

Tulalip Tribes Natural Resources Department

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Watershed Projects, Jobs-in-the-Woods*

Habitat Conditions and Chinook Use in the Pilchuck River

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Introduction

The Pilchuck River is a 341.9-km² sub-basin of the Snohomish River in Snohomish County, western Washington (Figure 1). Fishery co-managers (Northwest Treaty Indian Tribes and the Washington Department of Fish and Wildlife) break the 64.4 km long Pilchuck River into 3 reaches: the lower, middle and upper reach (WDF et al. 1993). The lower reach extends from the mouth of the river to 28th Place NE (RK 19.3). The City of Snohomish is located near the mouth. The lower Pilchuck is zoned for rural residential units $\leq$ 5 acres and 10-acre agricultural lots. Gravel mining operations were located within the floodplain between RK 9.5 – 10.7. Historically, sand and gravel were mined from the stream channel, gravel bars and the adjacent floodplain. Little Pilchuck and Dubuque Creeks are the largest tributaries in the lower basin, entering the system near RK 14.4.

The middle Pilchuck extends from 28th Place NE to the City of Snohomish dam (RK 19.3 - 42.5). The City of Granite Falls is located at RK 32. The middle Pilchuck is zoned for rural residential units $\leq$ 5 acres and forestry. Forestland ownership is both private and public. The upper Pilchuck extends from the dam to the headwaters (RK 42.5 – 64.4). Federal, state and private forestry is the sole land use in the upper Pilchuck. The headwaters of the Pilchuck River drain the narrow valley between Bald Mountain and the ridge northwest of Spada Lake. Boulder and Kelly Creeks join the Pilchuck River at river kilometer (RK) 50.5 and 48.6 respectively and drain the southern flank of Mount Pilchuck. The headwater streams are located at a range of 1160 to 850 m in elevation and are supplied by snowmelt in the early spring.

In the Pilchuck River watershed, land uses such as upland timber production and floodplain forest clearing, draining of floodplain wetlands, unnatural constriction of the river, reduced floodplain connectivity due to bank hardening and levee building, and agricultural practices have disturbed the natural surface and subsurface drainage networks (Booth, 1991). These changes have in turn affected the routing and timing of flow, sediment and large woody debris in the river system. Changes in these processes are recognized to adversely affect the formation and maintenance of salmonid habitat in the Snohomish River basin (SBSRTC, 1999).

Fish Use

Salmonid use of the Pilchuck River includes chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*). Chinook and coho salmon are reported to use the entire basin as habitat (WDF et al. 1993). The chinook salmon spawning in the Pilchuck River are included with the Skykomish chinook population by the Puget Sound Technical Recovery Team (Ruckelshaus et al. 2003). The

first chinook salmon typically enter the Pilchuck River in mid-August and migrate to their terminal spawning grounds. Flow in riffles is shallow and early returning fish usually elect to spawn low down in the system. Chinook are highly keyed to freshets caused by late summer and fall rainstorms. Based on field observations during the course of the study, fish move quickly upstream to spawning grounds during higher flows, rather than holding for longer periods of time in pools. Fish entering the Pilchuck later in the season can take advantage of the freshets and migrate further upstream to spawn. The majority of chinook spawn by early to mid-October.

Study Area

The study area extends from the Three Lakes Road Bridge (RK 5.8) to below Granite Falls (RK 29.3) and was broken into kilometer long segments for discussion (Figure 2). The study area was chosen due to its consistent use by chinook salmon. It comprises a portion of the lower and middle reaches of the Pilchuck River. Although low numbers of fish spawn below RK 5.8, this section of the river was not included. Channel gradient typically ranged between 0.5 to 2 percent in the study area with localized areas of gradient $\geq 3\%$.

The Tulalip Tribes wrote a Bureau of Indian Affairs (BIA) Jobs in the Woods grant in order to fulfill some basic research questions regarding salmonid habitat in the Pilchuck River. Many of these questions are stated data gaps in two Snohomish Basin Salmonid Recovery Technical Committee (SBSRTC) documents, the Habitat Conditions Review (HCR) and the Technical Work Plan. This report describes and maps the distribution and current condition of salmonid habitat, large woody debris, chinook spawning, stream temperature and riparian condition within the 23.5 km long study area. Further, this report makes suggestions regarding improving salmonid habitat and riparian function in the study area. This report supersedes any previous progress report issued to the BIA.

Geology of the Pilchuck River Watershed

Throughout the Puget Sound, Tertiary sedimentary and metamorphic rocks (+40 million years ago, mya) are overlain by volcanic rocks (5 – 40 mya) such as granite, granodiorite, andesite and basalt. The Puget Lobe of the Cordilleran ice sheet covered portions of the Puget Sound region (1.6 mya – 13,500 years ago, ya), during which time the surficial geology of the region was reworked many times. The advance and retreat of the glaciers left multiple series of outwash deposits that are separated by compact till, covering earlier formations. The Vashon stade (20,000 – 13,500 ya) of the Fraser glaciation was the most recent ice-sheet advance in the area.

Tertiary sedimentary rock (66-1.6 mya) and transitional beds are two pre-Fraser glaciation deposits that survived the reworking of the landscape that occurred during the Vashon stade.

These rock formations are partially responsible for habitat formation on the Pilchuck River. Reddish to tan Tertiary sedimentary rock is typically lensed and interbedded shale, sandstone, siltstone and pebble conglomerate (Minard, 1985b). The beds are generally thick and well indurated and tend to erode slowly. Coalified logs are abundant in the siltstone beds along the Pilchuck River (Minard, 1985b), an excellent example can be seen on the left bank 0.3 km downstream of 28th Place NE.

Transitional beds consist of 50 m thick, wet beds of gray clay, silt and fine sand (Minard, 1985a) and lie below the advance outwash. This layer was deposited in lakes formed by ice dams and contains rounded rock, which looks like recent alluvium. These deposits are distinguished from Vashon outwash by the presence of fossils. Transitional beds are impermeable and quite unstable, which gives rise to slope failure (Booth, 1990).

River valley and streamside deposits in the area are comprised of Holocene (< 10,000 years ago) alluvium, deposited since the Vashon stade receded. These deposits are anywhere from 2 to 20 m thick. Gravel mining of these deposits has occurred directly adjacent to and within the Pilchuck River. Collins (1991) reports that as recently as 1991 mining rates were greater than the rate of deposition and that between 1972 and 1991 the river degraded by an average of 1.52 feet from RK 11.7 to 0.6. Areas of localized bed degradation were found in two reaches (RK 1.1 – 3.5 and 7.6 – 10.1) downstream of the two largest mines (Collins, 1991) below the Dubuque Road Bridge.

At RK 16.5, upstream of the Russell Road Bridge, Holocene age deposits from landslides, slumps and earthflows are located in the bluffs on the right bank of the river. The material in the slides is mostly derived from Vashon till and sand of the advance outwash. The slides along Russell Road are mostly inactive and are several hundred years old, however some activity is evident through creep, likely due to high soil moisture content (Booth, 1990). The southernmost slide on the road is younger and still active. These slides are isolated from the river by the road and are therefore not a sediment source. Downstream of Russell Road Bridge (0.3 km) the river interacts with a till scarp, creating a large deep holding pool for salmon. The scarp intermittently fails, filling in portions of the pool.

Hydrology of the system

The hydrologic period of record on the Pilchuck River is not consecutive. The mainstem was gauged (USGS gauge number 12152500) daily at Granite Falls from 1911 to 1957; peak flows were recorded through 1979. More recently, the river has been gauged near the City of Snohomish since 1992 (USGS gauge number 12155300). Mean daily flow for the period of record at Granite Falls was 343.6 cfs. Peak flows ranged from 2,240 to 10,500 cfs occurring in

the months of December, January and February. A Log Pearson Type III analysis was performed on peak flow data to determine flow exceedence values for the Granite Falls gauge (Appendix 1). The 2, 10 and 100-year flows are approximately 5,045, 7,760 and 10,778 cfs respectively.

Base flow is considered an issue in the Pilchuck River basin (WDF et al. 1994 and SBSRTC, 1999). Base flow in the Pilchuck is primarily groundwater fed; there are few if any snowfields in the sub basin by the end of June. During the low flow season the lower sections of Little Pilchuck Creek and Dubuque Creek have been observed to have greatly diminished surface flow, thereby limiting surface water contribution to the mainstem. Total surface water certificates and claims to surface water from the mainstem Pilchuck River is 12.6 cfs, or 8.1 million gallons per day (MGD). The City of Snohomish extracts approximately 1 MGD (1.5 cfs) from its run of the river dam, located at RK 43.1. The city has a water right claim for 5 million gallons per day (7.7 cfs) from the Pilchuck River (Mark Beardslee, personal communication, 2/18/03). Further reduction of base flow occurs when the levels of adjacent floodplain lakes drop below the elevation of the river and water flows from the river into the floodplain.

Granite Falls is supplied with water from Snohomish Public Utility District #1. The Granite Falls wastewater treatment plant pumps a monthly average of 190,000 gallons per day (0.29 cfs) of treated wastewater into the river at RK 31.7 during the summer and monthly average of 210,000 gallons per day (0.32 cfs) in the winter. Currently reported City of Granite Falls wastewater discharge likely has little effect on the overall flow volumes in the Pilchuck River, as they are < 0.1% of the mean daily flow. The effects of the wastewater discharge on water quality are not considered in this report.

Although mostly rural, the response of the Pilchuck River to storms is similar in magnitude to that of an urbanizing stream. Generally in the PNW, rainfall intensity is lower than the rate at which the soil can absorb precipitation (Booth, 1991). However, with changes to the landscape and the natural surface and subsurface drainage systems, the river tends to respond quickly to precipitation inputs. Forest practices impact interception by vegetation and disrupt storage of water in the soil. Road networks intercept shallow subsurface flow and re-route precipitation to surface waters more rapidly than what is found in a natural system (Wigmosta and Perkins, 2001).

Side channel

In the winter of 2000, a large apex jam at RK 23.5, initiated by multiple spruce, hemlock and cottonwood key pieces, created scour at the head of a former side channel. The 400 m side channel re-opened, capturing approximately 40% of the flow from the mainstem. There is now a forested island between the mainstem and side channel. The flow in the side channel has

resulted in bank erosion, which in turn has led to the recruitment of many large cottonwood trees, forming two additional jams. Old pieces of large woody debris (LWD) that had previously fallen into the abandoned side channel have also been recruited into these new jams.

The side channel was used as a reference site to evaluate the overall study area in terms of habitat and wood distribution. It is reasonable to assume that the side channel represents the habitat and wood distribution that would have been found in a much less disturbed Pilchuck River. There is no bank hardening and no agricultural practices on either bank of the side channel. In-channel wood length and diameter are most likely smaller than historical pieces due to past wood harvesting. The riparian zone limits future recruitment in the side channel. The majority of the riparian zone width is greater than 55 m wide or the height of 1 site potential tree (SPT) on both banks of the side channel, while stand age and species composition vary. The forest on the left bank was logged approximately 60 years ago and contains a mixture of conifer and deciduous trees, although large areas are dominated by young alders and willows. Young alders and willows dominate the right bank. The banks of the side channel are 1 m high and are comprised of erodible alluvium tightly packed with silt and clay. To date, chinook adults have not used the side channel for spawning and no holding behavior has been observed. Coho salmon have been observed using the side channel for holding, spawning and rearing in 2001 and 2002.

Survey Methodology

Habitat surveys

Habitat surveys were conducted in August of 2002. Definitions for habitat units and large woody debris were taken from Northwest Indian Fisheries Commission (NWIFC) Timber Fish and Wildlife (TFW) habitat and large woody debris survey protocols (Pleus et al. 1999; Schuett-Hames et al. 1999). Field survey forms are included in the Appendix 1. Wetted channel and bankfull widths were visually estimated for each habitat unit. Every tenth unit, these metrics were measured with a tape. Estimated width measurements were then tested with regression using the measured widths. Estimated wetted widths were consistently acceptable, while bankfull widths were consistently underestimated. Bankfull widths were recalculated based on results from the regression analysis. See Appendix 1 for the regression formula. Water depth was measured with a stadia rod. Length of habitat units was measured using a metric line box. Despite precautions taken, measured lengths tended to be shorter than lengths taken from the 2001 Snohomish County Surface Water Management updated hydro layer. Corrections were made to measured lengths by calculating the differences between distances measured in the field and distances measured on the hydro layer between hard points, bridges for example. Unit lengths were increased based upon a multiplier calculated for each reach.

Habitats were broken into three units, pools, glides and riffles. A minimum criterion for pool area and residual depth was applied to pool data. For a mean bankfull width ≥ 20 m, the minimum unit area (length x width) was 5.0 m^2 and minimum residual depth (pool maximum depth – pool tail depth) was 0.40 m (Schuett-Hames et al. 1999). Pools were further divided into primary and secondary pools. Primary pools were defined as having widths greater than 50% of the wetted channel width. Secondary pools are defined as occupying less than 50% of the wetted channel width and were often embedded within or adjacent to riffles or glides. The call of a secondary pool was typically made when the pool exhibited the morphology of having a pool head (region of scour) and a hydraulic control. Secondary pools that did not meet the minimum pool criteria were added to the most similar adjacent habitat unit. The forming mechanism for pools was identified and broken into the following categories, wood (including jams), riprap (including rock groins), and bed/bank. The bed/bank category describes pools that are either formed by interactions with the transitional beds or Tertiary sedimentary rock, with large boulders in the channel, or with the streambed.

The habitat surveys separated glide habitat from riffle habitat for two reasons. First, the low gradient and lack of hydraulic roughness in the Pilchuck River was conducive to forming glide habitat, which was distinctly different in depth and velocity from riffle habitat. Second, chinook in the Pilchuck River tend to spawn in the transition from glide to riffle. Glides were defined as shallow to deep, rapidly moving water. The channel bottom in glides was typically flat but had areas of scour, for example where a rock from a riprap structure had fallen into the river. Riffles are defined as shallow with surface turbulence associated with increased flow velocity over gravel and cobble beds (Schuett-Hames et. al, 1999). The TFW riffle definition includes deeper areas without surface turbulence like a glide or pocket water and areas with more surface turbulence like cascades. For this survey, riffles were identified as shallow, rapidly moving water with surface turbulence and generally occurred in areas of locally increased gradient.

Reach breaks were determined post data entry using gradient breaks and channel morphology as determinants. Slopes were calculated using USGS 10 m digital elevation models on ArcView ArcGIS Spatial Analyst and were field checked for accuracy with a clinometer. Reaches were classified by channel type, pool riffle, plane-bed and forced pool-riffle, according to Montgomery and Buffington (1997).

Spawner Surveys

The Tribes conducted spawner surveys in September 1999 and October 1999, 2001 and 2002. The 1999 survey area was from RK 6.4-63.1 (excluding RK 46.5 – 50.5), 2001 surveys were from RK 14.2 – 38.6 and RK 41.5-45.1 and 2002 surveys were from RK 5.8-29.3 and 34.8-37. Spawner surveys were conducted to identify the distribution of chinook use in the Pilchuck River. Additional notes were taken regarding coho, chum and pink use of particular areas of the river. Chinook redds were marked on maps and then transferred onto a GIS layer.

