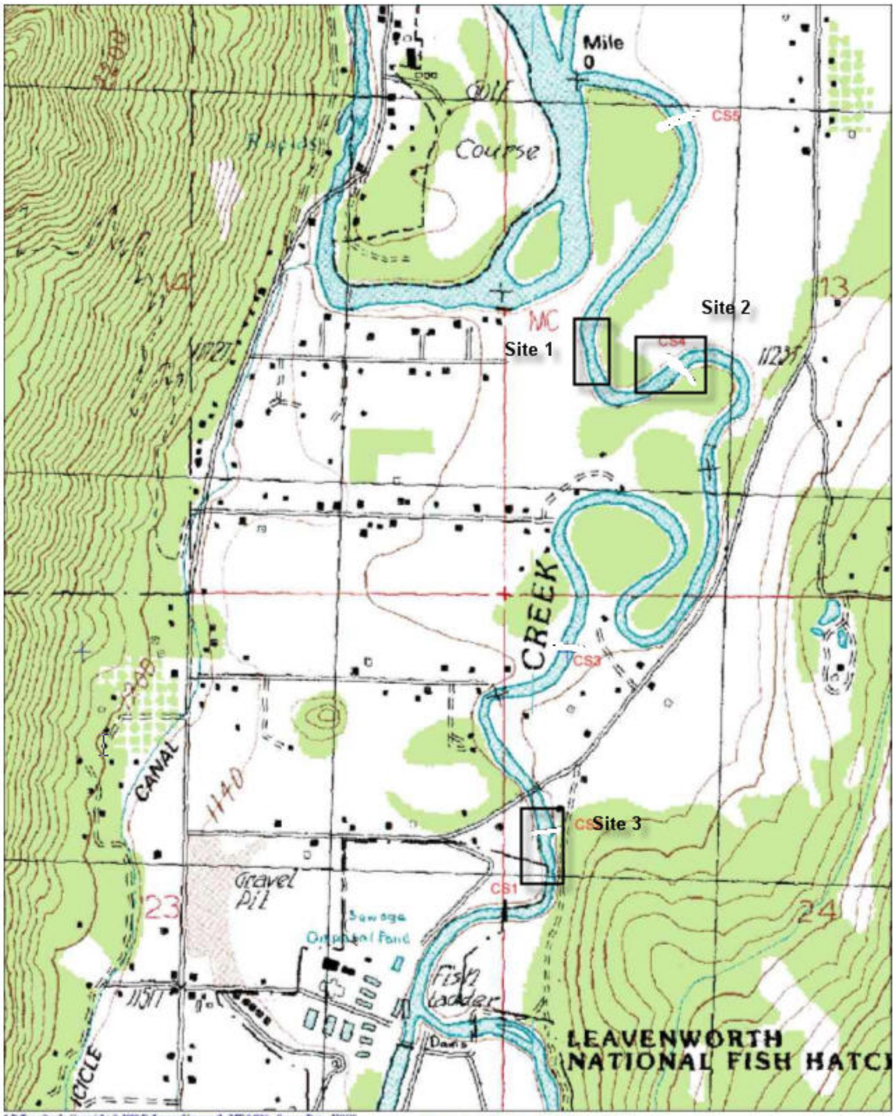
The Bureau of Reclamation (Reclamation) (in coordination with the WRIA 45 Instream Flow Subcommittee) conducted an instream flow study on Icicle Creek near Leavenworth, Washington during 2004 and 2005. The purpose of this study was to characterize the relationship between stream flow and fish habitat on Icicle Creek, downstream from the Leavenworth National Fish Hatchery to its mouth at the Wenatchee River. This technical information can be used by the Wenatchee Watershed Planning Unit as the basis for instream flow recommendations that will be included in the final Wenatchee Watershed Plan by April 2006.

Study Area

The Icicle Creek study area extended from its confluence with the Wenatchee River (RM 0.0) upstream to the Leavenworth National Fish Hatchery (RM 2.7) (Figure 1). This area of the stream exhibits a very flat slope and is characterized by a meandering pattern. Chinook salmon (*Oncorhynchus tschawytscha*), steelhead trout (*O. mykiss*), coho salmon (*O. kisutch*), and bull trout (*Salvelinus confluentus*) utilize this area as a transportation corridor for both upstream and downstream movement, migration, and juvenile rearing. This area is recognized as prime spawning and incubation habitat for spring Chinook salmon as well as steelhead trout. Adult spring Chinook salmon returning to the hatchery are targeted by both sport and tribal fishers in Icicle Creek from mid May through July.

Hydrology

Recent stream gage records (water years 2000-2004) for Icicle Creek were retrieved from the U.S. Geological Survey (USGS) gage located above Snow Creek (Figure 2). This gage does not record real-time information. Peak flows occur during late spring and low flows occur during late summer and fall. Flows during this period ranged from 58 cfs (11/1/02) to 3,610 cfs (6/15/02). During the study, stage and discharge data were recorded periodically in Icicle Creek at the East Leavenworth Road Bridge (Figure 3). This information could be used to develop a rating curve for Icicle Creek and allow flow estimates based on stage readings.



3-D TopoQuads Copyright © 1999 DeLorme Yarmouth, ME 04096 Source Data: USGS 350 ft Scale: 1 : 12,000 Detail: 14-0 Datum: WGS84

Figure 1. Study site locations on Icicle Creek for instream flow assessment.

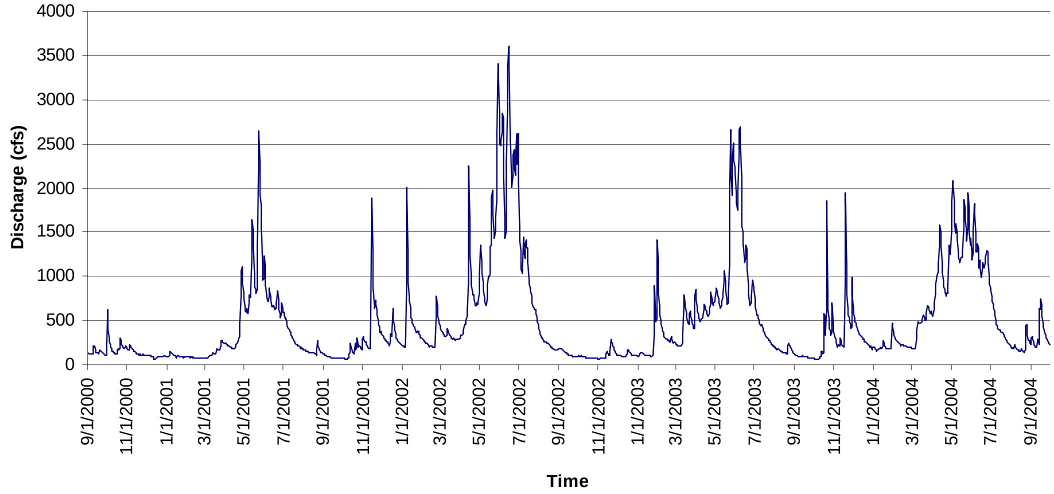


Figure 2. Recent Icicle Creek discharge records at USGS Gage number 12458000 located above Snow Creek near Leavenworth, Washington.

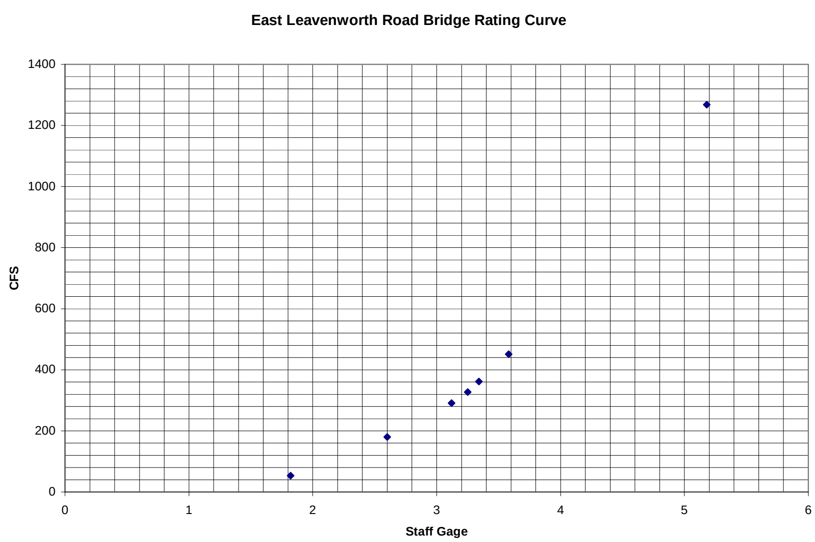
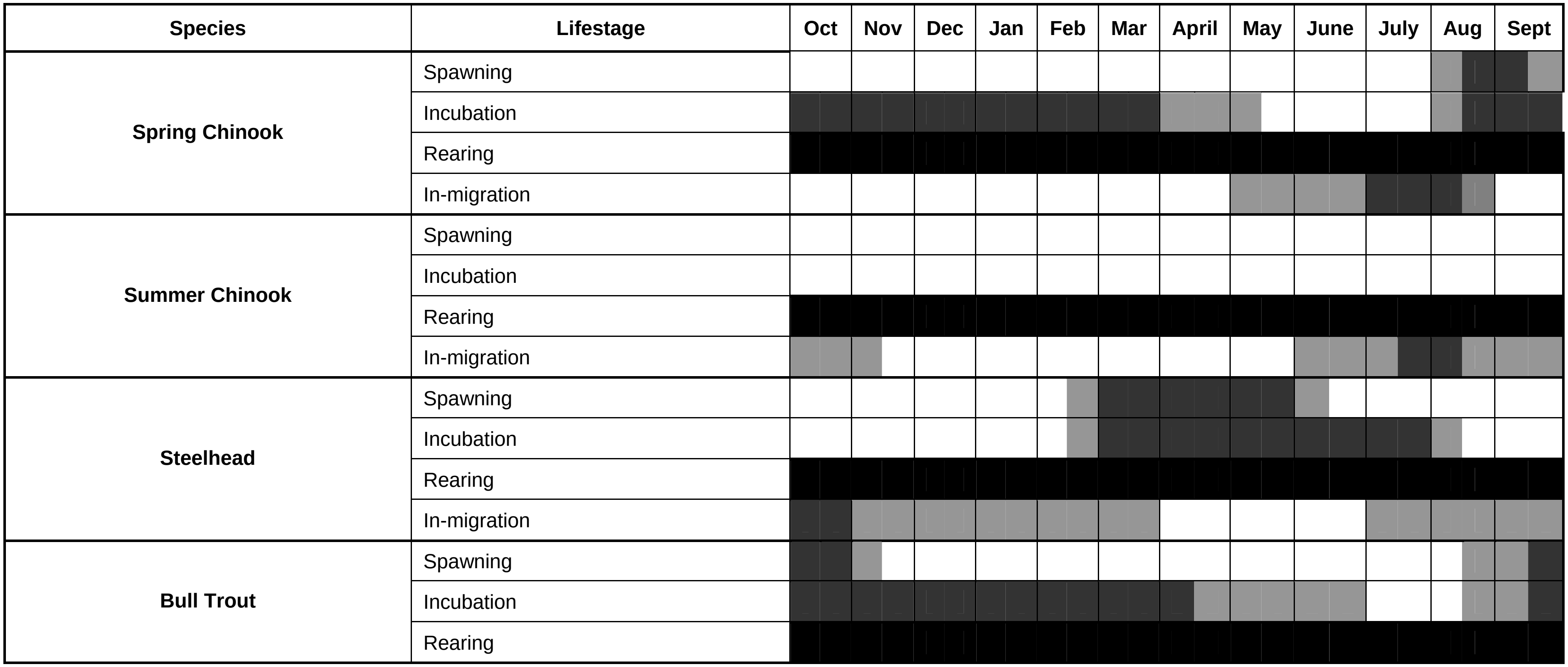


Figure 3. Stage-discharge relationship for Icicle Creek.

Affected Species and Life Stages

Chinook salmon, steelhead trout, and bull trout are federally listed species in the Wenatchee basin and were selected by the Planning Unit as the species of interest for this study. All of these species use Icicle Creek during some part of their life cycle. Figure 4 presents life-stage timing of salmonids in Icicle Creek. Anadromous fish use Icicle Creek in a variety of ways. Adults use the river as an upstream migration corridor to spawning grounds and Leavenworth Fish Hatchery. Salmonid fry and smolts use the river as a downstream migration corridor on their journey towards sea. Migration of salmonids was not addressed in this study. The analysis focused on spawning and rearing habitat for Chinook salmon, steelhead, and bull trout. Fish passage flows were not addressed.



<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key: Black indicates periods of heaviest use
Grey indicates periods of moderate use
Blank areas indicate periods of little or no use

Figure 4. Icicle Creek periodicity chart for selected fish species.

Methods

The method used to study Icicle Creek was the U.S. Fish and Wildlife Service (USFWS) Physical Habitat Simulation System (PHABSIM) application of the Instream Flow Incremental Methodology (IFIM). Generally, instream flow study procedures followed the Washington Department of Fish and Wildlife/Washington Department of Ecology (WDFW/WDOE) Instream Flow Guidelines (2004). The PHABSIM method is based on the premise that stream dwelling fish prefer a certain range of depths, velocities, substrates and cover types, depending on the species and life stage, and that the availability of these preferred habitat conditions varies with streamflow. With input from streamflow, substrate, and cover type measurements, PHABSIM quantifies habitat availability over a range of flows. It is important for the water manager to recognize that the result of the study is not a set value but a range of values to be used as a tool for determining relative amounts of habitat available at various stream flows.

PHABSIM requires hydraulic and habitat suitability data to determine the instream flow requirements for the species and/or life history stage of interest. Several hydraulic sub-models can be used with PHABSIM. Field data collection was designed to accommodate any of these models. The field methods and hydraulic analysis followed the conventional three-velocity method, or regression method, where full sets of depth and velocity data were collected at each station along the transects at the low, middle, and high flow calibration measurements. An additional calibration data set was collected in October, 2004. Water surface elevations (WSEs) were also taken at all calibration flows, and discharge measurements were made concurrently while collecting the depth and velocity information at each transect and calibration flow.

Reclamation's Technical Service Center (TSC) in Denver, Colorado, with assistance from Reclamation's Wenatchee Office and the Chelan County Conservation District, collected and compiled existing data and conducted the study. These tasks are briefly outlined below.

Transect Locations

Eleven transects were selected within three separate study sites on Icicle Creek (Figure 1) by the Wenatchee Instream Flow Subcommittee and were approved by participating resource agencies. The methodology for selecting these transects is discussed in the Draft Scoping Report prepared by EES Consulting, Inc. (2004). Transect location and descriptions are shown in Table 1 below.

Table 1. Transect descriptions for Icicle Creek instream flow assessment.

Reach	Study Site	No.	Description	River Mile
1	1	1	Riffle	0.2
		2	Glide	0.2
		3	Pool Tailout	0.2
		4	Pool	0.2
	2	1	Riffle	0.4
		2	Glide	0.4
		3	Pool Tailout	0.4
		4	Pool	0.4
	3	1	Glide	2.2
		2	Pool Tailout/glide	2.2
		3	Pool	2.4

Habitat Typing

Reclamation obtained an aerial video survey of Icicle Creek from EES Consulting. The video was used to generally characterize habitat types throughout Icicle Creek downstream from Leavenworth Fish Hatchery. In addition, Reclamation measured longitudinal lengths of each habitat type described by the transects in Table 1 (pool, pool tailout, glide, riffle) using kayaks and a laser rangefinder downstream from the boat ramp at RM 2.6 on August 17, 2005. The “cumulative-lengths” approach described by Bovee (1997) was used to determine proportions of different mesohabitat types in the Icicle Creek study area.

Depth, Velocity, and Water Surface Elevation Measurements

Field data were collected according to Bovee (1997) using standard surveying equipment at four discharges. Vertical elevations were established throughout each habitat type using a total station instrument (Bovee 1997). A benchmark was established at each study site (with rebar) and assigned the arbitrary elevation of 100.00 feet. All elevations were referenced to this benchmark and transects in each study site were "tied together" by surveying their relative elevation. Water surface elevations were measured to the nearest 0.01 ft near the water’s edge along each transect at all discharges. Channel cross sections were measured (vertical and horizontal) to the nearest 0.1 ft between headpins at each transect during high discharge. Below water channel cross sections were determined by subtracting measured depths from the WSE at the high flow. Discharge measurements at each transect were taken during each survey. A temporary staff gage was installed at each site so that fluctuations in WSE could be monitored during data collection.

Depth and velocity measurements in wadeable sections of each transect were made with a USGS topset wading rod and a Marsh McBirney Model 2000 current meter. Velocity was measured at sixth tenths of the depth when depth was less than 2.5 feet and at two tenths and eight tenths of the depth at depths greater than or equal to 2.5 feet. In deeper sections, depth and velocity were made from a boat with similar equipment (i.e., 10-foot wading rod). Depths and mean column velocities were measured at various points along each transect. Stationing across transects was oriented with 0.0 on the left bank looking upstream for modeling purposes. Streambed elevations and water depths were measured to the nearest 0.1 ft. Water velocity was measured to the nearest 0.1 ft/sec. Velocity calibration sets were collected at four different time periods between October, 2004 and August, 2005 in an attempt to cover a range of flows. Velocities at the two pool transects at sites 2 and 3 were not measured in July, 2005 because shallow riffles prevented use of the available boat.

Substrate and Cover Codes

Washington agencies (WDFW/WDOE) have standard substrate and cover codes in their Instream Flow Guidelines Report (2004) (Table 2). These codes were used by Reclamation in the Icicle Creek study. Dominant and subdominant substrate types were recorded. Since PHABSIM can only accept one cover/substrate code, substrate codes were used where no cover was present and cover codes were used where cover was present, as suggested by Jim Pacheco (personal communication, 9/26/05). For the transects in this study, cover occurred primarily along the edges of the stream with silt and sand substrate. Substrate/cover codes used the format “ab.c”. For substrates, “a” was the code for the dominant particle size, “b” was the component code for the subdominant particle size, and “c” was tenths of cell area covered by the dominant (50% or greater) substrate type. For example, the code 46.8 indicated 80% medium gravel and 20% small cobble. Cover codes used the same format, but “a” and “b” were always 0 and “c” defined the type of cover. For example, 00.1 was an undercut bank, 00.2 was overhanging vegetation, etc.

Habitat Suitability Criteria (HSC)

Species habitat suitability criteria (HSCs) are required for PHABSIM analysis. Habitat suitability criteria, or curves, are interpreted using a suitability index (SI) on a scale of 0 to 1, with 0 being unsuitable and 1 being most utilized or preferred. Habitat suitability criteria that accurately reflect the habitat requirements of the species of interest are essential to developing meaningful and defensible instream flow recommendations. The recommended approach is to develop site-specific criteria for each species and life stage of interest. An alternative involves using existing curves and literature to develop suitability criteria for the species of interest. Limited site-specific HSC data are available in Icicle Creek and time and budgetary constraints precluded developing HSCs specific to Icicle Creek. Thus, Reclamation used the established spawning and rearing HSCs for Washington State (Jim Pacheco, personal communication, 9/26/05) and summarized in Appendix A, including updated bull trout criteria (EES Consulting 2005).

Table 2. Substrate and cover coding systems used for Icicle Creek instream flow study (derived from WDFW/WDOE Instream Flow Guidelines (2004).

