Upper White Watershed Spring Chinook Redd, Scour, and Cross-Section Assessments: 1995 - 2001

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ABSTRACT

From the fall of 1995 to the spring of 2001 we investigated spring chinook redds, channel scour and surface elevations in the Upper White watershed of western Washington. The primary purpose for our work was to establish a baseline for monitoring changes that are expected to result from watershed restoration. We implemented a one-year reconnaissance study of channel cross-sections and scour monitors in the Clearwater River, and, a five-year study on redd disturbance from gravel scour and changes in channel morphology associated with peak discharges primarily in the Greenwater River, but also including the Clearwater and White Rivers.

Two large floods in the Clearwater River caused major channel realignments and habitat changes that indicated poor survival for salmonid incubation. Our results from the Greenwater River showed that during two of five years 92% of redds had a good likelihood of survival. During the other three years our redd results showed likelihood of good survival for 79%, 72% and 50% of redds. However, redd data included only scour of the surface; bed scour monitor data for two of four years in the Greenwater indicated a greater level of redd loss was occurring with greater than 50% of monitors scouring to 15 cm, the chinook top of egg pocket depth.

Greenwater River scour monitor and redd site data for fall 1996 to late winter 2001 showed a strong negative correlation between increasing annual peak incubation discharge and scour depth. We also found a strong positive relationship between the maximum annual incubation peak discharge and the percent of sites scoured to 15 cm, and between the maximum annual incubation peak discharge and the percent of redds with a poor likelihood of embryo and alevin survival to emergence. Based on the relationship between peak discharge and scour level, flows of 1235 cfs (2-year return interval) are predicted to scour 25% of scour monitors to ≥15 cm, flows of 2073 cfs (4-year return interval) scour 50% of monitors to ≥15 cm, and, flows of 2912 cfs (7-year return interval) are predicted to scour 75% of monitors to ≥15 cm.

Historically (pre-1970, n = 41 years), discharges predicted to have scoured ≥50% of monitor sites in spawning habitat to ≥15 cm occurred at a 5.9-year frequency. Currently (1970 to 2000, n=16 years) these discharges are expected to occur at a 3.0-year frequency, nearly twice as often ($p = 0.0826$). Our research supports the need for restoration of watershed processes (e.g., hydrology and sediment production) that affect depth of gravel scour in chinook spawning habitat.

INTRODUCTION

White River spring chinook (*Oncorhynchus tshawytscha*) are a state critical stock (Washington Department of Fisheries et al. 1993), and a threatened species under the federal Endangered Species Act. This native stock of salmon had returning adult numbers to the Upper White watershed as low as six in the mid-1980s (Washington Department of Fish and Wildlife et al. 1996). Extensive stock and habitat restoration efforts are occurring and between 1995 and 2001 an average of 868 adults returned each year (Table 1).

Table 1. Upper White River adult chinook numbers. (Source: unpublished data from Washington Department of Fish and Wildlife, Puyallup Tribal Fisheries and Muckleshoot Tribal Fisheries.)

Stream	**Incubation Year**													
	1995		**1996**		**1997**		**1998**		**1999**		**2000**		**2001**	
	Fish	Redds	Fish	Redds	Fish	Redds	Fish	Redds	Fish	Redds	Fish	Redds	Fish	Redds
Upper White[1]	605		628		402		320		553		1523		2002	
Clearwater[2]	78	31			63	25	45	18	43	17	200	80	248	99
Greenwater[2]	36	14	188	75	100	40	78	31	203	81	190	76	558	223
Huckleberry[2]	1	-			3	1	0	0	75	30	145	58	210	84
W.F. White[2]					3	1							78	31

[1] Number of adult chinook transported above Mud Mountain Dam from U.S. Army Corp of Engineer's Buckley trap facility on the White River.
[2] Fish numbers are estimates using 2.5 fish per redd.

Primary historical spawning grounds for the spring chinook are located in the 240,000-acre Upper White watershed which originates in glaciers on the north side Mount Rainier. This basin is located on the west slope of the Cascade Mountains in the Puget Sound region of Washington State (Figure 1). The Clearwater, Greenwater, Huckleberry and West Fork White are important spawning tributaries. Additionally, unknown numbers of spring chinook spawn in the mainstem White River. The White River spring chinook spawn from mid-August into September, and fry emerge in late February and early March.

The major land uses in the Upper White watershed are forestry and recreation. Negative impacts to fish habitat from these land uses have: (1) increased sediment delivery to basin channels, (2) changed hydrology due to clearcut harvest and roads, and, (3) disturbed riparian zones and wood loading and function in channels (Ketcheson et al. 2003, USDA Forest Service 2000, Weyerhaeuser 1999). The Clearwater and Greenwater Rivers are on Washington State's list of impaired waters due to temperatures that exceed state standards. As a result of these listings, and the concern that factors driving increased water temperatures (e.g., loss of riparian forests and channel widening) could also indicate fish habitat impairments, three baseline monitoring assessments were undertaken to better understand current conditions, and to provide a yardstick to measure recovery over time resulting from implementing watershed analysis prescriptions and a water quality/watershed restoration plan (Ketcheson et al. 2003, Upper White River Chinook TMDL Framework Team 1998). The first assessment by Black et al. (2003) provides habitat

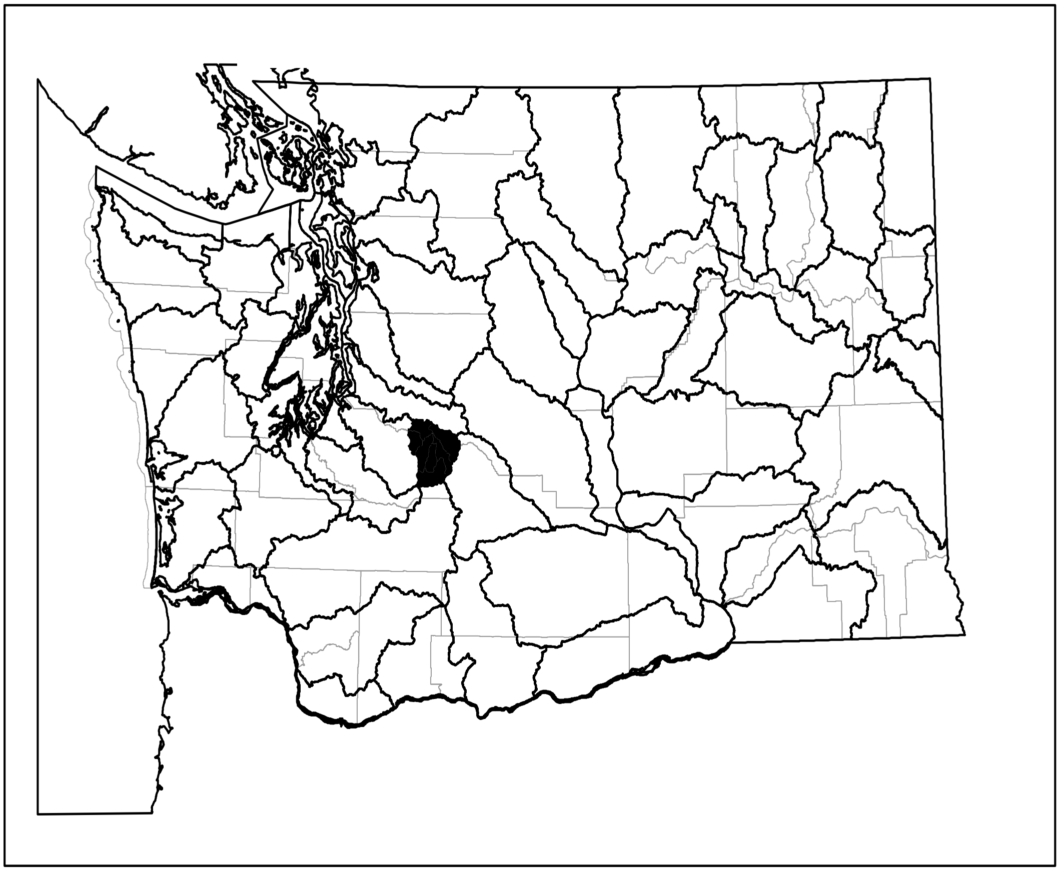


Figure 1. The location of the Upper White watershed within Washington State.

data and high resolution digital imagery for long-term monitoring segments. A second assessment by Schuett-Hames et al. (2003) provides temperature data.

This report presents results from the third assessment. The primary purpose of this work was to document and evaluate channel characteristics affecting spring chinook redd survival.

The assessment contains two studies:

Study 1) Reconnaissance scour monitor and cross-section investigations in the Clearwater River from fall 1995 to late winter 1996. The purpose was to gain data on potential affects from gravel scour on spring chinook and other salmonid redds in the Clearwater River; and,

Study 2) A baseline for redd survival based on scour, aggradation, and flow characteristics during incubation. During the 1996 redd incubation cycle, individual chinook redds in the Clearwater, Greenwater and mainstem White Rivers were monitored for habitat type, location, and mound surface elevation. Throughout the 1997 – 2000 incubation periods, chinook redds and surveyed channel cross-sections with scour monitors were studied in the Greenwater River.

METHODS

Study Area

Study sites are located in the non-glacial Clearwater and Greenwater Rivers and the glacial White River, within the Upper White watershed. The first step in selecting sampling sites was to divide the Clearwater and Greenwater rivers into segments based on gradient, confinement and major tributaries (Pleus and Schuett-Hames 1998). Segment gradients ranged from 0.7 to 1.9%, confinement ratios were moderate to unconfined, and stream orders were 3 to 5. Segments were chosen for study based on either current use for spawning by chinook or suitability for spawning. The study site in the White River was based only on active spawning. Table 2 provides characteristics of the individual study segments.

Table 2. Characteristics of the Clearwater, Greenwater and White River study segments.

River	Segment[1]	River Miles[2]	Order[3,4]	Gradient[1,4] Percent	Confinement[5]
Clearwater	1	0.0 - 1.1	3	1.9	U to M
Clearwater	2	1.1 - 2.3	3	1.6	M
Clearwater	3	2.3 - 3.1	3	1.3	M
Greenwater	2	1.0 - 1.5	4	0.8	M
Greenwater	3	1.5 - 2.4	4	0.8	M
Greenwater	8	5.5 - 6.8	4	1.5	M
White	-	41.9 - 42.2	5	0.7	U

[1] Based on Pleus and Schuett-Hames (1998).
[2] Based on Williams et al. (1975).
[3] Strahler stream order (Dunne and Leopold 1978).
[4] From USGS 7.5' topographic map.
[5] Based on Washington Forest Practices Board (1997). U = unconfined (valley > 4 channel widths), M = moderately confined (valley is 2 - 4 channel widths).

Channel Cross-section Surveys

Cross-sections

Cross-section transects were installed across riffles, pool tailouts, and riffle crests using standard survey and channel cross-section techniques. A TopCon AT-G4 auto level (with accuracy in 1 km for double run leveling of 2.0 mm) and metric rod were used. Elevations were read to the nearest millimeter. Benchmark elevations were read at the start and end of each cross-section survey for quality assurance. Left and right bank tail pins as well as benchmarks were installed back from the stream banks to minimize loss from flood events. Back-up benchmarks were established in case flood damage occurred.

Cross-sections were established and surveyed prior to or within several weeks after chinook spawning in the fall (usually the first week of October) to document bed elevations at the beginning of egg incubation; they were resurveyed late winter (usually the first week of March) to document elevations at fry emergence. During the winter of 1995 - 1996, two cross-section tailpins were lost due to flood erosion at Clearwater cross-sections #3 and #7. Resurveys for these cross-sections were accomplished by compass bearing from remaining tail-pins.

Pebble Counts

Cross-section pebble counts were taken within the bankfull channel parallel to, and within 1 m upstream and downstream of the cross-section line. Full transects were sampled until the number of particles measured was over 100. Methods followed Wolman (1954).

Scour Monitor Surveys

Scour monitor surveys were adapted from Schuett-Hames et al. (1999). Scour monitors were similar to those used by Tripp and Poulin (1986). They were constructed with four primary components:

(1) A wood dowel anchor to hold the monitor in the stream bed;
(2) A metal cable 1.46 m long that extended through the anchor, and held all components together;
(3) Ten 4 cm diameter plastic wiffle balls threaded onto the cable such that when the monitor was installed with all balls fully inserted into the stream bed, the anchor depth was 0.67 m; and,
(4) A wiffle ball filled with foam and a metal disc with the equipment number attached as a float at the top end of the metal cable.

As scour occurs, balls are released from the channel bed and float up to the end of the cable. Depth of scour in 4 cm increments is determined by counting how many balls have been released. In cases where monitors washed out or otherwise could not be found, standard elevation data were taken at the monitor site and used to provide a minimum scour level.

Figure 2. Craig Graber with scour monitor equipment.

Monitors were inserted into spawnable habitat along the surveyed cross-sections at approximately 1 m intervals. Monitors were deployed through the use of an inserter with an inside pounding point and an outside sleeve. This equipment, along with a scour monitor is shown in Figure 2. The inserter was pounded into the gravel bed with a metal rod. When the correct depth was reached, the point was removed and the monitor was lowered down into the gravel. The outer sleeve was then removed, leaving the cable, equipment number, and float exposed. After moderate flow years, most monitors were restored for the next year's use by excavating around the monitor and reburying balls that had been released. New monitors were installed when necessary.

Surveyed elevations of monitor locations were taken along with the cross-section survey. Scour monitors were checked at the end of the 1995 incubation period to determine number of balls exposed/depth of scour. During the 1997 to 2000 periods, monitors were checked periodically, and after peak discharges. Final evaluation of monitors occurred at the end of the incubation period when cross-sections were resurveyed. An exception was during the 1997 cycle when substantial scour and burial necessitated additional work during August low flow conditions to excavate monitor locations.

Chinook Redd Surveys

In 1996, only a sub-sample of redds were surveyed in Greenwater Segment 2, Clearwater Segment 1, and the White River. Within Greenwater Segment 3 for 1996 through 2000, redd survey data were collected at 100% of sampleable chinook redds. This typically excluded one to two redds that were in swift water with unsafe working conditions, or locations where later spawning fish were active near an earlier chinook redd. Data were collected in the fall after spawning (usually the first week of October), and late winter after completion of incubation (customarily the first week of March). Redds in the Clearwater and Greenwater Rivers were located and flagged during spawning surveys by the Puyallup Tribal Fisheries Department and Washington Department of Fish and Wildlife, respectively. In addition, chinook radio tagging studies by Puyallup Tribal Fisheries facilitated finding redds in the White River.

Non-intrusive methods were used to minimize potential for disturbance of the redd environment. All persons working on this aspect of the study were briefed on egg sensitivity to disturbance within the early incubation period.

At each redd the following data were taken:

(1) Elevation of the redd mound top using standard survey techniques (as described above under cross-section installation and survey);
(2) Location information to allow the redd to be refound (including upstream and downstream distances to tailpins on the stream bank);
(3) Habitat type according to TFW ambient monitoring protocols (Schuett-Hames et al. 1994);
(4) Site sketch, showing channel morphology and flow characteristics for the redd vicinity; and,
(5) Photos of each redd to assist with data interpretation.

In October 2000 and 2001 mound elevation height was measured at redds not yet disturbed by flow. This was done by taking surface elevation measurements of the undisturbed streambed immediately adjacent to the left and right of the mound sides. The average of these two measurements was compared with the top of mound elevation to determine mound height.

Peak Discharge

Peak discharge data were provided by the USGS for the Greenwater River USGS flow station number 12097500. Currently, this is the only active station in the Upper White watershed.

There are other historic gauges in the Upper White, but they were typically operated for short periods (5 to 10 years). All other active gauges are now downstream of Mud Mountain Dam and do not reflect flow conditions in the upper watershed.

Data Analysis

Cross-section data were analyzed to identify changes in habitat, mean bed elevation within the bankfull channel, bankfull width, and channel location.
Pebble counts were used to develop surface particle size distributions and compute the d50 size (median particle size where 50% of the particles are finer. Pebble count analyses were performed using a software macro developed by Devin Smith, (formerly of the Northwest Indian Fisheries Commission).

Data from scour monitors were used to calculate mean depth of scour and bed surface elevation change at cross-sections and segments, for each year. Analyses of redd data included reviewing data for changes in habitat type, mound elevation, and the presence of surface flow. The redd factors were analyzed to provide a determination of the likelihood of chinook survival to emergence and overall likelihood of survival characteristics for each study year. We used the chinook egg impact depth of 15 cm as the expected top of the egg pocket based on DeVries (1997).

We used correlation analysis and simple linear regression to investigate relationships between annual incubation peak discharge, and scour and/or redd results. In addition, a z-test of two-proportions was used to analyze the relationship between annual peak discharge frequencies for varying levels of spawning gravel scour for two time periods.

RESULTS

1995 - 1996 Clearwater Cross-section and Scour Study

During the 1995 Clearwater study two large peak discharge events occurred. Based on data from the Greenwater gauge, those events exhibited >10-year and >25-year recurrence interval discharges. Cross-section bankfull widths increased by a mean of 14 m (36%) and average bed elevations increased by 0.23 m. No scour monitors were able to be found due to severe channel disturbance. Of the 24 scour monitor locations, 10 no longer had surface flow at the end of chinook incubation, and 23 had incurred habitat changes. Complete results for the 1995 study are presented in Appendix A.

1996 – 2001 Upper White Watershed Redd, Cross-section and Scour Study

Results for incubation years 1996 to 2000 follow. Cross-section and scour survey results are reported first, followed by redd survey results, and the relationship between scour monitor and redd site data. Note that in 1996 there were redd studies but not cross-section and scour studies.