Wood Debris Surveys

Surveys of LWD and jams occurred during the habitat surveys. LWD data were recorded for every habitat unit that contained wood. Wood survey forms are located in the Appendix 1. Pleus et al. (1999) defined LWD as having a minimum diameter of 0.1 m and a minimum length of 1.0 m. Wood included in the survey was, dead, located within the bankfull channel; exceptions were made for LWD associated with jams. Diameter of the wood was estimated and tallied in 7 categories (10-20 cm, 21-30 cm, 31-40 cm, 41-50 cm, 51-60 cm, 61-70 cm and 70+ cm). Wood length and presence of rootwads were not recorded. The size of key pieces, as defined by TFW is scaled to the bankfull width of the river. Table 1 below is taken from Appendix C of the 1999 TFW method manual for monitoring large woody debris. The origin of this table is the fish module of the 1997 Washington Forest Practices Board (WFPB) methodology for conducting Watershed Analysis. Although the average bankfull width of the Pilchuck River was > 30 m, these wood diameters and lengths were applied to key pieces found in the river. These criteria were amended slightly, using a maximum wood diameter category of 70+ cm.

Table 1. WFPB key piece criteria.

Minimum Diameter of LWD (m)	Minimum Length (m) for BFW > 15 – 20
0.60	32
0.65	28
0.70+	24

Debris jams are defined as accumulations of a minimum of 10 pieces of LWD that are touching. Also a minimum of 0.1 m of a piece of wood in the jam had to either be extending into the bankfull channel or above bankfull height (Schuett-Hames et al. 1999).

The removal of wood from the bankfull channel was recorded. Evidence of wood removal included drag marks of logs towed off of gravel bars, recent sawdust, and piles of bucked logs on gravel bars. Locations of wood theft are reported in the discussion section.

Riparian zone surveys

The riparian zone was surveyed during the habitat survey. Standing in the channel, the assessor categorized the riparian condition on both banks by estimating riparian zone width, density, age and species composition. In the office, riparian widths were measured on a Snohomish County 2001 waterbodies layer (which shows bankfull width) overlaid onto 1998 orthophotos in GIS. The standard was to measure from the edge of the waterbody to the outward edge of the riparian zone. When questions arose, field data were compared against aerial photos to ensure correctness of riparian width characterization. Riparian zone information was entered on a GIS layer along the stream channel, and was color-coded to denote width. If a road was encountered along the stream bank, the riparian zone was measured from the riverbank to the streamside edge of the road, regardless of forest presence on the other side of the road. Table 2 shows buffer width categories used for delineating the riparian zone.

Table 2: Riparian buffer width categories.

Buffer width category	Width (m)
0	0 – 15
1	15 – 30
2	30 – 45
3	45 – 55
4	> 55

The riparian zone was classified by dominant composition, age and density, using methodology from the riparian module for watershed analysis (WFPB, 1997) (Table 3). For example, buffers

comprised of sparse, large (> 50 cm DBH) cottonwoods that do not extend 15 m from the river bank were classified as deciduous, old and sparse (DOS), with a buffer width category of 0.

Table 3. Riparian zone classification

Vegetation type	Age	Density
Conifer (C)	Young (Y)	Sparse (S)
Deciduous (D)	Medium (M)	Medium (M)
Mixed (M)	Old (O)	Dense (D)

Temperature surveys

Temperature data were collected in 2001 and 2002 throughout the mainstem of the Pilchuck. Distribution of gauges ranged from RK 5.8 - 23.7, and from RK 5.8 – 29.3 in 2001 and 2002 respectively (Figure 2). Temperature data was collected using Onset StowAway loggers that were calibrated prior to use. Data collected are accurate within $\pm 0.2^{\circ}\text{C}$. Loggers were protected with foam pipe insulation and were zip tied to LWD submerged in pools near the bottom of the river. Since river depth varied, loggers were not placed at uniform depths.

Results

Reaches

The 23.5 kilometers of river surveyed were broken into fourteen reaches (Figures 3 a-b). This map was created using the 2001 Snohomish County Surface Water Management updated hydro layer that was overlaid onto 1998 orthophotos and shows the reaches, numbered from downstream to upstream and the habitat units in each reach. Reach lengths ranged from 0.3 km to 6.5 km. Average bankfull width in the Pilchuck River study area was 34.3 m. Reach average bankfull widths ranged from 25.1 to 62.2 m. Channel types found in the Pilchuck River were forced pool-riffle and plane-bed. A summary of reach habitat characteristics and fish use is presented in Table 4.

Habitat Distribution

Figure 3 a-b shows each habitat unit in the river. Generally, pools have greater width than length. Glide and riffle habitat are dominant throughout the area, except for in the side channel, Reach 12, where pool habitat is dominant (Figure 4). Habitat in the side channel is more evenly distributed between the three types, and pool habitat comprises 41.2% of the available stream habitat. No other reach contains as large a percentage of pool area.

Pools with residual depths of 0.9 to 1 m in depth were the most frequent, while deeper pools are less frequent (Figure 5). Figure 6 shows the frequency of pool volumes in the study area, volume

categories include the number displayed as a minimum and includes volumes up to the next category. For example, pools grouped in 400 m³ covers a range between 400-599 m³. Pools with volumes < 200 m³ were the most frequent followed by pools < 400 m³. The median pool volume is 322 m³.

Pool area is partially determined by forming mechanism. Mean area of pools formed by riprap is greater in all reaches with pools except for Reach 12 (side channel), where there is no artificial bank hardening and Reach 14, where bed/bank interactions dominate pool formation. The mean areas of pools grouped by forming mechanism were tested using a one-way ANOVA with a post-hoc Bonferroni multiple comparison test. The mean area of pools formed by riprap is significantly higher than the mean area of pools formed by wood ($P \leq 0.004$). There is no significant difference between the mean area of bed/bank pools and riprap pools.

Figure 7 shows the number of pools created by riprap, bed/bank interactions and wood. Riprap and wood formed pools each account for 39% of pools in the study area and bed/bank pools account for the remaining 22%. The influence of wood in pool formation generally decreases in a downstream direction. Bed/bank formed pools increase in frequency upstream of RK 18. The number of riprap pools increases in a downstream direction. Riprap and other forms of bank hardening are the main sources of in-channel roughness in the lower portion of the Pilchuck River.

Fish Distribution

Figure 8 a-d shows the long profile of the study area. The intent of this graphic is to show relative thalweg and water elevations and the location of debris jams, riprap and chinook redds (1999, 2001 and 2002). Typically the dips in the thalweg elevation in Figure 8 are pools, although they are occasionally deep glides. The presence of riprap on the graphic corresponds to the location of a pool formed by riprap and does not account for all bank hardening in the system. The side channel long profile is included in Figure 8c.

It is interesting to note the absence of fish redds in certain reaches, or portions of reaches (Figure 8 a-d). The majority of redds are found within forced pool-riffle channel types, while few redds are found in the plane-bed channels. Plane-bed channels have little to no variation in thalweg depth and infrequent natural roughness features, such as wood debris jams. The habitat found in these reaches is generally a long glide, represented in the figure where the water surface elevation line is directly above the thalweg elevation line. In an extreme case of spawning in a plane-bed channel (Reach 13), a chinook redd was found 600 m upstream and 800 m downstream from the closest pools, both of which were secondary pools (Figure 8d).

Figure 9 shows a relationship between the number of channel widths between pools and the density of redds per kilometer in forced pool-riffle and plane-bed channel types. Using the 1999 redd surveys we found that the reaches with the highest redd counts have lower pool spacing; this implies that there is a shorter distance between spawning grounds and holding pools. The majority of fish (66%) spawn in reaches with pool spacing less than $3 \text{ CW} \cdot \text{pool}^{-1}$. These reaches are generally forced pool-riffle channel types. Plane-bed reaches in the Pilchuck River had higher average pool spacing than forced pool-riffle reaches, with spacing of $13.3 \text{ CW} \cdot \text{pool}^{-1}$ and $1.9 \text{ CW} \cdot \text{pool}^{-1}$ respectively.

Holding pools were determined by identifying the nearest pool, upstream or downstream of surveyed chinook redds. Holding pools used by chinook varied in forming mechanism and volume. 44% of the holding pools were formed by riprap having an average volume of 986 m^3 , 30% were formed by bed/bank interactions with an average volume of 760 m^3 and 26% were formed by LWD having an average volume of 383 m^3 . The average volume of holding pools was 689 m^3 , while the majority of pools in the area had a volume of $< 320 \text{ m}^3$.

Fish Passage

It is our hypothesis that freshets partially determine the extent of chinook use of the Pilchuck River. Typically, daily stream flow is below 80 cfs during the onset of chinook migration and rises only when rainstorms occur. Stream flow in the Pilchuck River responds rapidly to precipitation. Input as low as 0.3 inches in 24-hours, recorded at Paine Field, Everett, WA, causes the river to raise an order of magnitude in a few hours. Stream flow returns to pre-storm levels within approximately 24 hours after the end of the storm (Figure 10). In 1999, daily flows were well above 100 cfs, measured at Snohomish, in early to mid August. These flows may have enabled fish to migrate farther upstream at an earlier date. Tulalip Tribes snorkel surveyors sighted a chinook above the City of Snohomish dam on September 8, 1999. Flows remained approximately 65 cfs until October 8th, when a storm raised flows to 862 cfs and within 96 hours flows averaged 120 cfs, enabling a later group of fish to move into position for spawning in upstream reaches. Redds were located above Granite Falls at RK 31.3 and 33.

In 2001, the first rainstorm occurred in late August, which would have moved early returning fish out of the lowest reaches of system (Figure 11). Flows ranged from 60 - 80 cfs until a second freshet of 338 cfs occurred in late September. This storm would have served to move the majority of migrating fish higher into the system. The timing of storms may impede chinook from migrating to the upper reaches of the watershed. In 2001 spawning surveys above Granite Falls found no redds. Neither adult chinook nor redds were seen above the dam in the late fall of

2001. Fish may have elected to spawn in lower reaches of the river as a result of the seasonal drought and high temperatures.

In 2002, flows remained approximately 55 cfs for the majority of the spawning period (Figure 12). The first freshet above 100 cfs occurred in mid-September. The timing of higher flows may have limited fish access to higher spawning grounds in the system. Surveys above Granite Falls in mid-October found no chinook carcasses and no redds.

Large Woody Debris and Jam Distribution

Figure 13 shows wood counts in individual habitat units along the length of the study area. Single pieces of wood dominate the lower reaches (Reaches 1 - 8) and jams are infrequent. At RK 16.9 (Reach 9), jams are more frequent, and contain a more significant portion of wood found in the reaches. RK 16.9 is located approximately 100 m upstream of the Russell Road Bridge and is an area of local channel aggradation. Jams are bunched in their distribution in a portion of Reach 10 (RK 17-18), Reaches 11 and 12 (RK 22.5 to 25) and Reach 14 (RK 27-27.7), in areas with locally high width to depth ratios (W:D).

Wood size was small, the majority of pieces having a diameter ≤ 30 cm (Figure 14). Small single pieces (≤ 30 cm) of wood are dispersed throughout the bankfull channel, on top of gravel bars, embedded in banks and within the low flow channel. Wood pieces in the pools are typically small, 41% of the wood found in pools has a diameter < 20 cm and 70% of the wood has a diameter < 30 cm. These smaller pieces are not individually capable of contributing to habitat formation processes by maintaining position in the channel during higher flows. Wood debris jams recruit these transient pieces of LWD during high flow events, thus more wood was found in jams than found as individual pieces in the study area.

43 key pieces were found in jams in the study area, these pieces were a minimum of 60 cm in diameter with length scaled to mid-point diameter according to parameters found in Table 1. Of the 42 jams that were identified in the study area, 28 of them did not contain key pieces according to WFPB criteria. A review of large diameter wood found in jams without key pieces shows that the > 30 cm size classes of wood are present (Figure 15). Combined, LWD pieces in the diameter size classes of 31 – 40 cm and 41 – 50 cm initiated 19% of the jams found in the study area. Often, qualifying large diameter pieces (≥ 61 cm) did not meet the key piece length criteria for reasons such as breakage and wood removal. However, these pieces formed 24% of the jams in the study area, while pieces of the same diameter that met the WFPB length requirements, formed 33% of the jams. As a group, wood pieces that initiated debris jams, but do not fall into a WFPB category are termed ‘unclassified key pieces’.

Figure 16 shows a relationship between wood presence and channel type. Typically, wood counts are higher in the forced pool-riffle sections of the river than in the plane-bed reaches. Two forced pool reaches, 12 and 14, have wood counts of 100.4 and 55.4 pieces-CW⁻¹. The upstream increase in wood frequency, specifically in forced pool-riffle channels, can be seen in the transition between Reaches 8 and 9 in this graphic.

Figure 17 a-b shows chinook redd (1999, 2001 and 2002) and wood debris jam distributions in the Pilchuck River. The 1999 and 2001 redd data were collected prior to habitat surveys, however, redds were placed at approximated habitat units in Figure 17 to denote the importance of certain reaches for chinook spawning habitat. Low numbers of chinook tend to spawn throughout the study area. It appears that chinook tend to spawn more consistently and in higher numbers in the upper reaches of the Pilchuck River study area. Wood jams are generally absent from the river below Reach 9, excepting portions of Reaches 3 and 5, where the river has created meander cutoffs. There are frequent relict jams in the lower portion of Reach 11 (RK 18.8 – 19.2) that occur above bankfull flow. These jams exist on gravel bars that are covered with willow and alder trees that are approximately 10-15 years old. Presumably, these jams were bar apex or flow deflection jams that were abandoned by the river. Reach 13 is a plane-bed channel that contains no jams and is impacted by riprapping associated with Route 92.

Riparian Zone Condition

Figure 18 a-b show the riparian buffer widths, dominant vegetation and stand age and density on both banks from RK 5.9 to 29.3. A color and a number corresponding to a buffer width category denote the widths on the map. The lettering on the map is associated with the dominant riparian species class, age and density in a specific portion of a reach. 51% of the 47 km of riverbank (left and right banks combined) surveyed in the Pilchuck River has a riparian zone width > 1 SPT. However, the age and species composition of the riparian buffer varies within this width category. The riparian forest is not contiguous and 33% of the riparian forest having a width > 1SPT surveyed is deciduous, young and dense (DYD).

55% of the 23.5 km length of right bank surveyed has a buffer width of 0 – 15 m. The right bank riparian forest consists of 65% deciduous, young and dense (DYD), 31% deciduous, mid-aged and sparse (DMS) and 4% deciduous, young and sparse (DYS). The near term recruitment potential from these areas is extremely low, due to a species composition dominated by alder and willow, low density and young age of the riparian zone. Bank hardening on the right bank also reduces local recruitment. In contrast, 21% of the left bank riparian zone has a width of 0-15 m. Of the 73% of the forest on the left bank that exceeds 1 SPT, 39% is mixed, old and dense

(MOD) and 22% of the buffer is mixed, old and sparse (MOS), and of higher LWD recruitment potential.

Figure 19 shows wood counts and the percent length of the right and left banks of each reach that has a buffer width of 0 – 15 m, buffer category 0. Typically, reaches with a greater amount of category 0 riparian buffer width provide less recruitment to the channel and less wood is found in the adjacent and downstream reaches. The upper reaches of the study area have a lower percentage of category 0 buffer width and as a result, there is a higher wood count than in lower reaches. The left bank of the river in the study area has a lower percentage of category 0 buffer width. Table 5 summarizes the riparian and LWD condition of each reach using criteria from the Snohomish River Basin Salmonid Habitat Conditions Review, 2002. Three criteria, buffer width, average stem diameter and LWD counts are combined to rate each reach as intact, moderately degraded and degraded. The HCR call was degraded for all reaches excepting Reaches 8 and 9.

Future key piece recruitment is possible from groups of 25 – 50 year old cottonwoods (galleries) on the Pilchuck River (Figure 20). The galleries in Reach 6 and 10 are partially to fully cutoff from the river by bank hardening. The river is actively recruiting trees from cottonwood galleries in Reaches 11 and 12. These trees are important to future wood recruitment and jam formation in the Pilchuck River, where cottonwood trees are the key pieces in recently formed jams. Collins et al. (2002a) point out the importance of cottonwood as key pieces in the Nisqually River, due to the species relatively quick growth and large bole size.