Substrate Code	Description
1	Silt, clay, organic
2	Sand
3	Small gravel (0.1-0.5”)
4	Medium gravel (0.5-1.5”)
5	Large gravel (1.5-3”)
6	Small cobble (3-6”)
7	Large cobble (6-12”)
8	Boulder (>12”)
9	Bedrock

Cover Code	Description
0.1	Undercut
0.2	Overhang
0.3	Rootwad
0.4	Logjam/submerged brush pile
0.5	Log (s) parallel to bank
0.6	Aquatic vegetation
0.7	Short (<1’) terrestrial grass
0.8	Tall (>3’) dense grass
0.9	Vegetation beyond bank-full waters edge

Hydraulic Model Selection and Calibration

Reclamation used the USGS Windows version of PHABSIM (Waddle 2001) for the analysis of Icicle Creek data. PHABSIM has several submodels available for hydraulic simulations. These include STGQ (IFG4), WSP, and MANSQ (Waddle 2001), with STGQ being the most rigorous in terms of data requirements. The WSP model is used for backwaters (e.g., pools). Each hydraulic model requires multiple flow measurements to extend the predictive range. Depending on model performance, the predictive range may be restrictive or wide ranging (i.e., 0.1 to 10 times the measured discharges) (Waddle 2001). Field sampling was designed to collect data in formats suitable for application in any of the hydraulic models identified above. The following approach was used:

- Enter field data into appropriate format for water surface simulations
- Calibrate simulated WSEs using STGQ, MANSQ, or WSP (depending on site specific conditions) to measured WSEs
- Simulate a range of flows to predict WSEs
- Simulate depths and velocities for range of flows that occur during the irrigation season
- Calibrate velocities using velocity adjustment factors (VAF’s) and velocity regression (simulated within 0.2 ft/sec of measured velocities-Jim Pacheco, personal communication, 9/22/05)
- Evaluate simulation range based on VAF’s and other calibration sub-models

- Document acceptable range of simulations
- Conduct velocity simulation production run for applicable range of flows that may occur during the irrigation season.

Development of Flow vs. Habitat Functions

The TSC utilized the PHABSIM suite of programs developed by USGS to compute Weighted Usable Area (WUA) as a measure of available habitat. Weighted usable area (WUA) was calculated for each discharge of interest between 20 and 800 cfs. Weighted usable area is an index of habitat availability or quantity for the selected species/life stage at each simulated flow. After the hydraulic models were calibrated, transect weighting and lengths to simulate a 1,000 foot reach were added as shown in Table 4. Final hydraulic model runs produced input for the HABTAE habitat sub-model of PHABSIM. The WUAs for selected life stages and species were computed in HABTAE using the standard multiplicative computation option (Jim Pacheco, personal communication, 11/22/05) to multiply the depth, velocity, and substrate/cover HSC values at predicted hydraulic conditions, and cell surface area. The output from the HABTAE simulation was habitat area, expressed as WUA (ft^2/ 1000 ft). WUA versus flow relationships were computed for each study site separately and as a composite (all study sites combined). For presentation purposes, WUA was also normalized as a percentage of maximum habitat. It should be noted that there is a level of uncertainty associated with WUAs. Sources of uncertainty include errors in HSCs, hydraulic simulations, or selection of options to simulate microhabitat (e.g., geometric versus multiplicative means). Recognition that there is uncertainty in these sources is important in the interpretation and use of PHABSIM model results (Bovee et al. 1998).

Results

Transect weighting for habitat modeling was based on the proportions of habitat types in Icicle Creek. Individual study site transects were weighted empirically using results from the "cumulative-lengths" analysis (Table 3). Since Study Site 3 only included glide, pool tailout, and pool transects, weights were based on cumulative lengths of only these three habitat types at this site. Table 4 summarizes transect weights for each study site separately and as a composite (all study sites combined).

Table 3. Proportions of habitat types in Icicle Creek.

Habitat type	Cumulative length (ft)	Proportion (%)
Pool	6,497	46.9
Pool tailout	388	2.8
Riffle	1,912	13.8
Glide	5,064	36.5
Total	13,861	100

Table 4. Transect weights for each study site and composite (all transects).

Study Site 1 transect no.	Habitat Type	Weight (%)
1	Riffle	13.8
2	Glide	36.5
3	Pool Tailout	2.8
4	Pool	46.9
Study Site 2 transect no.		
1	Riffle	13.8
2	Glide	36.5
3	Pool Tailout	2.8
4	Pool	46.9
Study Site 3 transect no.		
1	Glide	42.40
2	Pool Tailout/glide	3.20
3	Pool	54.40
Composite transects numbered from downstream to upstream		
1	Riffle	6.90
2	Glide	12.16
3	Pool Tailout	0.93
4	Pool	15.63
5	Riffle	6.90
6	Glide	12.16
7	Pool Tailout	0.93
8	Pool	15.63
9	Glide	12.16
10	Pool Tailout/glide	0.93
11	Pool	15.63

Four sets of calibration flow data were developed from the field measurements. Actual measured flows surveyed in Icicle Creek are summarized in Table 5. The October, 2004 calibration data set was considered appropriate to use based on a comparison of cross sectional profiles among sample dates that showed very little change in stream channel morphology between October, 2004 and August, 2005. This was possibly a result of a drought and a subsequent unusually low spring (2005) peak flow that did not scour the channel.

Table 5. Calibration flows measured from lowest to highest at the Icicle Creek study sites.

Flows (cfs)	**Survey Dates**
47-59	August 16, 2005
178-195	July 6-7, 2005
240-244	October 26-27, 2004
327-362	June 14-15, 2005

Results of the PHABSIM analysis are summarized below. Photos and coordinates (NAD 83) of the study sites during the July, 2005 survey are shown in Figure 5.

Study Site 1- July, 2005- N 47º34'57.3"; W 120º39'29.5"

Study Site 2-July, 2005- N 47º34'25.3"; W 120º39'45.7"

Study Site 3-July, 2005- N 47º33'48.1"; W 120º40'03.4"

Figure 5. Photos of each study site in Icicle Creek, July, 2005.

Hydraulic WSE model calibration results are summarized in Table 6. The best WSE calibration occurred using STGQ (glides and riffles) and WSP (pools) sub-models. Simulated WSEs were within 0.05 ft of measured WSEs for all transects. The PHABSIM IFG4 input file with all 11 transects combined is located in Appendix B.

Multiple velocity calibration data sets were used as independent data sets for velocity modeling purposes. The velocity adjustment factor (VAF) is an index used by the velocity simulation model to adjust individual cell velocities/cell discharges. The VAF is the ratio of the flow requested for simulation and the flow calculated from velocity simulations. The VAF adjusts individual cell velocities by multiplying the VAF times the initial velocity to give a new velocity. Generally, the relationship between discharge and VAF is such that at simulated flows lower than the velocity calibration flows, the VAF is less than 1.0 and at simulated flows greater than the velocity calibration flow, VAF is greater than 1.0 (Waddle 2001). Table 7 presents VAFs for all transects over a range of simulated flows. The apparent “breaks” in VAF (i.e., occasional declines in VAF as flows increase) are due to using different velocity calibration sets to produce the velocity templates used for velocity simulation. Within the range of discharges for which a particular set of calibration velocity measurements were used to develop the velocity template, ascending VAF versus flow relationships indicated the expected outcome of velocity simulations. Although WDOE suggests an acceptable VAF range of 0.8-1.2 (Jim Pacheco, personal communication, 9/22/05), there is no basis for judging the “validity” or quality of the hydraulic simulations based strictly on the magnitude of the range in computed VAF values (i.e., no specific set of envelope values that the VAF should absolutely lie within) (Waddle 2001). The “shape” of the VAF versus discharge plot is a better indicator of model performance than the VAF magnitude. Based on this criterion, examination of Table 7 indicates that VAFs increase with discharge for each velocity calibration set, suggesting good model performance. Also, measured velocities across each transect closely matched simulated velocities at the calibration flows (i.e., within ± 0.2 ft/sec).

Table 6. Water surface elevation calibration results for Icicle Creek study sites.

Transect	Distance from next downstream transect (ft)	Water surface elevations (ft)											
		Measured	Simulated	Difference	Measured	Simulated	Difference	Measured	Simulated	Difference	Measured	Simulated	Difference
Study Site 1			47.0 cfs			178.2 cfs			244.4 cfs			358.6 cfs	
1	0	87.02	87.01	-0.01	87.53	87.56	0.03	87.73	87.71	-0.02	87.90	87.90	0.00
2	84	87.04	87.02	-0.02	87.51	87.56	0.05	87.73	87.71	-0.02	87.91	87.89	-0.02
3	250	87.68	87.68	0.00	88.18	88.18	0.00	88.43	88.43	0.00	88.62	88.62	0.00
4	56	87.69	87.68	-0.01	88.17	88.20	0.03	88.50	88.46	-0.04	88.65	88.67	0.02
Study Site 2			53.5 cfs			195.4 cfs			240.6 cfs			361.8 cfs	
1	0	91.07	91.06	-0.01	91.39	91.43	0.04	91.54	91.51	-0.03	91.67	91.67	0.00
2	105	91.41	91.40	-0.01	91.85	91.88	0.03	91.97	91.97	0.00	92.17	92.16	-0.01
3	56	91.44	91.44	0.00	91.88	91.88	0.00	92.05	92.05	0.00	92.22	92.22	0.00
4	38	91.44	91.44	0.00	91.89	91.89	0.00	92.05	92.06	0.02	92.24	92.24	0.00
Study Site 3			58.5 cfs			186.8 cfs			239.7 cfs			327.1 cfs	
1	0	90.41	90.41	0.00	91.08	91.10	0.02	91.35	91.30	-0.05	91.56	91.58	0.02
2	204	90.88	90.88	0.00	91.53	91.53	0.00	91.74	91.74	0.00	91.99	91.99	0.00
3	406	90.92	90.89	-0.03	91.51	91.56	0.05	91.83	91.78	-0.05	92.05	92.05	0.00

Table 7. Velocity adjustment factors for transects at each study site at simulated flows in Icicle Creek.

Flow (cfs)	Study Site 1 Transect Number 1	2	3	4	Flow (cfs)	Study Site 2 Transect Number 1	2	3	4	Flow (cfs)	Study Site 3 Transect Number 1	2	3
20	0.5	0.4	0.5	0.7	20	0.8	0.7	0.5	0.5	20	1.2	0.8	0.4
30	0.7	0.6	0.7	1.0	30	0.9	0.8	0.7	0.7	30	1.0	0.9	0.6
40	0.8	0.7	0.8	1.2	40	0.9	0.9	0.8	0.9	40	1.0	1.1	0.8
47.0*	0.9	0.7	0.8	1.4	50	0.9	1.0	1.0	1.1	50	0.9	1.2	1.0
50	0.4	0.4	0.5	0.5	53.5*	0.9	1.0	1.0	1.2	58.5*	0.9	1.2	1.1
60	0.5	0.4	0.6	0.5	60	0.7	0.6	0.5	0.3	60	1.0	0.6	0.3
70	0.5	0.5	0.6	0.6	70	0.7	0.6	0.5	0.3	70	1.0	0.6	0.3
80	0.6	0.5	0.6	0.7	80	0.7	0.7	0.6	0.4	80	1.0	0.7	0.4
90	0.6	0.6	0.7	0.7	90	0.7	0.7	0.6	0.4	90	1.0	0.7	0.4
100	0.6	0.6	0.7	0.8	100	0.7	0.7	0.6	0.4	100	1.0	0.7	0.4
120	0.7	0.7	0.8	0.9	120	0.8	0.8	0.7	0.5	120	1.0	0.8	0.5
140	0.8	0.8	0.8	1.0	140	0.8	0.8	0.8	0.6	140	1.0	0.9	0.6
160	0.8	0.8	0.9	1.1	160	0.8	0.9	0.9	0.7	160	1.0	0.9	0.6
178.2*	0.9	0.9	1.0	1.2	180	0.9	0.9	1.0	0.7	180	1.0	1.0	0.7
180	0.8	0.8	0.7	0.9	195.4*	0.9	1.0	1.1	0.8	186.8*	1.0	1.0	0.7
200	0.9	0.8	0.8	1.0	200	0.9	0.9	0.9	0.8	200	1.1	0.9	0.8
244.4*	1.0	0.9	0.8	1.1	240.6*	0.9	1.0	1.0	1.0	239.7*	1.1	1.0	0.9
250	0.8	0.8	0.8	0.9	250	0.9	0.9	0.8	0.8	250	1.0	0.9	0.8
300	0.9	0.9	0.9	1.0	300	0.9	1.0	0.9	0.9	300	1.0	1.0	0.9
350	0.9	1.0	1.0	1.1	350	1.0	1.0	1.0	1.0	327.1*	1.0	1.0	0.9
358.6*	1.0	1.0	1.0	1.1	361.8*	1.0	1.0	1.1	1.1	350	1.0	1.1	1.0
400	1.0	1.1	1.1	1.2	400	1.0	1.1	1.1	1.2	400	1.0	1.1	1.1
450	1.1	1.2	1.1	1.3	450	1.0	1.2	1.2	1.3	450	1.0	1.2	1.2
500	1.2	1.3	1.2	1.4	500	1.1	1.2	1.3	1.4	500	1.1	1.3	1.3
550	1.3	1.4	1.2	1.5	550	1.1	1.3	1.4	1.5	550	1.1	1.3	1.4
600	1.3	1.4	1.3	1.6	600	1.2	1.3	1.5	1.7	600	1.1	1.4	1.5
650	1.4	1.5	1.4	1.7	650	1.2	1.4	1.6	1.8	650	1.1	1.5	1.6
700	1.5	1.6	1.4	1.8	700	1.2	1.4	1.7	1.9	700	1.1	1.5	1.7
750	1.5	1.7	1.5	1.9	750	1.3	1.5	1.8	2.0	750	1.1	1.6	1.8
800	1.6	1.7	1.5	1.9	800	1.3	1.5	1.8	2.1	800	1.1	1.6	1.9

* Calibration flow

Figures 6-17 show WUA versus flow graphs for rearing and spawning life stages. Actual WUA values are presented in Tables 8-11.

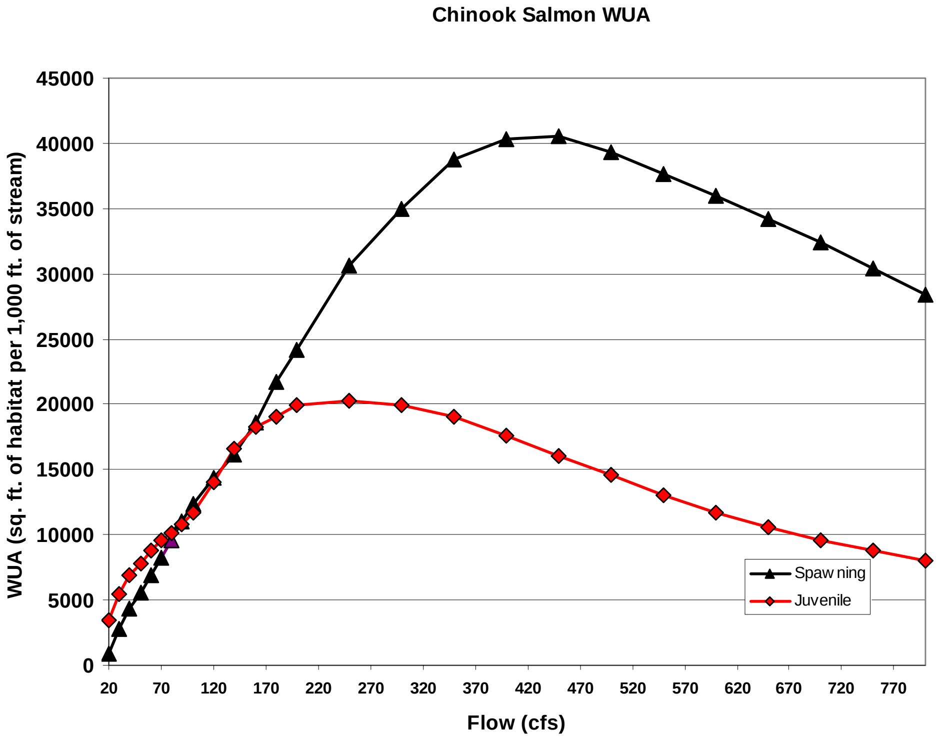


Figure 6. Weighted usable area versus flow relationships for Chinook salmon in Icicle Creek, Study Site 1.

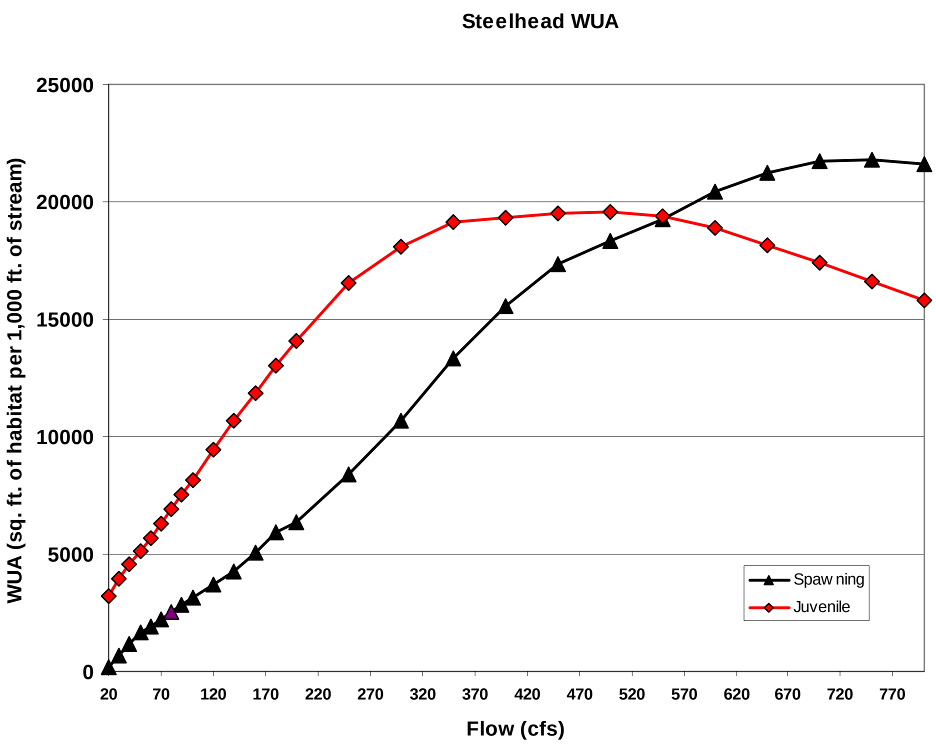


Figure 7. Weighted usable area versus flow relationships for steelhead in Icicle Creek, Study Site 1.