Cross-section and Scour Surveys

Cross-section Surveys

Four cross-sections with scour monitors were established fall of 1997 in the Greenwater River (Segment 3 river miles 1.5 and 2.3, and Segment 8 river miles 5.6 and 6.8). Cross-sections and monitors were established fall of 1999 Segment 8 at river miles 5.9 and 6.5 when morphology changes made original Segment 8 locations no longer suitable for study objectives. The cross-sections are coded as GW#1 (i.e. Greenwater #1) through GW#6 with #1 being furthest downstream and the others sequentially upstream. Figures 3 and 4 show the cross-section locations. All cross-sections were located at riffle crest features, but also included portions of pool tailouts and riffles. These habitat features changed over time in GW#2, 3 and 6 to include pool habitat. Table 3 provides characteristics of the cross-section locations, including years where data were taken. Individual cross-section graphs, photos and analyses are provided in Appendix B.

Cross-section pebble count data is reported in Table 4. From 1998 to 2000, the median grain size (d50) at cross-sections in Segment 3 ranged from 46 to 61 mm. The d50s from 1998 and 1999 at Segment 8 cross-sections ranged from 27 to 95 mm.

Average elevation change between bankfull channels during the study is shown in Table 5. Between fall of 1997 and late winter 2001, the mean bed elevation change at cross-section GW#1 ranged from -1 cm to +2 cm from the initial fall 1997 survey. GW#2 showed an increased average bed elevation of 3 cm to 8 cm over this same period. With the exception of GW#4, which registered no change during the one incubation season of survey effort, average bankfull elevations in Segment 8 cross-sections incurred the greatest change. Bed elevation at cross-section GW#6 decreased 6 cm, GW#3 decreased 11 cm, and GW#5 decreased 14 cm.

Table 3. Characteristics of Greenwater River cross-section locations.

Cross-section # and Location[1]	River Mile	Data Years (Incubation cycles)	Bankfull Width (m) and Date	Gradient %[2]	Confine-ment[3]	Habitat Features	Observed Use by Spawning Fish
GW#1 Seg3:RP0+00 m	1.5	1997-1998 1998-1999 1999-2000 2000-2001	23.12 3/3/01	0.8	M	Riffle crest/ Riffle/ Pool-tailout	Chinook and coho redds in vicinity fall 1996, 1997, 1999 and 2000. Chinook redd on cross-section fall 1999 and 2001. Coho redd on cross-section fall 2000.
GW#2 Seg3:RP14+41 m	2.3	1997-1998 1998-1999 1999-2000 2000-2001	22.20 3/18/01	0.8	M	Riffle crest/ Pool-tailout/ Riffle	Chinook redds in vicinity fall 1996, 1997, 1999, 2000. Chinook redds (2) on cross-section fall 1997. Coho redds on cross-section fall 2000. Coho redds in vicinity fall 1997, and 2000.
GW#3 Seg8:RP1+24 m	5.6	1997-1998 1998-1999	49.20 3/5/99	1.3	U	Pool-tailout/ Riffle crest fall '97; change to Pool tailout - by 3/99	Coho redds in vicinity fall 1997, 1998. (Post-study, fall 2001, chinook redds observed on and near cross-section.)
GW#4 Seg8:RP6+70 m	5.9	1999-2000	27.35 3/1/00	1.7	M	Riffle crest	Steelhead redd in vicinity spring 1999.
GW#5 Seg8:RP15+29 m	6.5	1999-2000	19.70 3/1/00	1.5	U	Riffle crest	Steelhead redd in vicinity spring 1999.
GW#6 Seg8: RP18+44 m	6.8	1997-1998 1998-1999	29.60 3/4/99	1.5	M	Riffle crest - 1997 to 1998; Pool – 1999	None observed.

[1] Cross-sections are named according to stream (GW is Greenwater), segment number, reference point number, and distance upstream from the reference point.
[2] From USGS topographic map.
[3] Based on Washington Forest Practices Board (1997). M = moderately confined (valley width is 2 - 4 channel widths). U = unconfined (valley width is greater than 4 channel widths).

Scour Monitor Surveys

Scour monitor results are presented by cross-section in Table 6, and further summarized by segment in Table 7. Of particular interest for this analysis are levels of bed scour measured by the monitors, or surface elevation changes at the monitor sites likely to cause impact to incubating embryos, alevin and emerging fry (i.e., survival to emergence). In this sense, the scour monitor sites are used as surrogate redds. Scour ≥15 cm is used as the default top

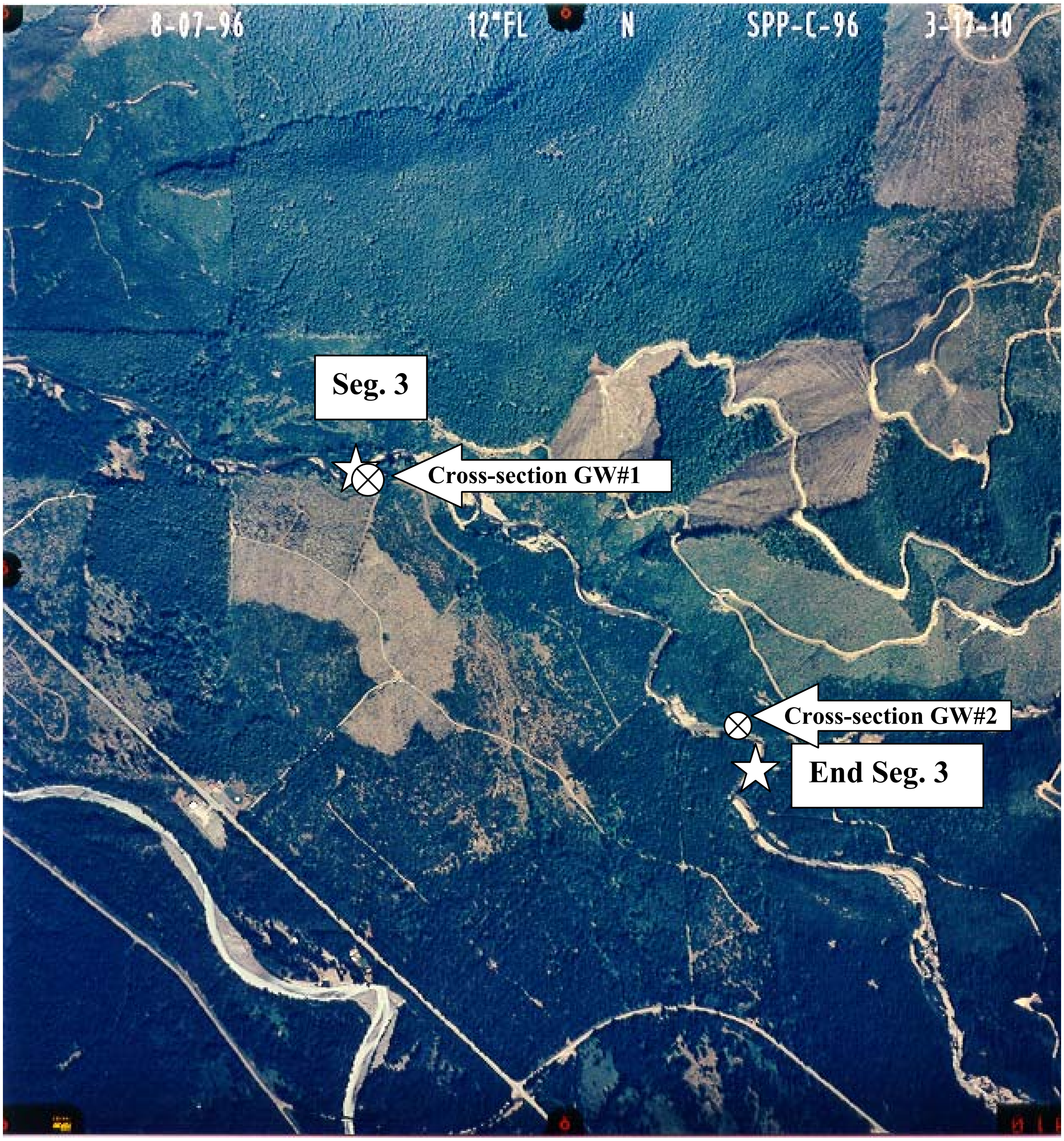


Figure 3. Greenwater River Segment 3 and cross-section locations (T19NR9E Section 11, river miles 1.5 - 2.4).

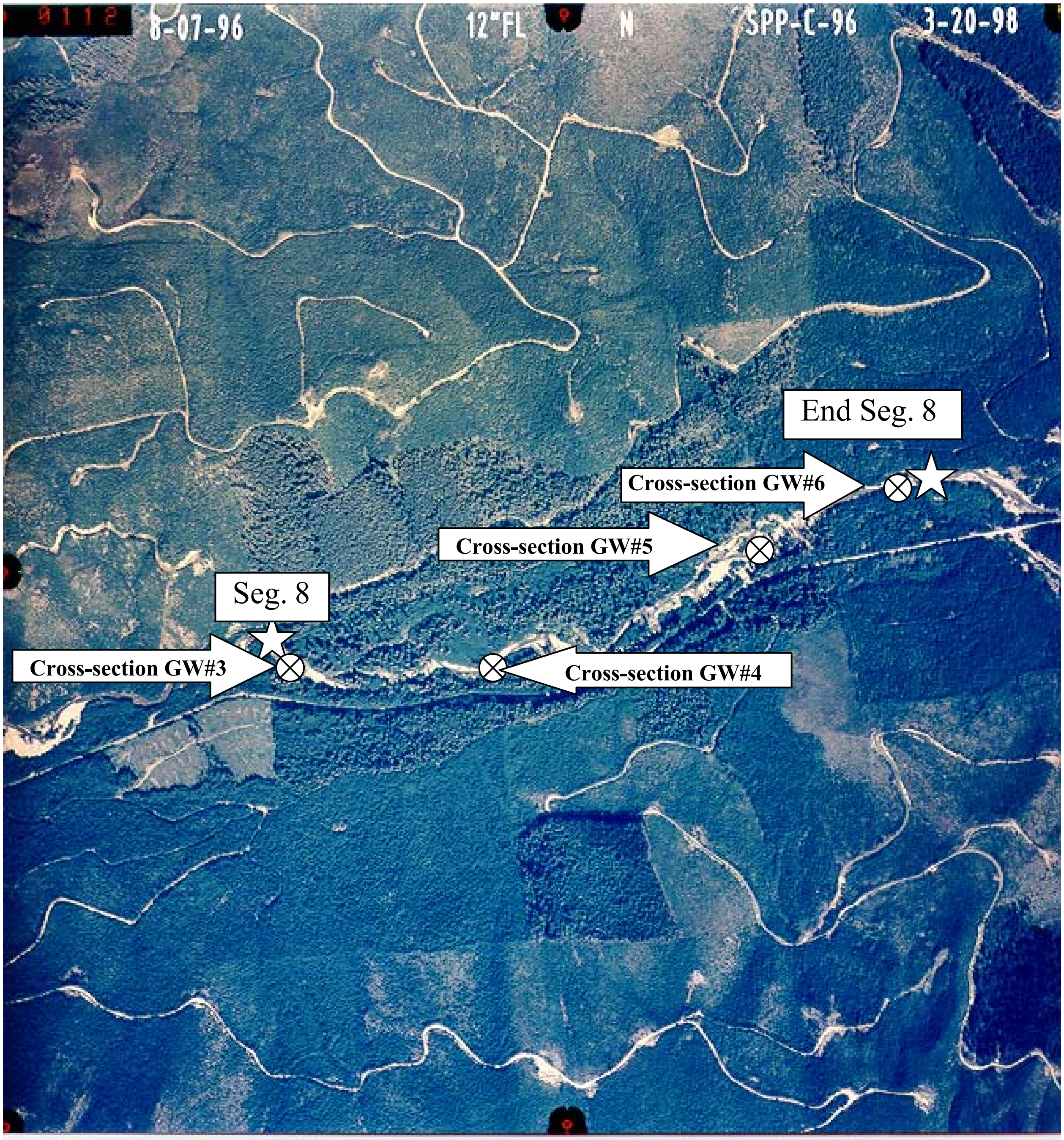


Figure 4. Greenwater River Segment 8 and cross-section locations (T19NR10E Sections 20 and 21, river miles 5.5 – 6.8).

Table 4. Greenwater River cross-sections median grain sizes (d50) from pebble count data.

Site # and Date	Pebble Size Categories (in mm) >256	180-256	128-180	90-128	64-90	45-64	32-45	22-32	16-22	11-16	8-11	6-8	4-6	2-4	<2	Total	d50
Size class upper bound:	*358*	*256*	*180*	*128*	*90*	*64*	*45*	*32*	*22*	*16*	*11*	*8*	*6*	*4*	*2*		
GW#1: 10/2/98	3	5	10	21	12	25	24	15	5	7	3	2	0	1	17	150	**46**
Cumulative percent:	*100%*	*98%*	*95%*	*88%*	*74%*	*66%*	*49%*	*33%*	*23%*	*20%*	*15%*	*13%*	*12%*	*12%*	*11%*		
GW#1: 10/6/99	2	8	10	23	31	25	19	9	10	1	1	0	1	0	15	155	**61**
Cumulative percent:	*100%*	*99%*	*94%*	*87%*	*72%*	*52%*	*36%*	*24%*	*18%*	*12%*	*11%*	*10%*	*10%*	*10%*	*10%*		
GW#1: 10/5/00	1	5	9	21	20	37	16	12	5	4	4	3	1	1	10	149	**54**
Cumulative percent:	100%	99%	96%	90%	76%	62%	38%	27%	19%	15%	13%	10%	8%	7%	7%		
GW#2: 10/1/98	2	2	3	13	37	40	19	16	6	0	1	0	0	0	3	142	**57**
Cumulative percent:	*100%*	*99%*	*97%*	*95%*	*86%*	*60%*	*32%*	*18%*	*7%*	*3%*	*3%*	*2%*	*2%*	*2%*	*2%*		
GW#2: 10/6/99	0	2	6	17	29	25	18	15	9	2	2	2	1	0	9	137	**52**
Cumulative percent:	*100%*	*100%*	*99%*	*94%*	*82%*	*61%*	*42%*	*29%*	*18%*	*12%*	*10%*	*9%*	*7%*	*7%*	*7%*		
GW#2: 10/6/00	10	4	3	23	17	23	16	14	5	1	2	1	0	2	2	123	**60**
Cumulative percent:	*100%*	*92%*	*89%*	*86%*	*67%*	*54%*	*35%*	*22%*	*11%*	*7%*	*6%*	*4%*	*3%*	*3%*	*2%*		
GW#3: 10/15/98	0	2	4	8	25	17	12	1	3	5	1	3	0	6	50	137	**27**
Cumulative percent:	*100%*	*100%*	*99%*	*96%*	*90%*	*72%*	*59%*	*50%*	*50%*	*47%*	*44%*	*43%*	*41%*	*41%*	*36%*		
GW#4: 10/5/99	1	4	8	21	40	31	28	24	15	10	4	2	0	1	4	193	**50**
Cumulative percent:	*100%*	*99%*	*97%*	*93%*	*82%*	*62%*	*46%*	*31%*	*19%*	*11%*	*6%*	*4%*	*3%*	*3%*	*2%*		
GW#5: 10/5/99	12	16	25	29	17	10	10	10	1	2	3	0	0	1	19	155	**95**
Cumulative percent:	*100%*	*92%*	*82%*	*66%*	*47%*	*36%*	*30%*	*23%*	*17%*	*16%*	*15%*	*13%*	*13%*	*13%*	*12%*		
GW#6: 10/15/98	4	4	13	13	7	9	12	7	5	3	3	0	0	1	20	101	**44**
Cumulative percent:	*100%*	*96%*	*92%*	*79%*	*66%*	*59%*	*50%*	*39%*	*32%*	*27%*	*24%*	*21%*	*21%*	*21%*	*20%*		

Table 5. Greenwater River cross-sections elevation changes across bankfull channels, relative to the initial survey. Measurements are in meters.

Cross-section	Fall '97	Late Winter '98	Fall '98	Late Winter '99	Fall '99	Late Winter '00	Fall '00	Late Winter '01
Segment 3								
GW#1	Initial survey	0.01	0.02	-0.01	-0.01	-0.01	-0.01	0.00
GW#2	Initial survey	0.05	0.03	0.03	0.03	0.06	0.08	0.06
Segment 8								
GW#3	Initial survey	-0.03	-0.01	-0.11				
GW#4					Initial survey	0.00		
GW#5					Initial survey	-0.14		
GW#6	Initial survey	0.01	-0.04	-0.06				

of egg pocket depth based on DeVries (1997). We additionally use 10 cm of aggradation as a threshold for assuming survival to emergence impact[1].

In Segment 3, GW#1 and #2 monitors indicated little to no scour or deposition during incubation years 1997 and 2000. However in both 1998 and 1999, scour and deposition at the monitors was extensive. In 1998, 94% of the monitors in this segment scoured ≥15 cm. Deposition ≥10 cm occurred at 41% of monitor sites and all sites that had ≥10 cm deposition also scoured ≥15 cm. In 1999, 53% of the monitors in Segment 3 scoured to ≥15 cm; an additional 26% of the monitors had deposition ≥10 cm.

Some monitors at Segment 8 cross-sections registered scour ≥15 cm during all three years of survey effort. The percentage of monitors with scour ≥15 cm was 11% for incubation year 1997, 71% in 1998, and 46% for 1999. Deposition ≥10 cm at scour monitor locations occurred at 32% of sites in 1997, and at 35% of sites in 1998. Of these sites, none scoured ≥15 cm in 1997 (note however one monitor was not found), and in 1998, 33% (2) scoured ≥15 cm.