Instream large woody debris removal

Removal of instream large woody debris occurs in the Pilchuck River system. Stream surveyors recorded incidents of instream cutting near cottonwood galleries in Reach 11 at RK 21.5, Reach 18 at the upstream end of the side channel RK 23.5, Reach 11 from RK 24.7 to RK 25 (Figure 20). The practice was recorded upstream of Granite Falls at RK 38.7 and RK 37 during a spawner survey in 2002. The removal occurs during low flow season, typically when adult chinook are in the system. LWD pieces targeted are long, large boles that are currently or potentially beneficial to instream habitat. Practitioners drive vehicles through the river and onto gravel bars, where they tow wood out of the bankfull channel, cut it into manageable pieces and haul it out of the system.

Temperature

Figure 21 a-b shows the number of days in August that the 7-day moving average of daily maximum stream temperatures met HCR spawning temperature criteria (shown in Figure 21). The majority of days surveyed in August 2001 were degraded downstream of the gauge in the side channel (RK 23.1). In 2002, the majority of days were degraded at all sites, except for a pool at RK 29.3, downstream of Granite Falls. The northern aspect of the pool, created by interaction with Tertiary sandstone, protects the river from direct insolation.

Figures 22 and 23 show the 7-day moving average of maximum temperature at OK Mill Road Bridge (RK 14.1) and the side channel (RK 23.1) in 2001. Fish typically enter the Pilchuck River in mid-August and experience 7-day maximum average temperatures above the degraded range for weeks to a month. Low discharge of the Pilchuck River affects summer and late fall stream temperatures. Stream temperature responds quickly to initial changes in stream flow as a result of precipitation. Note the troughs in stream temperature correspond to peaks in flow. The changes in stream flow have a short-term effect on temperature, with maximum temperatures returning to pre-storm levels within a day.

Discussion

Chinook salmon returns to the Pilchuck River have not been consistently monitored over time. Estimates of chinook salmon returns to the Pilchuck River since 1999 range from 100 to 200 fish. It is presumable that availability of suitable habitat and water quantity and quality has an effect on both juvenile and adult survival and abundance. Land uses have contributed to changes in flow routing and timing in the river, low channel roughness, prevalent bank armoring, and a lack of habitat complexity in the channel. Glides that are long and often shallow dominate habitat in the river. Pool spacing is frequently high, thereby offering little migratory refuge for adult chinook and other salmonids. Off-channel rearing habitat does not exist in the Pilchuck River study area, except in the side channel, Reach 12 (RK 23.1). The Pilchuck River has been placed on the 303(d) list for excessive temperature levels (WDOE, 1997) and experiences temperatures well above 15.5°C during chinook migration.

Habitat and Fish Distribution

Forced pool-riffle and plane-bed channel types are in the Pilchuck River study area. Plane-bed reaches are typically former forced pool-riffle reaches that have lost in-channel roughness elements, such as LWD (Montgomery et al. 1999). This process of channel simplification has

resulted in large habitat units in the Pilchuck that are often several channel widths long. Glides with lengths over 100 m and depths less than 50 cm were not infrequent in the river. These glides result from a combination of factors, presence of bank hardening, increased sediment load, removal of instream LWD and a lack of wood recruitment from the riparian zone.

Surface areas of pools formed by wood pieces and jams are significantly smaller than pools formed by riprap. Riprap often impacts long sections of a riverbank, scouring long and narrow pools. Riprap tends to affect greater lengths of a stream channel than wood. Riprap decreases vegetation on stream banks (Schmetterling et al. 2001) reducing availability of food sources for juvenile salmon. Simplified pools formed by riprap do not provide overhead cover (Crook and Roberston 1999) or visual separation (Fausch 1993) required by adult and juvenile salmon. Riprapped banks and associated affected areas have relatively simplified sediments and this may have consequences for available food, cover and spawning sites (Garland et al. 2002).

Bed/bank formed pools are deep, longitudinal scour pools formed when the Pilchuck River interacts with the transitional beds and Tertiary sedimentary deposits. Resulting pool morphology tends to be narrow and deep with clay or sandstone ledges that provide cover to fish. The banks of the Pilchuck River from Dubuque Road (RK 9.5) to OK Mill Road (RK 14.2) are sporadically lined with a transitional bed deposit (Minard, 1985a). The river interacts directly with the transitional bed deposits on the left bank downstream from Machias (RK 13.1). The result is a large deep pool, which chinook and steelhead use for holding. Steelhead use a pool scoured into Tertiary sandstone at RK 17.4 for holding. Similar pools are located on the left bank of the river from RK 18.8 to RK 23.6 and at RK 29.1.

Pool spacing in the Pilchuck River study area ranged from 0.5 to 17.5 CW·pool⁻¹. Pool spacing in the study area averaged 7.0 CW·pool⁻¹, while in forced pool riffle reaches pool spacing averaged 2.0 CW·pool⁻¹. Pool spacing in the Stillaguamish and Snohomish Rivers ranged between 3.0 and 5.0 CW·pool⁻¹ and 3.0 CW·pool⁻¹, respectively (Collins et al. 2002a). Collins et al. (2002a) reported that 1.4 CW·pool⁻¹ is considered to be representative of an unmanaged section of the Nisqually River.

In the Pilchuck River study area, chinook salmon preferentially spawn in forced pool-riffle reaches over plane-bed reaches. Montgomery et al. (1999) report that chinook redd densities in the Stillaguamish River vary dramatically between channel types, with chinook selecting pool-riffle and forced pool-riffle channels. Redd densities in pool-riffle, forced pool-riffle and plane-bed channels ranged from 4.2 – 16.2, 2.5 – 13.8 and 0 redds/km respectively in the Stillaguamish

River (Montgomery et al. 1999). Coho in the Skagit River avoid plane-bed reaches and spawn selectively in pool riffle and forced pool-riffle channels (Montgomery et al. 1999).

Chinook in the Pilchuck River spawn in the downstream ends of glides. It has long been observed that many salmonids, including chinook, prefer to spawn in the transitional area between pools and riffles (Bjornn and Reiser, 1991). The behavior exhibited by chinook in the Pilchuck River may be in response to channel simplification that has resulted in a lack of in-channel woody debris and complex habitat. It is possible chinook are spawning in glide-riffle transitions because they are more frequent than pool-riffle transitions. Localized gradient breaks determine the transition from glide to riffle habitat. Surface water – groundwater exchange may occur at these transitions.

Chinook, as well as coho, pink and chum salmon appear to consistently use Reach 7 upstream of OK Mill Road Bridge for spawning. Reach 11 has low pool spacing and portions of this long reach are used consistently by spawning chinook. Chum salmon spawn in the lower portion of Reach 11 yearly. No chinook redds have been sighted in the side channel reach however coho salmon redds were seen in 2001 and 2002. This lack of chinook spawning can be attributed to the relative instability of the channel and that chinook may be less opportunistic in their selection of spawning locations than coho.

Large Woody Debris and Jam Distribution

LWD plays a major role in the geomorphology of coarse bedded rivers, influencing fish habitat on a reach and lower scale (pools) (Crook and Robertson, 1999). Wood distribution and abundance affects the presence and quality of pool habitats used by juvenile and adult salmon. Wood is known to increase channel complexity (Bisson et al. 1987), provide velocity refuge (Bjornn and Reiser, 1991) and provide temperature refuge (Torgerson et al. 1999). It is expected that wood distribution would tend to clump throughout the longitudinal profile of a large channel (Fetherston et al. 1995), in areas of locally high W:D or within debris jams (Figure 13). Collins et al. (2002b) report that 90% of the pieces of LWD were found in jams on the unmanaged reach in the Nisqually River. Overall, 62% of the LWD in the study area was found in jams. In reaches 12 and 14, 95% and 90% respectively of LWD was found in jams. Jams function to trap smaller pieces that would be transported out of the system, thus forming more densely packed jams. The increased density of a jam increases the hydraulic influence and capability to form habitat features in the river. Wood not incorporated into jams in the study area was scattered within the bankfull channel, on gravel bars and buried within the base flow channel.

Jam frequency decreases dramatically downstream of the Russell Road Bridge (Figure 13). The transition of jam distribution at RK 16.9 is due to a lack of locally recruited wood and a lack of wood transport downstream of the bridge. The upstream portion of Reach 9 is aggrading due to constriction caused by Russell Road Bridge, resulting in a locally increased W:D and increased wood deposition and jam presence (Figure 17a). The change in the distribution of single wood pieces at RK 14 (lower Reach 7) is in part due to increased transport capacity of the river (Figure 14). The cross-section of the river at this site is observed to be largely rectangular with little variation in the thalweg depth. Dubuque and Little Pilchuck Creeks join the Pilchuck River below RK 14, which increases the transport capacity of the river at higher flows. The relatively small diameter pieces of wood recruited from the riparian zone and from upstream are buoyant and readily transported at high flows.

Table 6 summarizes wood counts and large woody debris metrics used in western Washington. LWD (0.1 m diameter and 1 m length) counts in the Pilchuck River system range from 0.5 pieces·CW⁻¹ to 100.4 pieces·CW⁻¹. The Washington Forest Practices Board (WFPB) diagnostic rating for a 'good' channel condition ($0 > \text{BFW} > 20$) is 2 pieces·CW⁻¹. The WFPB defines LWD as having a midpoint diameter of 0.1 m and a minimum length of 2 m; therefore the wood counts in this study are high in comparison.

Average wood counts in unmanaged western Washington streams are higher than wood loading in the Pilchuck River. Unmanaged streams with bankfull widths > 30 – 100 m contained a median LWD count of 208 pieces·100 m⁻¹ of stream channel (Fox et al. 2003). Fox (2001) defines LWD as having a midpoint diameter of 0.1 m and a minimum length of 2 m, which reduces the eligible amount of LWD in the Pilchuck River for comparison. No section of the study area has a wood count comparable to an unmanaged system with a similar bankfull width (Table 6). Fox et al. (2003) found that the WFPB target for LWD in streams with BFW < 20 m is lower than what is present in unmanaged channels and suggests 208 pieces·100 m of channel length as a 'good' instream condition in a stream the size of the Pilchuck River (BFW > 30 – 100 m). New targets suggested by Fox et al. (2003) reference bankfull widths and can be applied to a wider range of streams in western Washington.

Collins et al. (2002a), report wood counts in representative reaches of the Stillaguamish River contain 52 pieces·km⁻¹ or 5.4 pieces·CW⁻¹. While the Stillaguamish River drainage basin is an order of magnitude larger than the Pilchuck, it is worthwhile to review wood counts in similarly impacted basins. Collins et al. (2002a) define LWD as having a minimum diameter of 0.15 m and a minimum length of 2 m; therefore LWD with a diameter < 15 cm counted in the Pilchuck is ineligible in the study. Table 6 reports data under the 'Collins' column that do not include

information collected in the study area for the 10-20 cm size category. 5 of the 14 reaches in the Pilchuck River study area are similar to or higher than wood counts found in the Stillaguamish River.

The size criterion for LWD is often changed to suit the purposes of a study, but generally falls within a diameter of 10 to 20 cm and a length of 1 to 2 m. Using a low size threshold for LWD allows for the consideration of small pieces that are important in biological processes, such as providing cover for fish and substrate for macroinvertebrate colonization. However, such criteria do not take into consideration the sizes of LWD necessary to initiate wood debris jams.

Key Pieces

Key pieces of LWD are large enough to initiate jam formation. Jams in the study area were initiated by LWD which did not meet WFPB key piece criteria for rivers with BFW > 15 – 20 m (see Table 1), whereas the Pilchuck River study area has an average BFW of > 34.3 m. The majority of jams were initiated by wood with diameters > 50 cm, while a small portion of the jams found were initiated by wood with diameters $\leq$ 50 cm (Figure 16). Small diameter unclassified key pieces ($\geq$ 31 – 50 cm) account for 19% of the jams and were stabilized by being embedded in the channel or buried in gravel bars. Jams initiated by small diameter wood were relatively small, averaging 12.4 LWD pieces per jam. Unclassified key pieces with diameters > 60 cm did not meet the WFPB length criteria due to breakage or wood removal, however they initiated 26% of the jams within the study area.

Key piece criteria and loading parameters vary depending on the source. National Marine Fisheries Services defines a 'Properly Functioning Condition' for key pieces in a river to be > 50 pieces of LWD/km with pieces having a minimum length of 15.2 m and 0.6 m diameter. WFPB criteria are listed in Table 1. Fox et al. (2003) compare the frequency of key pieces in unmanaged streams versus the recommendations of the WFPB ($0.5 \text{ pieces} \cdot \text{CW}^{-1}$) for channels with BFW (> 10 – 20 m). They found the WFPB recommendations to be higher than what is found in unmanaged streams of that size. They suggest for a 'good' channel condition that a river with BFW > 10 – 100 m contain > 4 key pieces/100 m channel length, as there is no clear relationship between the number of key pieces present and channel width.

Fox et al. (2003) provide a target of a minimum volume of 10.5 m^3 for a key piece in a river with a BFW > 30 – 50 m. They further suggest that rootwads are necessary for stability in a river of this size, as they found that 91% of key pieces had rootwads attached. Presence of rootwads on key pieces was not taken into account during the Pilchuck study. Table 7 provides key piece criteria (rootwads attached) for the Pilchuck River using the suggested minimum volume and the

diameter size classes found to initiate jams in the study area. Jams initiated by small diameter LWD (≤ 50 cm) are not taken into consideration, as they were generally not associated with pool formation.

Table 7. Minimum key piece dimensions for the Pilchuck River (volume = 10.5 m^3).

Diameter Size Class (cm)	Minimum Length (m)
51-60	19.1
61-70	16.2
70+	14.0

With regard to recent work by Fox et al. (2003) and observations made in the study area, it is suggested that key pieces in the Pilchuck River are smaller than the criteria suggested by both NMFS and the WFPB and the sizes listed in Table 7 could serve as minimum guidelines for key pieces in the Pilchuck River.

Landscape Management Implications of Instream LWD

The presence of wood debris jams drives salmonid habitat components on three landscape scales, in-channel, reach scale and valley bottom (Collins et al. 2003). Instream wood debris creates pools (Bilby and Likens 1980; Bisson et al. 1987; Montgomery et al. 1995), velocity refuge and cover for fish (Bisson et al. 1987; Fausch 1993) and bank stability (Keller and Swanson, 1979). On a reach scale, wood debris jams store sediment (Swanson et al. 1976; Beschta 1979; Megahan 1982; Keller et al. 1995; Fetherston 1995) and create complex channel configurations (Keller and Swanson 1979; Nakamura and Swanson 1993; Abbe and Montgomery 1996). On a floodplain scale, wood debris jams route floodwaters onto the valley floor (Collins et al. 2003), creating off channel habitat for rearing juvenile salmon. The lack of instream wood and floodplain connectivity in the Pilchuck River study area prevents natural recovery of salmonid habitat. Riprap prevents wood accumulations from forming and reshaping the river channel and floodplain, a process necessary for creating and maintaining complex instream habitat. Levees prevent floodplain inundation that in turn prevents the creation of necessary off channel habitat to protect juvenile salmonids from being displaced by floods (Crook and Robertson, 1999).

From a management standpoint, decreasing pool spacing by adding LWD to the plane bed reaches in the system may eventually decrease channel width, and increase the usable area for

fish habitat. Wood debris jams will store sediment within the channel, increase the depth of the channel, and provide deep, complex pools that are lacking in the study area. By reducing the distance between suitable holding pools for chinook, fish will have increased options for holding and spawning area selection.