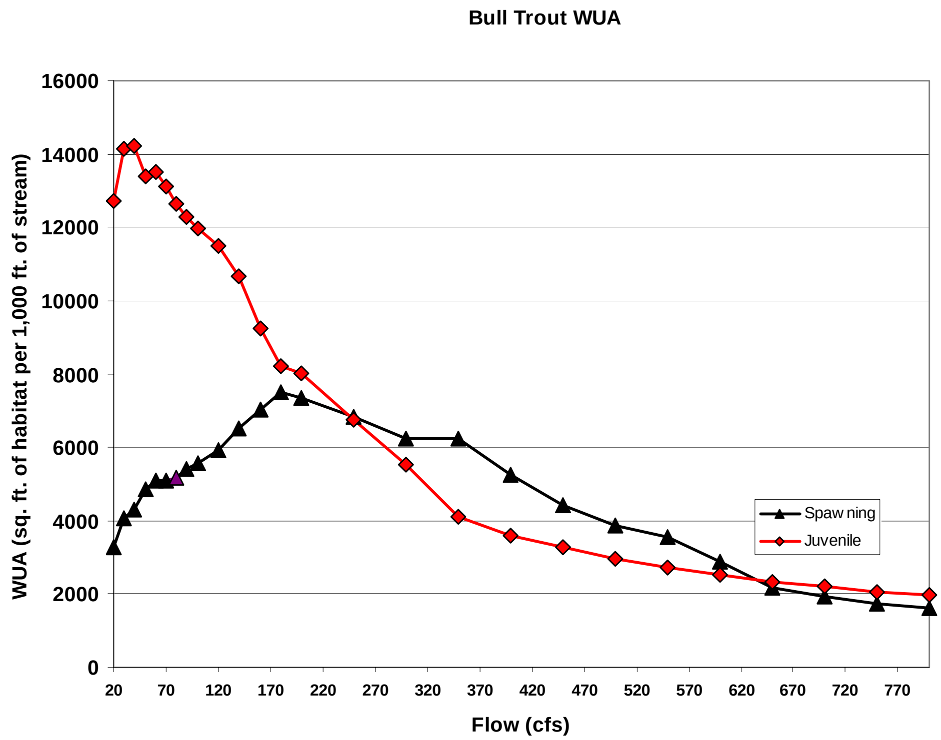


Figure 8. Weighted usable area versus flow relationships for bull trout in Icicle Creek, Study Site 1.

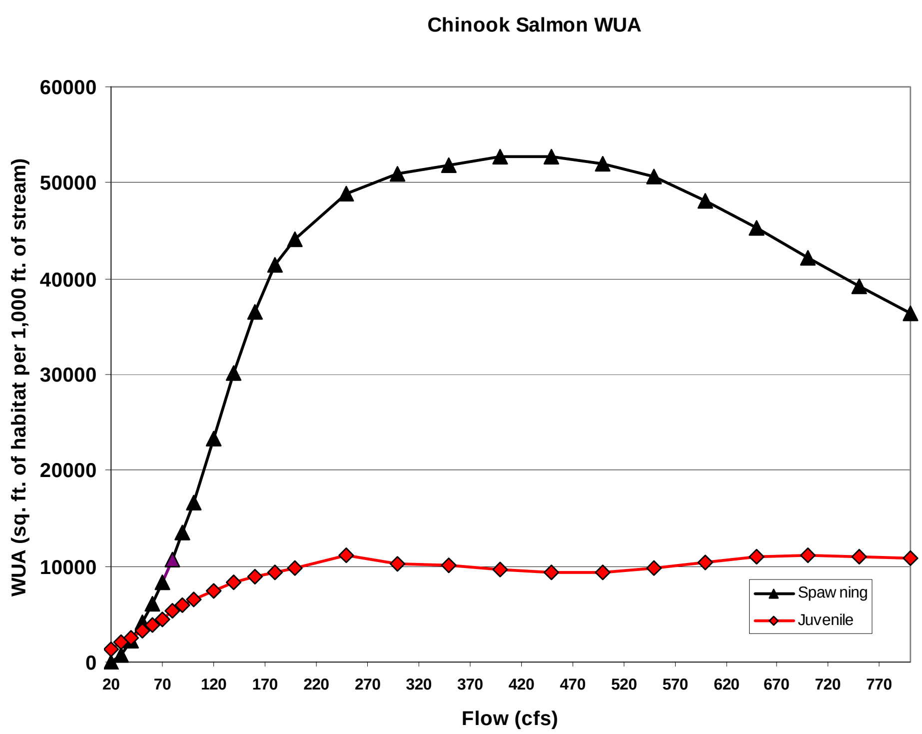


Figure 9. Weighted usable area versus flow relationships for Chinook salmon in Icicle Creek, Study Site 2.

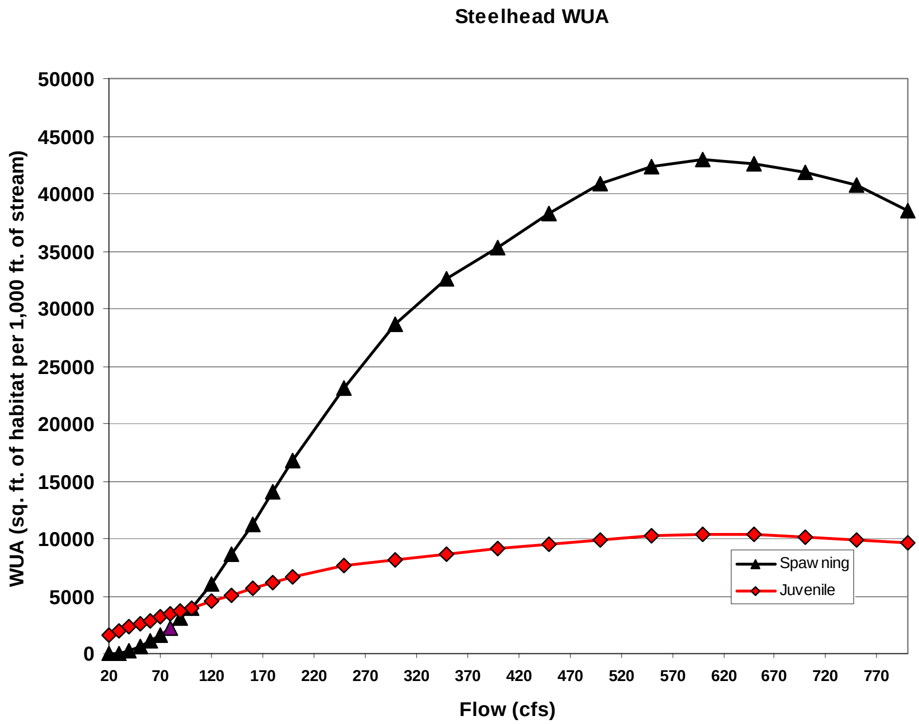


Figure 10. Weighted usable area versus flow relationships for steelhead in Icicle Creek, Study Site 2.

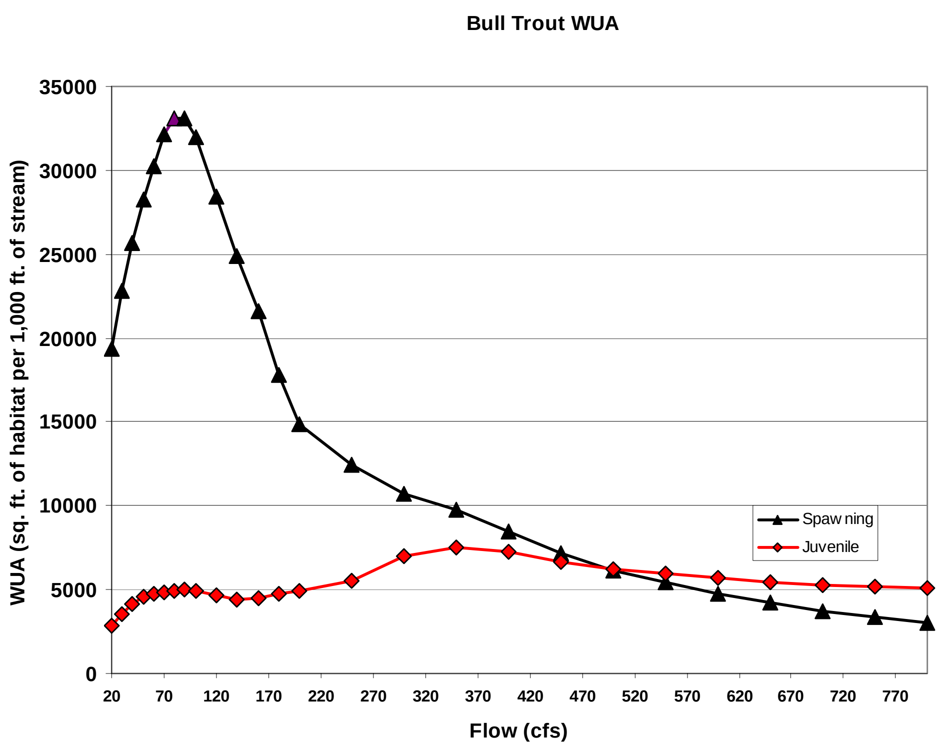


Figure 11. Weighted usable area versus flow relationships for bull trout in Icicle Creek, Study Site 2.

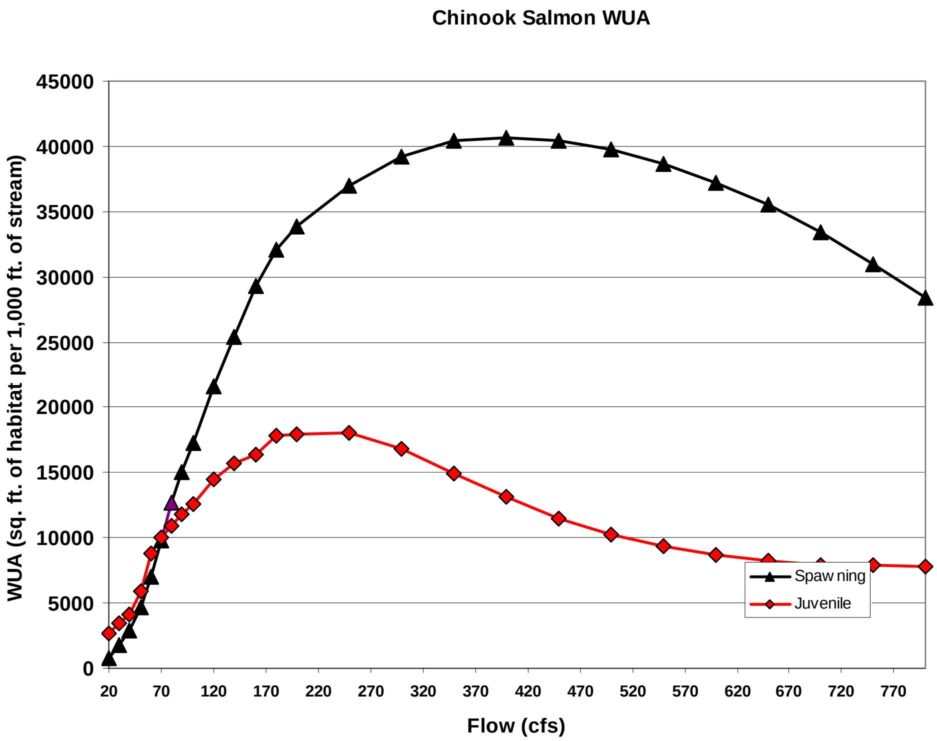


Figure 12. Weighted usable area versus flow relationships for Chinook salmon in Icicle Creek, Study Site 3.

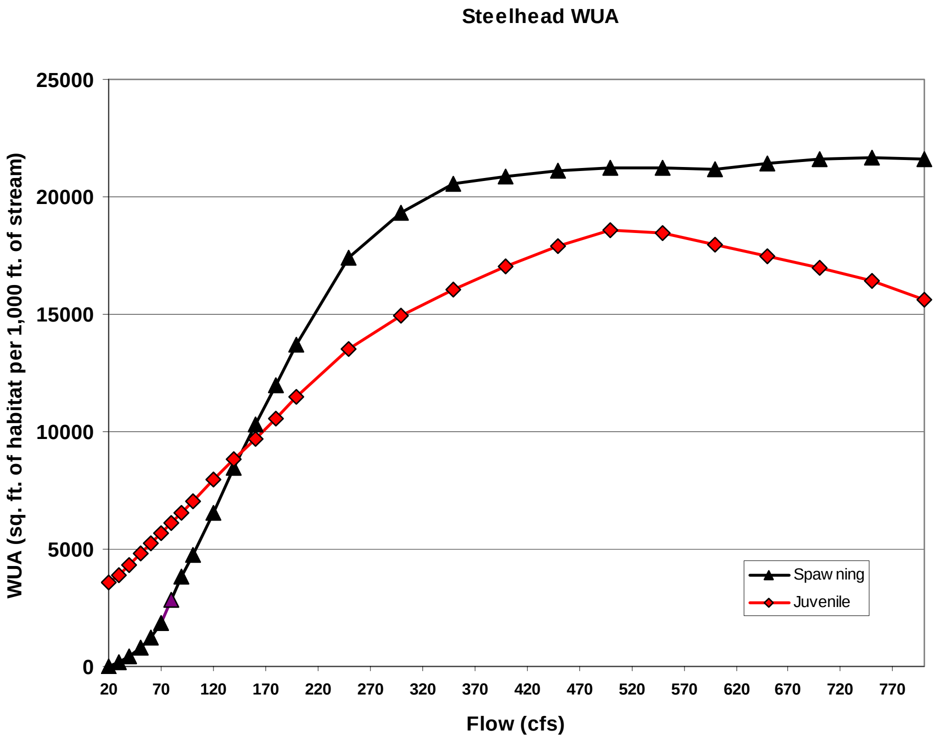


Figure 13. Weighted usable area versus flow relationships for steelhead in Icicle Creek, Study Site 3.

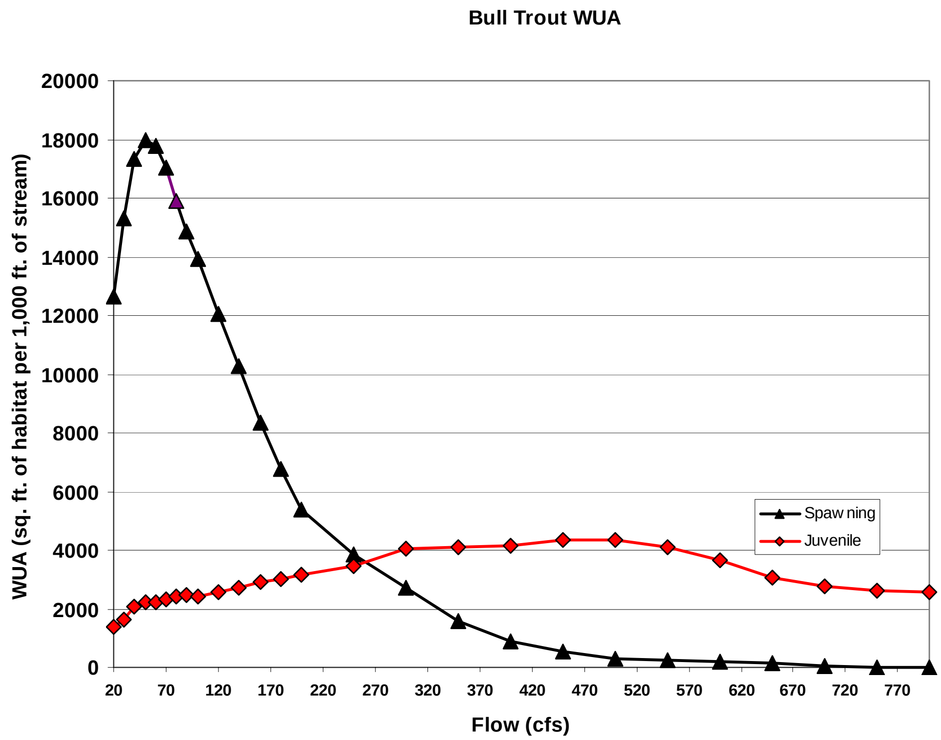


Figure 14. Weighted usable area versus flow relationships for bull trout in Icicle Creek, Study Site 3.

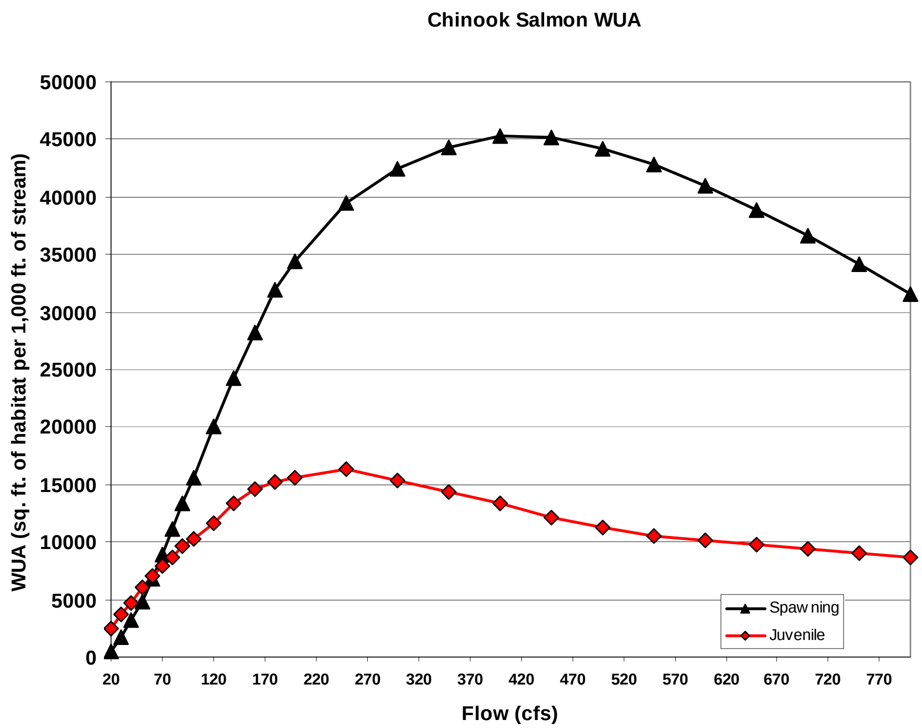


Figure 15. Weighted usable area versus flow relationships for Chinook salmon in Icicle Creek, Composite.

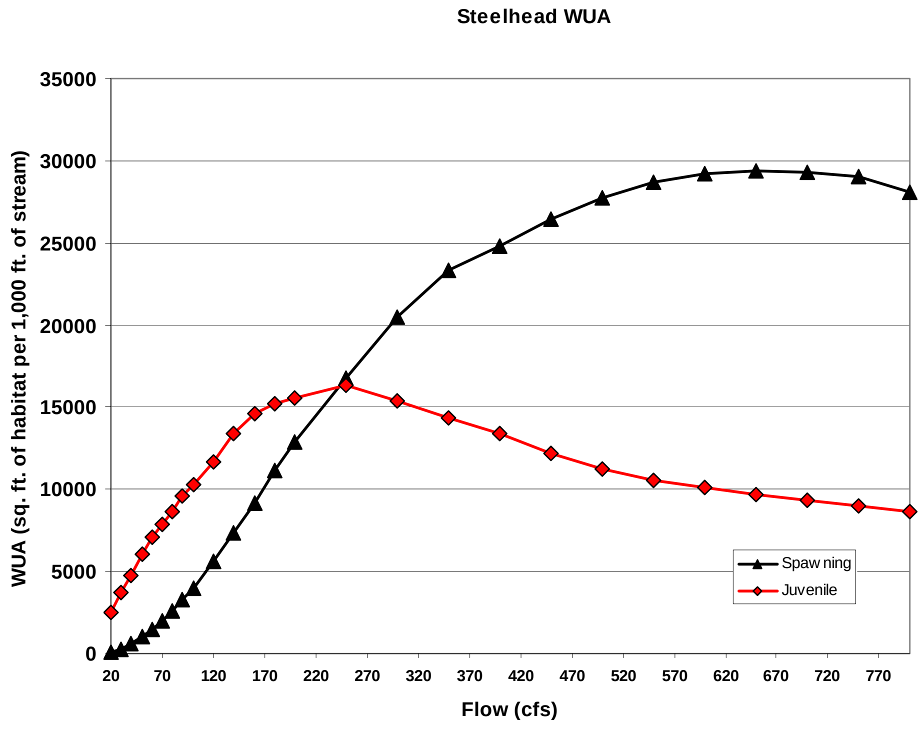


Figure 16. Weighted usable area versus flow relationships for steelhead in Icicle Creek, Composite.