[1] Aggradation of 10 cm increases the vertical distance that emerging alevin/fry must travel through to reach the surface by 66%. Alevin use a variety of behaviors to assist with emergence including the ability to "butt" themselves upward through sands deposited on top of the gravel bed (Bams 1969). Conversely, extensive literature has documented fine sediments in spawning gravels as a significant impediment to both embryo survival and salmon emergence success (Koski 1966, 1975; McNeil 1964; Tagart 1976, 1984). In numerous cases in the Greenwater, both surface and depth observations of high fine sediment levels were made by the authors. Fine sediment levels measured in the lower Greenwater River (RM 0.0 - 0.6) in 1995 were 14.2% fines ≤ 0.85mm (Keown and Summers 1998). This level is recognized as causing impact to salmonid embryo survival to emergence (Peterson et al. 1992).

Table 6. Cross-section scour monitor data summary.

Cross-section	Incubation Year	# of monitors	Mean scour at monitors (cm)	# of monitors scour ≥15 cm	% of monitors scour ≥15 cm	Mean surface elevation change at monitors fall to late winter (cm)	# of monitors with aggradation ≥10 cm	% of monitors with aggradation ≥10 cm
Segment 3								
GW#1	**1997**	**10**	**-3.2 (range = 0 to -8; stdev = 3.2)**	**0**	**0**	**-0.4 range = -3.7 to 3.3 stdev = 2.3**	**0**	**0**
	1998	**10**	**-26.8 (range = -12 to -36; stdev = 8.4)**	**9**	**90**	**+1.8 range = -14.7 to 16.4 stdev = 10.9**	**3 (3/3 also scoured to ≥15 cm)**	**30**
	1999	**10**	**-12.4 (range = -24 to 0; stdev = 8.5)**	**5**	**50**	**+4.4 range = -9.3 to 11.0 stdev = 6.4**	**3 (1/3 also scoured 4 cm, 2/3 0 cm)**	**30**
	2000	**10**	**0.0 (range = 0 to 0; stdev = 0)**	**0**	**0**	**+0.6 range = -7.9 to 7.9 stdev = 4.6**	**0**	**0**
GW#2	**1997**	**10**	**-2.8 (range = -8 to 0; stdev = 3.8)**	**0**	**0**	**+0.5 range = -6.2 to 7.3 stdev = 4.8**	**0**	**0**
	1998	**7**	**-34.3 (range = -40 to - 24; stdev = 6.0)**	**7**	**100**	**5.3 range = -15.2 to 22.1 stdev = 15.8**	**4 (4/4 also scoured to ≥15 cm)**	**57**
	1999	**9**	**-10.7 (range = -20 to 0; stdev = 7.7)**	**5**	**56**	**1.8 range = -9.7 to 16.9 stdev = 8.9**	**2 (these had no scour)**	**22**
	2000	**9**	**0.0 (range = 0 to 0; stdev = 0.0)**	**0**	**0**	**-2.6 range = -7.1 to 2.3 stdev = 2.8**	**0**	**0**
Segment 8								
GW#3	**1997**	**9**	**-9.5 (n=8, 1 not found (range = -36 to 0; stdev = 13.5)**	**2**	**25**	**7.5 range = -23.0 to 30.4 stdev = 20.8**	**5 (3/5 with no scour, 1/5 with 8 cm scour, 1/5 not found)**	**56**
	1998	**7**	**-49.3 (range = -72 to 0; stdev = 26.3)**	**6**	**86**	**-37.7 range = -69.4 to 4.1 stdev = 22.5**	**0**	**0**
GW#4	**1999**	**6**	**-1.3 (range = -8 to 0; stdev = 3.3)**	**0**	**0**	**2.2 range = -3.0 to 7.5 stdev = 3.8**	**0**	**0**
GW#5	**1999**	**7**	**-30.3 (range = -44 to -12; stdev = 10.6)**	**6**	**86**	**-26.9 range = -39.4 to -11.7 stdev = 8.9**	**0**	**0**
GW#6	**1997**	**10**	**0.0 (range = 0 to 0; stdev = 0)**	**0**	**0**	**0.7 range = -7.3 to 9.6 stdev = 5.0**	**1**	**10**
	1998	**10**	**-24.8 (range = -76 to 0; stdev = 23.5)**	**6**	**60**	**8.9 range = -76.7 to 55.3 stdev = 43.0**	**6 (2/6 with scour ≥15 cm, 4/6 no scour)**	**60**

Table 7. Segment scour monitor data summary.

Incubation year	# of monitors	Mean scour at monitors (cm)	# of monitors with scour ≥15 cm	% of monitors scour ≥15 cm	Mean surface elevation change at monitors fall to late winter (cm)	# of monitor sites with surface elevation scour ≥15 cm	% of monitor sites with surface elevation scour ≥15 cm	# of monitor sites with aggradation ≥ 10 cm	% of monitor sites with aggradation ≥ 10 cm
Segment 3									
1997	20	-3.0 (range = 0 to -8; stdev = 3.4)	0	0	+0.1 (range = -6.2 to 7.3; stdev = 3.7)	0	0	0	0
1998	17	-29.9 (range = -40 to -12; stdev = 8.3)	16	94	+3.3 (range = -15/2 tp 22.1; stdev = 12.8)	1	6	7 (7/7 also scoured ≥15 cm)	41
1999	19	-11.6 (range = -24 to 0; stdev = 8.0)	10	53	3.1 (range = -9.7 to 16.9; stdev = 7.6)	0	0	5 (1/5 scoured 4 cm, 4/5 scoured 0 cm)	26
2000	19	0.0 (range = 0 to 0; stdev = 0)	0	0	-0.9 (range = -7.9 to 7.9; stdev = 4.0)	0	0	0	0
Segment 8									
1997	18	-4.2 (range = -36 to 0; stdev = 9.9)	2	11	3.9 (range = -23.0 to 30.4; stdev = 14.7)	1	5	6 (1/6 with 8 cm scour, 4/6 with 0 cm scour, 1/6 not found)	32
1998	17	-34.9 (range = -76 to 0; stdev = 0)	12	71	-10.3 (range = -76 to 55.3; stdev = 42.3)	8	47	6 (2/6 scoured ≥15 cm, 4/6 had 0 cm scour)	35
1999	13	-16.9 (range = -44 to 0; stdev = 16.9)	6	46	-13.5 (range = -39.4 to 7.5; stdev = 16.5)	6	46	0	0

Relationship between Peak Discharge and Scour

In this section we analyze the relationship between annual incubation peak discharges and scour monitor results through correlation and linear regression analyses. Data on peak discharge events measured by the USGS Greenwater @ Greenwater gauge (12097500) from October 1995 through May 2001 are shown in Table 8. The peak flow of 5,900 cfs on February 8, 1996 is the largest discharge recorded during this interval. It has a recurrence interval of >25 years. The next largest annual peak was 3,672 cfs (30 December 1998), with a recurrence interval of >10 years. Incubation years 1996, 1997, and 1999, all had peak discharge events between 1,000 and 2,000 cfs (1540, >2-year frequency; 1040, <2-year frequency; and, 1587 >2-year frequency

Table 8. October 1995 to May 2001 peak discharges for high flow events over 500 cfs, at the Greenwater River USGS flow station number 12097500[1] in the White/Puyallup Basin, Washington. Shaded cells include peak discharges during the chinook incubation period. The highest peak event within each period is in boldface type.

Water Year	Date	Discharge In Cubic Feet/Second (Cubic Meters/Second In Parenthesis)	Event Frequency[2]
1996			
Oct. 1, 1995 to Sept. 30, 1996	11/11/95	1430 (40)	>2 year
	11/28/95	4240 (120)	>10 year
	12/13/95	708 (20)	<2 year
	12/31/95	888 (25)	<2 year
	1/8/98	961 (27)	<2 year
	1/16/96	702 (20)	<2 year
	2/8/96	**5900 (167)**	**>25 year**
	2/19/96	697 (20)	<2 year
1997			
Oct. 1, 1996 to Sept. 30, 1997	11/28/96	850 (24)	<2 year
	1/1/97	1520 (43)	>2 year
	1/7/97	988 (28)	<2 year
	2/1/97	719 (20)	<2 year
	2/15/97	**1540 (44)**	**>2 year**
	3/20/97	1070 (30)	<2 year
	4/20/97	961 (27)	<2 year
	4/27/97	882 (25)	<2 year
	5/15/97	1450 (41)	>2 year
	6/1/97	825 (23)	<2 year
1998			
Oct. 1, 1997 to Sept. 30, 1998	**10/30/97**	**1040 (29)**	**<2 year**
	12/29/97	552 (16)	<2 year
	5/2-3/98	627 (18)	<2 year
1999			
Oct. 1, 1998 to Sept. 30, 1999	11/13/98	742 (21)	<2 year
	11/21/98	534 (15)	<2 year
	11/26/98	748 (21)	<2 year
	12/30/98	**3672 (104)**	**>10 year**
	1/15/99	888 (25)	<2 year
	5/25/99	888 (25)	<2 year
	6/16/99	771 (22)	<2 year
2000			
Provisional data.	11/26/99	1568 (44)	>2 year
Oct. 1, 1999 to Sept. 30, 2000	12/11/99	1559 (44)	>2 year
	12/15/99	**1587 (45)**	**>2 year**
	4/15/00	577 (16)	<2 year
	5/23/00	553 (16)	<2 year
2001			
Provisional data. Note: all	**10/1/00**	**261 (7)**	**<2 year**
discharges are <500 cfs.	2/4/01	212 (6)	<2 year
Oct. 1, 2000 to May 31, 2001	4/30/01	417 (12)	<2 year

[1] Period of record for gauge: 1911 - 1912 (fragmentary); 1929 - 1977; 1980 - 1993 (seasonal); 1993 - present. Gauge elevation: 1727 ft. Extremes for period of record: maximum discharge 5900 cfs 2/8/96. Extremes outside of period of record: maximum discharge 10,500 cfs 12/2/77.

[2] Event frequencies from Sumioka et al. (1997). The 2-year frequency is 1,300 cfs; 10-year is 3,280 cfs; 25-year is 4,890 cfs; and 50-year is 6,450 cfs.

respectively). The highest flow reported for the 2000 incubation period occurred 1 October 2000. This flow was 261 cfs.

Correlation analysis results for scour monitor data and peak flows of record during each study year incubation period are shown in Table 9. There was a strong relationship between peak flow and mean scour depth in Segments 3 and 8. Coefficients of correlation (r) for peak flow and mean scour depth at scour monitors indicate strong negative linear relationships for Segment 3 (r = -0.9906) and Segment 8 (r = -0.9746). Peak flow and mean bed elevation change at monitor sites showed a strong positive linear relationship for Segment 3 (r = 0.8318), but a negative and weaker relationship for Segment 8 (r = -0.5211).

Coefficient of determination (R^2) values for peak flow with mean scour, and bed elevation changes at monitor sites are high for Segment 3. The Segment 3 R^2 value for peak flow and mean scour depth indicates 98% of the variation in mean scour depth is explained by variation in peak flow. Segment 8 R^2 values are high for peak flow and scour relationships (R^2 of 0.9498), but low for bed elevation change.

Simple linear regression analyses for peak discharge and mean scour depth for Segments 3 and 8 are shown in Table 10 and in Figures 5 and 6. The analysis for Segment 3 indicates that for each additional 100 cfs of flow during a peak discharge, close to 1 cm (0.91 cm) of scour is predicted to occur (p = 0.0094, 95% confidence bounds are 0.5 to 1.3 cm).

Combined data for Segments 3 and 8 also have high significance (p = 0.0002). For each additional 100 cfs of flow during a peak flow event, 1 cm of scour is predicted to occur. The 95% confidence bounds for this analysis are 0.7 to 1.3 cm. Segment 8 results also predict close to 1 cm (1.08 cm) of scour for each additional 100 cfs during a peak flow event. This result is not significant (due to small sample size).

An additional linear regression analysis for Segment 3 was done to investigate the relationship between annual incubation peak discharges and percent of monitors scoured to ≥15 cm (Figure 7). This analysis is significant (p = 0.0005). The regression equation predicts that for each additional 100 cfs of instantaneous peak discharge, close to 3% (2.98%) of monitor locations will scour to ≥15 cm. The specific critical discharge threshold for scour to ≥15 cm to begin was not determined by this study, but falls between 1,000 and 1,587cfs (at the USGS gauge).

Use of the regression equation allows prediction of the peak discharge levels where 25, 50 and 75% of monitors will scour to ≥15 cm. Table 11 includes the results for these predictions. For a peak discharge of 1235 cfs (2-year return interval), 25% of monitors are predicted to scour to ≥15 cm. During a peak flow of 2073 cfs (4-year return), 50% of monitors are predicted to scour to ≥15 cm and a discharge of 2912 cfs (7-year return), is predicted to scour 75% of monitors to ≥15 cm.

Table 9. Correlation analysis for 1997 to 2000 Greenwater annual incubation peak discharges, with channel scour and aggradation.

Variables	**Segment 3**		**Segment 8**	
	r	***R^2***	***r***	***R^2***
Scour Monitor Data at Scour Monitor Sites				
Peak flow and mean scour at scour monitors	-0.9906	0.9813	-0.9746	0.9498
Peak flow and % of monitors scoured to ≥15 cm	0.9420	0.8874	0.9126	0.8328
Bed Surface Elevation Data at Scour Monitor Sites				
Peak flow and mean surface elevation change at scour monitors	0.8318	0.6920	-0.5211	0.2719
Peak flow and % of monitor sites with surface elevation scoured to ≥15 cm	0.9280	0.8611	0.6763	0.4573
Peak flow and % of monitors with aggradation ≥ 10 cm	0.9222	0.8504	0.3920	0.1536
Mean scour and mean aggradation at monitor sites	-0.8493	0.7213	0.6991	0.4888

Table 10. Regression analysis for 1997 – 2000 peak incubation discharges (cfs) and mean scour depth (cm) at Greenwater Segments 3 and 8 scour monitors.

Regression	**Linear Regression Equation**	**Test of Equation Slope and Model**	
		***p*-value**	**Significance**
Segment 3	Y = -0.0091x + 3.8404	**0.0094**	High significance at alpha .05
Segment 8	Y = -0.0108x + 4.0608	0.1439	Not significant at alpha .05
Segments 3 and 8	Y = -0.0100x + 3.9970	**0.0002**	High significance at alpha .05

Table 11. Greenwater Segment 3 linear regression results for annual incubation peak discharge and percent of monitors scoured to ≥15 cm.

% of monitors scoured to ≥15 cm (95% bounds)	**Peak discharge (cfs)**	**Return interval (years)** [1]	**95% bounds on peak discharge (cfs)**	**90% bounds on peak discharge (cfs)**
	X = (y + 11.790) / 0.0298		x = (y + 11.790) / 0.0404 x = (y + 11.790) / 0.0191	x = (y + 11.790) / 0.0382 x = (y + 11.790) / 0.0213
25 (11 to 39)	1235	2	911 to 1926	963 to 1727
50 (36 to 64)	2073	4	1529 to 3235	1618 to 2901
75 (56 to 94)	2912	7	2148 to 4544	2272 to 4075

[1] Based on the full period of record; provided by G. Ketcheson, hydrologist, Mt. Baker Snoqualmie National Forest.

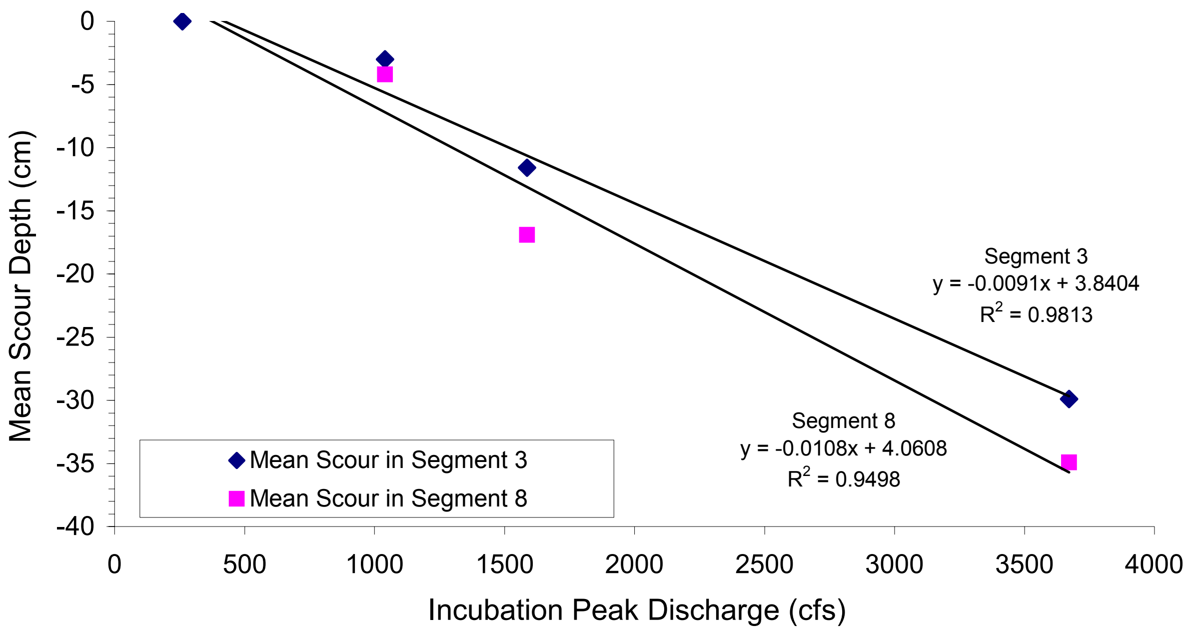


Figure 5. Greenwater Segments 3 and 8 regression analyses for incubation peak discharge and mean scour. Data is from incubation years 1997 to 2000.