Riparian Zone

Riparian zones of alluvial rivers tend to have a diverse plant community due to response to the natural annual hydrograph (Trush et al. 2000) and the seasonal variation of the water table (MacDonald et al. 1991). Geomorphic processes, such as avulsions and mass wasting, determine the landscape structure of stream channels and floodplains, which in turn determines the spatial pattern and successional development of the riparian zone (Gregory et al. 1987; Trush et al. 2000). A river with high floodplain connectivity and instream wood loading has diverse riparian stand ages and species composition and shows a pattern of dynamic stability. Geomorphically complex riverine landscapes allow for recruitment of LWD on a yearly basis, rather than in a single large episode (Wissmar et al. 2003), e.g. a braided reach with forested islands provides more opportunity for LWD recruitment than a single channel. Jams add to floodplain forest complexity by creating forest development refugia (Abbe and Montgomery, 1996) where patches of trees reach an age above the natural disturbance regime of the floodplain. Collins et al. (2003) found that the Snohomish and Stillaguamish Rivers, both single channel rivers, lack the ability to recruit wood for two reasons, the lack of contact with the floodplain and the lack of a floodplain forest.

The majority of the riparian zone of the Pilchuck River is considered degraded by HCR standards in terms of width, vegetation type and stand age (Table 5). The riparian buffer is fragmented and discontinuous both parallel and perpendicular to the river. Future LWD recruitment potential in the Pilchuck River is low in most reaches due to small stem diameters, vegetation types, and bank hardening. Cottonwood galleries located on portions of the river offer limited future recruitment potential for key pieces of LWD. However, these galleries and instream wood are threatened by wood removal. Also, riprap prevents recruitment of LWD throughout the study area and at cottonwood galleries (Figure 20). The degradation of the riparian zone has resulted in a decrease of in-channel LWD with respect to both the side channel (Reach 12) and unmanaged conditions.

Temperature

The Pilchuck River study area is degraded by HCR standards with respect to chinook migration temperatures (Figures 23-24). Reduced base flows, a degraded riparian zone, and a lack of connectivity to floodplains are factors that affect the natural temperature regulation system in

Puget Lowland streams (Booth, 1991); these factors occur in the Pilchuck River and are probably influencing the observed temperature conditions. Removal of the riparian zone and the subsequent increase in channel width of the Pilchuck River has created a wider gap in the riparian canopy than what is found in the side channel, Reach 19. An increase in stream width and the corresponding increase in surface area will lead to an increase in net solar radiation a stream receives (Beschta et al. 1987). Increased sunlight exposure in a river can increase primary production (Gregory et al. 1987) and lead to decreased dissolved oxygen levels in the river, adding further stress to migrating salmon. Unsuitable temperatures can lead to disease outbreaks in migrating and spawning fish and alter the timing of migration (Bjornn and Reiser 1991).

Chinook return to the Snohomish River basin prior to fall rainstorms and the resulting lower stream temperatures. When staging for spawning, fish generally hold in a pool in close proximity to spawning grounds. Native salmon have evolved a flexibility to cope with the variability in flow timing, temperature and turbidity in natal streams (Bjornn and Reiser 1991). Large, deep pools are generally considered the primary freshwater holding habitat used by chinook (Healey 1991). Holding is a method for chinook to conserve fat reserves and energy for spawning (Torgerson et al. 1999). The deep and complex pools that chinook have evolved to hold in until proper temperatures and flows are achieved are infrequent in the Pilchuck study area. A lack of these pools can affect the suitability of a stream for coldwater fishes (MacDonald et al. 1991). Although chinook are actively seeking larger pools for holding in the Pilchuck River, average pool volume is less than 200 m³ while the average holding pool volume is 689 m³, these pools are not offering thermal refuge to migrating salmon.

Spring chinook in the John Day River in Oregon find thermal refuge in both pools formed by tributaries and pools shaded by landforms such as cliffs (Torgerson et al. 1999). Pools in the Pilchuck that are shaded by Tertiary sandstone and transitional bed cliffs may offer cooler temperatures to migrating and resident fish (Figure 23 a). Chinook in the Pilchuck River may be able to thermoregulate behaviorally, as in the Yakima River, where spring chinook fitted with temperature sensitive radio transmitters were found to use behavioral thermoregulation to keep internal temperatures 2.5°C below ambient temperature (Berman and Quinn 1991). This is a significant difference in temperature with respect to metabolic rates experienced by migrating or resting fish. Torgerson et al. (1999) found that presence of spring chinook in certain warm reaches of the John Day River indicates that tradeoffs between pool availability and stream temperature play important roles in determining the longitudinal extent and carrying capacity of spring chinook habitat.

Summary

The Pilchuck River requires the addition of instream wood and replanting of a riparian zone in order to support increased numbers of chinook and other anadromous salmonids. In-channel wood is necessary to create complex habitat and deep holding pools, to narrow stream channels and to help reduce stream temperatures. Replanting the riparian zone will increase bank cohesion, reduce erosion and make LWD available for recruitment. It is not necessary to plant only climax species in a riparian planting. Collins et al. (2003) found that in the mid-19th century, hardwood tree species dominated the species composition of floodplain forests of the Puget Lowlands while western redcedar (*Thuja plicata*) dominated the forests in terms of basal area. Alder has proved to be important in nutrient cycling between stream channels and the floodplain through the hyporheic zone (Ritzenthaler, 1998). Collins et al. (2001a) suggest that cottonwood is a valuable addition to riparian zones and for recruitment into rivers as a short-term solution. These trees could fill the key piece 'gap' until riparian zones have recovered a natural species composition and age distribution. Cottonwood grows quickly, reaching the size of key pieces needed in the Pilchuck River within 30 to 50 years.

Suggestions for habitat enhancement:

General Suggestions for enhancement:

- Reduce bank hardening and provide areas of floodplain connectivity throughout the study area.
- Decrease pool spacing throughout the study area by adding roughness elements such as large woody debris within the long glides. Use Figure 3 a-b for locations.
- Replant the riparian zone with a mix of hardwood and conifer species. Use Figure 18 a-b for locations.

Specific Locations for enhancement:

- **Reach 3, RK 7.5 – 7.7**, is the site of a meander cutoff, where the river has moved from the left bank to the right bank and is flowing in a former mainstem channel closer to the right bank. (Figure 20) Riprap on the right bank upstream of the channel has created local scour. This change in elevation between the meander bend and the cutoff most likely initiated the cutoff. The opening to the meander bend is partially maintained by a wood debris jam. The former meander bend serves as an overflow channel during high flows and is dry during low flows.

Enhancement: Replace groins at upstream (RK 7.7) and downstream (RK 7.5) ends of meander cutoff with debris jams to increase holding pool frequency and complexity of habitat.

- **Reach 4, RK 7.9 – 9.5**, is a plane bed reach with simplified channel geometry. A single secondary pool is present in this reach, underneath an abandoned bridge. The streambed of the upper portion of Reach 4, downstream of Dubuque Road Bridge, has degraded by 2 – 4 feet due to effects of mining and localized increase in gradient (Collins, 1991).

Enhancement: Immediately downstream of the Dubuque Road bridge (RK 9 – 9.5) add wood to store sediment and to decrease degradation of the streambed.

Enhancement: Add wood at intervals throughout the reach in order to increase hydraulic roughness and scour pool habitat. Wood will decrease pool spacing in this section of the reach. Work with landowners to replant the riparian zone and to minimize impacts of riprap.

- **Reach 5, RK 9.7 - 10.2**, is directly upstream of Dubuque Road Bridge. Gravel mining occurred in this area, and stopped as recently as the early 1990's. The channel is aggrading due to downstream channel constriction and a reduction in channel gradient (Collins 1991). The Dubuque Road Bridge and associated riprap and dikes on the right bank that protect floodplain mine pits from the river have restricted the Pilchuck River from a portion of its historical lateral range. When a river is prevented from migrating laterally by riprap or other bank hardening, the river will tend to incise, leading to steepened banks and erosion (Scmetterling et al. 2001). In 2001, the river moved back to the left bank, eliminating the meander cutoffs and eroding the access road to a small housing development. Snohomish County hardened the bank and added groins in this location. Until the constriction of the river is reduced, the river will continue to migrate across the aggradation area and to erode stream banks further upstream.

Enhancement: Realign Dubuque Road Bridge to eliminate constriction of the river. Immediately upstream of the bridge, reduce constriction of the river by levees and riprap in this area. Levees could be set back from the river on the right bank, while protecting the mine pits from recapture by the river. Explore opportunities to backfill unused floodplain mine pits to reduce groundwater capture.

Enhancement: Place wood debris jams on the left bank at RK 10.2, to direct flows into gravel aggradation area. Place additional LWD hard points throughout the gravel bars to encourage channel braiding and riparian vegetation recruitment. Replant the riparian zone on the left bank at RK 10.2.

- **Reach 7, RK 14 -15.3.** Pool spacing in this reach is high, however 50% of the pools are formed by riprap. Chinook, coho, chum and pink salmon consistently use this area for spawning and holding.

Enhancement: Add LWD throughout the area as roughness elements to improve pool quality and enhance cover. Wood will help to rework the gravels in the reach that are covered with fine sediment.

Enhancement: Plant the riparian zone on the left bank throughout reach for shading, leaf litter and eventual LWD recruitment.

- **Reach 9, RK 16.4,** downstream of Russell Road Bridge and the till scarp. The meander bend downstream of the bridge has avulsed and been cutoff several times over the period of aerial photographic record. Recently (the last 10-20 years), the river has moved dramatically from the left bank, where a wood debris jam developed at the upstream end of the meander cutoff, to the right bank, where the river flows along a till scarp. Chinook use the area for holding and low levels of spawning.

Enhancement: Reopen the abandoned meander cutoff on the left bank of the river by adding LWD to the existing wood debris jam to help intercept flow at the upstream end of the cutoff. The abandoned meander cutoff could provide summer rearing habitat and off-channel habitat.

Enhancement: Plan to eventually remove Russell Road Bridge and associated bank hardening from this geomorphically active section of the river. Purchase property on the south side of the bridge to allow for natural avulsion processes. Properties on the north and south sides of the river can be reached without the bridge.

- **Reach 11, RK 18.7 – 20.2,** has low habitat diversity and contains hundreds of pieces of LWD within the bankfull channel. Chinook spawn in the downstream ends of glides in this portion of the reach.

Enhancement: Decrease pool spacing by moving existing LWD to wetted channel and supplement with large pieces of LWD. This will also rework gravels

to be suitable for spawning. Replant right bank riparian zone. Work with landowner to reduce or halt use of stream ford during spawning season.

- **Reach 11, RK 20.2 - 20.8.** The 250 m long glide at RK 20.4 is used regularly by chinook and chum salmon for spawning.

Enhancement: Replant riparian zone on both banks. Add wood throughout section. Work with landowner to reduce or halt use of stream ford during spawning season. Wood removal enforcement is necessary at the cottonwood gallery at RK 20.8.

- **Reach 11, RK 22 - 22.4.** Reach has low pool spacing. Reduced flow in the main channel, due to side channel capturing approximately 40% of the flow may eventually allow riparian encroachment from the left bank of the stream channel. Currently, the reduced flow has diminished pool volumes in the reach.

Enhancement: Replant right bank riparian zone with mixed hardwood and conifer species. Work with landowners to remove riprap on right bank of the river. In-channel wood removal enforcement is necessary at cottonwood gallery, upstream end of side channel, RK 23.1.

- **Reach 11, RK 24.6 – 24.9.** There is a high flow channel on the right bank, which flows through a portion of the cottonwood gallery (Figure 20). This high flow channel is a potential location for a channel avulsion or a side channel. Old debris jams have been stranded on gravel bars as the river has shifted back and forth through out the bankfull area of the reach. Upstream, several jams have formed recently from cottonwood trees recruited from the left bank of the river. These pieces have lodged against jams on mid-channel bars and are recruiting wood as it is transported downstream.

Enhancement: Add a wood debris jam to the upstream end of the high flow channel to increase potential to form a side channel, which could serve as off channel habitat for fish.

- **Reach 13, RK 25.2 – 26.7.** One pool is located within this 1.6 km long portion of the study area. Chinook migrate through this section of the river on the way to upstream habitat.

Enhancement: Add LWD to decrease pool spacing, to re-sort sediment and to retain organic matter.

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Figures

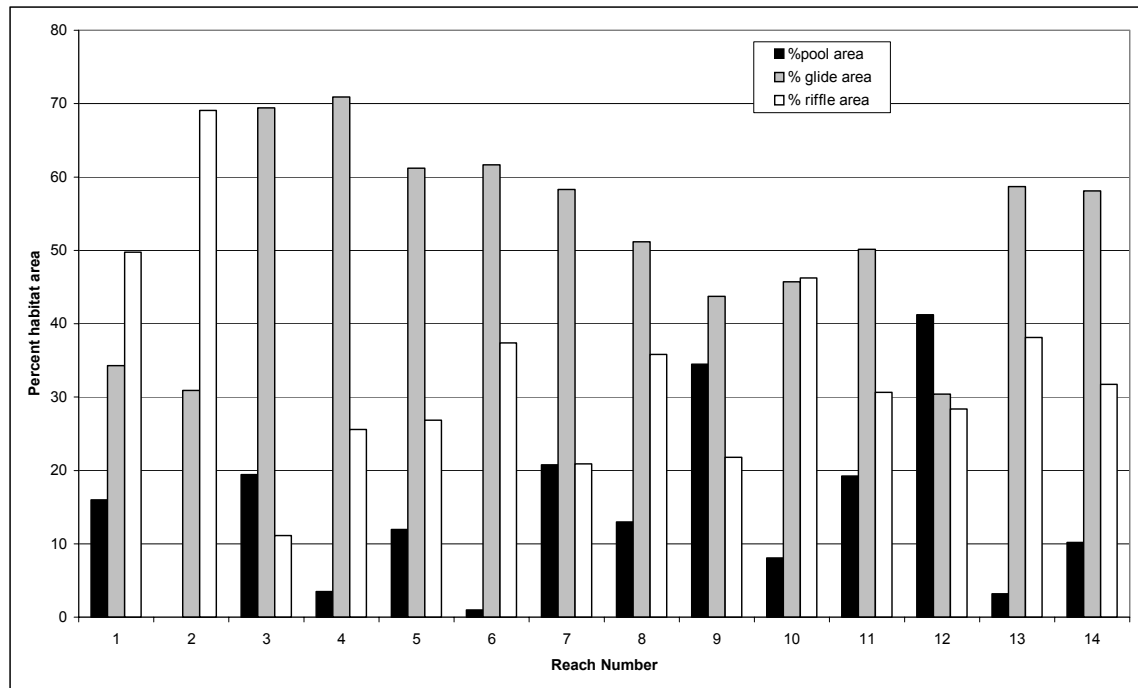


Figure 4. Percent habitat area by reach.