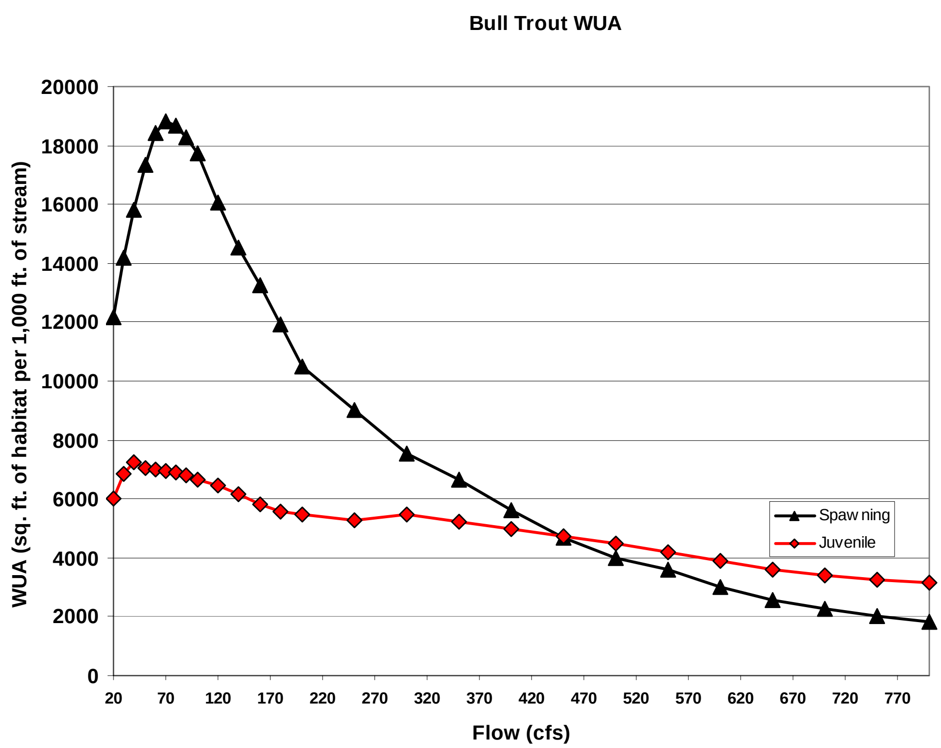


Figure 17. Weighted usable area versus flow relationships for bull trout in Icicle Creek, Composite.

Table 8. Weighted usable area (WUA) (ft^2/1,000 ft) versus flow in Icicle Creek, Study Site 1.

Flow (cfs)	Total Area	Chinook Salmon WUA		Chinook Salmon Percent of maximum WUA		Steelhead WUA		Steelhead Percent of maximum WUA		Bull Trout WUA		Bull Trout Percent of maximum WUA	
		Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile
20	103,107	934	3,439	2.3	16.9	182	3,222	0.8	16.5	3,267	12,704	43.4	89.3
30	106,958	2,782	5,424	6.9	26.7	649	3,926	3.0	20.1	4,089	14,135	54.4	99.4
40	108,775	4,333	6,925	10.7	34.1	1,192	4,545	5.5	23.2	4,289	14,220	57.0	100.0
50	108,340	5,542	7,810	13.7	38.4	1,640	5,135	7.5	26.2	4,869	13,391	64.7	94.2
60	113,059	6,887	8,790	17.0	43.3	1,923	5,699	8.8	29.1	5,096	13,527	67.7	95.1
70	114,028	8,207	9,538	20.2	46.9	2,208	6,296	10.1	32.2	5,102	13,108	67.8	92.2
80	114,955	9,583	10,106	23.6	49.7	2,519	6,914	11.6	35.3	5,190	12,654	69.0	89.0
90	115,850	11,024	10,771	27.2	53.0	2,824	7,547	13.0	38.6	5,417	12,269	72.0	86.3
100	116,670	12,367	11,721	30.5	57.7	3,121	8,165	14.3	41.7	5,574	11,981	74.1	84.3
120	117,962	14,343	14,064	35.4	69.2	3,690	9,424	16.9	48.2	5,911	11,491	78.6	80.8
140	118,847	16,102	16,631	39.7	81.8	4,281	10,667	19.7	54.5	6,518	10,654	86.7	74.9
160	119,522	18,566	18,236	45.8	89.7	5,035	11,877	23.1	60.7	7,037	9,242	93.6	65.0
180	116,012	21,720	19,058	53.6	93.8	5,899	13,032	27.1	66.6	7,522	8,224	100.0	57.8
200	120,297	24,204	19,991	59.7	98.4	6,378	14,054	29.3	71.8	7,345	8,036	97.6	56.5
250	121,098	30,677	20,320	75.7	100.0	8,399	16,517	38.6	84.4	6,851	6,742	91.1	47.4
300	121,816	35,018	19,967	86.4	98.3	10,656	18,087	48.9	92.4	6,239	5,516	82.9	38.8
350	122,766	38,716	19,089	95.5	93.9	13,359	19,163	61.3	97.9	6,230	4,099	82.8	28.8
400	123,320	40,322	17,604	99.5	86.6	15,578	19,332	71.5	98.8	5,240	3,606	69.7	25.4
450	123,692	40,530	16,069	100.0	79.1	17,337	19,488	79.6	99.6	4,422	3,282	58.8	23.1
500	124,030	39,264	14,622	96.9	72.0	18,334	19,565	84.2	100.0	3,852	2,964	51.2	20.8
550	124,345	37,613	13,050	92.8	64.2	19,290	19,367	88.6	99.0	3,567	2,725	47.4	19.2
600	124,639	35,927	11,663	88.6	57.4	20,412	18,878	93.7	96.5	2,900	2,518	38.6	17.7
650	124,914	34,185	10,568	84.3	52.0	21,215	18,157	97.4	92.8	2,178	2,331	29.0	16.4
700	125,175	32,360	9,629	79.8	47.4	21,715	17,382	99.7	88.8	1,923	2,195	25.6	15.4
750	125,419	30,412	8,785	75.0	43.2	21,780	16,607	100.0	84.9	1,757	2,074	23.4	14.6
800	125,655	28,372	7,995	70.0	39.3	21,579	15,815	99.1	80.8	1,615	1,977	21.5	13.9

Table 9. Weighted usable area (WUA) (ft^2/1,000 ft) versus flow in Icicle Creek, Study Site 2.

Flow (cfs)	Total Area	Chinook Salmon WUA		Chinook Salmon Percent of maximum WUA		Steelhead WUA		Steelhead Percent of maximum WUA		Bull Trout WUA		Bull Trout Percent of maximum WUA	
		Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile
20	103,289	21	1,411	0.0	12.6	0	1,662	0.0	15.9	19,353	2,826	58.5	37.4
30	110,897	780	2,017	1.5	18.0	47	1,984	0.1	19.0	22,819	3,566	68.9	47.2
40	118,633	2,263	2,587	4.3	23.1	256	2,288	0.6	21.9	25,708	4,190	77.7	55.4
50	126,993	4,152	3,216	7.9	28.7	632	2,583	1.5	24.8	28,224	4,554	85.2	60.2
60	127,722	6,113	3,867	11.6	34.5	1,100	2,873	2.6	27.5	30,254	4,715	91.4	62.4
70	128,293	8,265	4,511	15.7	40.3	1,627	3,160	3.8	30.3	32,129	4,824	97.0	63.8
80	128,775	10,697	5,293	20.3	47.3	2,277	3,438	5.3	33.0	33,107	4,939	100.0	65.3
90	129,212	13,455	6,001	25.5	53.6	3,051	3,720	7.1	35.7	33,105	4,975	100.0	65.8
100	129,747	16,582	6,570	31.4	58.7	3,922	4,001	9.1	38.4	31,985	4,923	96.6	65.1
120	130,749	23,316	7,406	44.2	66.2	6,107	4,563	14.2	43.7	28,399	4,683	85.8	61.9
140	131,538	30,079	8,293	57.0	74.1	8,641	5,110	20.1	49.0	24,911	4,397	75.2	58.2
160	132,176	36,473	8,908	69.2	79.6	11,284	5,632	26.2	54.0	21,611	4,514	65.3	59.7
180	132,725	41,423	9,369	78.6	83.7	14,086	6,122	32.8	58.7	17,795	4,741	53.7	62.7
200	133,099	44,048	9,769	83.5	87.3	16,846	6,610	39.2	63.4	14,822	4,942	44.8	65.4
250	133,827	48,870	11,195	92.7	100.0	23,082	7,613	53.7	73.0	12,484	5,517	37.7	73.0
300	134,430	50,978	10,302	96.7	92.0	28,613	8,160	66.5	78.2	10,754	6,981	32.5	92.3
350	134,955	51,762	10,060	98.2	89.9	32,539	8,634	75.7	82.8	9,807	7,560	29.6	100.0
400	135,430	52,651	9,665	99.9	86.3	35,302	9,122	82.1	87.5	8,510	7,252	25.7	95.9
450	135,773	52,727	9,340	100.0	83.4	38,216	9,518	88.9	91.2	7,194	6,640	21.7	87.8
500	136,087	52,025	9,365	98.7	83.7	40,893	9,938	95.1	95.3	6,141	6,237	18.5	82.5
550	136,378	50,654	9,775	96.1	87.3	42,386	10,306	98.6	98.8	5,449	5,935	16.5	78.5
600	136,634	48,103	10,433	91.2	93.2	42,997	10,431	100.0	100.0	4,732	5,719	14.3	75.7
650	136,873	45,261	10,933	85.8	97.7	42,557	10,312	99.0	98.9	4,194	5,479	12.7	72.5
700	137,100	42,228	11,100	80.1	99.2	41,856	10,084	97.3	96.7	3,702	5,275	11.2	69.8
750	137,315	39,231	10,984	74.4	98.1	40,786	9,837	94.9	94.3	3,375	5,155	10.2	68.2
800	137,520	36,317	10,846	68.9	96.9	38,459	9,645	89.4	92.5	3,043	5,084	9.2	67.2

Table 10. Weighted usable area (WUA) (ft^2/1,000 ft) versus flow in Icicle Creek, Study Site 3.

Flow (cfs)	Total Area	Chinook Salmon WUA		Percent of maximum WUA		Steelhead WUA		Percent of maximum WUA		Bull Trout WUA		Percent of maximum WUA	
		Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile
20	71,360	743	2,679	1.8	14.9	3	3,562	0.0	19.2	12,640	1,382	70.3	31.7
30	73,865	1,729	3,411	4.3	18.9	184	3,903	0.8	21.0	15,307	1,622	85.1	37.2
40	75,691	2,946	4,149	7.2	23.0	430	4,346	2.0	23.4	17,356	2,084	96.5	47.8
50	76,931	4,631	5,855	11.4	32.5	792	4,811	3.7	25.9	17,989	2,242	100.0	51.4
60	82,456	7,064	8,827	17.4	48.9	1,224	5,246	5.7	28.2	17,774	2,199	98.8	50.5
70	85,775	9,857	9,974	24.2	55.3	1,852	5,677	8.6	30.6	17,048	2,331	94.8	53.5
80	87,264	12,687	10,897	31.2	60.4	2,832	6,122	13.1	33.0	15,880	2,439	88.3	56.0
90	88,114	15,072	11,800	37.1	65.4	3,824	6,563	17.7	35.3	14,859	2,447	82.6	56.2
100	88,355	17,219	12,541	42.3	69.5	4,729	7,012	21.8	37.7	13,941	2,430	77.5	55.8
120	88,791	21,603	14,439	53.1	80.0	6,562	7,933	30.3	42.7	12,027	2,562	66.9	58.8
140	89,182	25,440	15,720	62.6	87.1	8,446	8,851	39.0	47.6	10,267	2,726	57.1	62.5
160	89,405	29,311	16,417	72.1	91.0	10,281	9,707	47.5	52.3	8,327	2,898	46.3	66.5
180	89,600	32,091	17,870	78.9	99.1	11,991	10,571	55.4	56.9	6,781	3,020	37.7	69.3
200	89,775	33,824	17,942	83.2	99.5	13,683	11,467	63.2	61.7	5,393	3,174	30.0	72.8
250	90,163	36,997	18,038	91.0	100.0	17,428	13,524	80.5	72.8	3,876	3,458	21.5	79.3
300	90,507	39,209	16,780	96.4	93.0	19,328	14,925	89.2	80.3	2,719	4,039	15.1	92.7
350	135,110	40,451	14,943	99.5	82.8	20,529	16,050	94.8	86.4	1,591	4,112	8.8	94.3
400	91,513	40,664	13,162	100.0	73.0	20,875	17,051	96.4	91.8	907	4,131	5.0	94.8
450	92,111	40,381	11,446	99.3	63.5	21,140	17,911	97.6	96.4	536	4,358	3.0	100.0
500	93,068	39,746	10,259	97.7	56.9	21,260	18,576	98.1	100.0	290	4,332	1.6	99.4
550	93,629	38,683	9,369	95.1	51.9	21,240	18,487	98.0	99.5	245	4,079	1.4	93.6
600	94,163	37,158	8,735	91.4	48.4	21,179	17,966	97.8	96.7	176	3,643	1.0	83.6
650	94,668	35,506	8,228	87.3	45.6	21,405	17,460	98.8	94.0	127	3,048	0.7	69.9
700	95,153	33,398	7,906	82.1	43.8	21,630	16,970	99.8	91.4	71	2,778	0.4	63.7
750	95,616	30,963	7,873	76.1	43.6	21,663	16,427	100.0	88.4	18	2,620	0.1	60.1
800	96,060	28,433	7,806	69.9	43.3	21,584	15,643	99.6	84.2	4	2,576	0.0	59.1

Table 11. Weighted usable area (WUA) (ft^2/1,000 ft) versus flow in Icicle Creek, composite of all sites.

Flow (cfs)	Total Area	Chinook Salmon WUA		Percent of maximum WUA		Steelhead WUA		Percent of maximum WUA		Bull Trout WUA		Percent of maximum WUA	
		Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile	Spawning	Juvenile
20	93,122	536	2,493	1.2	15.2	63	2,760	0.2	17.3	12,177	6,013	64.7	82.9
30	98,455	1,715	3,719	3.8	22.7	283	3,251	1.0	20.4	14,193	6,871	75.4	94.7
40	102,564	3,169	4,760	7.0	29.1	606	3,719	2.1	23.3	15,816	7,257	84.1	100.0
50	106,249	4,853	6,038	10.7	36.9	1,030	4,186	3.5	26.2	17,340	7,034	92.1	96.9
60	109,816	6,794	7,062	15.0	43.1	1,462	4,652	5.0	29.1	18,430	7,013	97.9	96.6
70	111,322	8,938	7,887	19.7	48.2	1,964	5,102	6.7	31.9	18,817	6,942	100.0	95.7
80	112,228	11,128	8,683	24.6	53.1	2,570	5,561	8.7	34.8	18,687	6,896	99.3	95.0
90	112,901	13,420	9,598	29.6	58.6	3,286	6,012	11.2	37.6	18,260	6,793	97.0	93.6
100	113,466	15,606	10,324	34.5	63.1	3,987	6,466	13.6	40.5	17,756	6,647	94.4	91.6
120	114,442	20,064	11,694	44.3	71.5	5,612	7,399	19.1	46.3	16,063	6,463	85.4	89.1
140	115,167	24,209	13,389	53.5	81.8	7,384	8,339	25.1	52.2	14,548	6,177	77.3	85.1
160	115,708	28,264	14,626	62.4	89.4	9,180	9,225	31.2	57.8	13,266	5,820	70.5	80.2
180	116,109	31,936	15,190	70.6	92.8	11,112	10,078	37.8	63.1	11,908	5,567	63.3	76.7
200	116,397	34,356	15,591	75.9	95.3	12,864	10,876	43.7	68.1	10,516	5,465	55.9	75.3
250	117,038	39,437	16,366	87.1	100.0	16,782	12,676	57.1	79.4	9,038	5,293	48.0	72.9
300	117,624	42,445	15,408	93.8	94.1	20,458	13,824	69.6	86.6	7,553	5,460	40.1	75.2
350	118,239	44,317	14,348	97.9	87.7	23,341	14,652	79.4	91.7	6,643	5,224	35.3	72.0
400	118,780	45,263	13,377	100.0	81.7	24,762	15,202	84.2	95.2	5,609	4,992	29.8	68.8
450	119,197	45,192	12,170	99.8	74.4	26,432	15,635	89.9	97.9	4,658	4,728	24.8	65.1
500	119,701	44,187	11,256	97.6	68.8	27,742	15,961	94.3	99.9	3,994	4,461	21.2	61.5
550	120,080	42,859	10,551	94.7	64.5	28,667	15,970	97.5	100.0	3,588	4,188	19.1	57.7
600	120,438	41,007	10,098	90.6	61.7	29,174	15,695	99.2	98.3	3,021	3,906	16.1	53.8
650	120,766	38,875	9,721	85.9	59.4	29,411	15,187	100.0	95.1	2,540	3,580	13.5	49.3
700	121,076	36,574	9,347	80.8	57.1	29,300	14,648	99.6	91.7	2,245	3,387	11.9	46.7
750	121,379	34,120	9,020	75.4	55.1	28,999	14,102	98.6	88.3	2,032	3,253	10.8	44.8
800	121,648	31,514	8,666	69.6	53.0	28,116	13,461	95.6	84.3	1,844	3,165	9.8	43.6

Discussion

The results presented in this report summarize the hydrology and habitat in Icicle Creek. PHABSIM analysis of the data collected and compiled for this study resulted in graphs that illustrate the relation between WUA and discharge. The highest point on the curves represents the discharge at which habitat is optimized for the life stage of interest. It should be understood that WUAs do not address water availability in any way and even the unregulated flow may commonly exceed or be less than the discharge at which maximum WUA is available. The amount of WUA available, in terms of lost or gained, can be determined by comparing to a reference or unregulated streamflow condition. Typically, the maximum, percentiles, or inflections are chosen from these curves at the level of protection desired or at points above which greater amounts of flow only provide minor gains in usable habitat.

The actual habitat experienced by fish in any river depends on the flow regime of the river. The development of habitat conditions over a period of time is an integral part of the comparison of flow regimes and developing target flows for aquatic needs. Habitat time series analysis involves interfacing a time series of streamflow data with the functional relationship between streamflow and habitat (WUA) (Bovee et al. 1998). This computational process is done for each flow regime alternative and life stage. Flow and habitat duration statistics are developed that allow a direct comparison of the changes that occur in both flow and habitat under a range of conditions. The amount of WUA available, in terms of lost or gained, can be determined by comparing WUA for an alternative flow regime to a reference or unregulated stream flow condition. The decision point in PHABSIM is a comparison of flow regimes.

The natural hydrograph needs to be considered when developing flow targets. In drought years, summer flows that provide maximum possible habitat may not be attainable because of the hydrologic limits on the stream.

Finally, it should be noted that PHABSIM was designed as a tool to provide science-based linkage between biology and river hydraulics with results to be used in negotiations or mediated settlements (Arthaud et al. 2001).