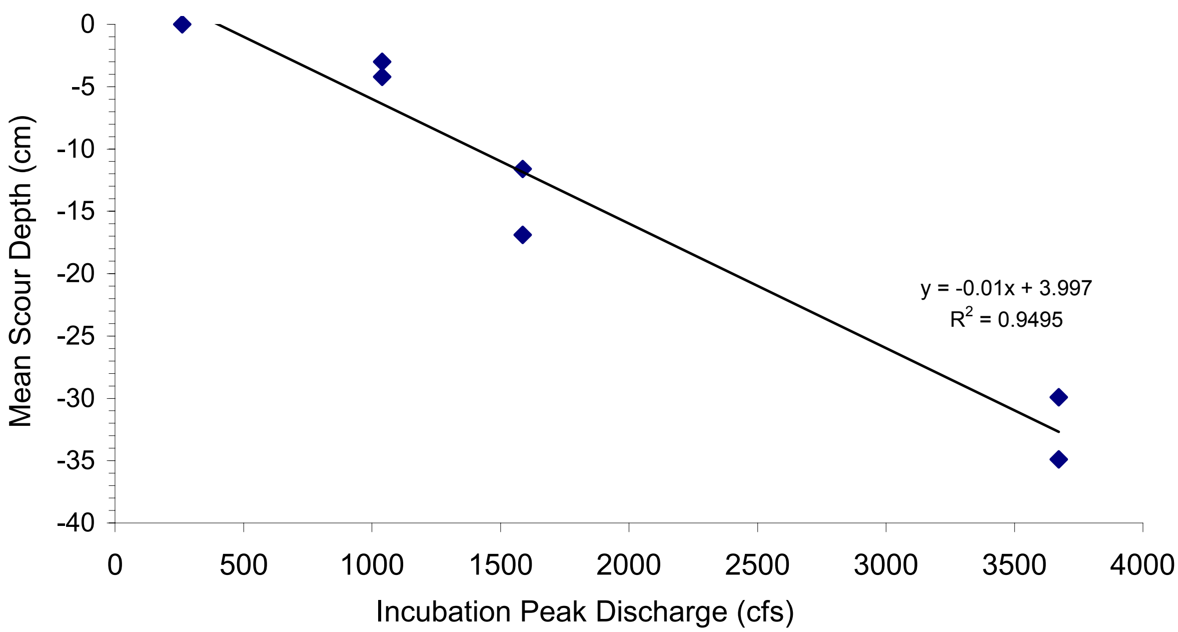


Figure 6. Greenwater Segments 3 and 8 combined regression analysis for peak flow and mean scour during chinook incubation. Data is from incubation years 1997 to 2000.

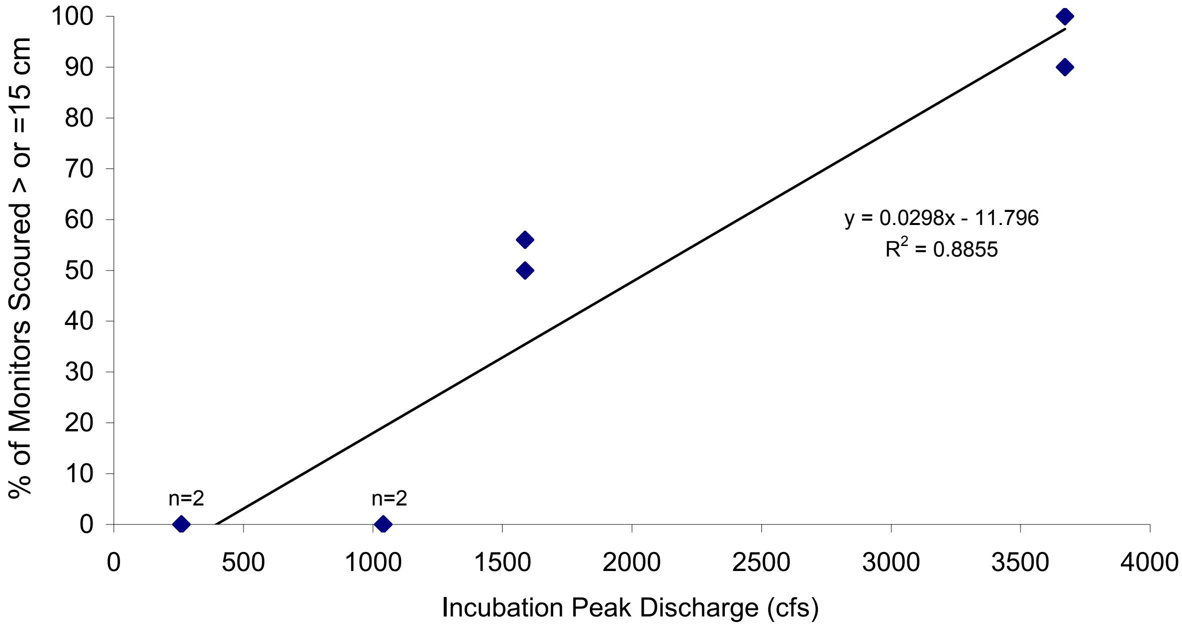


Figure 7. Incubation peak discharge and percent of monitors scoured to ≥15 cm for Greenwater Segment 3 cross-sections. Data is from incubation years 1997 to 2000.

Redd Surveys

In this section we first present the results are first presented for changes to redd mound surface elevation, surface flow, and habitat. This is followed by an evaluation of these factors for individual redd sites to allow estimation of the likelihood of chinook survival to emergence. Finally, redd analysis and scour monitor data are compared to draw overall conclusions about redd survival.

During incubation years 1996, 1997, 1998, 1999 and 2000, a total of 76 chinook redds in the Upper White watershed were monitored to estimate the likelihood of embryo mortality from scour, deposition, habitat change and surface flow at the end of incubation. In 1996 10 redds were monitored in the Clearwater River, four in the White River, and 17 in the Greenwater River. For 1997 through 2000, only redds in the Greenwater were monitored (12 in 1997, 2 in 1998, 18 in 1999 and 13 in 2000). These redds were all in Segment 3 as no chinook were known to spawn in Segment 8. However, in 1998, two coho redds were monitored in Greenwater Segment 8. Measurements were taken near the beginning of incubation, and then again near the time of fry emergence. Appendix C contains photos of redd locations illustrating types of changes to the redd environment that were encountered. The appendix also includes a table with the analysis data for each redd.

Redd Mound Surface Elevation Changes

Elevation changes at 72 chinook redds measured both fall and late winter ranged from -53 cm to +115 cm. Due to the loss of tail pins, or, flow levels too deep or swift, we could not remeasure the elevations for four redds although data for other parameters were taken. Table 12 summarizes redd surface elevation change data by segment and year. Of the 72 chinook redds, eight (11%) had surface elevation change showing degradation of ≥15 cm, and eight others had surface elevation increases ≥10 cm.

A correlation analysis was performed to more closely look at the relationship between peak flow and surface elevation change at redds in Segment 3 of the Greenwater River. This location was chosen for further analysis due to close proximity to the USGS gauge (located approximately 300 m downstream of Segment 3), and due to the 5 years of redd data available for this segment. Table 13 presents the results of this analysis. Coefficient of correlation (r) values for peak flow level and mean surface elevation change at redds, as well as percent of redds with surface elevation scoured to ≥15 cm indicate strong linear relationships between factors (the first is a negative relationship, while the second is positive. Coefficient of determination (R^2) values indicate 91% of the variation in mean surface elevation change at redds, and 90% of the variation in percent of redds with surface elevation degradation to ≥15 cm are explained by peak flow. Peak flow and percent of redds with surface elevation increases ≥10 cm did not show evidence of a linear relationship, and only 4% of the variability in percent of redds with elevation increases ≥10 cm was explained by peak flow.

Surface Flow at the End of Incubation

Only 1 of 76 (1.3%) redds no longer had water flowing over the redd at the end of incubation. This site was located in the White River in 1996.

Habitat Changes

We monitored 76 chinook redds for habitat changes between fall and late winter. All habitats were either pool tailouts or riffles. Riffle locations included side-channel, secondary-channel and mainstem locations as well as thalwegs, non-thalwegs, riffle crests and non-riffle-rests. By late winter, 13 redd locations had visible habitat changes. These included: channel morphology change from single strand to braided; change of thalweg to the redd location; secondary channel redd location becoming primary channel thalweg; main channel location becoming secondary channel; partial bar formation over redd location; riffle crest location change to pool tailout, and pool tailout to riffle.

Likelihood of Embryo Survival to Emergence Based on Field Results

We used data from the redd surveys to estimate the likelihood of survival for each redd. Three potential mortality indicators (surface elevation change, surface flow, and habitat change) were evaluated for each redd. Mortality (hence a poor rating) was assumed if: 1) surface elevation decreased ≥15 cm or increased ≥10 cm, 2) if water was no longer flowing on the redd site at the end of the incubation period, or 3) there was a major change in channel morphology as indicated by a shift in habitat. Redd locations with no negative mortality indicators were given a good rating. An uncertain rating was given where evidence pointed to concerns for survival, but data were not specific enough for classification as a negative mortality factor.

Fifty-two of the chinook redds (68%) were categorized as having a good likelihood of embryo survival from observed factors. Three redds (4%) had uncertain survival and 21 redds (28%), had a poor likelihood of survival. For those redds with poor likelihood of survival, scour was a

Table 12. Chinook redd surface elevation change.

River and Segment	Incubation year	# redds with elevation data[1]	Mean surface elevation change fall to late winter (cm)	# redds scour ≥15 cm [2]	% redds scour ≥15 cm [2]	# redds aggradation ≥ 10 cm	% redds aggradation ≥ 10 cm
Clearwater Segment 2	1996	10	0.9 (range = -28.7 to 60.1; stdev = 29.6)	3	30	3	30
White River	1996	2	101.9 (range = 88.3 to 115.4; stdev = 19.2)	0	0	2	100
Greenwater Segment 2	1996	2	-9.6 (range = -4.2 to -14.5; stdev = 7.0)	0	0	0	0
Greenwater Segment 3	1996	14	-8.3 (range = -33.6 to 10.0; stdev = 13.0)	2	14	0	0
Greenwater Segment 3	1997	12	-2.7 (range = -20.2 to 55.5; stdev = 20.3)	0	0	1	8
Greenwater Segment 3	1998	1	-52.9	1	100	0	0
Greenwater Segment 8	1998	2 (Coho redds)[3]	5.1 (range = -38.1 to 48.3; stdev = 61.1)	1	50	1	50
Greenwater Segment 3	1999	18	-6.2 (range = -33.8 to 15.6; stdev = 12.3)	2	11	2	11
Greenwater Segment 3	2000	13	-0.2 (range = -8.0 to 9.5; stdev = 4.5)	0	0	0	0

[1] Four redds were unable to have elevation re-measured late winter due to swift water conditions, or erosion of tail pins and are not included in this table.
[2] This is from the estimated original streambed elevation. This is assumed to be 7 cm below the mound measurement location based on Greenwater River chinook redd measurements (n=8).
[3] These coho redds are not included in further data analysis.

factor in 10 cases, bed elevation increase in nine, and flow in one. A major habitat change was a factor in 12 cases, and was often in conjunction with elevation increase. Table 14 summarizes this data and Appendix C includes the redd specific data.

Similar to the scour monitor data, these results varied according to peak flow level during the incubation period. Figure 8 shows the data points and linear regression lines for Greenwater

Table 13. Correlation analysis for 1996 to 2000 annual incubation peak discharges with channel scour and aggradation at Greenwater River Segment 3 chinook redds.

Variables	**Segment 3**	
	r	***R^2***
Peak discharge and mean surface elevation change at redd sites	**-0.9536**	**0.9093**
Peak discharge and % of redds with surface elevation scoured to ≥15 cm[1]	**0.9494**	**0.9014**
Peak discharge and % of redds with aggradation ≥ 10 cm	-0.1862	0.0347

[1] Scour is measured from the estimated original streambed elevation. We use 7 cm below the mound top based on chinook redd measurements from the Greenwater River.

Table 14. Summary of redd likelihood of survival results.

Location	**Year**	**Peak incubation discharge (cfs)[1]**	**# Good (%)**	**# Uncertain (%)**	**# Poor (%)**
Clearwater Seg. 1 (part)	1996	1540	3 (30)	1 (10)	6 (60)
White RM 41.9-42.2	1996	1540	0 (0)	0 (0)	4 (100)
Greenwater Seg. 2 (part)	1996	1540	2 (67)	0 (0)	1 (33)
Greenwater Seg. 3	1996	1540	11 (79)	0 (0)	3 (21)
Greenwater Seg. 3	1997	1040	11 (92)	0 (0)	1 (8)
Greenwater Seg. 3	1998	3672	0 (0)	1 (50)	1 (50)
Greenwater Seg. 3	1999	1587	13 (72)	0 (0)	5 (28)
Greenwater Seg. 3	2000	261	12 (92)	1 (8)	0 (0)
Total			**52 (68)**	**3 (4)**	**21 (28)**

[1] Discharges at the Greenwater USGS gauge.

Segment 3. The relationships between good and poor with incubation peak discharge were significant (good %: $p = 0.008$, and poor %: $p = 0.0047$). For the relationship between uncertain % and peak discharge, $p = 0.0794$.

Relationship between Scour Monitor and Redd Derived Data

The purpose for scour monitors was to support the interpretation of redd data. To assist with this need, Table 15 provides a comparison for Greenwater Segment 3 1996 to 2000, percent of redds with poor survival, and, scour to the top of egg pocket data. Data from redds shows the best case scenario view of survival. For example, based only on redd data, the mean percent of redds with poor survival for incubation years 1996 to 2000 was 23%. This is in contrast to scour monitor data which had a mean of 36% of monitor sites with scour to the top of the default egg pocket depth. This is not unexpected, as other than bed surface degradation, scour cannot be observed at redds.

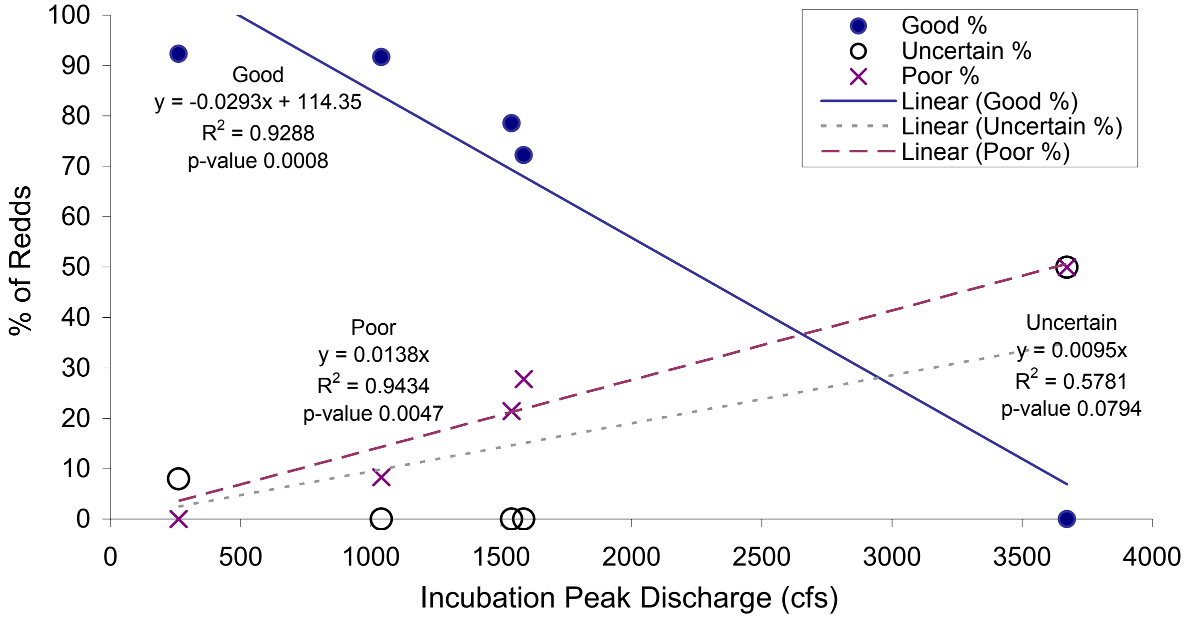


Figure 8. Greenwater Segment 3 redd likelihood of survival (based on surface elevation, surface flow characteristics, and habitat changes) and varying flow levels.

Because the cross-section/scour monitor sites were installed on spawning gravels, were often used as spawning sites, and contained the same habitat types used by chinook for spawning, it is reasonable to consider monitor data as surrogate scour data for redds. A t-test (paired two sample for means) for percent poor redds and percent of monitors scoured to ≥15 cm for 1996 to 2000, failed to reject a null hypothesis that the mean of the population difference is zero. This provides further inference that redd and scour monitor results work in tandem. However, scour data is segment-based and cannot be applied to specific redds. Both data sets provide unique looks at the redd environment. Used together they provide substantial information on embryo survival to emergence for chinook redds.

Table 15. Greenwater Segment 3 summary of percent of redds with poor survival, and scour monitor data.

Year	**Redds**	**Scour Monitors**
	% Poor	**% Scoured to ≥15 cm**
1996	21	34[1]
1997	8	0
1998	50	94
1999	28	53
2000	8	0
Mean	**23**	**36**

[1]Derived from peak discharge for incubation year 1996, and regression equation for flow and % of monitors scoured to ≥15 cm: $y = 0.298x - 11.796$.

DISCUSSION AND SUMMARY

Data for the Clearwater and White Rivers provide insights into dynamics affecting redd survival for these rivers. The primary study objective, baseline development for chinook redd survival based on bed scour and changes in redd site conditions has been accomplished for the Greenwater River. This baseline provides a yardstick with which to compare redd environment condition over time. It is an important component of Clean Water Act and USFS Water Quality Restoration Planning for the Upper White watershed.

In addition to providing a baseline, the Greenwater study provides information for watershed restoration and salmonid recovery planning. Montgomery and Buffington (1998) link increased scour depth to changes in sediment supply and discharge for channel types in this study. It is therefore of interest to ascertain whether delivery rates of sediment and water have changed due to management in ways that decrease the likelihood of chinook survival to emergence.