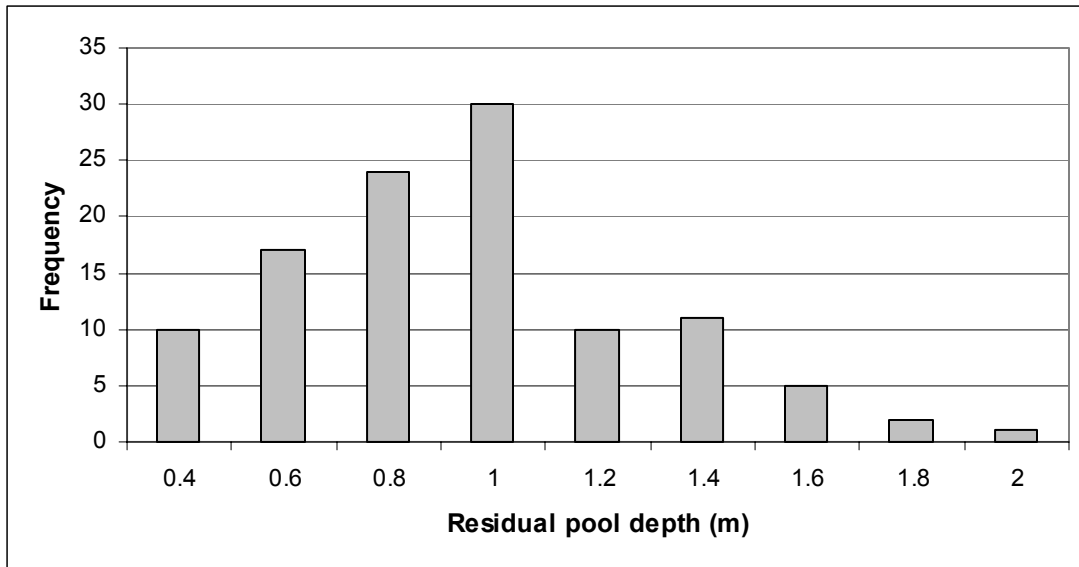


Figure 5. Frequency of residual pool depth.

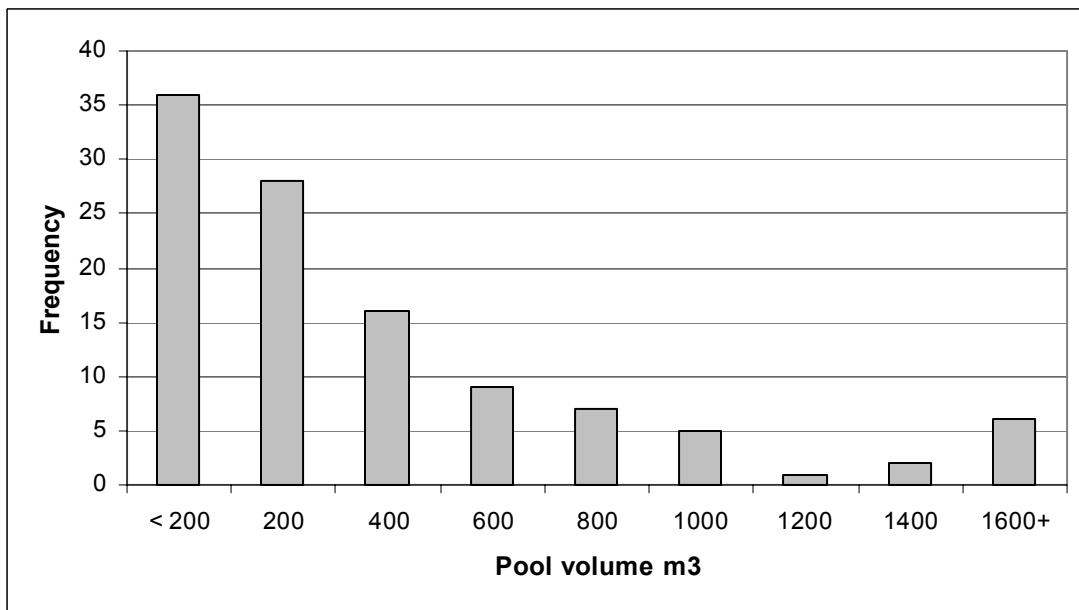


Figure 6. Frequency of pool volume.

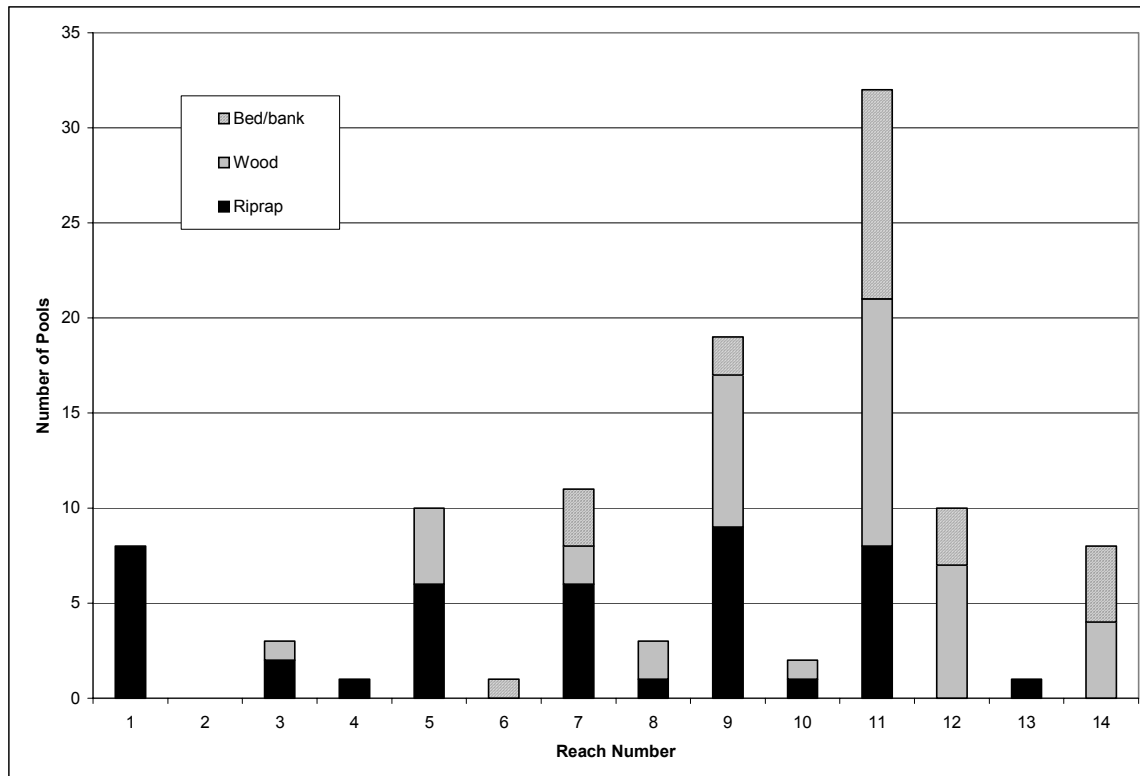


Figure 7. Number of pools formed by wood, riprap and bed/bank interactions by reach.

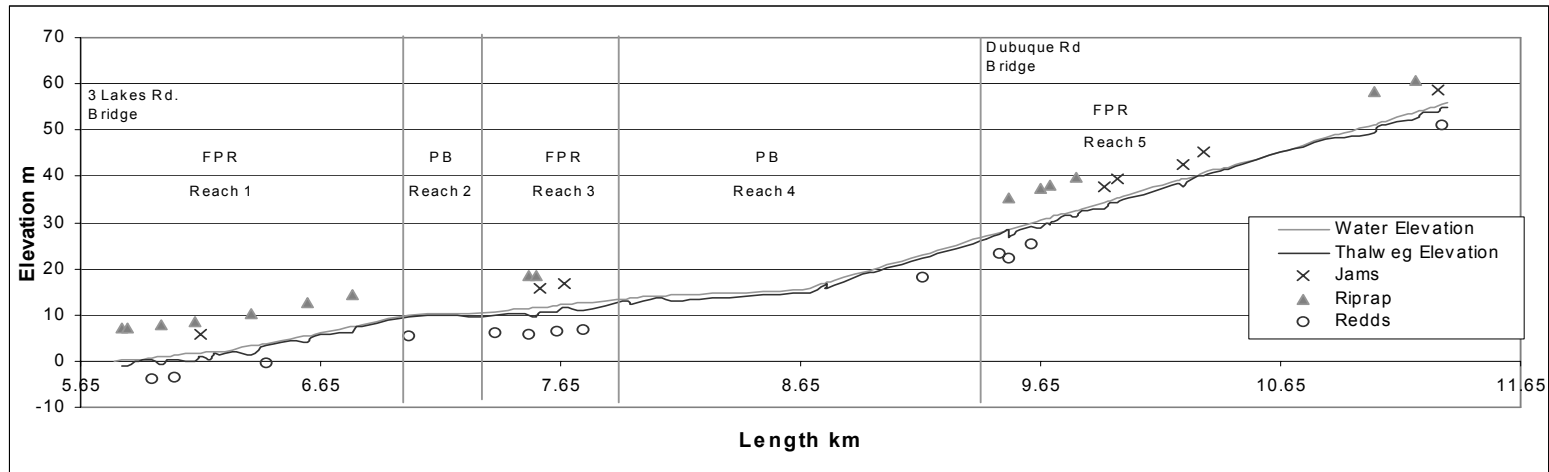


Figure 8a. Long profile reach 1 - 5. (FPR = forced pool riffle channel type, PB = plane bed channel type)

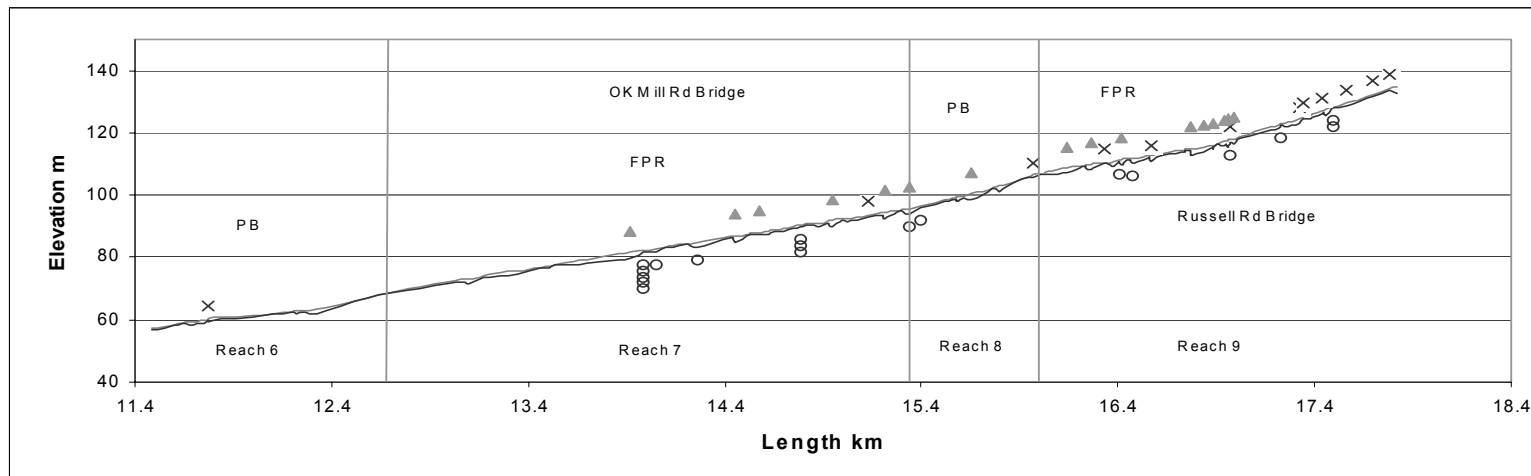


Figure 8b. Long profile reach 6 - 9. There is vertical exaggeration in this graphic. The graphic was based on individual reach gradients. A continuous water surface elevation was created by multiplying channel gradient by river kilometer (gradient*unit length = vertical increase/unit). Thalweg elevations were obtained by subtracting the maximum unit depth from gradient-based water surface elevations. For each redd and jam, 5-10 meters were added or subtracted to the river elevation. This way, multiple redds could be displayed at the same location along the long profile.

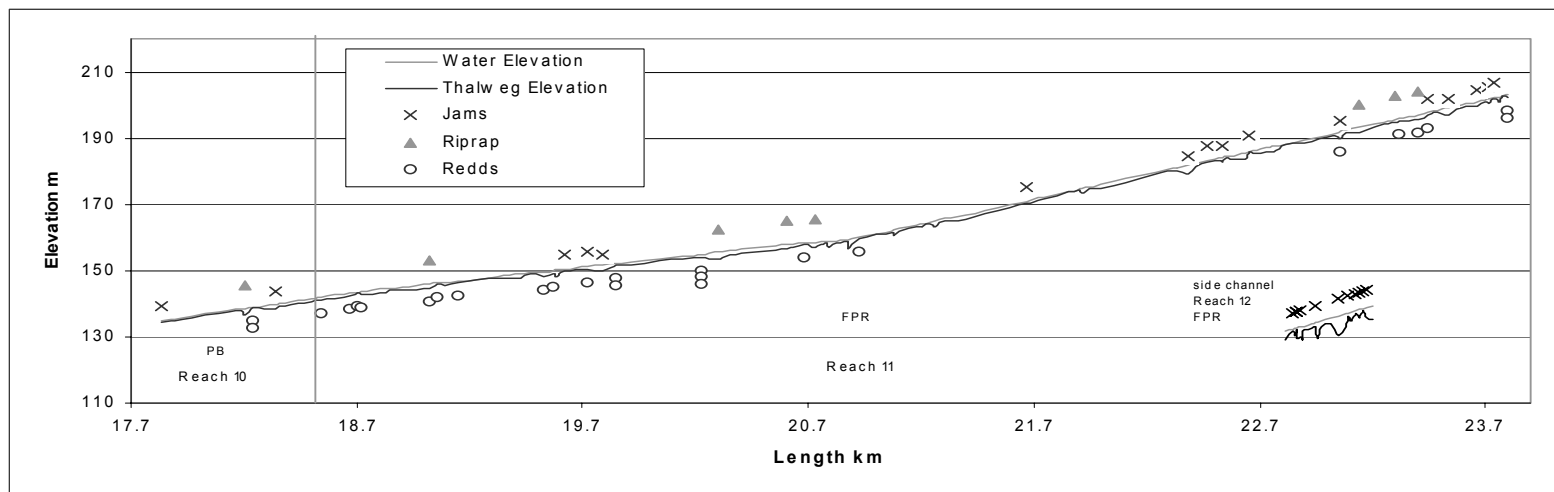


Figure 8c. Long profile reach 10 - 12.

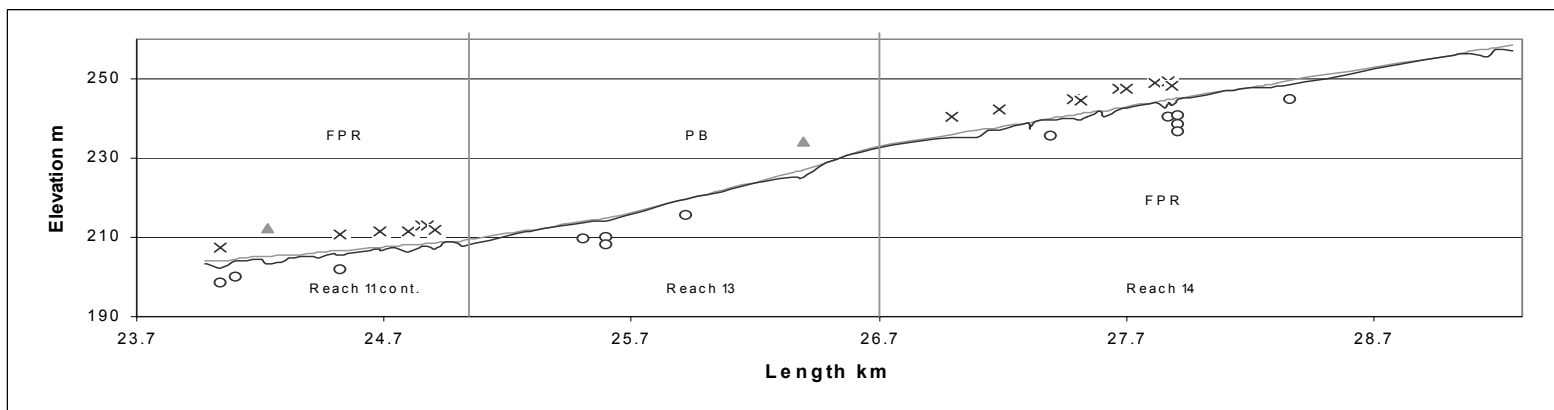


Figure 8d. Long profile reach 11 cont. - 14.