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Appendix A – Depth and Velocity Habitat Suitability Criteria for Icicle Creek

Chinook juveniles			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0.09	0	0
0.35	0.26	0.45	0
0.45	0.93	1.35	0.5
0.7	1	1.55	0.8
1.15	0.9	2.2	1
1.25	0.75	99.99	1
2.3	0.08		
3.6	0		
Chinook spawning			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0	0	0
0.5	0	0.5	0
1	0.9	1.2	1
1.75	1	3	1
2.25	1	3.5	0.5
4	0	4.5	0.07
		5	0
Steelhead juveniles			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0.23	0	0
0.25	0.3	0.25	0
0.9	0.8	1.8	0.39
1.35	1	2.65	1
1.55	1	2.95	1
2.6	0.8	4.5	0.64
2.95	0.39	99.9	0.64
3.65	0.22		
5.5	0.16		
6	0		
Steelhead spawning			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0	0	0
0.55	0	0.65	0
2.5	1	1.25	1
3.25	1	1.55	1
3.45	0.62	2.4	0.5
5	0	99.99	0.5
Bull trout juvenile/adult rearing			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0.16	0	0
0.1	1	0.45	0
0.4	1	1.3	0.56
0.8	0.2	1.5	1
1.6	0.2	2	1
2.8	0	2.1	0.67
		2.9	0.67
		3	0

Bull trout spawning			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0.03	0	0
0.35	0.48	0.1	0
0.5	1	0.3	0.18
0.95	1	0.5	1
1.1	0.4	0.7	1
2	0.13	1.3	0.29
2.1	0	2.1	0.2
		2.2	0
Coho spawning			
Velocity (ft/sec)	Preference	Depth (ft)	Preference
0	0.4	0	0
0.25	0.4	0.45	0
1.05	1	1.15	0.75
1.8	0.81	2.05	1
2.65	0.29	3.25	0.09
3.9	0	4	0.01
		5	0