Increased sediment supply from forest management to study watersheds is documented in watershed analyses for both state regulated (Weyerhaeuser 1999) and federal (USDA Forest Service 2000) lands. The watershed analysis of the Upper White and Greenwater basins by the Mount Baker Snoqualmie National Forest (USDA Forest Service 2000) uses watershed vegetation disturbance level as an indicator for likelihood of increased mass wasting hazards and changes in flow from rain-on–snow events and roads. High disturbance levels (>20% vegetation disturbance) were found in the lower Greenwater and West Fork White rivers as well as lower Huckleberry Creek. Moderate disturbance levels (10 – 20%) were found throughout most other areas of the basin, with the exception of wilderness and National Park lands.

USDA Forest Service (2000) examined peak flows for the Greenwater USGS gauge. The magnitude of a given return frequency flood was found to have increased post-1970, when most harvest and road building was occurring. Watershed factors that increase peak discharge (reviewed by USDA Forest Service 2000; and Mastin 1998) are present in the Greenwater River. However, climatic factors (e.g., a change in precipitation), could be responsible for a portion of the change in flood frequencies. G. Ketcheson (pers. comm. 2002, hydrologist with Mt. Baker Snoqualmie National Forest) analyzed daily air temperatures for June through August, and monthly precipitation for November through February to assist with interpretation of the increased return frequency in the Greenwater River. He reviewed the air and precipitation data from the 1940s to 1998 for stations at Greenwater, Paradise and Buckley. No visual trend was evident that would support the changed flood frequency.

Mastin (1998) performed linear regression and Mann-Kendall statistical procedures on annual precipitation data and annual mean temperature from Mud Mountain Reservoir (within the White River Basin) as well as three nearby locations outside of the basin. He failed to find evidence of changing precipitation trends between 1950 and 1995. He did find the mean annual temperature at the Mud Mountain Reservoir showed a slight increasing trend, but the relationship between temperature and flooding remained difficult to quantify. Although these analyses do not rule out the possibility that a change in climatic factors is affecting peak flows, the available information indicates management practices are linked to increased flood return intervals in the Greenwater River.

Seiler et al. (2000) established the basin scale effect of peak incubation flow on chinook smolt production for the Skagit River. Egg to migrant survival has ranged from a low of 1% during the 1990 highest flow study year, to as much as 22% during 1993, the year with the lowest peak recorded during their study. Basin scale relationships between peak incubation flow and smolt production for other species and watersheds have also been developed (Seiler and Kishimoto 1997, Seiler 2000) and it is reasonable that there is a similar relationship for smolts from the Upper White/Puyallup system as well.

It is of importance therefore, to consider whether changes to return frequency floods for the Greenwater are causing a change in the rate at which extensive scour to egg pocket depth is occurring. To address this, we categorized Greenwater gauge annual incubation peak discharge data for water years pre 1970, and 1970 to 2000 according to discharge peaks predicted to scour 0, 25, 50 and 75% of scour monitors to 15 cm, the top of egg pocket depth. A z-test of the difference between two proportions was used to determine whether the probabilities have changed between the two periods.

The results (Table 16) show probabilities between the two periods for scour ≥15 cm are significantly different (p = 0.0826) for lower and higher discharges. The probability for the annual incubation peak discharge predicted to scour between 0 and 50% of monitors has changed from 0.83 to 0.67 with corresponding return frequencies (based on the probabilities) of 1.2 and 1.5 years. Conversely, annual incubation peaks predicted to scour ≥50% of monitors to egg pocket depth have increased from a probability of 0.17 (a 5.9-year return frequency) to 0.33 (a 3.0-year return frequency).

The lower portion of the table provides a closer look at incubation peak flows and associated probabilities for scour ≥15 cm. This categorization does not meet z-test sample size requirements, and therefore no significance is shown. The largest change has occurred in the categories of 0 and 75% of monitors. Flows predicted to scour 0% of monitors ≥15 cm had a probability of 0.63 (1.6-year frequency) in the earlier period, versus 0.44 (2.3-year frequency) more recently. Flows predicted to scour 75% of monitors to ≥15 cm previously had a probability of 0.10 (10.3-year frequency) but now have a 0.22 probability (4.5-year frequency) and are occurring twice as often.

Decreased probabilities for low scour years and increased probabilities for high scour years have negative implications for salmonid recovery. Hence the restoration of watershed processes that promote recovery of natural sediment production rates and frequency of peak discharges are key elements needed for salmonid recovery in the Greenwater River, and more broadly in other watersheds within the Upper White watershed that may have similar watershed management histories.

In summary, this study has provided documentation for streams in the Upper White watershed of chinook redd characteristics at the beginning and end of incubation. For the Greenwater River, strong negative significant relationships were found between increasing peak flow levels and mean scour depth, and strong positive relationships were found between increasing flow amounts and percent of scour monitors scoured to the top of egg pocket depth, and to percent of redds with a poor likelihood of survival. Watershed management and restoration of watershed processes that prevent increased sediment production and increased frequency for peak discharge events are of importance to improve chinook redd likelihood of survival.

Table 16. Z-test of the difference between two-proportions for Greenwater River annual incubation peak discharge probabilities for water years pre-1970, and 1970 to 2000 and percent of monitors scoured to ≥15 cm (top of egg pocket depth). Annual peak discharge data and return intervals were provided by G. Ketcheson, Hydrologist, USFS.[1]

Predicted % of monitors scoured ≥15 cm	Annual Incubation Peak (cfs)	Pre-1970 Water Years n = 41[2]		1970 – 2000 Water Years n = 18[3]		Significance	
		# peaks	probability	# peaks	probability	*p*-value	Alpha 0.10
<50	0 to 2072	34	0.8293	12	0.6667	**0.0826**	Significant
≥50	≥2073	7	0.1707	6	0.3333	**0.0826**	Significant
Total:		41	1.0000	18	1.0000		
0	0 to 1234	26	0.6342	8	0.4444		
25	1235 to 2072	8	0.1951	4	0.2222		
50	2073 to 2911	3	0.0732	2	0.1111		
75	>2912	4	0.0976	4	0.2222		
Total:		41	1.0001	18	0.9999		

[1] Incubation peak discharges occur September through February. Return intervals are: 1235 cfs – 2 years; 2073 cfs – 4 years; 2912 cfs – 7 years.
[2] 41 water years with record are 1912, 1930 – 1969. Note that water years run from October 1 to September 30 and are labeled by convention with the year that starts January 1st. Incubation years are labeled a year earlier, i.e. incubation year 1999 is water year 2000.
[3] 18 water years with record are 1970 – 1978, 1993 – 1999, and provisional data years 2000 – 2001.

CITATIONS

Bams, R.A. 1969. Adaptations of sockeye salmon associated with incubation in stream gravels. Pages 71-81 *in* T. G. Northcote, editor. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. University of British Columbia. Vancouver, B.C.

Black, R.W., A. Haggland and G. Crosby. 2003. Characterization of instream hydraulic and riparian habitat conditions and stream temperatures of the Upper White River Basin, Washington, using multispectral imaging systems. Water-Resources Investigations Report 03-4022. U.S. Geological Survey. Tacoma.

DeVries, P. 1997. Riverine salmonid egg burial depths: Review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54:1685-1698.

Dunne, T. and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company. New York.

Keown, C. and J.H. Summers VII. 1998. Upper White River spring chinook habitat assessment study; Interim report on 1995 water temperatures and spawning gravel composition. Publication No. 98-304. Washington Department of Ecology. Olympia. 34 p. + app.

Ketcheson, G., P. Leinenbach, J. Schuett-Hames, T. Whiley and C. James. 2003. Mt. Baker Snoqualmie National Forest, Upper White watershed sediment and temperature TMDL for aquatic habitat: Submittal report. Washington Department of Ecology. Olympia. 107 p. + app.

Koski, K. V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. M.S. thesis. Oregon State University, Corvallis.

Koski, K. V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. dissertation. University of Washington, Seattle.

Mastin, M.C. 1998. Flood potential of South Prairie Creek, Pierce County, Washington. U.S. Geological Survey. Water-Resources Investigations Report 98-4009. Tacoma. 75 p.

McNeil, W.J. 1964. Environmental factors affecting survival of young salmon in spawning beds and their possible relation to logging. Manuscript Report No. 1. U.S. Fish and Wildlife Service Biological Lab. Auk Bay, AK. 25 p.

Montgomery, D.R. and J.M Buffington. 1998. Channel processes, classification, and response. Chapter 2 *in*: Naiman, R.J. and R.E. Bilby, eds. River ecology and management; Lessons from the Pacific Coastal Ecoregion. Springer. New York. 705 p.

Peterson, N.P., A. Hendry and T.P. Quinn. 1992. Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target conditions. TFW-F3-92-001. Washington Department of Natural Resources. Olympia. 75 p.

Pleus, A.E. and D. Schuett-Hames. 1998. TFW monitoring program method manual for stream segment identification. TFW-AM9-98-001. Northwest Indian Fisheries Commission. Olympia. 39 p. + app.

Schuett-Hames, D., A. Pleus, L. Bullchild and S. Hall. 1994. Timber-Fish-Wildlife; Ambient monitoring program manual. TFW-AM9-94-001. Northwest Indian Fisheries Commission. Olympia.

Schuett-Hames, D., R. Conrad, A.E. Pleus and K. Lautz. 1999. TFW monitoring program methods manual for the salmonid spawning gravel scour survey. TFW-AM-99-008. Washington Department of Natural Resources. Olympia. 41 p. + app.

Schuett-Hames, J.P., C. Keown and C.M. James. 2003. Upper White watershed stream temperature data report; In progress. Washington Department of Ecology. Olympia.

Seiler, D. 2000. 2000 wild coho forecasts for Puget Sound & Washington coastal systems. Washington Department of Fish and Wildlife. Olympia. 32 p.

Seiler, D. and L. Kishimoto. 1997. 1997 Cedar River sockeye salmon fry production evaluation. Washington Department of Fish and Wildlife. Olympia. 26 p.

Seiler, D., L. Kishimoto and S. Neuhauser. 2000. Annual report; 1999 Skagit River wild 0+ chinook production evaluation. Washington Department of Fish and Wildlife. Olympia. 75 p.

Sumioka, S.S., D.L. Kresch and K.D. Kasnick. 1997. Magnitude and frequency of floods in Washington. USGS Water-Resources Investigations Report 97-4277. Accessed through the internet 4/27/01 at site http://wwwdwatcm.wr.usgs.gov/report/flood-freq/index.html.

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

Tagart, J. V. 1984. Coho salmon survival from egg deposition to fry emergence. Pages 173 -182 *in* J. M. Walton, J.M. and D.B. Houston, eds. Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles.

Tripp, D.B., and V.V. Poulin. 1986. The effects of logging and mass wasting on salmonid spawning habitat in streams on the Queen Charlotte Islands; Land Management Report 50. British Columbia Ministry of Forests and Lands. Victoria, B.C. 29 p.

Upper White River Chinook TMDL Framework Team. 1998. White River spring chinook habitat guidance; A water quality management approach for the upper White River: Version 1.0. Washington Department of Ecology. Olympia. 80 p.

Upper White River Spring Chinook Habitat Monitoring Steering Group. 1997. Rough draft; White River spring chinook habitat baseline monitoring plan. Unpublished report. Washington Department of Ecology. Olympia. 7 p. + app.

USDA Forest Service. 2000. Upper White & Greenwater watershed analysis. Mount Baker-Snoqualmie National Forest. Enumclaw. 142 p. + app.

Washington Department of Fish and Wildlife, Puyallup Indian Tribe and Muckleshoot Indian Tribe. 1996. Recovery plan for White River spring chinook salmon. Washington Department of Fish and Wildlife. Olympia. 81 p.

Washington Department of Fisheries, Washington Department of Wildlife and Western Washington Treaty Indian Tribes. 1993. 1992 Washington State salmon and steelhead stock inventory: SASSI. Washington Department of Fish and Wildlife. Olympia. 212 p.

Washington Forest Practices Board. 1997. Board Manual: Standard methodology for conducting watershed analysis; under Chapter 222-22 WAC; Version 4.0. Washington Department of Natural Resources. Olympia. 112 p. + app.

Weyerhaeuser. 1999. Clearwater and Middle White watershed analysis; Draft. Washington Department of Natural Resources. Enumclaw.

Williams, R.W., R.W. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization; Volume 1; Puget Sound Region. Washington Department of Fisheries. Olympia.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union. 35:951-956.

APPENDIX A: 1995-1996 Clearwater Cross-section and Scour Surveys

In the fall of 1995 cross-sections with scour monitors were established in the Clearwater River. Large floods occurred 28 November 1995 and 8 February 1996 causing extensive changes to the Clearwater River; these changes were documented at the cross-sections. The Clearwater River does not have a flow gauge. However, the nearby Greenwater River gauge registered the November peak discharge as having a >10 year recurrence interval, and the February discharge as having a >25 year recurrence interval. The purpose of this appendix is to document the changes we observed and measured at the cross-sections and scour monitor sites, that resulted from the large discharge events. Where possible, effects are described relative to nearby redd locations.

During the 1995 spawning season, 31 chinook redds were located in the Clearwater River. Of these redds, 30 were between river miles 0.0 - 2.2 and one was between river miles 2.2 and 3.8 (Washington Department of Fisheries 1995 - 1997). In addition, we observed pink salmon spawning between river miles 0.0 and 3.1.

Cross-section Locations and Characteristics

Locations of established cross-sections and stream segmentation within the Clearwater River are shown in Figures 9 and 10. A total of seven cross-sections, two in Segment 1 at reference points 2+80 m and 5+22 m, and five in Segment 3 (reference points 0+14 m, 0+22 m, 2+47 m, 6+50 m, and 6+62 m) were established September 1995. The cross-sections are numbered CW#1 - 7, consecutively from the river mouth to the furthest upstream site.

Characteristics of the cross-section locations are provided in Table 17. Bankfull widths ranged from 13.90 m at the uppermost site to 21.18 m at the site closest to the river mouth. Stream gradients ranged from 1.3% to 1.8%. Based on methodologies in Washington Forest Practices Board (1997) five sites were characterized as moderately confined and two were unconfined. Habitat types included two pool tailout and five riffle locations. Four cross-sections had known spawning use by salmonids (steelhead or pink salmon) in 1995; the remaining three had either chinook, steelhead or pink redd locations within 10 m - 25 m. Steelhead emerged prior to this study; chinook and pink embryos were in the gravel during the study period.

Cross-section Results

Figures 11 to 17 contain individual cross-section graphs showing fall of 1995 and late winter 1996 elevations. Table 18 summarizes information on changes at the cross-sections between the two survey periods. All cross-section locations except for CW#2 incurred substantial changes to bankfull width, and to habitat characteristics.

At three cross-sections, CW#1, CW#6 and CW#7, channel thalwegs shifted to floodplain locations that had been outside of the active channel fall of 1995. Fall spawning areas were dewatered by these changes. In addition, thalweg shifts occurred at CW#3 and CW#4.

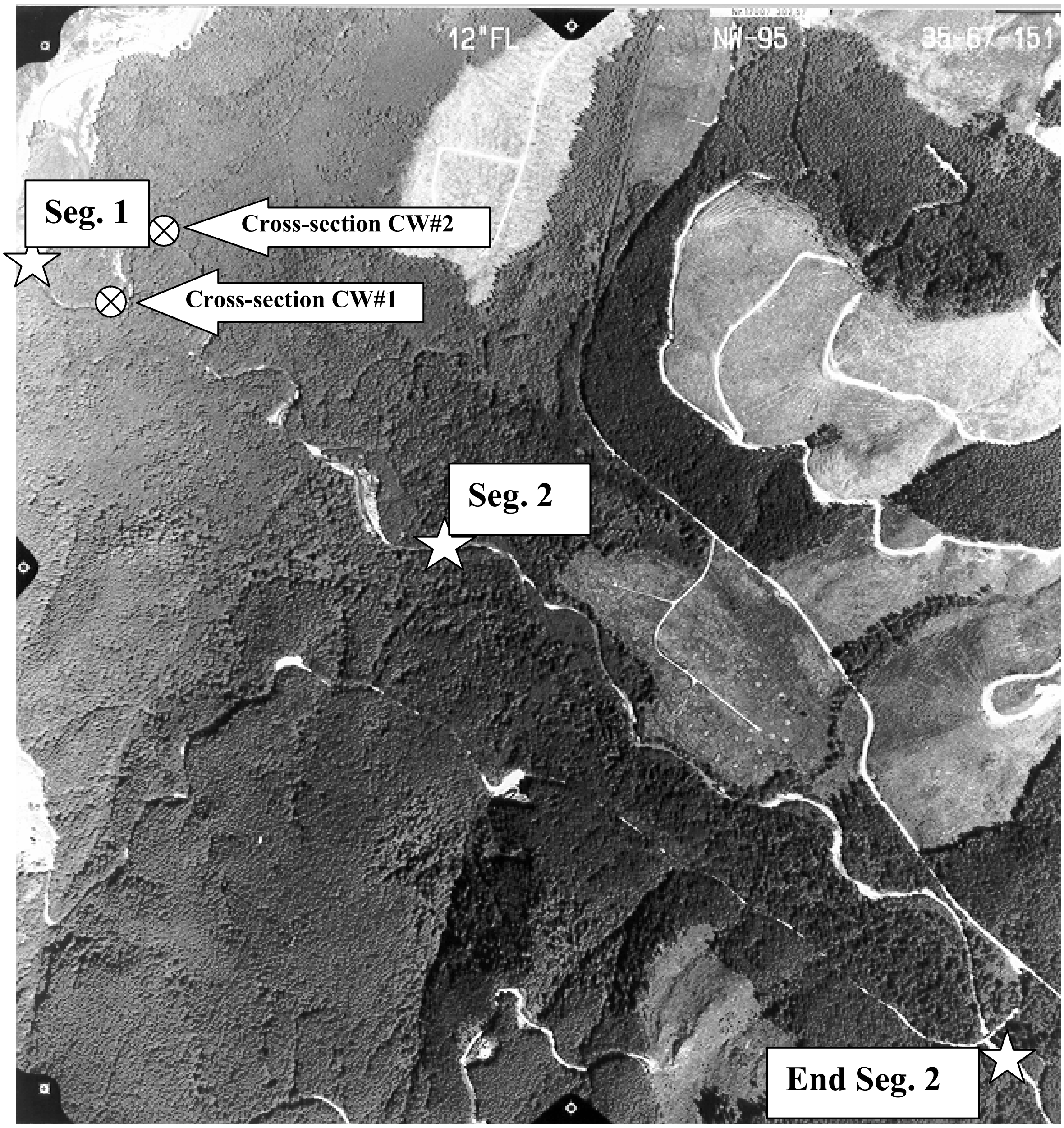


Figure 9. Clearwater Segments 1 and 2 and cross-section locations. (T19NR8E Sections 7,8,16,17 and 21; river miles 0.0-1.1 and 1.1 - 2.3).