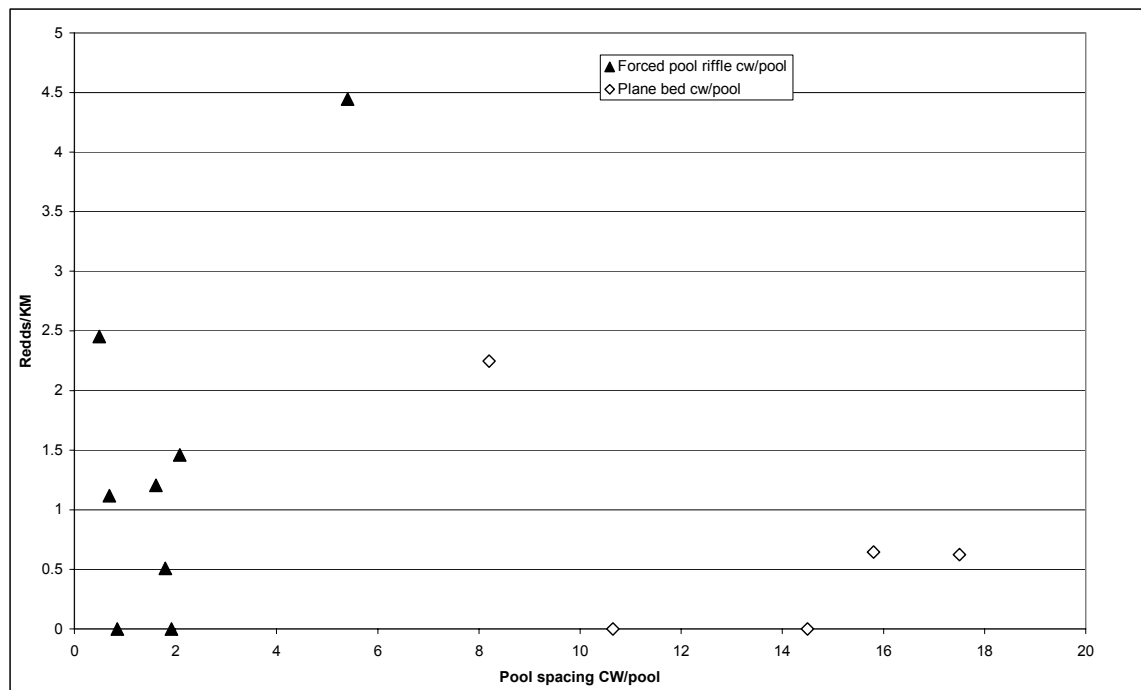


Figure 9. The number of redds per kilometer is influenced by channel type and pool spacing.

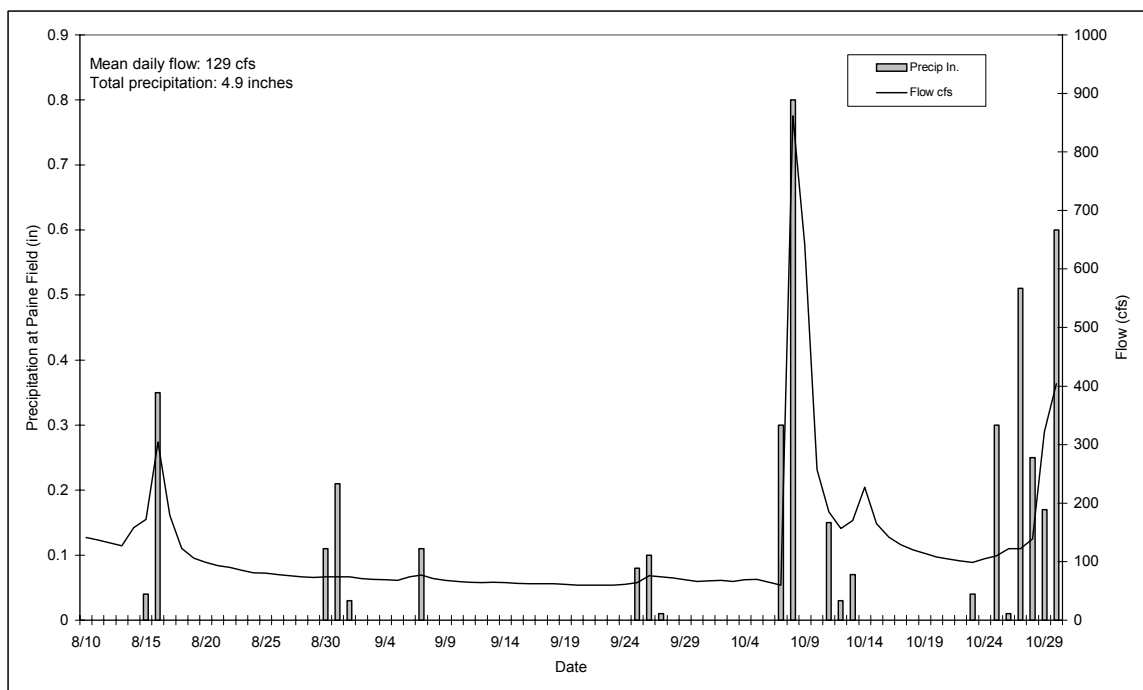


Figure 10. 1999 spawning flows.

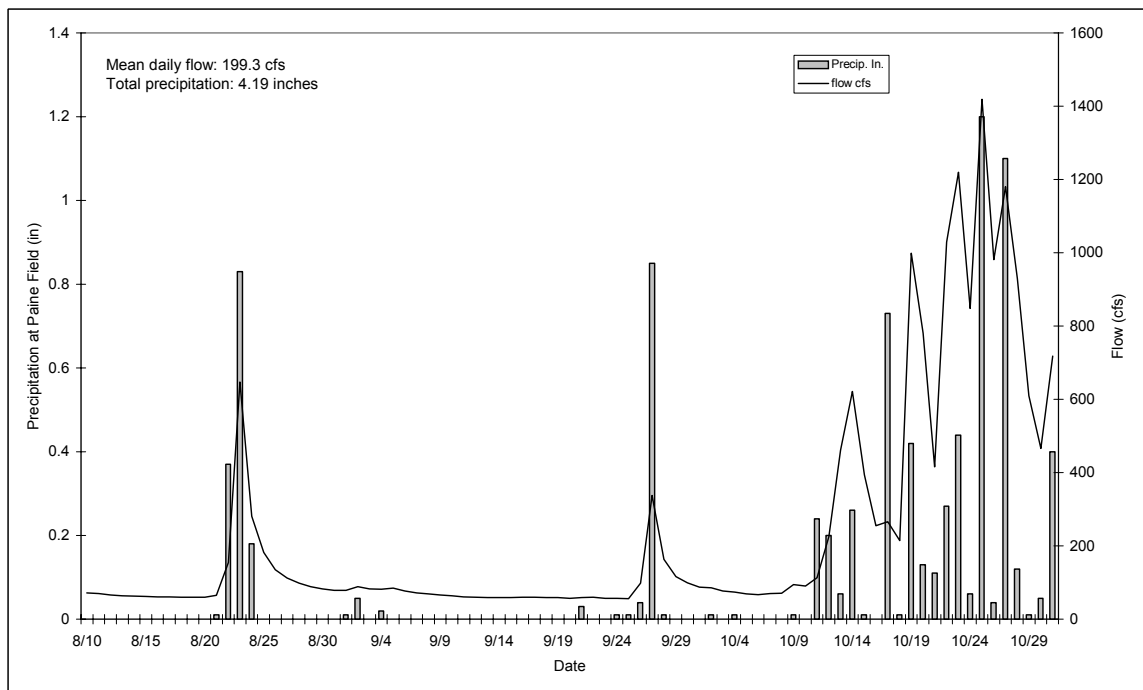


Figure 11. 2001 spawning flows

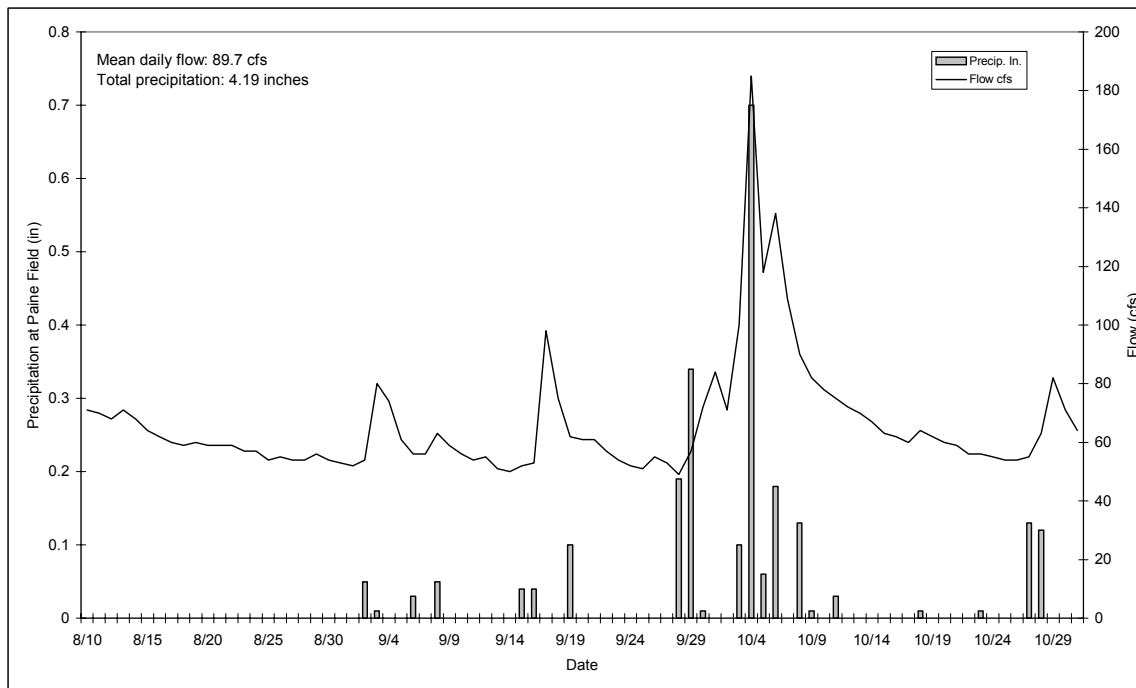


Figure 12. 2002 spawning flows.

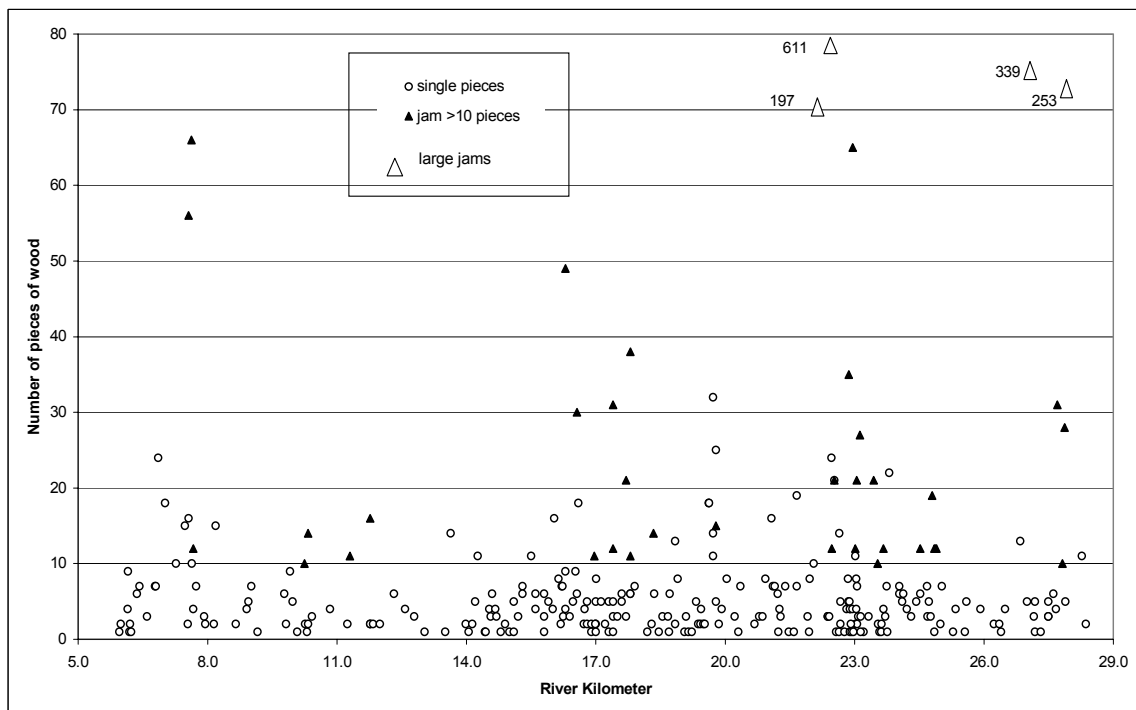


Figure 13. Wood grouping throughout the study area.

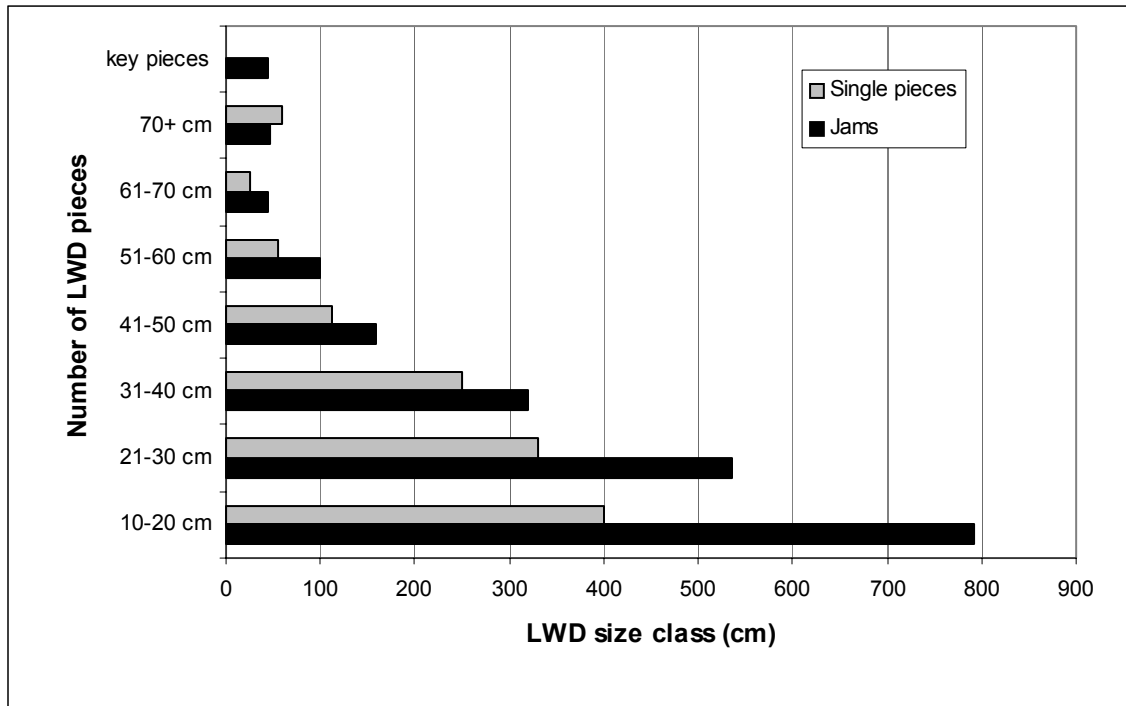


Figure 14. LWD distribution as individual pieces and in jams.