Appendix B – PHABSIM Input File for Icicle Creek

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Icicle Creek Composite
Export from PHABSIM for Windows
IOC       0000000100010000100000
QARD  20.0
QARD  30.0
QARD  40.0
QARD  50.0
QARD  53.5
QARD  60.0
QARD  70.0
QARD  80.0
QARD  90.0
QARD 100.0
QARD 120.0
QARD 140.0
QARD 160.0
QARD 180.0
QARD 195.4
QARD 200.0
QARD 240.6
QARD 250.0
QARD 300.0
QARD 350.0
QARD 361.8
QARD 400.0
QARD 450.0
QARD 500.0
QARD 550.0
QARD 600.0
QARD 650.0
QARD 700.0
QARD 750.0
QARD 800.0
XSEC   1.0       0.0 1.0     84.20   0.00012
       1.0  0.0 92.0  8.2 90.9 12.4 88.4 16.1 87.9 17.4 87.5 18.5 87.3
       1.0 18.7 87.0 20.0 86.5 22.0 86.3 24.0 86.5 26.0 86.8 28.0 86.9
       1.0 30.0 87.0 32.0 87.1 34.0 87.1 36.0 87.1 38.0 87.0 40.0 87.1
       1.0 42.0 87.0 44.0 86.9 46.0 86.8 48.0 86.8 50.0 86.7 52.0 86.6
       1.0 54.0 86.6 56.0 86.5 58.0 86.4 60.0 86.3 62.0 86.3 64.0 86.2
       1.0 66.0 86.2 68.0 85.9 70.0 85.9 72.0 85.8 74.0 85.7 76.0 85.7
       1.0 78.0 85.5 80.0 85.5 82.0 85.3 84.0 85.2 86.0 85.2 88.0 85.1
       1.0 90.0 84.9 92.0 84.7 94.0 84.5 96.0 84.2 98.0 84.2100.0 84.2
       1.0102.0 84.2106.0 84.5110.0 84.7114.0 85.3118.0 85.5122.0 85.9
       1.0126.0 86.3130.0 86.7131.5 87.0133.0 87.2134.8 93.9
NS     1.0       0.9       0.9  1.0  0.7  1.0  0.2  1.0  0.2  1.0  0.4
NS     1.0  1.0  0.4  1.0 12.9      25.9      35.8      54.5      54.5
NS     1.0      45.7      54.8      54.8      45.5      45.7      45.7
NS     1.0      54.8      54.8      54.8      74.8      74.8      74.7
NS     1.0      74.5      74.8      74.8      74.8      74.8      74.8
NS     1.0      74.8      47.6      47.6      74.6      74.6      74.7
NS     1.0      74.7      74.8      74.9      76.9      76.9      76.9
NS     1.0      76.9      76.6      76.6      67.5      67.9      67.9
NS     1.0      67.9      67.9      67.9  1.0 67.9      67.9      67.9
NS     1.0      67.9      67.9      67.9       0.2       0.9
WSL    1.0      86.7      86.8      86.9      87.0      87.0      87.1
WSL    1.0      87.2      87.2      87.3      87.3      87.4      87.5
WSL    1.0      87.5      87.6      87.6      87.6      87.7      87.7
WSL    1.0      87.8      87.9      87.9      87.9      88.0      88.1
WSL    1.0      88.1      88.2      88.2      88.2      88.3      88.3
CAL1   1.0     87.90    361.80    358.60
VEL1   1.0                 0.00 0.00 0.00 0.20 0.43 0.40 0.92 1.05 1.28
VEL1   1.0 1.24 1.24 1.19 1.24 1.28 1.40 1.35 1.40 1.55 1.56 1.56 1.33
VEL1   1.0 1.58 1.57 1.77 1.60 1.71 1.70 1.65 1.48 1.38 1.43 1.49 1.55
VEL1   1.0 1.62 1.81 1.79 1.93 1.77 1.88 1.97 1.79 1.99 2.05 2.11 1.87
VEL1   1.0 2.18 2.09 1.98 1.87 1.72 1.37 1.06 0.69 0.31 0.07
CAL2   1.0     87.73    240.60    244.40
VEL2   1.0                      0.00 0.03 0.00 0.83 0.72 0.82 0.79 0.90
VEL2   1.0 0.87 0.89 0.84 1.04 1.07 0.97 1.07 1.06 0.88 0.94 1.24 1.12
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VEL2   1.0 1.40 1.22 1.30 1.28 1.27 1.45 1.43 1.28 1.21 1.33 1.43 1.48
VEL2   1.0 1.41 1.49 1.61 1.66 1.60 1.54 1.59 1.63 1.60 1.35 1.57 1.44
VEL2   1.0 1.32 1.47 1.34 1.15 0.69 0.52 0.06 0.10 0.00 0.00
CAL3   1.0     87.53    195.40    178.20
VEL3   1.0                     0.00 0.35 0.35 0.83 0.81 0.83 0.70 0.71
VEL3   1.0 0.61 0.48 0.43 0.48 0.50 0.53 0.56 0.61 0.79 0.72 0.78 0.71
VEL3   1.0 0.83 0.95 0.94 0.91 0.89 0.97 1.09 1.05 1.06 1.14 1.09 1.31
VEL3   1.0 1.22 1.43 1.46 1.36 1.50 1.36 1.55 1.57 1.37 1.50 1.34 1.40
VEL3   1.0 1.13 1.18 0.96 0.78 0.62 0.02 0.14 0.08 0.00 0.00
CAL4   1.0     87.02     53.50     47.00
VEL4   1.0                               0.00 0.43 0.51 0.55 0.23 0.00
VEL4   1.0 0.00                0.00      0.00 0.00 0.06 0.08 0.19 0.23
VEL4   1.0 0.25 0.36 0.37 0.45 0.37 0.52 0.55 0.44 0.45 0.58 0.63 0.60
VEL4   1.0 0.72 0.70 0.68 0.79 0.78 0.71 0.74 0.57 0.58 0.47 0.49 0.30
VEL4   1.0 0.38 0.30 0.20 0.00 0.04 0.19 0.04 0.10 0.00
XSEC   2.0      69.0 1.0     84.70   0.00268
       2.0  0.0 91.6  3.1 90.4  5.4 88.8  9.0 87.8 10.0 87.9 11.4 87.5
       2.0 12.0 87.2 15.0 87.0 18.0 86.6 21.0 86.3 24.0 86.0 27.0 85.6
       2.0 30.0 85.7 33.0 85.2 36.0 85.2 39.0 85.4 42.0 85.6 45.0 85.6
       2.0 48.0 85.5 51.0 85.4 54.0 85.5 57.0 85.4 60.0 85.3 63.0 85.3
       2.0 66.0 85.3 69.0 85.4 72.0 85.4 75.0 85.4 78.0 85.3 81.0 85.2
       2.0 84.0 84.8 87.0 84.7 90.0 85.1 93.0 85.6 96.0 86.0 99.0 86.5
       2.0102.0 86.8105.0 87.2108.0 87.3111.0 87.4113.0 87.5114.0 87.7
       2.0115.2 87.9118.0 89.0119.3 90.5123.2 92.5
NS     2.0     0.9         0.9      11.9      22.9      22.9      21.8
NS     2.0      21.8      21.8      25.9      26.7      62.7      62.9
NS     2.0      65.6      56.6      56.6      76.8      76.8      56.9
NS     2.0      26.7      26.7      52.8      65.6      65.6      65.6
NS     2.0      65.6      65.6      56.8      56.8      56.6      56.6
NS     2.0      56.6      65.6      65.8      67.9      67.9      67.9
NS     2.0      67.9      67.9  1.0 67.9  1.0 67.9  1.0 67.9  1.0 67.9
NS     2.0  1.0 67.9       0.8       0.8       0.9
WSL    2.0      86.7      86.9      87.0      87.1      87.0      87.1
WSL    2.0      87.2      87.2      87.3      87.3      87.4      87.5
WSL    2.0      87.5      87.6      87.6      87.6      87.7      87.7
WSL    2.0      87.8      87.9      87.9      87.9      88.0      88.1
WSL    2.0      88.1      88.2      88.2      88.3      88.3      88.3
CAL1   2.0     87.91    361.80    385.10
VEL1   2.0                0.00 0.00 0.07 0.15 0.08 0.06 0.30 0.69 1.11
VEL1   2.0 1.74 2.00 1.71 1.73 1.29 0.88 0.62 0.59 1.09 1.37 1.71 1.93
VEL1   2.0 1.99 2.29 2.63 2.74 2.79 2.41 2.64 3.03 2.36 1.68 1.48 1.17
VEL1   2.0 1.05 0.93 0.74 0.43 0.20 0.05 0.00
CAL2   2.0     87.73    240.60    260.90
VEL2   2.0                0.00 0.00 0.00 0.03 0.15 0.13 0.03 0.13 0.40
VEL2   2.0 0.78 1.15 1.72 1.80 1.38 0.76 0.75 0.69 0.85 1.11 1.49 1.93
VEL2   2.0 2.09 2.06 2.14 2.43 2.66 2.07 2.00 2.66 1.77 1.25 0.79 0.56
VEL2   2.0 0.35 0.25 0.17 0.06 0.00 0.00
CAL3   2.0     87.51    195.40    178.20
VEL3   2.0                          0.00 0.08 0.12 0.13 0.13 0.09 0.05
VEL3   2.0 0.10 0.20 0.54 0.64 0.87 0.98 0.87 0.80 0.86 0.92 1.14 1.44
VEL3   2.0 1.68 2.00 2.08 2.62 2.42 1.74 1.99 2.17 1.08 0.61 0.27 0.08
VEL3   2.0 0.02 0.06 0.18 0.00 0.00
CAL4   2.0     87.04     53.50     50.90
VEL4   2.0                                    0.00 0.08 0.11 0.06 0.05
VEL4   2.0 0.08 0.10 0.08 0.08 0.05 0.04 0.05 0.03 0.12 0.14 0.33 0.74
VEL4   2.0 0.98 1.21 2.17 1.43 1.95 0.42 0.87 0.45 0.45 0.02 0.13 0.20
VEL4   2.0
XSEC   3.0     121.6 1.0     85.40   0.00054
       3.0  0.0 94.0  2.2 93.7  3.6 88.6  4.5 88.0  5.0 88.2  7.0 87.7
       3.0  8.0 87.2 12.0 87.0 16.0 86.8 20.0 87.2 24.0 87.5 28.0 87.7
       3.0 32.0 87.6 36.0 87.3 40.0 87.1 44.0 86.9 48.0 86.8 52.0 86.9
       3.0 56.0 86.9 60.0 87.0 64.0 87.3 68.0 87.4 72.0 87.4 76.0 87.2
       3.0 80.0 87.1 84.0 86.8 88.0 86.5 92.0 86.1 96.0 85.8100.0 85.6
       3.0104.0 85.5108.0 85.4112.0 85.5116.0 85.7120.0 86.5124.0 86.5
       3.0128.0 86.9132.0 87.3136.0 87.7141.0 88.2141.5 88.2145.0 88.6
       3.0164.6 91.2171.7 95.3
NS     3.0     0.9         0.9       0.2       0.2       0.2       0.2
NS     3.0     0.2        42.8      43.6      43.8      43.8      45.8
NS     3.0      45.8      53.7      53.7      35.8      35.8      35.8
NS     3.0      35.8      35.8      54.5      54.7      54.8      54.8
NS     3.0      54.7      54.7      54.7      54.7      54.7      54.8
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NS     3.0      54.8      54.9      45.7      45.7      65.7      65.7
NS     3.0      56.8      65.9      64.8  1.0 54.9  1.0 54.9  1.0 67.9
NS     3.0      67.9      16.5
WSL    3.0      87.3      87.5      87.6      87.7      87.7      87.8
WSL    3.0      87.8      87.9      87.9      88.0      88.1      88.1
WSL    3.0      88.2      88.3      88.2      88.3      88.4      88.4
WSL    3.0      88.5      88.6      88.6      88.7      88.7      88.8
WSL    3.0      88.8      88.9      88.9      89.0      89.0      89.1
CAL1   3.0     88.62    361.80    365.20
VEL1   3.0           0.00 0.16 0.67 0.92 1.17 1.43 1.36 1.12 1.36 1.47
VEL1   3.0 1.45 1.11 1.18 1.05 1.03 1.07 0.99 1.10 1.12 1.34 1.57 1.44
VEL1   3.0 1.36 1.59 1.61 1.56 1.64 1.95 1.64 1.86 1.82 1.63 1.85 1.93
VEL1   3.0 1.92 1.72 1.45 1.00 0.54 0.00
CAL2   3.0     88.43    240.60    252.80
VEL2   3.0                0.18 0.23 0.24 0.27 1.60 1.55 1.61 1.20 1.09
VEL2   3.0 1.03 0.90 0.95 0.75 0.79 0.79 0.84 0.85 0.94 0.93 1.14 1.14
VEL2   3.0 1.58 1.50 1.44 1.43 1.60 1.61 1.26 1.55 1.63 1.68 1.74 1.67
VEL2   3.0 1.57 1.59 1.29 0.65 0.00
CAL3   3.0     88.18    195.40    171.70
VEL3   3.0                     0.00 0.45 0.91 0.88 0.74 0.64 0.58 0.44
VEL3   3.0 0.38 0.46 0.47 0.39 0.43 0.37 0.42 0.50 0.50 0.54 0.72 0.67
VEL3   3.0 1.11 1.18 1.15 1.20 1.36 1.23 1.29 1.24 1.23 1.26 1.32 1.33
VEL3   3.0 1.17 1.21 0.59 0.00 0.00
CAL4   3.0     87.68     53.50     51.30
VEL4   3.0                          0.00 0.00 0.08 0.11 0.27 0.00 0.00
VEL4   3.0 0.00 0.15 0.13 0.07 0.09 0.06 0.02 0.02 0.12 0.02 0.21 0.17
VEL4   3.0 0.47 0.60 0.65 0.56 0.59 0.97 0.67 0.75 0.65 0.64 0.64 0.60
VEL4   3.0 0.53 0.20 0.00
XSEC   4.0       9.3 1.0     85.40   0.00054
       4.0  0.0 94.5  8.3 91.0 14.0 88.5 15.0 88.2 19.0 87.2 24.0 87.3
       4.0 29.0 87.4 34.0 86.6 39.0 86.8 44.0 86.4 49.0 86.0 54.0 85.4
       4.0 59.0 85.1 64.0 84.9 69.0 84.8 74.0 85.0 79.0 84.9 84.0 84.9
       4.0 89.0 84.8 94.0 84.5 99.0 84.5104.0 84.6109.0 84.7114.0 84.7
       4.0119.0 84.6124.0 84.8129.0 84.9134.0 85.5139.0 86.2144.0 87.5
       4.0146.8 88.0147.0 87.7148.4 88.2150.2 88.7152.4 89.7156.8 94.1
NS     4.0       0.9       0.2  1.0  0.2       0.2      21.8      22.9
NS     4.0      22.9      23.9      22.9      22.9      22.9      21.9
NS     4.0      22.9      22.9      21.9      21.9      21.9      21.9
NS     4.0      21.9      22.9      25.9      25.9      24.7      24.7
NS     4.0      52.7      65.6      56.6      56.8  1.0 65.8  1.0 65.8
NS     4.0  1.0 56.8  1.0 65.5  1.0 65.5  1.0 65.5      11.9       0.9
WSL    4.0      87.4      87.5      87.6      87.7      87.7      87.8
WSL    4.0      87.8      87.9      87.9      88.0      88.1      88.1
WSL    4.0      88.2      88.3      88.2      88.3      88.5      88.4
WSL    4.0      88.6      88.6      88.7      88.7      88.8      88.9
WSL    4.0      88.9      89.0      89.1      89.1      89.2      89.2
CAL1   4.0     88.65    361.80    320.00
VEL1   4.0           0.00 0.00 0.61 0.90 0.75 0.62 0.55 0.71 0.69 0.68
VEL1   4.0 0.66 0.70 0.65 0.81 0.76 0.79 0.88 0.88 0.90 0.88 0.83 0.94
VEL1   4.0 0.82 0.69 0.86 0.74 0.77 0.62 0.37 0.28 0.19 0.00
CAL2   4.0     88.50    240.60    235.40
VEL2   4.0           0.00 0.21 0.42 0.48 0.47 0.48 0.47 0.46 0.44 0.47
VEL2   4.0 0.48 0.50 0.51 0.53 0.55 0.61 0.65 0.67 0.68 0.74 0.71 0.65
VEL2   4.0 0.65 0.70 0.58 0.66 0.55 0.33 0.00 0.00 0.00
CAL3   4.0     88.17    195.40    146.70
VEL3   4.0                0.00 0.43 0.48 0.38 0.27 0.28 0.29 0.31 0.34
VEL3   4.0 0.30 0.35 0.34 0.40 0.39 0.43 0.57 0.48 0.54 0.40 0.52 0.50
VEL3   4.0 0.49 0.51 0.41 0.47 0.37 0.31 0.01 0.00 0.00
CAL4   4.0     87.69     53.50     30.70
VEL4   4.0                     0.07 0.08 0.00 0.03 0.10 0.14 0.13 0.10
VEL4   4.0 0.08 0.07 0.05 0.08 0.11 0.10 0.13 0.12 0.20 0.13 0.32 0.14
VEL4   4.0 0.19 0.12 0.11 0.12 0.05 0.06      0.00
XSEC   5.0     156.3 1.0     90.20   0.00478
       5.0  0.0 98.7 10.0 91.7 11.0 91.5 12.3 91.1 15.0 90.8 20.0 90.9
       5.0 25.0 90.4 30.0 90.2 35.0 90.3 40.0 90.8 45.0 91.0 50.0 90.9
       5.0 55.0 91.0 60.0 91.0 65.0 91.0 70.0 90.9 75.0 90.9 80.0 91.0
       5.0 85.0 90.9 90.0 90.9 95.0 90.7100.0 90.6105.0 90.6110.0 90.4
       5.0115.0 90.4120.0 90.5125.0 90.3130.0 90.4135.0 90.3140.0 90.6
       5.0145.0 90.8150.0 90.9154.0 91.1155.0 91.2160.0 91.3162.5 91.4
       5.0163.5 91.5165.0 91.7165.2 91.9166.3 95.3177.8 97.5
NS     5.0       0.9       0.1       0.1      54.9      54.9      54.9
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NS     5.0      54.6      54.6      54.6  1.0 54.6  1.0 45.6  1.0 54.6
NS     5.0  1.0 54.6  1.0 53.8  1.0 53.8      53.8      53.8      54.9
NS     5.0      54.9      54.8      54.8  1.0 54.8  1.0 54.6  1.0 54.6
NS     5.0  1.0 54.6  1.0 45.8  1.0 45.8      45.9      45.9      45.8
NS     5.0      45.8      45.8      45.8      45.8      43.9      43.9
NS     5.0       0.2       0.1       0.1       0.9       0.9
WSL    5.0      90.8      90.9      91.0      91.0      91.1      91.1
WSL    5.0      91.1      91.2      91.2      91.2      91.3      91.3
WSL    5.0      91.4      91.4      91.4      91.4      91.5      91.5
WSL    5.0      91.6      91.7      91.7      91.7      91.8      91.8
WSL    5.0      91.8      91.9      91.9      92.0      92.0      92.0
CAL1   5.0     91.07     53.50     57.20
VEL1   5.0                0.00 0.15 0.51 0.73 1.00 0.74 0.29 0.13 0.28
VEL1   5.0 0.00 0.00 0.00 0.33 0.81 0.43 0.58 1.41 1.36 1.51 1.86 1.42
VEL1   5.0 1.75 1.45 1.51 1.43 1.69 1.01 0.69 0.41 0.00
VEL1   5.0
CAL2   5.0     91.39    195.40    212.30
VEL2   5.0           0.00 0.40 0.82 1.35 1.64 2.56 1.57 1.35 0.89 0.95
VEL2   5.0 0.62 0.30 0.82 1.02 1.61 1.97 1.97 2.65 2.93 2.42 2.77 2.51