Bankfull widths became an average of 36% wider, late winter 1996. At CW#1, #6 and #7, the channel shifted to new locations and widening of nearly 30 m (57 to 68%) occurred. Widening also occurred in CW#3, #4 and #5. In these locations, widening ranged from 3.60 m to 5.07 m (16 to 25%).
Average elevation change across the bankfull channel between the fall 1995 survey and the late winter 1996 survey was evaluated for CW#1 through #5. The mean elevation change for these

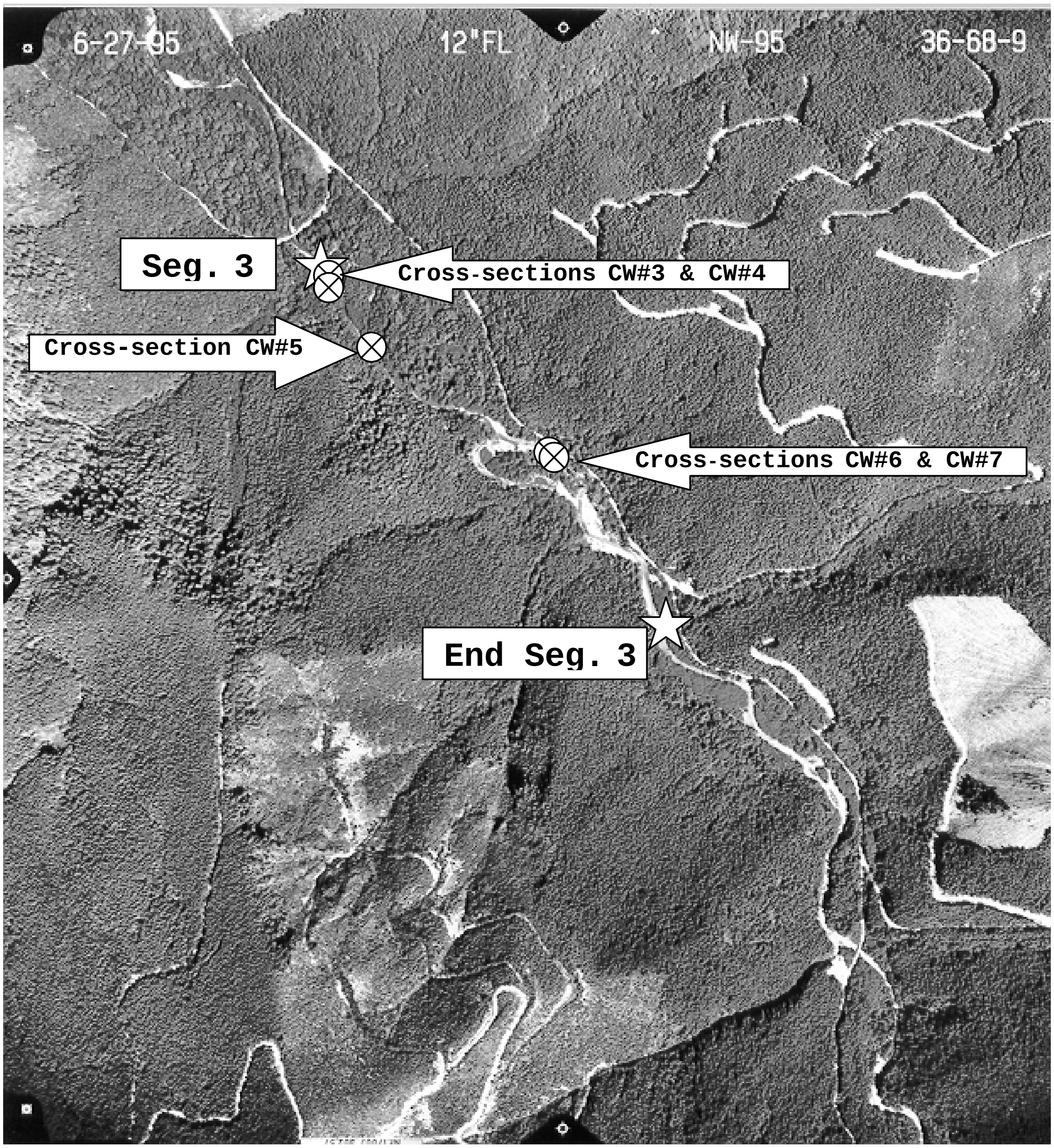


Figure 10. Clearwater Segment 3 and cross-section locations. (T19NR8E Section 21; river miles 2.3-3.1).

cross-sections was +23 cm. All locations aggraded with the least amount occurring at cross-section #2 (+9 cm) and the greatest aggradation occurring at cross-section #1 (+63 cm). The new, late winter channel at cross-sections #6 and #7 fell outside of the area surveyed fall 1995; as a result, an elevation change could not be calculated for these two sites.

Specifics for the different segments and cross-sections are provided below.

Table 17. Characteristics of Clearwater River channel cross-section locations.

Cross-section # and Location[1]		**River Mile**	**Bankfull Width (m) Fall 1995**	**Gradient %** [2]	**Confine-ment**[3]	**Habitat Type**	**Observed Use by Spawning Fish**
CW#1	Seg1:RP2+80 m	0.4	21.18	1.8	M	pool tailout	pink redds fall 1995.
CW#2	Seg1:RP5+22 m	0.5	20.15	1.8	M	riffle	chinook and pink redds fall 1995 (vicinity).
CW#3	Seg3:RP0+14 m	2.3	16.71	1.3	M	riffle	steelhead redd spring 1995.
CW#4	Seg3:RP0+22 m	2.3	18.90	1.3	M	riffle	steelhead redd spring 1995 (vicinity).
CW#5	Seg3:RP2+47 m	2.4	15.51	1.3	M	pool tailout	pink redds fall 1995 (vicinity).
CW#6	Seg3:RP6+50 m	2.7	14.62	1.3	U	riffle	steelhead redds spring 1995.
CW#7	Seg3:RP6+62 m	2.7	13.90	1.3	U	riffle	steelhead redds spring 1995.

[1]Cross-sections are numbered according to stream (CW is Clearwater) and sequential location upstream of mouth. Locations are by segment number, reference point number, and distance upstream from the reference point.
[2] From USGS topographic map.
[3]Based on Washington Forest Practices Board (1997). M = moderately confined (valley width is 2 - 4 channel widths). U = unconfined (valley width is greater than 4 channel widths).

Segment 1 Cross-sections (CW#1 and CW#2)

These cross-sections were located upstream from the mouth of the Clearwater River at 280 m (CW#1) and 522 m (CW#2). Fall of 1995 the river mouth to CW#2 was the densest spawning reach we observed on this river. Our observations included three chinook redds, each with three or more fish, and numerous pink redds and fish. For example, on September 15, 1995, we counted 19 pink redds (each with fish); this was before the spawning peak occurred.

Two large channel-bend landslides were located roughly 50 m downstream from CW#2. They supplied spawning gravels to downstream areas, and the deposits within the channel also created a back-up of spawning gravels that extended towards CW#2. Important spawning areas used by the pinks (many redds) and chinook (two redds) were: a channel that appeared to be newly cut (the old mainstem channel was dry) through a forested area immediately downstream of the landslides; and, the gravel accumulation backed-up behind slides at the river bend.

Additional areas used for spawning were: patches of gravel associated with boulders; and, pool tailouts formed by channel bends and obstructions at bends. This included one location where a log and debris jam alongside the channel was associated with a pool and tailout sequence.

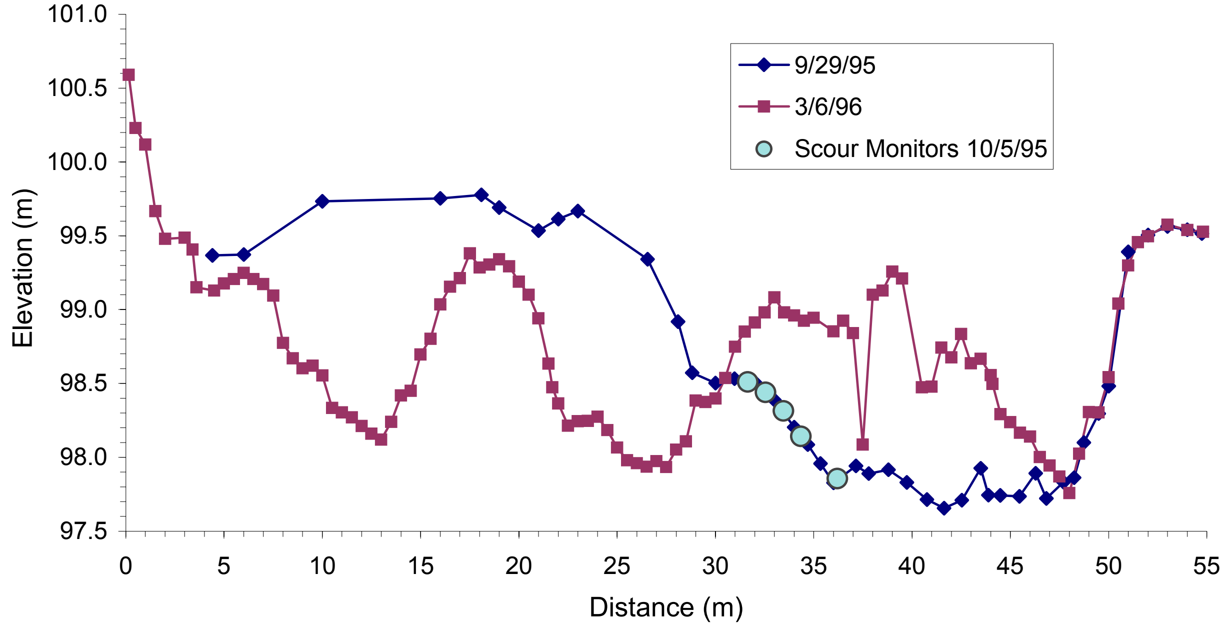


Figure 11. Clearwater cross-section #1. Location: Segment 1, reference point 2+80 m. Measurements taken fall of 1995 and late winter of 1996.

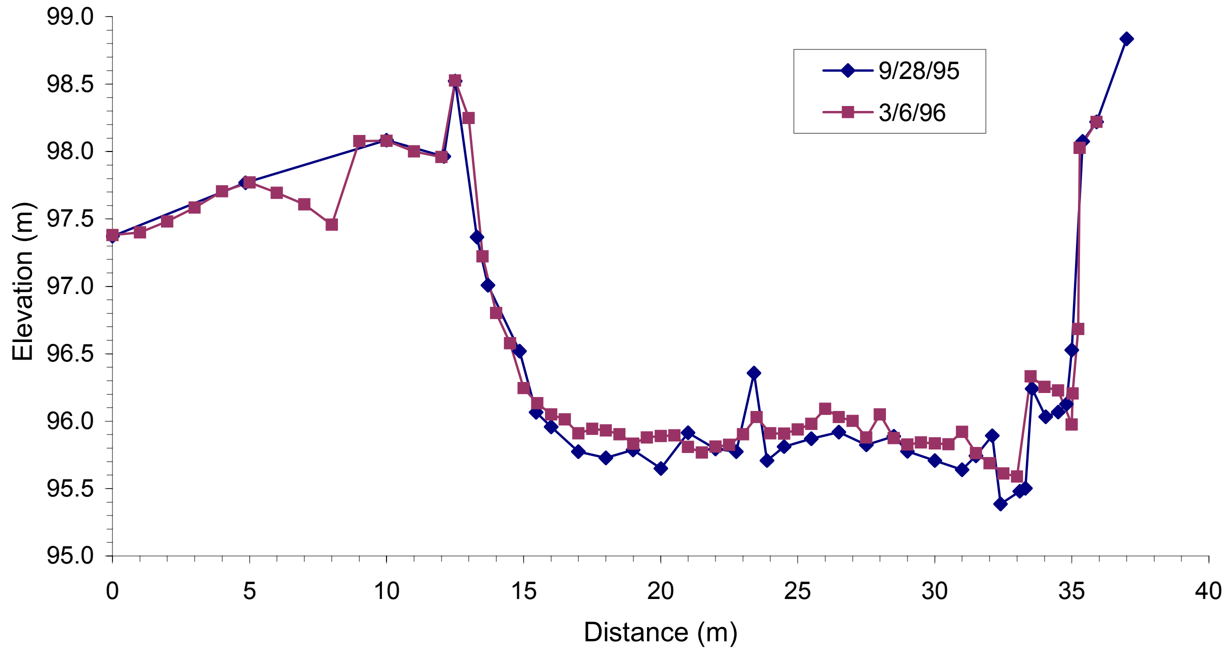


Figure 12. Clearwater cross-section #2. Location: Segment 1, reference point 5+52 m. Measurements taken fall of 1995 and late winter of 1996.

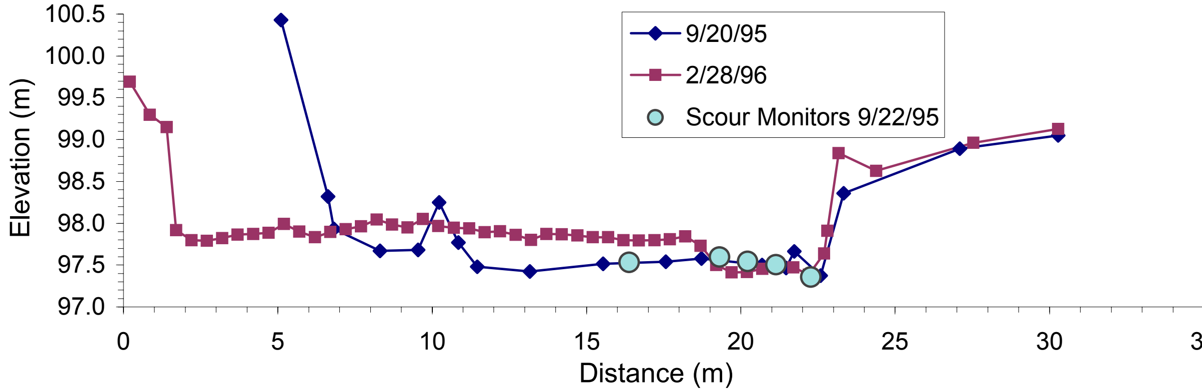


Figure 13. Clearwater cross-section #3. Location: Segment 3, reference point 0+14 m. Measurements taken fall of 1995 and late winter of 1996.

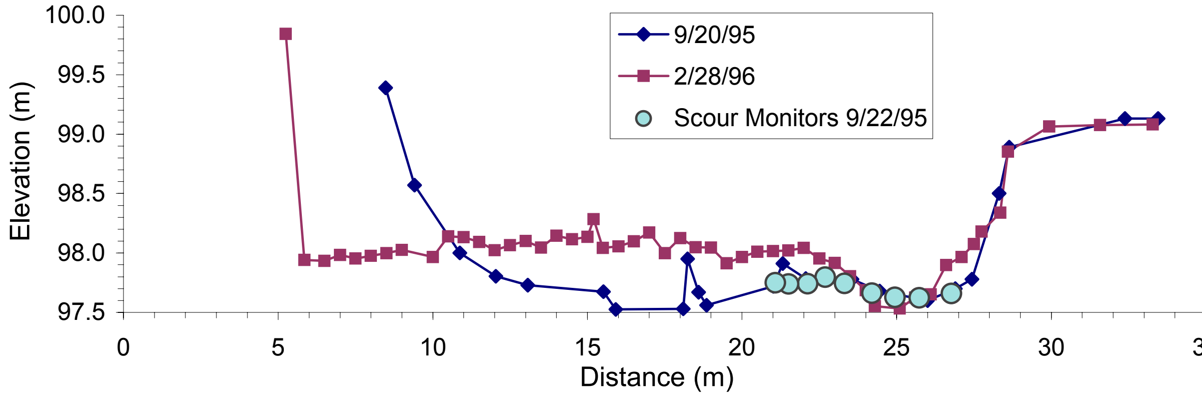


Figure 14. Clearwater cross-section #4. Location: Segment 3, reference point 0+22 m. Measurements taken fall of 1995 and late winter of 1996.