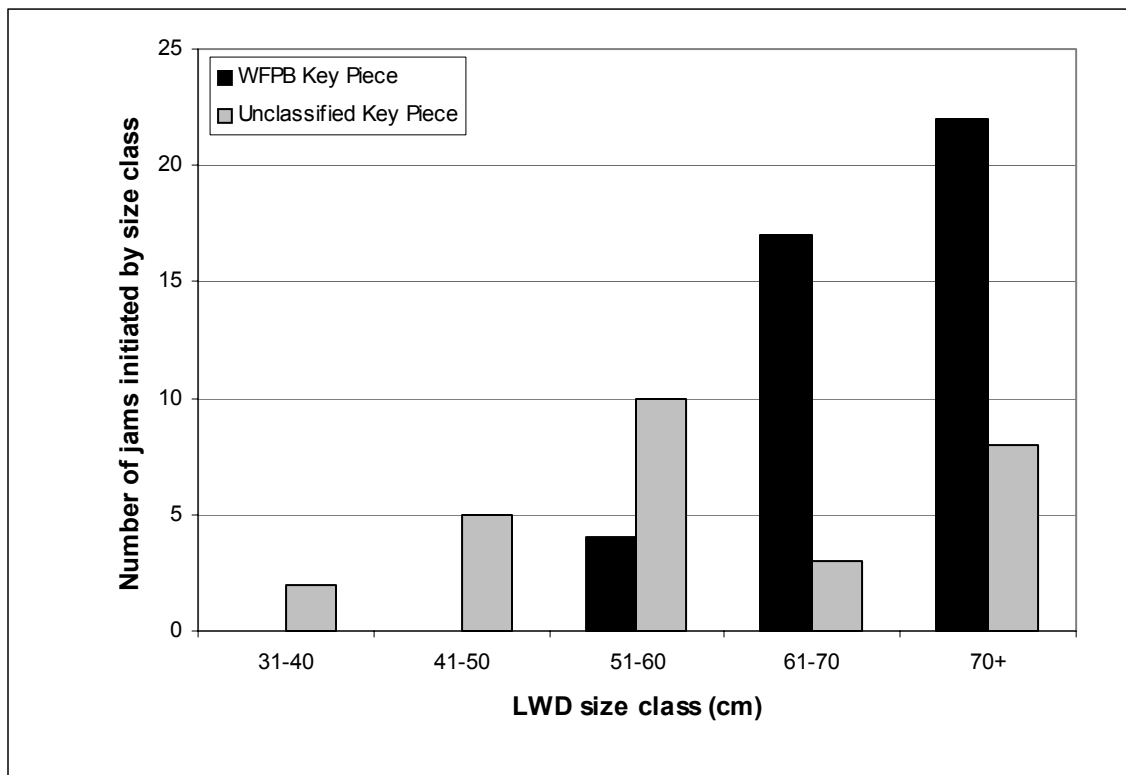


Figure 15. Key pieces found in study area.

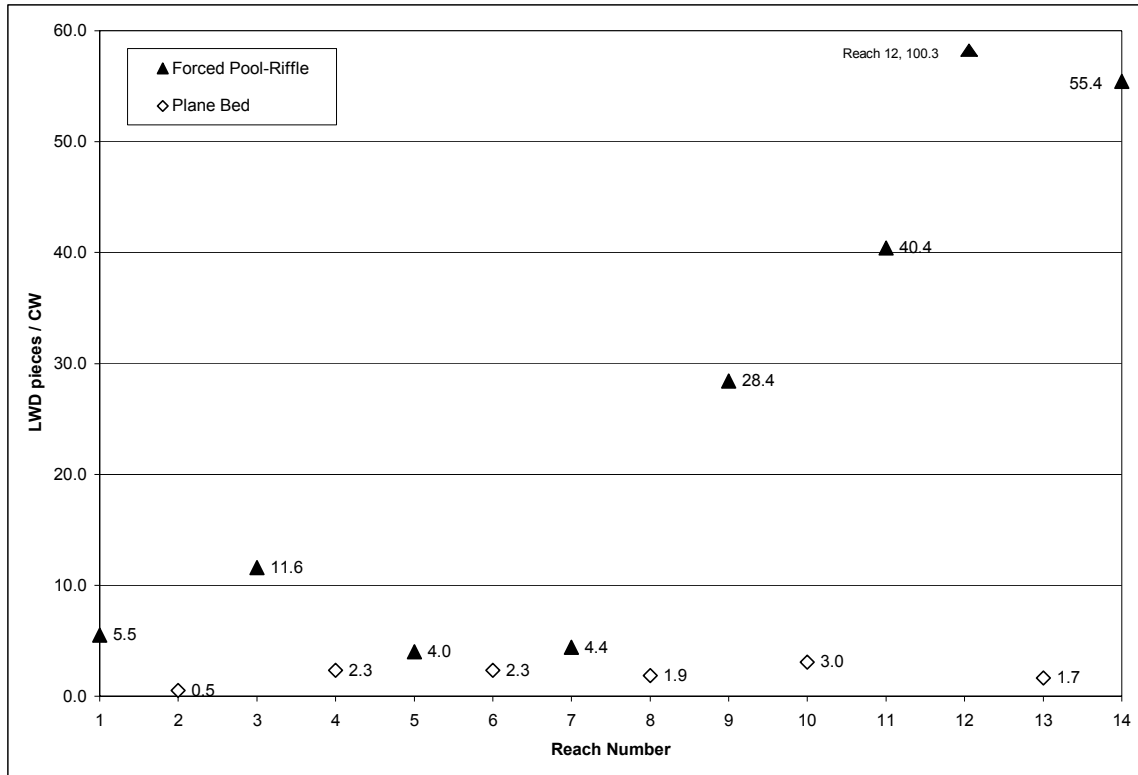


Figure 16. Channel type and wood frequency.

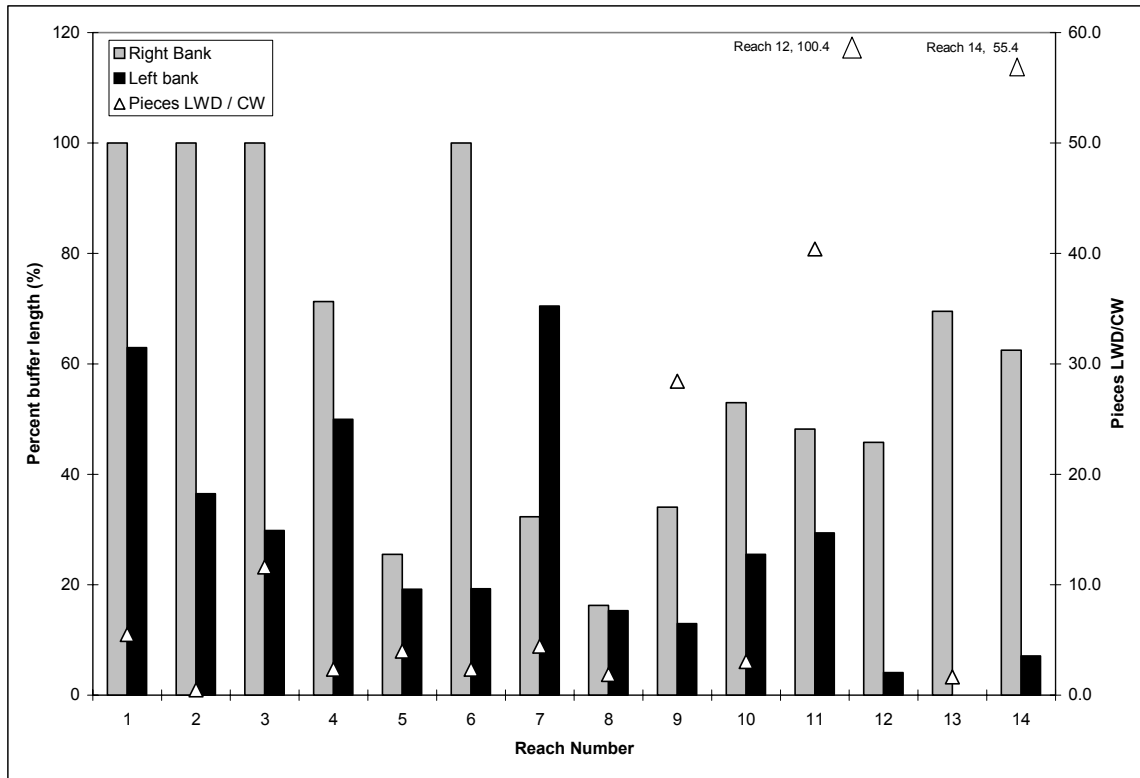


Figure 19. Percent right and left bank length with 0-15 m buffer widths and reach LWD frequency.

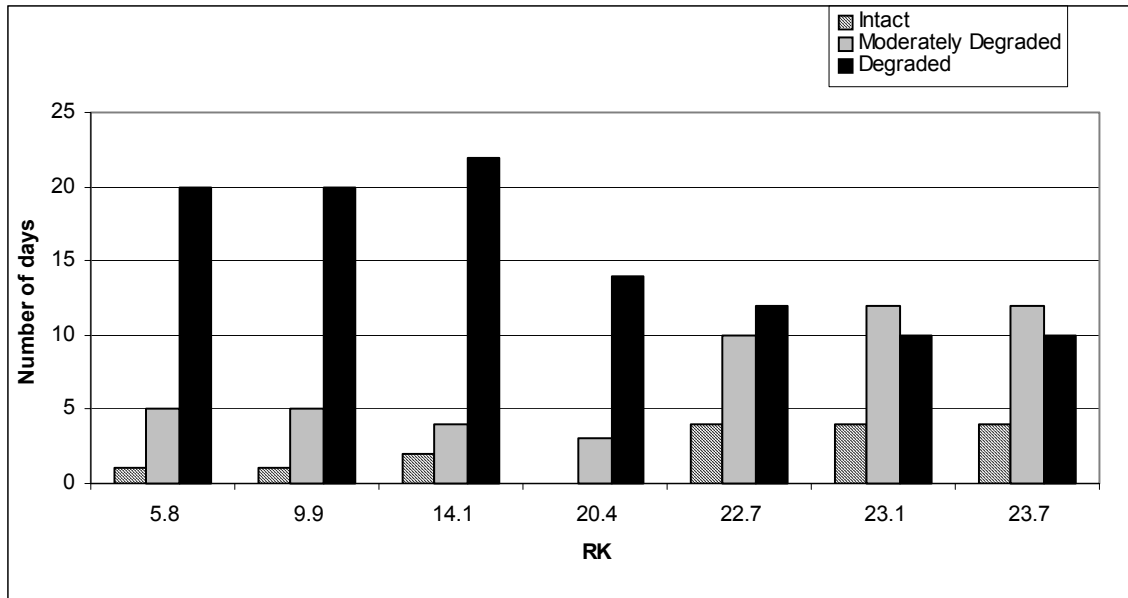


Figure 21a. August 2001 stream temperature with HCR criteria.

HCR spawning criteria.

Intact: 7-day moving average of daily maximums less than 13.9 C in spawning areas.

Moderately degraded: 7 - day moving average of daily maximums between 13.9 and 15.5 C in spawning areas.

Degraded: 7-day moving average of daily maximums greater than 15.5 C in spawning areas.

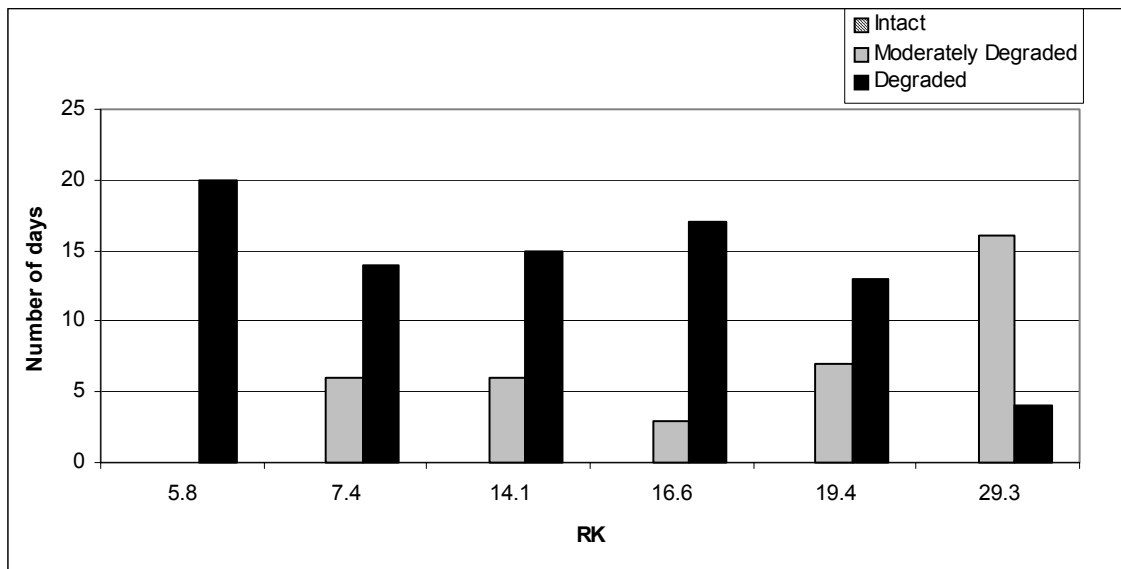


Figure 21b. August 2002 stream temperatures with HCR criteria.