VEL2   5.0 2.73 2.95 2.61 2.81 2.60 2.47 1.28 1.83 1.14 0.45 0.69 0.00
VEL2   5.0 0.00
CAL3   5.0     91.54    240.60    258.00
VEL3   5.0           0.00 0.50 0.99 1.87 2.35 2.60 1.78 1.27 0.98 0.93
VEL3   5.0 0.90 0.70 0.79 0.88 1.60 1.78 2.38 2.71 2.79 3.11 2.93 2.61
VEL3   5.0 3.07 2.77 3.00 2.66 3.33 3.40 1.89 1.83 1.70 1.57 0.51 0.25
VEL3   5.0 0.00
CAL4   5.0     91.67    361.80    387.80
VEL4   5.0      0.00 0.06 0.64 1.27 1.94 2.38 3.24 2.95 2.09 1.56 0.81
VEL4   5.0 0.66 0.50 0.23 0.47 1.46 1.95 2.97 3.46 3.53 3.54 3.53 3.63
VEL4   5.0 3.48 3.53 3.17 3.52 3.43 3.81 2.59 2.71 2.57 2.42 2.37 2.00
VEL4   5.0 1.55 0.00
XSEC   6.0      69.0 1.0     90.10   0.00090
       6.0  0.0 98.4  8.7 92.2 11.0 91.4 14.0 90.7 19.0 90.7 24.0 90.5
       6.0 29.0 90.5 34.0 90.9 39.0 90.8 44.0 90.6 49.0 90.4 54.0 90.5
       6.0 59.0 90.5 64.0 90.4 69.0 90.5 74.0 90.5 79.0 90.4 84.0 90.7
       6.0 89.0 90.5 94.0 90.2 99.0 90.1104.0 90.3109.0 90.3114.0 90.6
       6.0119.0 91.1124.0 91.2129.0 90.9134.0 90.7139.0 90.8144.0 90.6
       6.0149.0 90.6151.0 91.4152.0 92.0157.3 93.0160.1 93.9164.5 94.9
NS     6.0       0.9       0.2      58.8      58.8      58.8      53.8
NS     6.0      53.8      53.8      53.8      54.8      53.8      54.8
NS     6.0      53.9      53.9      53.9      52.9      52.9      52.9
NS     6.0      52.9      52.9      52.9      54.8      54.8      45.7
NS     6.0      45.7      45.7      45.9      45.9      45.9      45.9
NS     6.0  1.0 45.9  1.0 21.9      21.9       0.7       0.8       0.9
WSL    6.0      91.1      91.2      91.3      91.4      91.4      91.4
WSL    6.0      91.5      91.5      91.6      91.6      91.7      91.7
WSL    6.0      91.8      91.8      91.9      91.9      92.0      92.0
WSL    6.0      92.1      92.1      92.2      92.2      92.3      92.3
WSL    6.0      92.4      92.4      92.5      92.5      92.6      92.6
CAL1   6.0     91.41     53.50     53.50
VEL1   6.0           0.00 0.06 0.27 0.48 0.42 0.33 0.27 0.30 0.26 0.36
VEL1   6.0 0.35 0.45 0.43 0.66 0.52 0.42 0.63 0.65 0.76 0.91 0.70 0.80
VEL1   6.0 0.72 0.73 0.14 0.15 0.32 0.49 0.36 0.00
CAL2   6.0     91.85    195.40    195.40
VEL2   6.0           0.00 0.04 0.31 1.12 1.01 1.17 1.13 1.08 1.03 1.13
VEL2   6.0 1.14 1.01 1.20 1.25 0.90 1.13 1.23 1.39 1.18 1.39 1.39 1.33
VEL2   6.0 1.32 1.43 1.09 1.26 1.35 1.21 0.33 0.15
CAL3   6.0     91.97    240.60    240.60
VEL3   6.0           0.00 0.06 0.97 1.21 1.24 1.28 1.31 1.11 1.16 1.27
VEL3   6.0 1.18 1.49 1.27 1.36 1.28 1.13 1.27 1.39 1.60 1.78 1.53 1.73
VEL3   6.0 1.30 1.34 1.38 1.64 1.28 1.91 0.72 0.54 0.36
CAL4   6.0     92.17    361.80    361.80
VEL4   6.0      0.00 0.00 0.06 0.49 1.62 1.57 1.67 1.61 1.71 1.55 1.74
VEL4   6.0 1.78 1.67 1.56 1.57 1.42 1.77 1.88 1.92 1.84 1.69 1.93 1.89
VEL4   6.0 1.83 1.76 1.60 1.64 1.66 1.88 1.06 0.50 0.00
XSEC   7.0    121.7 1.0     88.80   0.00053
       7.0  0.0 96.8  5.7 92.2  6.5 91.9  7.0 91.4 10.0 90.4 15.0 89.0
       7.0 20.0 89.2 25.0 89.4 30.0 89.4 35.0 88.9 40.0 89.1 45.0 88.8
       7.0 50.0 88.8 55.0 88.8 60.0 88.8 65.0 89.0 70.0 89.0 75.0 89.1
       7.0 80.0 89.2 85.0 89.6 90.0 89.7 95.0 90.3100.0 91.0105.0 91.3
       7.0108.0 91.4110.0 91.4115.0 91.3120.0 91.1125.0 91.0130.0 90.9
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       7.0133.0 91.4134.5 91.9135.6 92.0136.0 92.2139.4 92.4144.4 95.5
       7.0156.6 97.4
NS     7.0       0.8      82.9      82.9      85.9      85.9      82.9
NS     7.0      28.9      23.5      34.5      54.5      46.7      63.7
NS     7.0      67.8      67.8      67.8      67.6      76.7      76.7
NS     7.0      67.7      67.7      65.8      56.8      56.9  1.0 56.9
NS     7.0  1.0 56.9  1.0 56.9  1.0 56.9  1.0 56.9  1.0 65.7  1.0 65.7
NS     7.0  1.0 65.7  1.0 12.7  1.0 12.7      12.7       0.2       0.8
NS     7.0       0.9
WSL    7.0      91.1      91.2      91.3      91.4      91.4      91.5
WSL    7.0      91.5      91.6      91.6      91.7      91.7      91.8
WSL    7.0      91.8      91.9      91.9      91.9      92.1      92.0
WSL    7.0      92.1      92.2      92.2      92.3      92.3      92.4
WSL    7.0      92.4      92.4      92.5      92.5      92.6      92.6
CAL1   7.0     91.44     53.50     50.90
VEL1   7.0                0.00 0.03 0.20 0.26 0.37 0.41 0.31 0.30 0.21
VEL1   7.0 0.23 0.24 0.25 0.31 0.26 0.28 0.27 0.28 0.28 0.25 0.19 0.00
VEL1   7.0 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
VEL1   7.0
CAL2   7.0     91.88    195.40    185.50
VEL2   7.0           0.00 0.11 0.22 0.46 0.57 0.74 0.69 0.77 0.85 0.83
VEL2   7.0 0.79 0.81 0.76 0.76 0.71 0.72 0.69 0.85 0.82 0.78 0.67 0.58
VEL2   7.0 0.55 0.51 0.43 0.42 0.48 0.65 0.30 0.00
VEL2   7.0
CAL3   7.0     92.05    240.60    232.30
VEL3   7.0           0.16 0.22 0.28 0.66 0.68 0.78 0.93 0.94 0.93 0.96
VEL3   7.0 0.87 0.90 0.89 0.95 0.94 0.83 0.91 0.84 1.00 0.79 0.78 0.80
VEL3   7.0 0.75 0.70 0.73 0.72 0.65 0.66 0.45 0.33 0.00
VEL3   7.0
CAL4   7.0     92.22    361.80    339.50
VEL4   7.0      0.00 0.21 0.32 0.42 0.73 0.88 0.95 1.02 1.26 1.20 1.47
VEL4   7.0 1.37 1.39 1.36 1.25 1.21 1.20 1.14 1.20 1.08 1.05 1.14 1.11
VEL4   7.0 1.10 1.10 0.86 0.83 0.87 0.96 0.80 0.58 0.19 0.00
VEL4   7.0
XSEC   8.0       9.3 1.0     88.80   0.00053
       8.0  0.0 97.4  7.2 92.0 11.7 91.2 12.0 91.4 13.7 90.1 18.7 88.6
       8.0 23.7 88.4 28.7 88.1 33.7 85.8 38.7 84.7 43.7 83.5 48.7 82.3
       8.0 53.7 81.7 58.7 81.2 63.7 82.2 68.7 82.7 73.7 84.7 78.7 87.2
       8.0 83.7 88.7 88.7 89.9 93.7 90.6 98.7 91.1103.7 91.3104.3 91.4
       8.0108.7 91.4113.7 91.3118.7 91.3123.7 91.4128.0 91.9129.3 92.2
       8.0144.7 96.0146.9 96.1
NS     8.0       0.7      88.9      88.9      88.9      88.9      22.9
NS     8.0      22.9      22.9      22.9      22.9      22.9      22.9
NS     8.0      22.9      22.9      27.9      27.9      62.9      62.9
NS     8.0      52.8      52.8      42.9      42.9      42.8  1.0 42.8
NS     8.0  1.0 42.8  1.0 42.6  1.0 24.7  1.0 24.7  1.0 24.7  1.0 12.9
NS     8.0       0.8       0.9
WSL    8.0      91.1      91.2      91.3      91.4      91.4      91.5
WSL    8.0      91.5      91.6      91.6      91.7      91.7      91.8
WSL    8.0      91.9      91.9      91.9      91.9      92.1      92.1
WSL    8.0      92.1      92.2      92.2      92.3      92.3      92.4
WSL    8.0      92.4      92.5      92.6      92.6      92.6      92.7
CAL1   8.0     91.44     53.50     15.20
VEL1   8.0                0.00 0.07 0.05 0.09 0.05 0.07 0.19 0.13 0.17
VEL1   8.0 0.14 0.12 0.04 0.03 0.05 0.00 0.09 0.06 0.05 0.06 0.00 0.00
VEL1   8.0      0.00 0.00
CAL2   8.0     91.89    195.40      0.00
VEL2   8.0
VEL2   8.0
VEL2   8.0
CAL3   8.0     92.05    240.60    230.70
VEL3   8.0      0.00 0.13 0.18 0.23 0.12 0.14 0.07 0.31 0.54 0.74 0.61
VEL3   8.0 0.76 0.69 0.59 0.36 0.44 0.29 0.09 0.01 0.10 0.07 0.02 0.05
VEL3   8.0 0.07 0.22 0.37 0.45 0.20
CAL4   8.0     92.24    361.80    318.50
VEL4   8.0      0.00 0.17 0.20 0.23 0.20 0.18 0.06 0.14 1.00 1.29 0.87
VEL4   8.0 1.00 0.63 0.88 0.31 0.19 0.34 0.26 0.27 0.41 0.56 0.55 0.05
VEL4   8.0 0.54 0.49 0.42 0.40 0.20 0.00
XSEC   9.0     156.3 1.0     89.30   0.00211
       9.0  0.0 96.8 13.0 93.3 24.0 91.6 24.3 91.1 24.5 89.6 30.0 89.4
       9.0 35.0 89.6 40.0 89.7 45.0 89.9 50.0 89.9 55.0 89.8 60.0 89.9
```

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       9.0 65.0 89.8 70.0 89.7 75.0 89.4 80.0 89.4 85.0 89.4 90.0 89.3
       9.0 95.0 89.5100.0 89.7105.0 89.9110.0 90.0115.0 90.4120.0 90.4
       9.0125.0 90.4130.0 90.6132.7 90.4134.3 91.1137.4 93.0141.5 98.1
NS     9.0       0.9       0.9      88.9      88.9      88.9      62.6
NS     9.0      34.9      45.6      45.6      53.7      53.7      54.6
NS     9.0      54.7      54.8      54.8      54.8      56.8      56.8
NS     9.0      56.8      56.8      54.8      54.8      54.8      62.8
NS     9.0      62.8  1.0 52.8  1.0 26.8  1.0 26.8       0.8       0.9
WSL    9.0      90.0      90.1      90.2      90.3      90.4      90.4
WSL    9.0      90.5      90.6      90.6      90.7      90.8      90.9
WSL    9.0      91.0      91.1      91.1      91.2      91.3      91.3
WSL    9.0      91.5      91.7      91.6      91.8      91.9      92.0
WSL    9.0      92.1      92.3      92.3      92.4      92.5      92.6
CAL1   9.0     90.41     53.50     58.50
VEL1   9.0                     0.43 0.67 0.30 0.17 0.49 0.89 1.79 1.76
VEL1   9.0 2.23 1.64 0.30 1.44 1.15 0.84 0.53 1.66 0.87 1.14 0.85 0.54
VEL1   9.0 0.59      0.00
CAL2   9.0     91.08    195.40    186.80
VEL2   9.0                0.00 1.23 1.78 1.58 1.21 0.94 0.99 1.21 1.08
VEL2   9.0 1.12 1.76 0.57 1.08 1.13 1.90 1.69 1.23 1.69 1.78 1.52 1.81
VEL2   9.0 1.34 1.34 0.67 0.00
CAL3   9.0     91.35    240.60    239.70
VEL3   9.0                0.00 0.75 1.74 1.46 1.27 1.05 1.20 1.20 1.74
VEL3   9.0 1.84 1.93 0.23 1.49 1.36 1.96 1.37 1.28 1.99 1.75 1.50 1.32
VEL3   9.0 1.54 1.14 0.57 0.00
CAL4   9.0     91.56    361.80    327.10
VEL4   9.0           0.00 0.00 0.64 1.69 1.94 1.77 1.71 1.73 1.62 1.76
VEL4   9.0 2.16 1.82 1.37 1.38 1.51 2.02 2.26 1.70 1.84 1.87 1.60 1.21
VEL4   9.0 1.19 1.24 0.62 0.11
XSEC  10.0     121.7 0.1     88.60   0.00015
      10.0  0.0 97.9  4.5 92.0  4.7 91.7  5.0 91.5  6.5 90.9  9.0 90.7
      10.0 14.0 90.4 19.0 90.4 24.0 89.8 29.0 89.3 34.0 89.2 39.0 89.2
      10.0 44.0 89.0 49.0 88.9 54.0 88.7 59.0 88.6 64.0 88.9 69.0 89.3
      10.0 74.0 89.7 79.0 89.7 84.0 89.6 89.0 89.4 94.0 89.3 99.0 89.4
      10.0104.0 89.6109.0 90.2114.0 90.6115.5 90.9117.6 91.5118.7 92.0
      10.0119.0 91.7122.5 95.8125.0 96.7
NS    10.0       0.9      12.9      12.9      12.9      25.8      25.8
NS    10.0      25.8      53.8      53.8      23.9      34.8      53.8
NS    10.0      54.8      54.8      43.8      45.8      53.8      53.8
NS    10.0      53.8      54.7      54.7      45.8      45.8      52.6
NS    10.0      56.8      56.8      56.8      56.8      21.9      21.9
NS    10.0  1.0 21.9       0.9       0.9
WSL   10.0      90.4      90.6      90.7      90.8      90.9      90.9
WSL   10.0      91.0      91.0      91.1      91.2      91.3      91.4
WSL   10.0      91.5      91.5      91.5      91.6      91.7      91.8
WSL   10.0      91.9      92.0      92.0      92.1      92.2      92.3
WSL   10.0      92.4      92.5      92.5      92.6      92.7      92.7
CAL1  10.0     90.88     53.50     46.20
VEL1  10.0                     0.00 0.14 0.09 0.10 0.25 0.28 0.37 0.45
VEL1  10.0 0.47 0.51 0.38 0.39 0.36 0.35 0.33 0.31 0.39 0.28 0.19 0.18
VEL1  10.0 0.10 0.06 0.08 0.00
CAL2  10.0     91.53    195.40    182.30
VEL2  10.0                0.00 0.04 0.07 0.30 0.52 0.66 0.81 0.94 1.05
VEL2  10.0 1.15 1.22 1.15 1.10 0.96 1.04 0.84 0.87 0.81 0.82 0.65 0.69
VEL2  10.0 0.50 0.51 0.29 0.15 0.00
CAL3  10.0     91.74    240.60    237.50
VEL3  10.0           0.00 0.07 0.11 0.14 0.46 0.59 0.83 0.97 0.91 1.29
VEL3  10.0 1.25 1.28 1.37 1.21 1.16 1.07 1.08 1.11 1.10 0.99 0.98 0.87
VEL3  10.0 0.73 0.55 0.36 0.32 0.27      0.00
CAL4  10.0     91.99    361.80    323.00
VEL4  10.0      0.00 0.02 0.18 0.28 0.38 0.65 0.88 0.84 1.11 1.25 1.44
VEL4  10.0 1.58 1.66 1.63 1.50 1.36 1.41 1.15 1.34 1.22 1.16 1.13 0.93
VEL4  10.0 0.79 0.60 0.56 0.42 0.28 0.00 0.00
XSEC  11.0     165.8 0.0     88.60   0.00015
      11.0  0.0 96.1  2.0 95.7  3.4 92.4  4.2 92.3  5.9 93.5  6.5 92.1
      11.0  7.0 90.9  9.8 90.9 11.5 88.4 14.0 86.7 17.0 89.0 20.0 85.0
      11.0 23.0 83.7 26.0 83.7 29.0 83.9 32.0 83.8 35.0 83.8 38.0 84.8
      11.0 41.0 85.4 44.0 85.9 47.0 86.3 50.0 86.8 53.0 87.1 56.0 87.7
      11.0 59.0 88.6 62.0 89.1 65.0 89.8 68.0 90.3 71.0 90.5 74.0 90.7
      11.0 76.0 90.9 77.0 91.0 78.8 91.4 80.0 92.1 82.1 93.9 86.8 94.9
NS    11.0       0.9       0.9       0.1      11.9      88.9      88.9
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NS    11.0       88.9       88.9       88.9       88.9       88.9       87.9
NS    11.0       87.6       82.9       82.9       87.9       87.9       76.8
NS    11.0       76.7       72.8       72.6       27.9       22.9       21.8
NS    11.0       25.8       25.8       25.6       21.9       21.9       21.7
NS    11.0       21.7       21.7       21.9       21.9       11.9       11.9
WSL   11.0       90.4       90.6       90.7       90.8       90.9       90.9
WSL   11.0       91.0       91.1       91.1       91.2       91.3       91.4
WSL   11.0       91.5       91.6       91.6       91.6       91.8       91.8
WSL   11.0       92.0       92.1       92.1       92.2       92.3       92.4
WSL   11.0       92.5       92.6       92.7       92.8       92.8       92.9
CAL1  11.0      90.92      53.50      43.80
VEL1  11.0                                 0.00 0.02 0.04 0.05 0.06 0.05
VEL1  11.0 0.00 0.41 0.40 0.43 0.38 0.33 0.26 0.17 0.12 0.03 0.03 0.08
VEL1  11.0 0.06 0.14 0.11 0.16 0.17 0.05 0.00
CAL2  11.0      91.51     195.40       0.00
VEL2  11.0
VEL2  11.0
VEL2  11.0
CAL3  11.0      91.83     240.60     266.40
VEL3  11.0                                 0.00 0.00 0.04 0.13 0.27 0.74
VEL3  11.0 1.75 1.45 1.63 1.65 1.31 1.12 0.84 0.62 0.39 0.22 0.01 0.10
VEL3  11.0 0.08 0.05 0.19 0.23 0.23 0.13 0.08 0.02 0.00
CAL4  11.0      92.05     361.80     322.50
VEL4  11.0                            0.00 0.10 0.20 0.20 0.05 0.25 1.10
VEL4  11.0 1.55 1.78 1.99 1.74 1.87 1.42 1.27 0.89 0.57 0.22 0.03 0.07