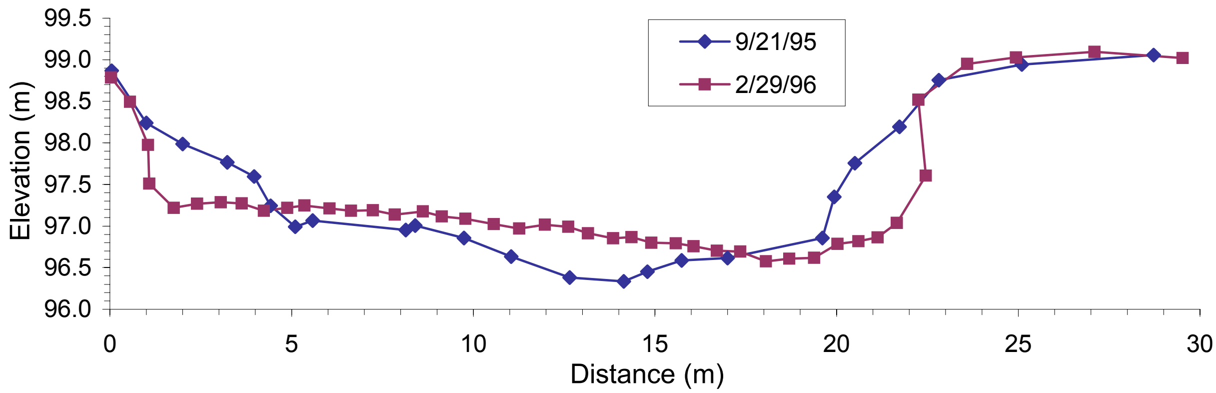


Figure 15. Clearwater cross-section #5. Location: Segment 3, reference point 0+22 m. Measurements taken fall of 1995 and late winter of 1996.

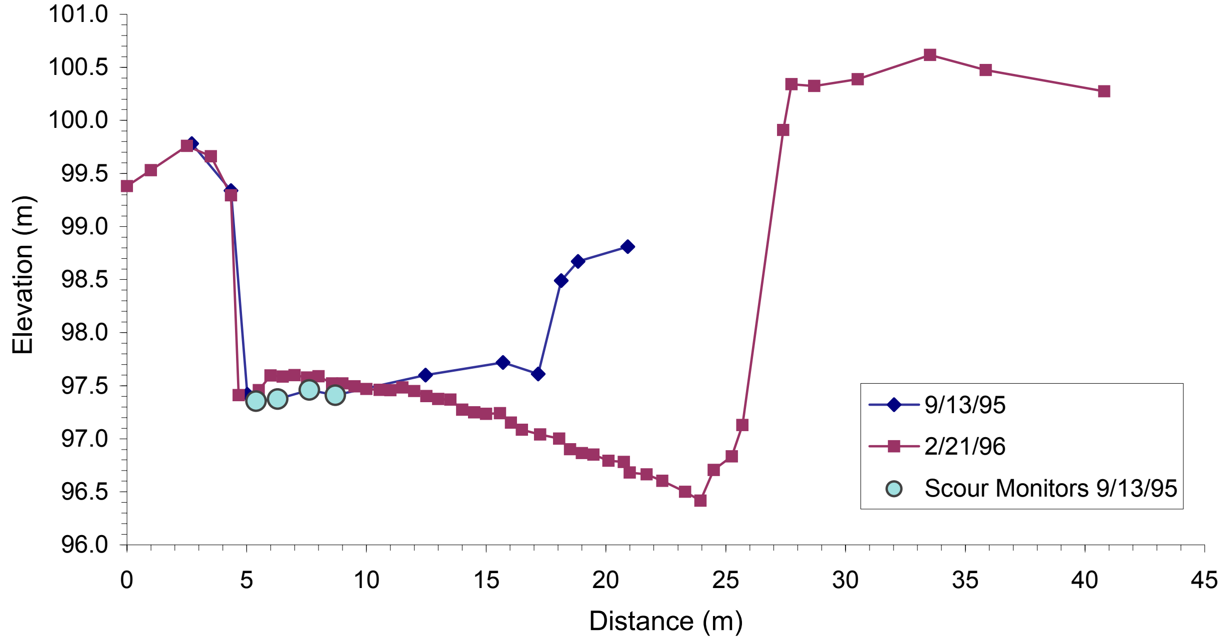


Figure 16. Clearwater cross-section #6. Location: Segment 3, reference point 6+50 m. Measurements taken fall of 1995 and late winter of 1996.

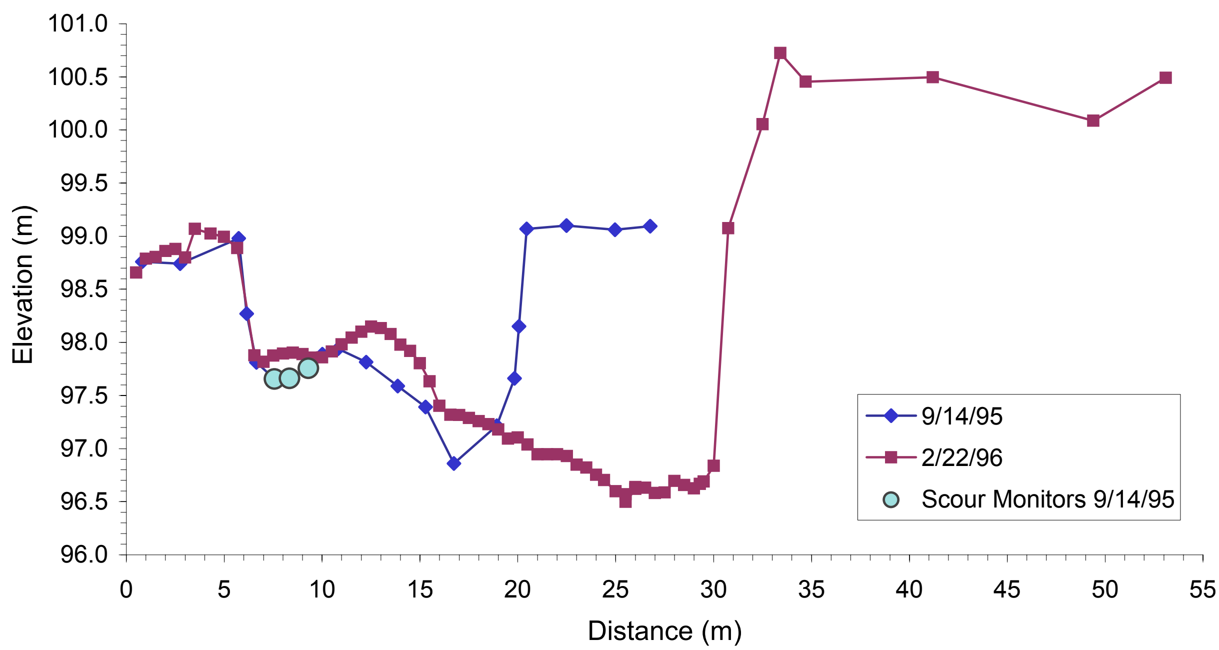


Figure 17. Clearwater cross-section #7. Location: Segment 3, reference point 6+62 m. Measurements taken fall of 1995 and late winter of 1996.

Table 18. Clearwater River cross-section changes fall of 1995 to late winter 1996.

Cross-section #	Bankfull Channel Width[1]				Elevation Change[2]	Habitat Type/Characteristics		Notes
	Fall 1995 (m)	Late Winter 1996 (m)	Change (m)	Change %	(m)	Fall 1995	Late Winter 1996	
CW#1	21.18	49.00	27.82	57	+0.63	pool tailout	braided channel	Four channels; primary is pool tailout
CW#2	20.15	20.15	0.00	0	+0.09	riffle	riffle	Channel similar
CW#3	16.71	21.47	4.76	22	+0.12	riffle	riffle	Thalweg shift
CW#4	18.90	22.50	3.60	16	+0.14	riffle	riffle	Thalweg shift
CW#5	15.51	20.58	5.07	25	+0.18	pool tailout	riffle	Pool gone
CW#6	14.62	44.51	29.89	67	Unavailable	riffle	gravel/silt bar	Primary channel in new location
CW#7	13.90	43.76	29.86	68	Unavailable	riffle	gravel/silt bar	Primary channel in new location
Mean:	17.28	31.71	14.43	36	+0.23			

[1] Due to extensive channel bank disturbance, late winter (2/28/96 - 3/6/96) bankfull widths are derived from field and cross-section data. At RP6+50 and 6+62 late winter bankfull widths are derived from summing the surveyed cross-section bankfull and the mean bankfull of the new primary channel.
[2]This is the average elevation change across the bankfull channel between the initial survey 9/13/95 - 10/6/96 and the resurvey 2/28/96 - 3/6/96.

Other than edge of channel wood and debris deposits, large wood was not present in the lower 600 m of the river.

CW#1

This cross-section was located across a pool tailout that spanned nearly the full channel width. A pink redd was built on the right side of the cross-section. The left bank floodplain above bankfull contained an old point bar vegetated with five-year-old alder trees and a filled in channel densely vegetated with two-year-old trees.

In March of 1996, the wetted channel location that existed in the fall of 1995 had become a gravel point bar and log jam. The active channel widened from 21.18 m to 49.00 m, (now including the older channel), taking on a braided channel form. The average bankfull channel elevation increased 63 cm; this was the largest change documented within the seven cross-sections. Note however, that close to 150 cm in depth of material was eroded where a new primary channel pool tailout habitat developed. Three side channels developed; one was a pool tailout and two were riffles. Figures 18A and 18C are photos of this site taken fall of 1995 and again in late winter 1996.

18A. View from left bank to right bank of CW#1 10-5-95.

18B. Viewing upstream from CW#1 10-5-95.

18C. Repeat view of area shown in 18A, after flood. Photo taken 3-6-96.

18D. Repeat view of area shown in 18B, after flood. This photo shows a channel change that occurred, leaving an important chinook and pink salmon spawning area without surface flow.

Figures 18A - D: Photos of the lower Clearwater River at and above cross-section #1. These photos show examples of the changes that occurred in the Clearwater River as a result of the February 1996 flood event.

CW#2

This site profile changed least of the seven cross-sections. Average elevation change was +9 cm and little to no bank erosion occurred leaving the bankfull width unchanged. Conversely, downstream of the cross-section, the landslides enlarged, and landslide related controls holding spawning gravel in place above the landslide changed. It appeared unlikely that the chinook redd or the pink redds would have survived this change. Figures 18, parts B and D, are photos of this location fall of 1995 and late winter 1996. The channel through the forested area where pinks and chinook spawned, filled with gravel and became dry. No survival of eggs or alevin would have been expected in this dry channel.

Segment 3 Cross-sections (CW#3 through CW#7)

Within Segment 3, five cross-sections (#3 - #7) were established. Cross-section locations #6 and #7 had been inventoried as the best spawning habitat in Segment 3 during 1995 fine sediment studies. This channel section does not show up on 1989 aerial photos but is visible on 1995 photos indicating that the channel had eroded through the floodplain forest during this time-frame. A lobe of gravel accumulations was within 100 m upstream of the cross-sections making the site potentially unstable. Cross-sections CW#3 and #4 represented a more stable reach within Segment 3. Spawning gravels were sparse however, and confined to a secondary riffle within the channel. The CW#5 pool tailout functioned with wood and rock controls and provided the best example of this type of habitat in the segment.

CW#3 and #4

This pair of cross-sections were located 8 m from each other within a straight, more stable stretch of the river. The left bank is at the base of a hillslope that provides confinement; the right bank is a low floodplain terrace. There was no large wood in the channel at these sites fall of 1995.

Gravel accumulations in the channel were primarily in association with large rocks or the lower energy secondary channel located near the right bank. The right bank vicinity was riffle habitat and had been spawned in spring of 1995 by steelhead.

During winter floods the right floodplain was inundated leaving the floodplain forest primarily intact but with sand deposits. The left bank incurred erosion of 3.60 m to 4.76 m. This erosion along the left bank could be seen both upstream and downstream from the cross-section locations. The trees that occupied this eroded strip were taken downstream; however, those large enough to span across the stream when they fell, had their tops sheared off and left remaining on the upper right banks.

Average elevation change at these sites was +12 cm at #3 and +14 cm at #4 although both sites additionally incurred scour within the spawning riffle habitat.

CW#5

Between fall 1995 and late winter 1996 this pool tailout cross-section aggraded an average of 18 cm. Concurrent with this the channel became 5.07 m wider. The site vicinity lost pool characteristics, and became a wide riffle. Other changes in the site vicinity included filling of a second upstream pool and downstream loss of an old growth conifer that had been recruited to the channel within the last year. This particular tree was the landmark piece of large woody debris within the lower 300 m of Segment 3. Following the winter floods, we did not see it within 500 m downstream.

CW#6 and #7

These upstream cross-sections were located 12 m from each other. As described earlier, they were within a potentially unstable new channel. Abundance of spawning gravels and newly recruited wood provided spawning habitat.

At the time of resurvey late winter 1996, most of the channel was dewatered and had a 10 cm thick layer of silt deposition on top of rocks. The right bank riparian zone had eroded: the loss of a large old growth stump that had been part of this riparian zone indicated a low past frequency of channel migration to the riparian area. The past location of the riparian zone became the channel thalweg. Additionally, adjacent to the thalweg was new riprap that provided stabilization for the Clearwater mainline road.

Upstream, a plug of gravels and logs apparently shifted the primary flow from this channel to an older channel. Fall of 1995 this older channel was full of gravel to approximately bankfull elevation and supported 5-year-old alders. Late winter 1996 the gravel was visibly eroded through and the location was a primary channel.

Scour Monitor Results

Scour monitor study results are provided in Table 19. A total of 24 monitors were installed at five cross-sections fall of 1995. Three were installed in Segment 1 at CW#1; fifteen additional attempts to install monitors in the cross-section were unsuccessful due to coarse subsurface substrate. Ten attempts at monitor insertion were made at CW#2, but due to coarse substrate none could be fully inserted. In the Segment 3 cross-sections (#3 and #4), installation was similarly difficult due to coarse substrate; a total of 14 monitors were installed. Two of these were installed with shortened anchor cables where substrate precluded full insertion. Note that had this approach been used elsewhere, more installations could have been successfully accomplished. Upriver at CW#6 and #7, a total of seven monitors were installed in spawning gravel within the cross-section transects.

Scour monitor locations were checked late winter coinciding with the cross-section resurveys. Timing was chosen to coincide with the expected emergence period for spring chinook fry and to document the level of scour that may have occurred during the incubation period.

No scour monitors could be relocated; analysis of the monitor locations therefore occurred through interpretation of the cross-section profiles, including wetted locations, and habitat types.

Table 19. Clearwater River scour monitor evaluation for likelihood of redd survival fall 1995 to late winter 1996.

Cross-section	Monitor #	Elevation Change [1] (cm)	Habitat Type		Likelihood of Redd Survival[2] (Using monitor sites as surrogate redds)	
			Fall 1995	Late Winter 1996	Category	Justification
Segment 1						
CW#1	**1**	100	pool tailout	dry, gravel bar, log jam	poor	dewatered
	2	78	pool tailout	dry, gravel bar, log jam	poor	dewatered
	3	67	pool tailout	dry, gravel bar	poor	dewatered
		mean=82				
Segment 3						
CW#3	**1**	3	riffle, secondary channel	riffle, primary channel	uncertain	change to primary channel
	2	-1	riffle, secondary channel	riffle, thalweg	uncertain	scour <15 cm; change to primary channel
	3	-13	riffle, secondary channel	riffle, thalweg	uncertain	scour <15 cm; change to primary channel
	4	-9	riffle, secondary channel	riffle, primary channel	uncertain	scour <15 cm; change to primary channel
	5	27	riffle, primary channel	riffle, primary channel	poor	aggradation >10 cm
		mean=-5				
CW#4	**1**	24	riffle, secondary channel	riffle, primary channel	poor	aggradation >10 cm; change to primary channel
	2	0	riffle, secondary channel	riffle/thalweg	uncertain	change to primary channel
	3	-9	riffle, secondary channel	riffle/thalweg	uncertain	scour <15 cm; change to primary channel
	4	-11	riffle, secondary channel	riffle/thalweg	uncertain	scour <15 cm; change to primary channel
	5	6	riffle, secondary channel	riffle, primary channel	uncertain	change to primary channel
	6	16	riffle, secondary channel	riffle, primary channel	poor	aggradation >10 cm; change to primary channel
	7	30	riffle, secondary channel	riffle, primary channel	poor	aggradation >10 cm; change to primary channel
	8	28	riffle, secondary channel	riffle, primary channel	poor	aggradation >10 cm; change to primary channel
	9	27	riffle, secondary channel	riffle, primary channel	poor	aggradation >10 cm; change to primary channel
		mean=12				
CW#6	**1**	10	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
	2	21	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
	3	12	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
	4	11	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
		mean=14				
CW#7	**1**	22	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
	2	24	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
	3	10	riffle, primary channel	dry, gravel/silt	poor	aggradation >10 cm; dewatered
		mean=**19**				

[1] This represents the change in elevation at scour monitor sites between fall 1995 and late winter 1996. During the resurvey no scour monitors were found. The late winter 1996 elevation data represents locations along the cross-section within 0.02 - 0.21 (mean 0.12) meters of original monitor locations.
[2] Data is from scour monitor locations in spawning habitat, but not in actual redds. No scour monitors were found late winter 1996; therefore, definitive scour information to relate to egg pocket depths was not available. Review of flow, habitat change and elevation data was used for likelihood of redd survival analysis.

Original monitor elevations were compared with the nearest cross-section elevations for the post-emergence periods. These locations were within 0.02 m - 0.21 m (mean of 0.12 m) of the original monitor distances.

Scour and Aggradation at Monitor Locations

Analysis of the end of embryo incubation period data showed that of the 24 monitor sites, five (21%) sustained scour. Levels of scour ranged from 1 cm to 13 cm with a mean scour level of 9 cm. Based on DeVries (1997), we use 15 cm as the top of the egg pocket depth for chinook salmon. No sites indicated scour to chinook egg pocket depth. Cross-section profile data is not able to show areas where channels scour and then refill with substrate; therefore these values are minimum scour values. Because no monitors could be found, ruling out scour to egg pocket depth is not possible.