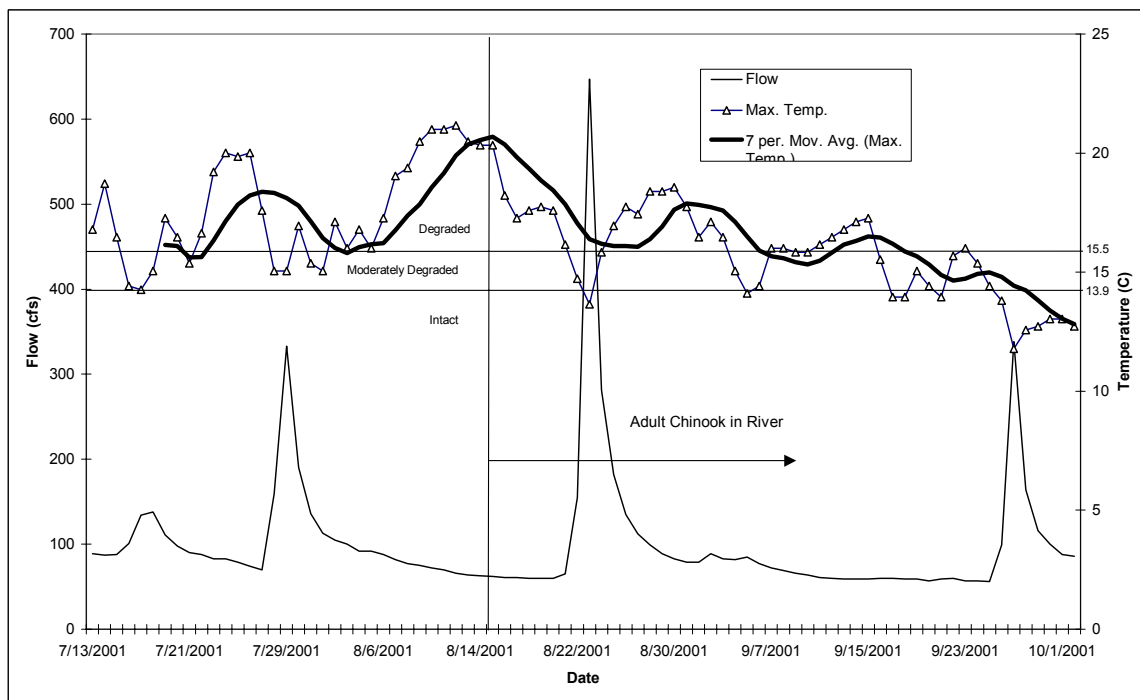
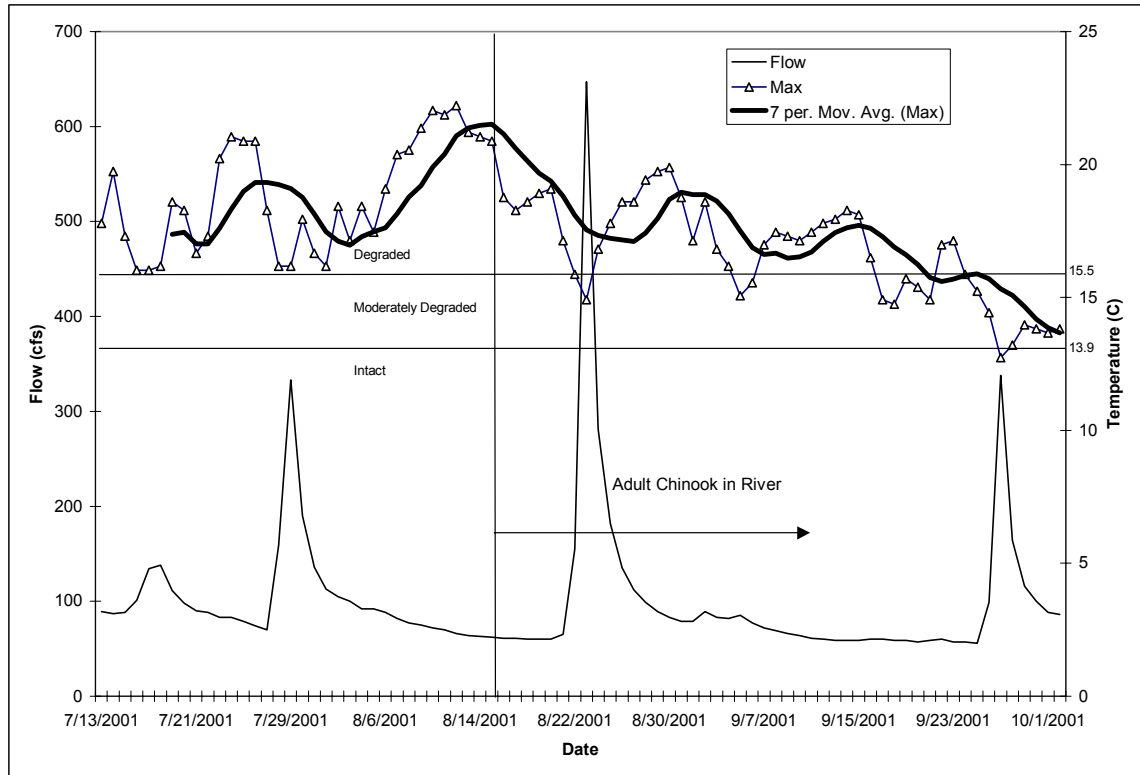


Table 4. Reach Characteristics Summary

Reach	Downstream River Kilometer	Length km	Gradient %	Channel Type	Reach Average Channel Width (m)	Reach Average BFW (m)	Number of Pools	Channel widths between pools	Total LWD	Pieces of wood per Channel Width	Jams	Total Number of Pieces LWD in Jams	Number of Redds 1999, 2001 and 2002
1	5.8	1.37	1	FPR	16.7	27.9	8	2.1	92	5.5	0	0	4
2	7.2	0.31	1	PB	20.3	27.8	0	no pools	10	0.5	0	0	1
3	7.5	0.45	2	FPR	16.2	62.2	3	5.4	188	11.6	3	134	3
4	7.9	1.60	1.5	PB	17.5	27.1	1	17.5	41	2.3	0	0	3
5	9.5	1.96	1	FPR	18.0	43.9	10	1.8	72	4.0	3	35	1
6	11.5	1.55	2.5	PB	15.8	25.9	1	15.8	37	2.3	1	16	1
7	13.0	2.36	1	FPR	19.2	32.9	10	1.9	85	4.4	0	0	11
8	15.4	0.65	2.5	PB	21.3	34.5	2	10.7	40	1.9	0	0	1
9	16.0	1.79	2	FPR	13.2	37.3	19	0.7	375	28.4	8	203	6
10	17.8	0.89	2.5	PB	16.4	34.6	2	8.2	50	3.0	1	14	5
11	18.7	6.52	2.5	FPR	17.2	36.1	35	0.5	695	40.4	14	201	22
12	22.8	0.40	1.5	FPR	10.2	35.1	12	0.9	1023	100.3	7	968	0
13	25.2	1.60	2.5	PB	14.5	25.2	1	14.5	24	1.7	0	0	4
14	26.8	2.49	3	FPR	12.9	35.9	8	1.6	715	55.4	5	641	7

Reach 12 = side channel

Table 5. Riparian condition summary.

			Right Bank			Left Bank			LWD	SBSRTC HCR Riparian zone and LWD Criteria			
Reach number	Reach Length (km)	Reach average channel width (m)	0-15 m buffer (%)	> 1 SPT buffer (%)	Dominant forest type	0-15 m Buffer (%)	> 1 SPT buffer (%)	Dominant forest type (total length)	Pieces / CW	HCR Call	Buffer width (1 SPT)	LWD	Stem Diameter
1	1.37	16.7	100	0	DYD	62.9	0	DYD	5.5	Degraded	Degraded	Intact	Degraded
2	0.31	20.3	100	0	DYD	36.5	64	DYD	0.5	Degraded	Degraded	Degraded	Degraded
3	0.45	16.2	100	0	DOD	29.8	70	DMD	11.6	Degraded	Degraded	Intact	Mod. Deg.
4	1.60	17.5	71.3	22	DYD	50	50	DYD	2.3	Degraded	Degraded	Intact	Degraded
5	1.96	18.0	25.5	19	DYD	19.2	60	MMD	4.0	Degraded	Degraded	Intact	Degraded
6	1.55	15.8	100	0	DMS	19.3	74	MMD	2.3	Degraded	Degraded	Intact	Mod. Deg.
7	2.36	19.2	32.3	35	DMS	70.5	21	DYD	4.4	Degraded	Degraded	Intact	Degraded
8	0.65	21.3	16.3	84	MMD	15.3	83	DMS	1.9	Mod. Deg	Intact	Mod. Deg	Mod. Deg.
9	1.79	13.2	34.1	66	DYD	13	77	DMS	28.4	Mod. Deg	Mod. Deg	Intact	Degraded
10	0.89	16.4	53	27	DYD	25.5	75	MOD	3.0	Degraded	Degraded	Intact	Mod. Deg.
11	6.52	17.2	46.5	15	DYD	29.4	81	MOD	40.4	Degraded	Degraded	Intact	Mod. Deg.
12	0.40	10.2	44.7	42	DYD	4.1	80	MOD	100.3	Degraded	Degraded	Intact	Mod. Deg.
13	1.60	14.5	69.5	31	DYD	0	100	CYD	1.7	Degraded	Degraded	Mod. Deg	Degraded
14	2.49	12.9	62.5	31	DMS	7.1	93	MOD	55.4	Degraded	Degraded	Intact	Mod. Deg.
HCR Criteria for Riparian Zone and shoreline vegetation/LWD													
			Intact			Moderately Degraded			Degraded				
Buffer width	>80% of stream shoreline has buffer width > 1 SPT					70-80% of stream shoreline has buffer width > 1 SPT				<70% of stream shoreline has buffer width > 1SPT			
LWD	2-4 pieces LWD/CW channel width > 20 m					1-2 pieces LWD/CW channel width > 20m				< 1 pieces LWD/CW channel width > 20 m			
Stem Diameter	Average stem diameter > 50 cm dbh					Average stem diameter 30 - 50 cm dbh				Average stem diameter < 30 cm dbh			

Table 6. LWD distribution metrics.

						Wood counts for bankfull channel width > 30m*					
						Jams			WFPB / SBSRTC 2 pieces / CW	Fox, 2001** 208 pieces / 100 m	Collins et al, 2002a*** 5.4 pieces / CW
Reach Number	Length (km)	Average Bankfull Width (m)	Average Channel Width (m)	Total Wood	Single Pieces	Jam Pieces	Number of Jams	Key Pieces	Pieces / Channel Width (d>10cm)	Pieces / 100 m	Pieces / Channel Width (d>20cm)
1	1.37	27.9	16.7	92	92	0	0	0	5.5	0.7	3.4
2	0.31	27.8	20.3	10	10	0	0	0	0.5	0.3	0.2
3	0.45	62.2	16.2	188	54	134	3	5	11.6	4.2	7.5
4	1.60	27.1	17.5	41	41	0	0	0	2.3	0.3	2.2
5	1.96	43.9	18.0	72	37	35	3	5	4.0	0.4	3.3
6	1.55	25.9	15.8	37	21	16	1	0	2.3	0.2	1.6
7	2.36	32.9	19.2	85	85	0	0	0	4.4	0.4	3.1
8	0.65	34.5	21.3	40	40	0	0	0	1.9	0.6	1.5
9	1.79	37.3	13.2	375	172	203	8	2	28.4	2.1	20.5
10	0.89	34.6	16.4	50	36	14	1	0	3.0	0.6	2.0
11	6.52	36.1	17.2	695	494	201	14	4	40.4	1.1	24.4
12	0.40	35.1	10.2	1023	55	968	7	14	100.3	25.6	62.5
13	1.60	25.2	14.5	24	24	0	0	0	1.7	0.2	1.4
14	2.49	35.9	12.9	715	74	641	5	13	55.4	2.9	28.7

* WFPB criteria are for channels with BFW >15-20 m

** Fox 2003, defines a 'good' wood loading rate for channels with BFW >30 -100 m as 208 pieces / 100m

*** Collins et al. 2002a findings in Stillaguamish River = 5.4 pieces/CW (LWD diameter $\geq$ 20 cm length and $\geq$ 2 m). Data in this column from the Pilchuck River is $\geq$ 20 cm and 1 m in length

Appendix 1

Exceedence Curves

Log Pearson Type III Exceedence Probabilities for the Pilchuck River at Granite Falls.

Source Data: <http://waterdata.usgs.gov/nwis/peak> gauge number 12152500

Table A 1. Exceedence Probability

Return Period	Exceedence Probability	K-value	Log Q	Q (ft./sec)	95% Confidence Limit Lower Limit	95% Confidence Limit Upper Limit
1	1	-3.93520	3.1335	1359.9	975.6	1710.5
2	0.5	-0.01667	3.7028	5044.6	4599.2	5530.8
5	0.2	0.84612	3.8282	6732.6	6108.0	7586.9
10	0.1	1.27033	3.8898	7759.2	6956.3	8946.7
25	0.04	1.71569	3.9545	9005.7	7943.8	10677.6
50	0.02	1.99956	3.9958	9902.9	8633.8	11967.7
100	0.01	2.25235	4.0325	10776.8	9292.7	13255.3

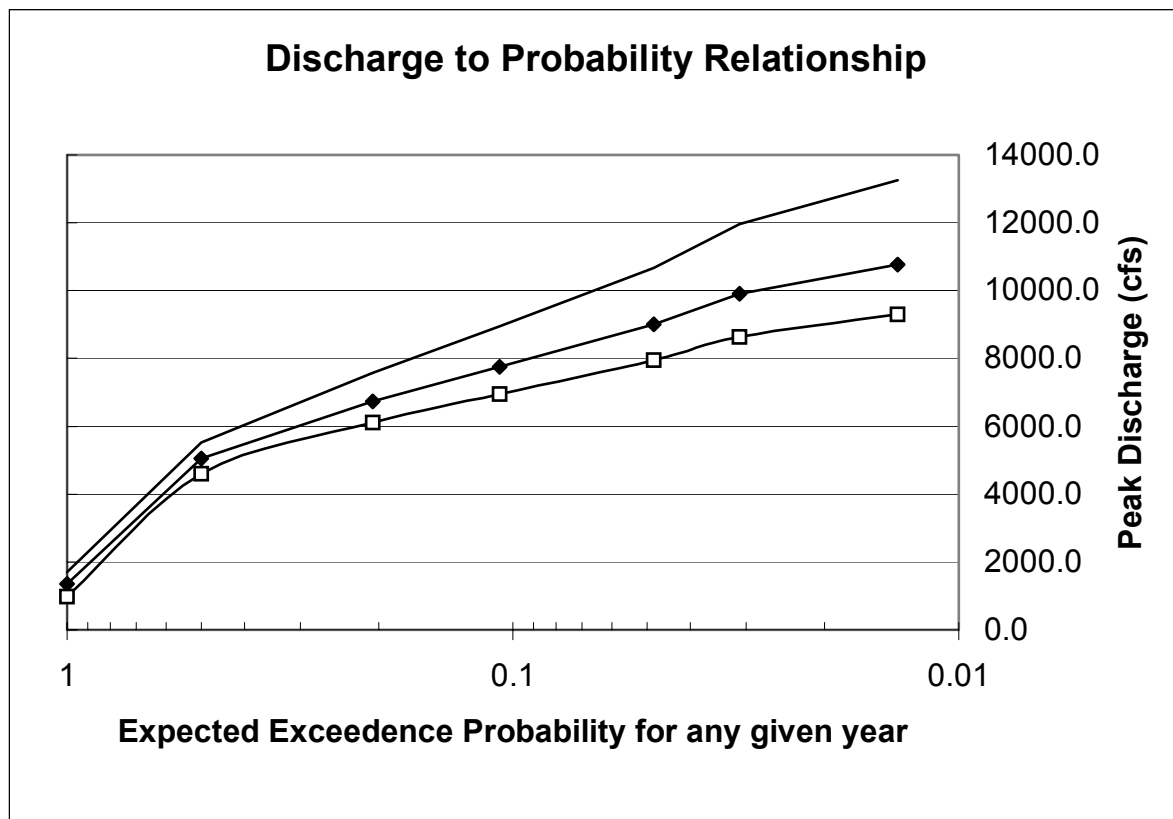


Figure A 1. Estimated discharge for a given expected exceedence probability in the Pilchuck River near Granite Falls, WA, fit to the Log Pearson Type III distribution. The 95% confidence limits for these estimates are also depicted. Note that the x-axis (in log scale) does not depict true probability scale.

Survey Forms

Habitat Survey 2002 Pilchuck River												
RK	Habitat Unit #	Unit Type	Length m	Depth cm	Pool type primary / secondary	Pool Forming mech	Tail out cm	Width m	Gradient % us/ds	Bankfull Width m	LWD?	Jam #
LWD/Jams Survey 2002 Pilchuck River												
RK	Habitat Unit #	Single LWD							Jam			
		10-20 cm	21-30 cm	31-40 cm	41-50 cm	51-60 cm	61-70 cm	70+ cm	Jam Number	Span	Height	# Key Pieces
Riparian Zone Survey Pilchuck River 2002												
		Right Bank				Left Bank						
RK	Habitat Unit #	Buffer Width	Age class	Species	Density	Buffer Width	Age class	Species	Density	Comments		

Bankfull Width Correction Formula

$$BFW_{\text{corr}} = 6.838642 + (0.913149 * BFW_{\text{est}})$$