VEL4  11.0 0.23 0.23 0.15 0.37 0.37 0.34 0.06 0.03 0.00 0.00
ENDJ
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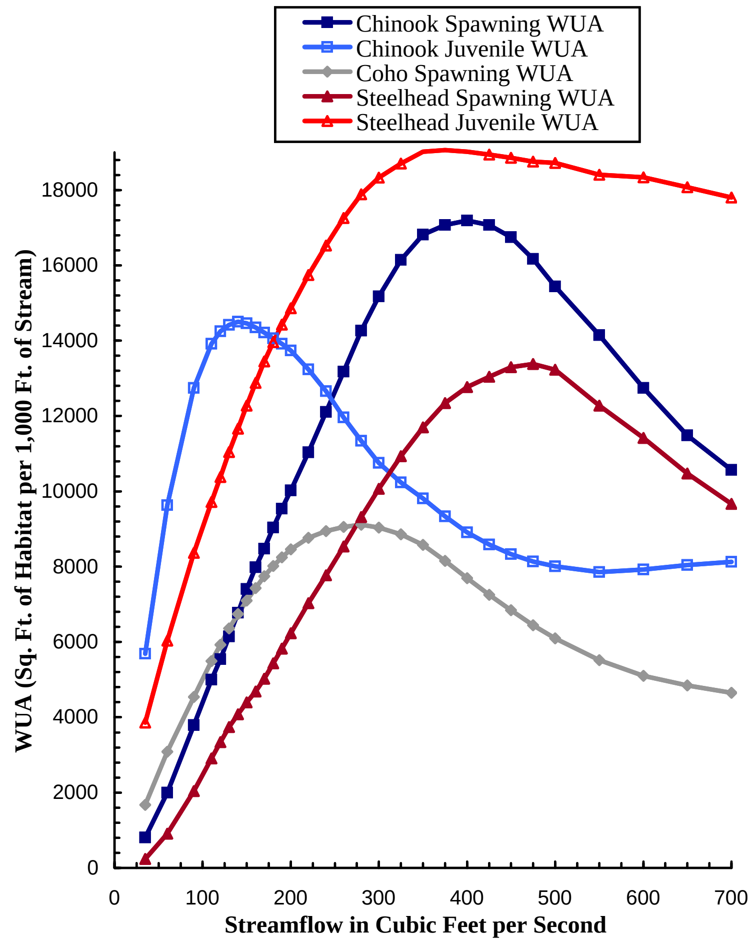
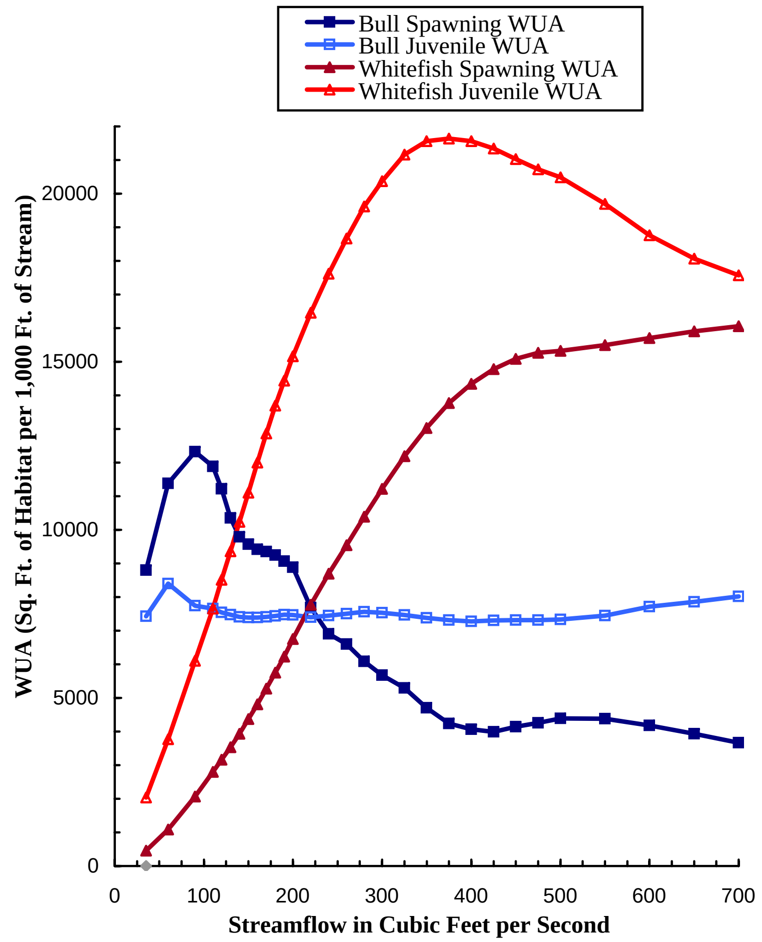
Chiwawa River at RM 7.0: Fish Habitat (WUA) vs Flow.



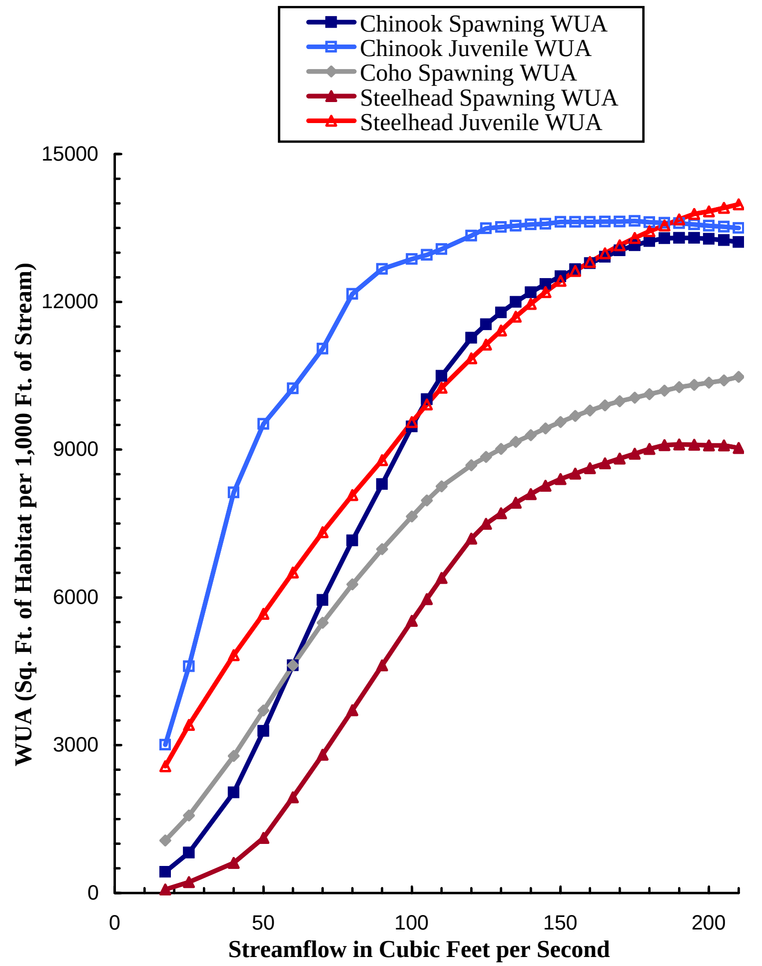
						Percent of Peak Habitat vs Flow				
Flow (cfs)	Chinook Spawning WUA	Chinook Juvenile WUA	Coho Spawning WUA	Steelhead Spawning WUA	Steelhead Juvenile WUA	Chinook Spawning WUA	Chinook Juvenile WUA	Coho Spawning WUA	Steelhead Spawning WUA	Steelhead Juvenile WUA
35	807	5685	1678	235	3859	5%	39%	18%	2%	20%
60	1994	9633	3084	914	6039	12%	66%	34%	7%	32%
90	3791	12740	4539	2044	8368	22%	88%	50%	15%	44%
110	4996	13913	5488	2909	9717	29%	96%	60%	22%	51%
120	5544	14250	5928	3339	10384	32%	98%	65%	25%	54%
130	6147	14421	6359	3736	11043	36%	99%	70%	28%	58%
140	6779	**14505**	6743	4079	11667	39%	**100%**	74%	30%	61%
150	7403	**14462**	7100	4394	12273	43%	**100%**	78%	33%	64%
160	7986	14353	7431	4683	12883	46%	99%	82%	35%	68%
170	8477	14217	7742	5021	13449	49%	98%	85%	38%	71%
180	9040	14060	8019	5430	13959	53%	97%	88%	41%	73%
190	9541	13919	8250	5825	14429	56%	96%	91%	44%	76%
200	10024	13738	8455	6228	14859	58%	95%	93%	47%	78%
220	11030	13236	8765	7029	15746	64%	91%	96%	53%	83%
240	12106	12655	8946	7774	16525	70%	87%	98%	58%	87%
260	13180	11965	9051	8538	17260	77%	82%	99%	64%	91%
280	14264	11341	**9110**	9319	17884	83%	78%	**100%**	70%	94%
300	15175	10758	9035	10069	18327	88%	74%	99%	75%	96%
325	16141	10234	8860	10929	18706	94%	71%	97%	82%	98%
350	16816	9809	8574	11698	**19014**	98%	68%	94%	87%	**100%**
375	17071	9333	8149	12346	**19056**	99%	64%	89%	92%	**100%**
400	**17191**	8910	7694	12766	**19015**	**100%**	61%	84%	95%	**100%**
425	17070	8585	7255	13041	18945	99%	59%	80%	97%	99%
450	16748	8328	6842	13292	18859	97%	57%	75%	99%	99%
475	16173	8138	6446	**13378**	18754	94%	56%	71%	**100%**	98%
500	15442	8012	6094	13224	18716	90%	55%	67%	99%	98%
550	14142	7856	5519	12277	18407	82%	54%	61%	92%	97%
600	12739	7927	5100	11416	18336	74%	55%	56%	85%	96%
650	11489	8045	4850	10477	18074	67%	55%	53%	78%	95%
700	10568	8129	4649	9668	17805	61%	56%	51%	72%	93%

Chiwawa River at RM 7.0: Fish Habitat (WUA) vs Flow.



Flow (cfs)	Bull Spawning WUA	Bull Juvenile WUA	Whitefish Spawning WUA	Whitefish Juvenile WUA	Bull Spawning % WUA	Bull Juvenile % WUA	Whitefish Spawning % WUA	Whitefish Juvenile % WUA
					Percent of Peak Habitat vs Flow			
35	8800	7425	453	2038	71%	88%	3%	9%
60	11378	**8401**	1083	3774	92%	**100%**	7%	17%
90	**12324**	7742	2071	6101	**100%**	92%	13%	28%
110	11882	7657	2796	7657	96%	91%	17%	35%
120	11222	7545	3159	8512	91%	90%	20%	39%
130	10355	7479	3534	9366	84%	89%	22%	43%
140	9795	7412	3933	10235	79%	88%	24%	47%
150	9569	7390	4369	11109	78%	88%	27%	51%
160	9423	7393	4811	11996	76%	88%	30%	55%
170	9351	7405	5275	12869	76%	88%	33%	59%
180	9251	7439	5755	13699	75%	89%	36%	63%
190	9068	7474	6233	14438	74%	89%	39%	67%
200	8889	7465	6752	15163	72%	89%	42%	70%
220	7685	7403	7774	16460	62%	88%	48%	76%
240	6905	7448	8693	17622	56%	89%	54%	81%
260	6604	7501	9547	18668	54%	89%	59%	86%
280	6087	7561	10393	19622	49%	90%	65%	91%
300	5674	7533	11216	20372	46%	90%	70%	94%
325	5291	7469	12191	21163	43%	89%	76%	98%
350	4709	7383	13030	**21559**	38%	88%	81%	**100%**
375	4236	7314	13767	**21639**	34%	87%	86%	**100%**
400	4063	7280	14342	**21565**	33%	87%	89%	**100%**
425	3994	7301	14783	21341	32%	87%	92%	99%
450	4143	7311	15083	21032	34%	87%	94%	97%
475	4259	7317	15268	20721	35%	87%	95%	96%
500	4392	7331	15327	20485	36%	87%	95%	95%
550	4377	7452	15496	19697	36%	89%	97%	91%
600	4182	7714	15701	18762	34%	92%	98%	87%
650	3937	7861	15907	18069	32%	94%	99%	84%
700	3667	8023	**16057**	17575	30%	96%	**100%**	81%

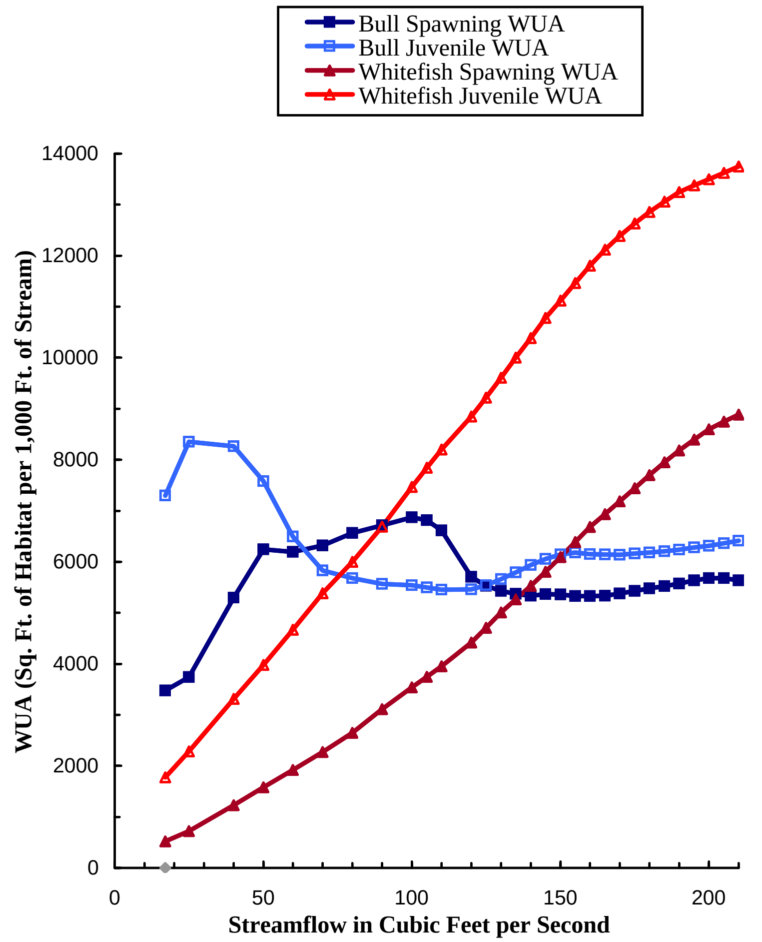
Nason Creek at RM 0.6: Fish Habitat (WUA) vs Flow.



Flow (cfs)	Chinook Spawning WUA	Chinook Juvenile WUA	Coho Spawning WUA	Steelhead Spawning WUA	Steelhead Juvenile WUA	Percent of Peak Habitat vs Flow: Chinook Spawning WUA	Chinook Juvenile WUA	Coho Spawning WUA	Steelhead Spawning WUA	Steelhead Juvenile WUA
17	428	3009	1065	72	2573	3%	22%	10%	1%	18%
25	817	4601	1574	220	3415	6%	34%	15%	2%	24%
40	2039	8131	2785	611	4829	15%	60%	27%	7%	35%
50	3292	9521	3704	1117	5667	25%	70%	35%	12%	41%
60	4618	10244	4619	1946	6504	35%	75%	44%	21%	47%
70	5947	11050	5486	2805	7327	45%	81%	52%	31%	52%
80	7153	12162	6268	3714	8079	54%	89%	60%	41%	58%
90	8302	12667	6980	4619	8790	62%	93%	67%	51%	63%
100	9467	12871	7641	5522	9561	71%	94%	73%	61%	68%
105	10024	12952	7968	5963	9918	75%	95%	76%	65%	71%
110	10499	13072	8256	6395	10253	79%	96%	79%	70%	73%
120	11268	13342	8685	7191	10851	85%	98%	83%	79%	78%
125	11544	13493	8849	7491	11131	87%	99%	84%	82%	80%
130	11783	13519	9015	7705	11419	89%	99%	86%	85%	82%
135	11996	13544	9157	7921	11701	90%	99%	87%	87%	84%
140	12192	13569	9293	8098	11956	92%	99%	89%	89%	86%
145	12358	**13584**	9429	8270	12202	93%	**100%**	90%	91%	87%
150	12517	**13620**	9561	8401	12425	94%	**100%**	91%	92%	89%
155	12660	**13625**	9681	8512	12629	95%	**100%**	92%	93%	90%
160	12785	**13620**	9795	8622	12811	96%	**100%**	93%	95%	92%
165	12914	**13629**	9896	8724	12988	97%	**100%**	94%	96%	93%
170	13044	**13629**	9980	8821	13148	98%	**100%**	95%	97%	94%
175	13151	**13641**	10056	8918	13297	99%	**100%**	96%	98%	95%
180	**13231**	**13615**	10128	9015	13433	**100%**	**100%**	97%	99%	96%
185	**13293**	**13601**	10196	**9095**	13553	**100%**	**100%**	97%	**100%**	97%
190	**13298**	**13595**	10266	**9107**	13671	**100%**	**100%**	98%	**100%**	98%
195	**13296**	13571	10312	**9098**	13784	**100%**	99%	98%	**100%**	99%
200	**13279**	13545	10357	**9084**	13840	**100%**	99%	99%	**100%**	99%
205	**13252**	13526	10408	**9083**	13906	**100%**	99%	99%	**100%**	99%
210	13213	13498	**10478**	9033	**13978**	99%	99%	**100%**	99%	**100%**

Updated 4/28/05 with new his curves and 2 attribute pcurve file JP

Nason Creek at RM 0.6: Fish Habitat (WUA) vs Flow.



					Percent of Peak Habitat vs Flow			
Flow (cfs)	**Bull Spawning WUA**	**Bull Juvenile WUA**	**Whitefish Spawning WUA**	**Whitefish Juvenile WUA**	**Bull Spawning % WUA**	**Bull Juvenile % WUA**	**Whitefish Spawning % WUA**	**Whitefish Juvenile % WUA**
17	3473	7299	521	1777	51%	87%	6%	13%
25	3738	**8352**	723	2287	54%	**100%**	8%	17%
40	5296	8263	1228	3312	77%	99%	14%	24%
50	6241	7579	1584	3979	91%	91%	18%	29%
60	6194	6497	1923	4667	90%	78%	22%	34%
70	6320	5831	2273	5386	92%	70%	26%	39%
80	6563	5677	2649	5998	95%	68%	30%	44%
90	6713	5564	3111	6691	98%	67%	35%	49%
100	**6874**	5540	3541	7470	**100%**	66%	40%	54%
105	6817	5500	3745	7847	99%	66%	42%	57%
110	6614	5450	3951	8199	96%	65%	44%	60%
120	5704	5460	4418	8850	83%	65%	50%	64%
125	5528	5539	4707	9216	80%	66%	53%	67%
130	5429	5662	5005	9607	79%	68%	56%	70%
135	5369	5793	5263	10000	78%	69%	59%	73%
140	5332	5937	5526	10388	78%	71%	62%	76%
145	5362	6056	5807	10780	78%	73%	65%	78%
150	5361	6140	6095	11118	78%	74%	69%	81%
155	5329	6181	6390	11463	78%	74%	72%	83%
160	5330	6151	6682	11804	78%	74%	75%	86%
165	5334	6143	6932	12117	78%	74%	78%	88%
170	5375	6136	7184	12390	78%	73%	81%	90%
175	5427	6160	7441	12632	79%	74%	84%	92%
180	5477	6179	7700	12857	80%	74%	87%	94%
185	5519	6207	7949	13061	80%	74%	89%	95%
190	5575	6241	8186	13245	81%	75%	92%	96%
195	5636	6280	8394	13379	82%	75%	94%	97%
200	5679	6312	8594	13498	83%	76%	97%	98%
205	5679	6363	8751	13620	83%	76%	99%	99%
210	5637	6416	8884	13749	82%	77%	**100%**	**100%**

Toe-Width Data for WRIA 45, (Measured 12/7/04 by Jim Pacheco)							
Stream Name	**Tributary to**	**Average Toe Width (in feet)**	**Toe-Width Flow for Fish Spawning and Rearing (in cfs)**				
			Chinook Spawning	*Coho & Chum Spawning*	*Steelhead Spawning*	*Steelhead Rearing*	*Salmon Rearing*
Mission Creek (0.5 miles past junkyard bridge)	Wenatchee River	10.7	25.7	12.3	24.2	4.7	4.2
Chumstick Creek (@ Church along Chumstick Hwy)	Wenatchee River	9.1	21.0	9.9	20.1	3.8	3.3

Toe-Width Method

The Toe-Width Method was developed by the Department of Fisheries (WDF), the Department of Game (WDG), and the U.S. Geological Service (USGS) in the 1970s at the request of the state legislature in response to the need to determine minimum instream flows for fish. After the legislature passed the Minimum Water Flows and Levels law in 1969 and the Water Resources Act of 1971, USGS collected water depths and velocities along transects over known spawning areas. WDF and WDG provided the criteria for salmon and steelhead spawning and rearing and the locations of the known spawning areas. After 9 years of data collection, USGS had measured 28 streams and rivers in eastern and western Washington. They had 84 study reaches with each reach consisting of 4 transects. They measured each transect at 8 to 10 different flows. USGS used the data from these 336 transects to calculate spawning and rearing flows for salmon and steelhead. Criteria for the needed spawning and rearing depths and velocities for each fish species and lifestage were used to calculate the square feet of habitat at each measured flow. These points of habitat quantity at different flows were connected to create a fish habitat versus streamflow relationship. Next, these fish habitat relationships were compared to many different variables in the watershed to determine if there were any correlations that could be used to avoid having to do so many flow measurements to calculate a spawning or rearing flow for a certain fish species. The toe-width was the only variable found to have a high correlation. The toe-width is the distance from the toe of one streambank to the toe of the other streambank across the stream channel. This width of the stream is used in a power function equation to derive the flow needed for spawning and rearing salmon and steelhead (Swift, 1976 and 1979).

Swift III, C. H. 1976. Estimation of Stream Discharges Preferred by Steelhead Trout for Spawning and Rearing in Western Washington. USGS Open-File Report 75-155. Tacoma, Washington.

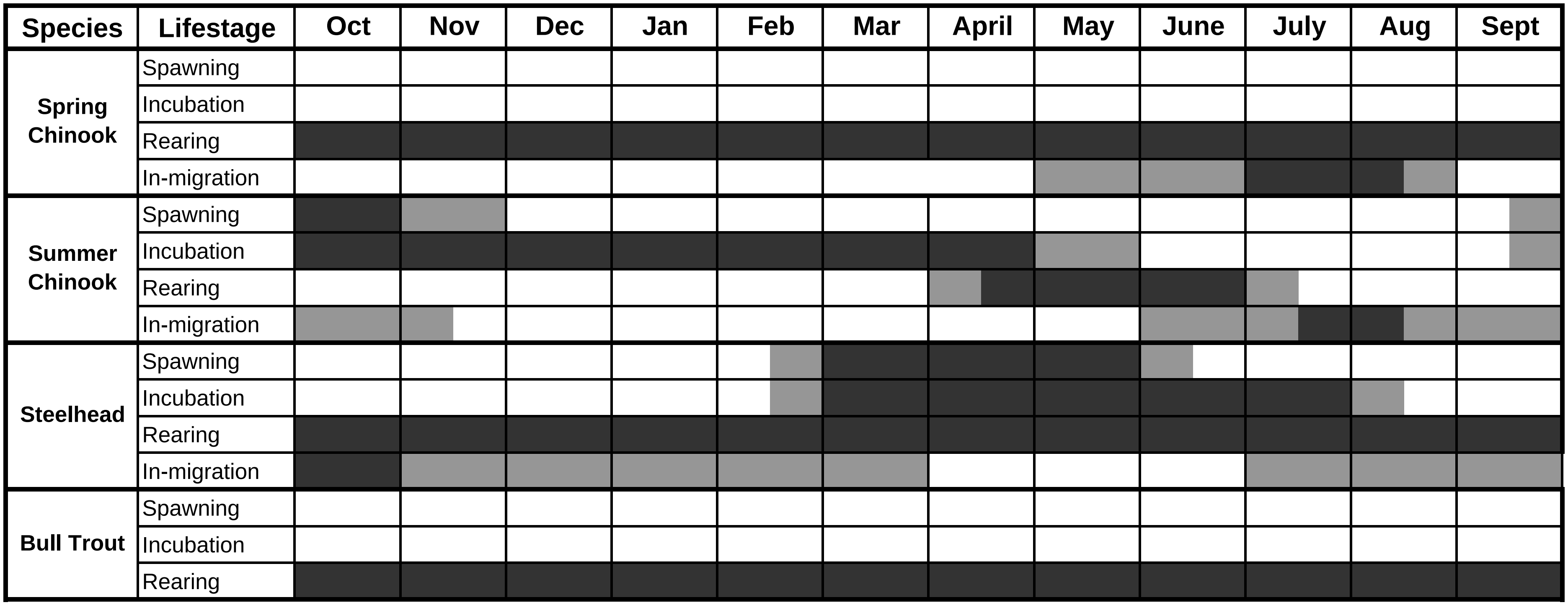
Swift III, C. H. 1979. Preferred Stream Discharges for Salmon Spawning and Rearing in Washington. USGS Open-File Report 77-422. Tacoma, Washington.

How to use Toe-Widths to set instream flows

1. Determine fish present in the system and their periodicity
2. For each month determine the priority species/lifestage
3. Enter the toe-width flow of the priority species/lifestage as the calculated instream flow. This will be the starting number for instream flow discussions
4. Modify the calculated number through negotiations using hydrology and the daily flow analysis to reach a planning unit recommended instream flow.

Lower Mainstem Wenatchee River

RM 0.0 to RM 25.6 (Tumwater Canyon)



<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

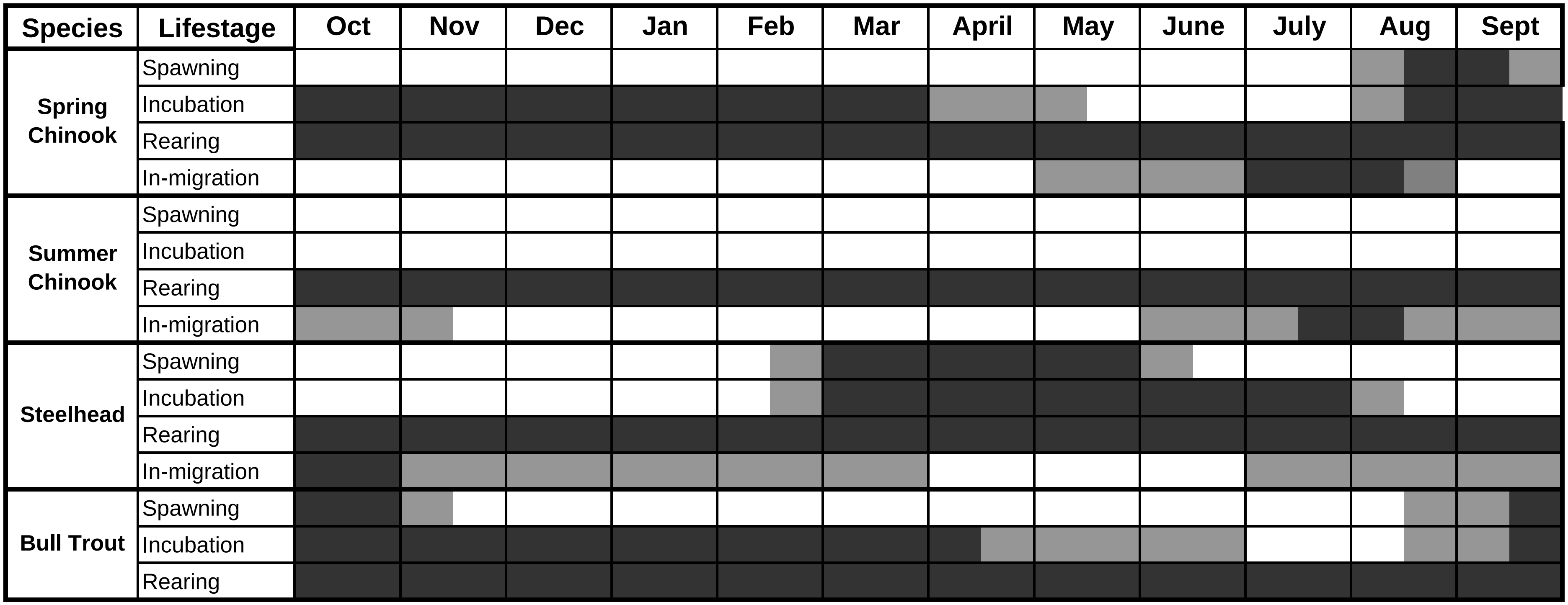
Key:

Black indicates periods of heaviest use

Grey indicates periods of moderate use

Blank areas indicate periods of little or no use

Icicle Creek Fish Periodicity



<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

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Chiwawa River Fish Periodicity

Species	Lifestage	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Spring Chinook	Spawning												
	Incubation												
	Rearing												
	In-migration												
Summer Chinook	Spawning	NOT PRESENT											
	Incubation												
	Rearing												
	In-migration												
Steelhead	Spawning												
	Incubation												
	Rearing												
	In-migration												
Bull Trout	Spawning												
	Incubation												
	Rearing												

<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key:

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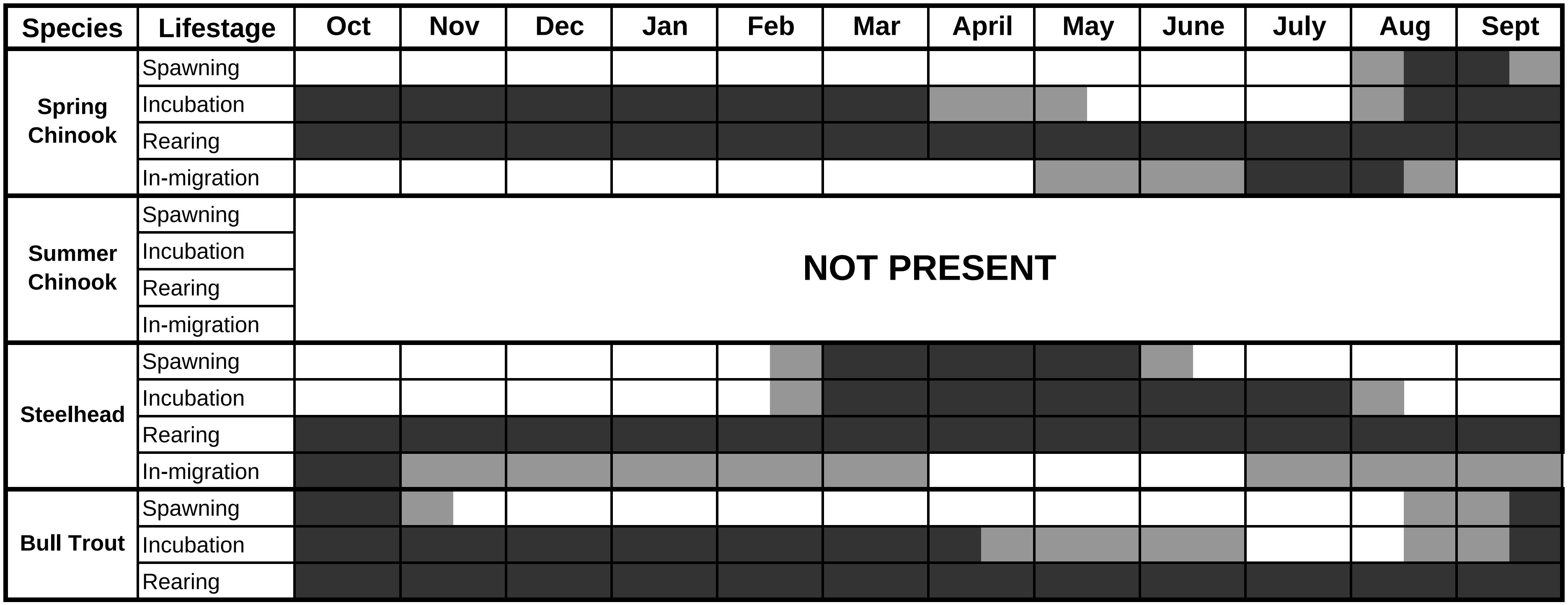
Nason Creek Fish Periodicity



Based on:

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key:

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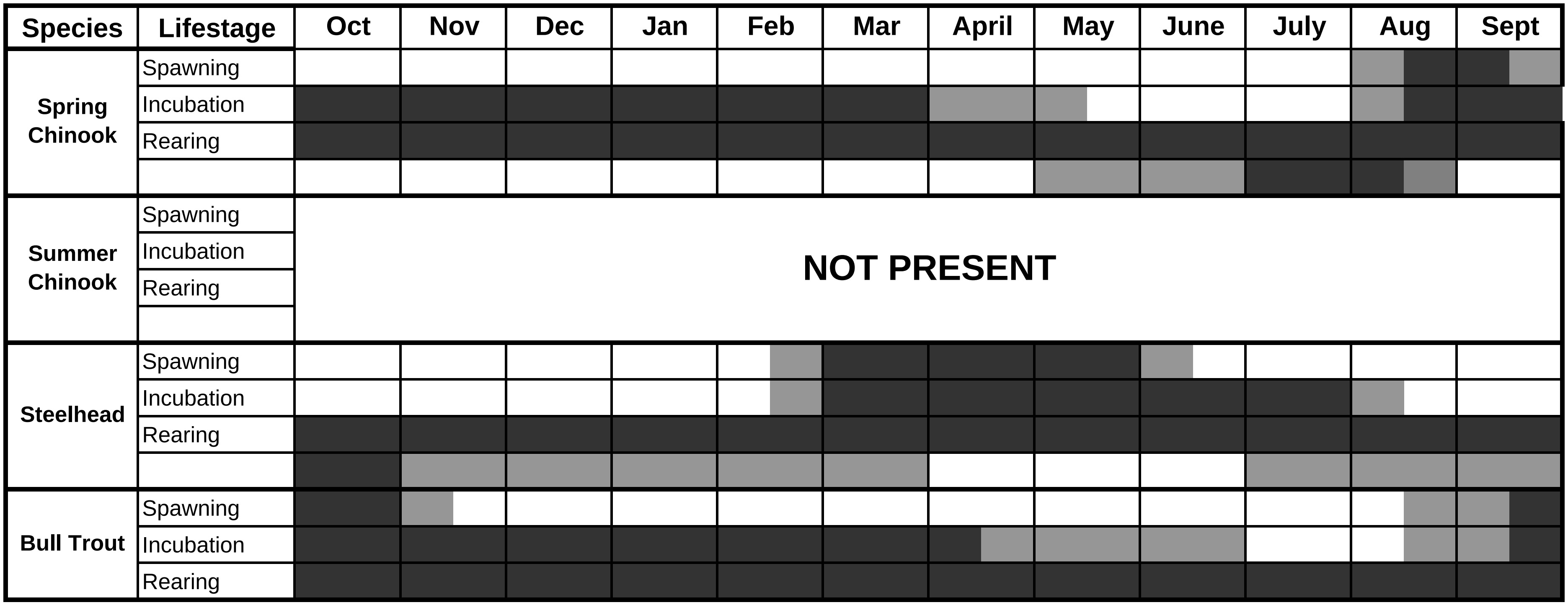
Blank areas indicate periods of little or no use

Peshastin Creek Fish Periodicity



Based on:

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

Key:

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Grey indicates periods of moderate use

Blank areas indicate periods of little or no use

Mission Creek Fish Periodicity

Species	Lifestage	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Spring Chinook	Spawning												
	Incubation												
	Rearing												
	In-migration												
Summer Chinook	Spawning												
	Incubation												
	Rearing												
	In-migration												
Steelhead	Spawning												
	Incubation												
	Rearing												
	In-migration												
Bull Trout	Spawning	NOT PRESENT											
	Incubation												
	Rearing												

<u>Based on:</u>

Andonaegui, C., 2001. *Salmon, Steelhead and Bull Trout Habitat Limiting Factors for the Wenatchee Subbasin (WRIA 45) and Portions of WRIA 40 within Chelan County (Squilchuck, Stemilt and Colockum Drainages).* Washington State Conservation Commission.

Comments from: USFS (Cam Thomas, Cindy Raekes), WDFW (Andrew Murdoch, Bob Vadas, Mark Cookson), USFWS (Kate Terrell) and NOAA-Fisheries (Dale Bambrick)

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Blank areas indicate periods of little or no use