One monitor site maintained the same elevation. Most sites (n = 18, 75%) incurred aggradation. The maximum aggradation recorded was 100 cm, the minimum for sites with aggradation was 3 cm, and the mean was 29 cm.

Habitat Changes at Monitor Locations

All but one of 24 monitor locations incurred a shift in habitat type between the time of monitor insertion, and the late winter 1996 check. Ten monitor sites (distributed over three cross-sections) were in locations where channel changes occurred that left monitor sites without surface flow. The remaining 13 sites all changed from riffles within secondary channels to swifter primary channels (including primary channel thalwegs).

Likelihood of Redd Survival

Based on bed surface scour, aggradation and habitat changes found, and by using each monitor site as a surrogate redd, the likelihood of survival to emergence was evaluated. The 10 locations (42%) that were dewatered were considered to have poor likelihood of survival. An additional six locations (25%) were evaluated as having poor likelihood of survival based on aggradation ≥10 cm, with five of these also incurring a habitat shift from a secondary channel to a primary channel. The remaining eight locations (33%) were rated uncertain. They all had a habitat shift from secondary channel to primary channel, and some incurred scour <15 cm or aggradation <10 cm, but did not trigger thresholds that would rate them as poor.

Discussion and Summary

The primary purpose of the Clearwater study was to gain reconnaissance level data on potential effects of gravel scour on spawning areas in the Clearwater River. High magnitude flood events winter of 1995 to 1996 shifted the study towards documentation of changes that occurred during a winter with major flood events and storm damage. Because no scour monitors could be found, cross-section profile results became important for the analysis. We suspect this year's data is representative of a high end scale of impact for channel and habitat impacts, including redd survival.

Scour monitor location results indicated a minimum of 67% of monitor sites representative of spawning areas, would have had poor survival. The remaining 33% of sites were of uncertain survival characteristics. Of the channel cross-sections, six of seven incurred habitat characteristic changes; four of the seven (57%) were substantial and are expected to represent loss of redds. Two others were thalweg shifts where possible loss was expected as described for the scour monitors within these cross-sections.

Neither the monitor, cross-section, or observational data and information represents a statistical sample of redd survival for the 1995 to 1996 incubation period in the Clearwater. However, where monitor and cross-section data is viewed in tandem with additional observations of changes to known spawning locations for pink and chinook salmon, especially in the lower 600 m of the Clearwater, all three elements collaboratively support that a finding of substantial habitat impact and redd loss.

At cross-sections #6 and #7 right bank riparian zone erosion included an area with an old growth stump indicating the river had not flowed in this location for at least several hundred years. This indicates the channel bank erosion magnitude and the shifting documented may have been an infrequent occurrence. However at cross-section areas #1 and #6 to #7, channels shifted to older existing locations with tree growth of 2 to 5 years old. Currently the frequency of major changes to stream habitat and resources such as described in this report appears to be occurring on a regular basis.

Watershed management that promotes stability of spawning gravels and lessens the rate of shifting of channel locations is important for White River spring chinook intergravel survival. We found little wood in the channel to allow holding and accumulation of spawing gravels. Extensive recruitment to the channel of large wood during winter floods from erosion such as at Segment 3 did not stay in the channel at the recruitment site. In Segment 3 and in Segment 1, we determined two large trees traveled 500 m or further downstream. For example, a riparian tree tagged 900 m upstream from the mouth was found, tag still on, 500 m downstream out of the channel on a lateral bar. Most wood recruited during the floods appeared to end up not in the channel, but on gravel bars. Landslide produced gravel and channel changes formed some of the best available spawning habitat in both stream segments studied. These areas were not, however, stable habitat features and mortality of redds in these areas was high.

Citations

DeVries, P. 1997. Riverine salmonid egg burial depths: Review of published data and implications for scour studies. Can. J. Fish. Aquat. Sci. 54:1685-1698.

Washington Department of Fish and Wildlife. 1995 - 1997. Unpublished spawning survey data. Wash. Dept. of Fish and Wildlife. Olympia, WA.

Washington Forest Practices Board. 1997. Board Manual: Standard methodology for conducting watershed analysis; under Chapter 222-22 WAC; Version 4.0. Wash. Dept. of Natural Resources. Olympia. 112 p. + app.

APPENDIX B: 1998-2001 Greenwater Cross-section Profiles and Analyses

This appendix contains graphs, photos, and interpretation for each of the Greenwater River cross-sections. The graphs are of two types: (1) the four fall surveys for cross-sections GW#1 and GW#2; and, (2) fall profiles at the beginning of chinook egg incubation, along with late winter, end of incubation profiles. Also plotted on fall and late winter graphs are bankfull locations, scour monitor derived data on depth of scour that occurred between the fall and late winter, and the chinook egg impact depth of 15 cm plotted below spawning gravel along the fall cross-section profile. Chinook and coho spawned on cross-sections GW#1 and GW#2. Redd locations are indicated in figures for these cross-sections.

Segment 3 Cross-section GW#1

Fall 1997 to Fall 2000

Figure 19 shows profiles from the four fall surveys. The most marked change in channel profile occurred winter of 1998 to 1999, concurrent with the largest flow during the study, a 10-year recurrence interval flow 15 December 1998. The bankfull channel widened 0.9 m and the cross-section retained this widening through the last survey of March 2001.

Fall 1997 to Late Winter 1998

Minor changes to the profile were recorded (Figure 20). The scour level remained above the chinook egg impact depth.

Fall 1998 to Late Winter 1999

Figure 21 depicts the channel widening described above. Note that the scour level as measured by monitors is ubiquitously below the 15 cm chinook egg impact depth, across the spawning habitat portion of the cross-section.

Fall 1999 to Late Winter 2000

Figure 22 depicts the profiles and Figures 23A-B provide fall and late winter photos of the cross-section. Fall 1999 to late winter 2000, the channel shape shifted with deepening of up to 20 cm occurring along one side, and aggradation of 10 cm occurring on the other side. This time-frame had three discharges with a >2-year recurrence interval. The first of these peaks (1568 cfs on 11/26/99) released the majority of scour balls for the year although the third peak of 1587 on 12/15/99 was the largest. The scour level documented by monitors was at the 15 cm chinook egg impact depth across much of the profile.

A chinook redd was built across two scour monitors that were 1 m apart. During construction, 2 balls at each of the monitors were released indicating the fish excavated 8 cm at the monitor locations. One monitor registered an additional 4 cm of scour due to December 1999 peak flows indicating scour occurred 4 cm deeper than the fish excavated. In addition, aggradation of 10 to 11 cm was measured along the cross-section at the redd March 2000.

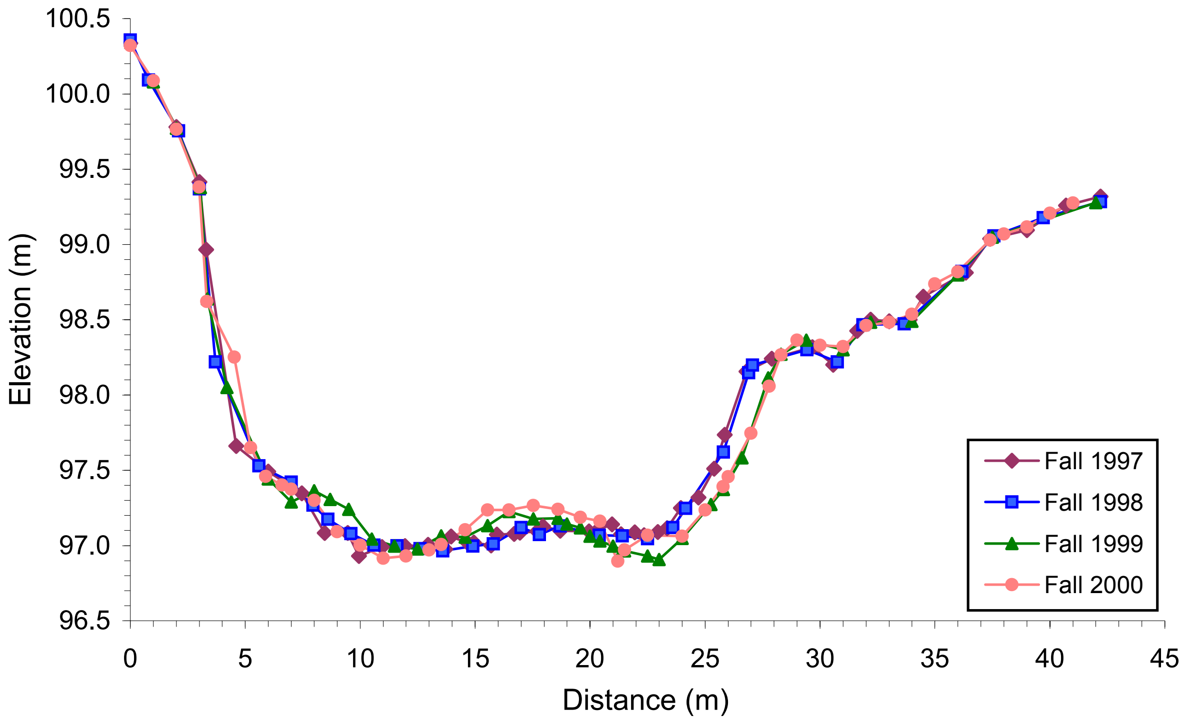


Figure 19. Greenwater cross-section 1 profiles for the falls of 1997 through 2000. Note the channel widening that occurred winter 1998 to 1999. (Seg. 3, R.P.0+00 m)

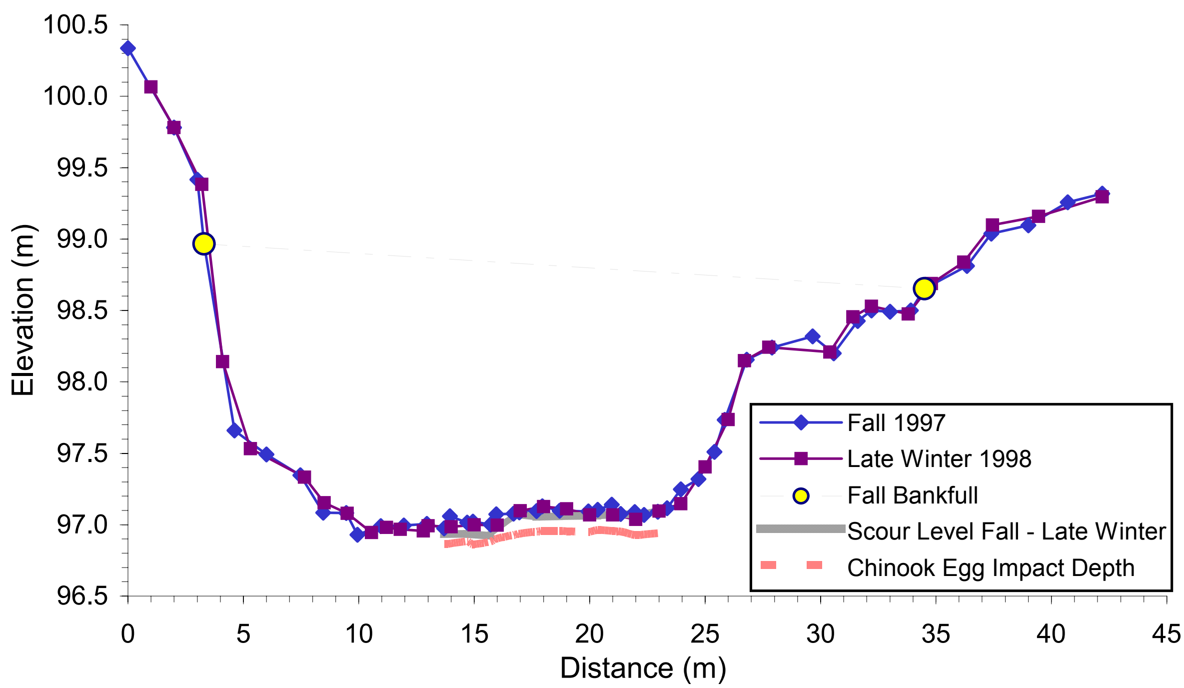


Figure 20. Greenwater cross-section #1 profiles for the 1997 chinook incubation period showing the intact chinook egg impact depth. (Seg. 3, R.P.0+00 m)

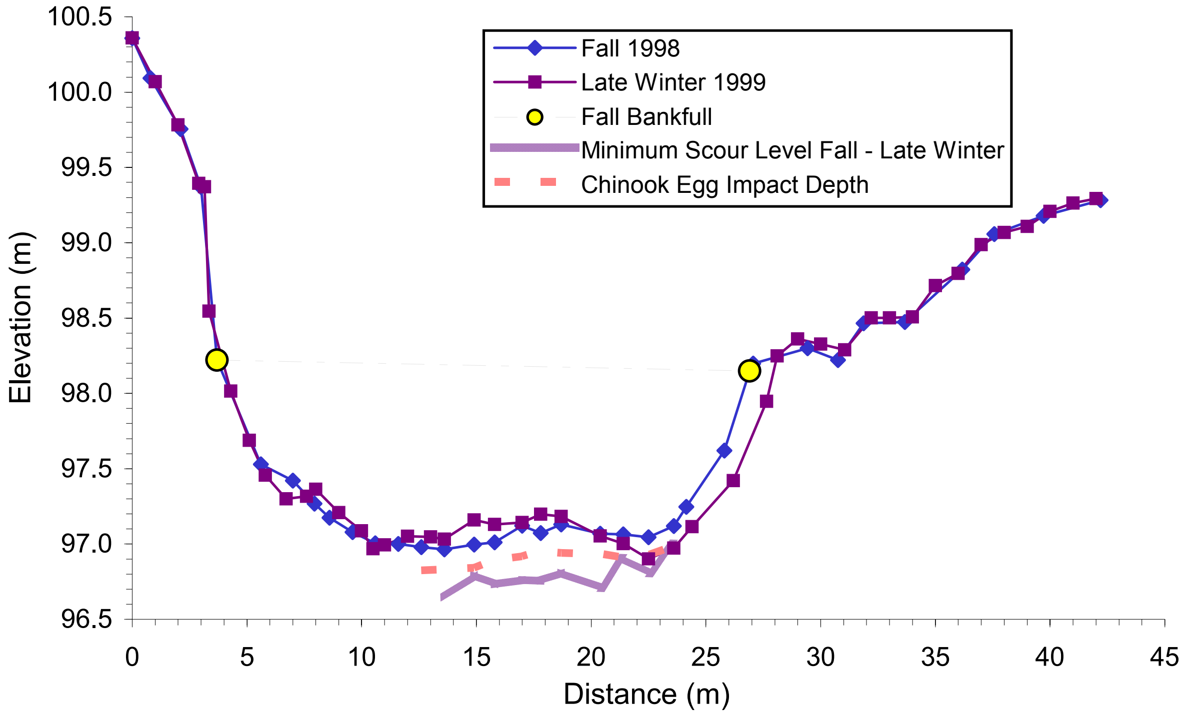


Figure 21. Greenwater cross-section #1 profiles for the 1998 chinook incubation period. Scour was deeper than the egg impact depth. (Seg. 3, R.P.0+00 m)

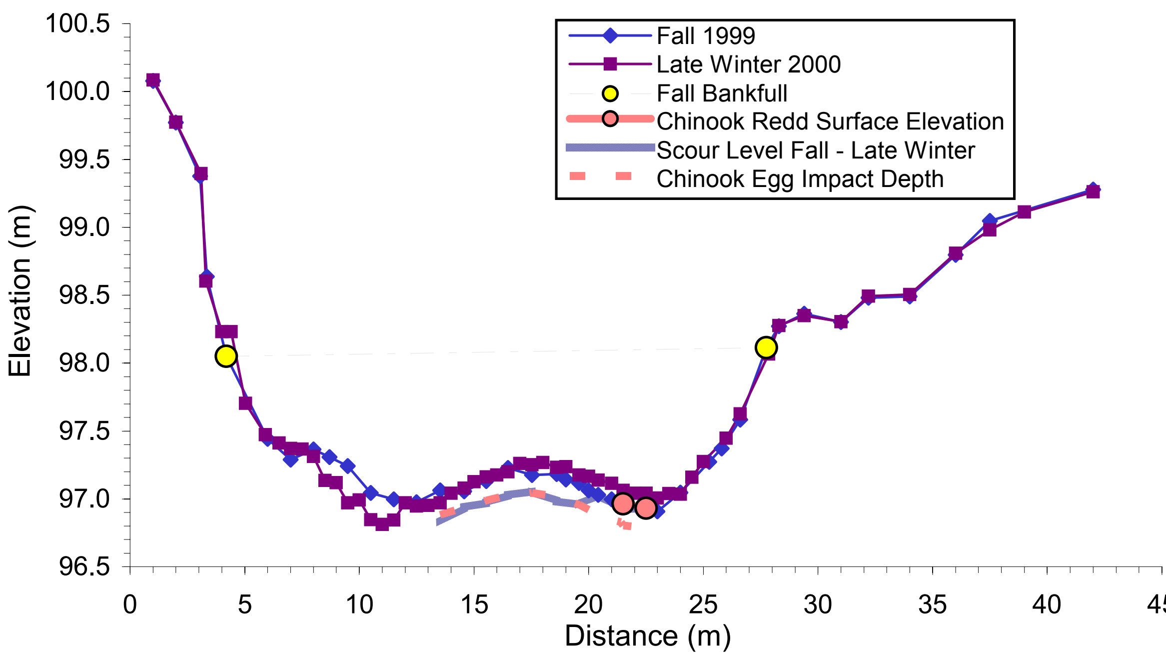


Figure 22. Greenwater cross-section #1 profiles for the 1999 chinook incubation period. Spawning released two balls at the redd. Because these were not available to be re-released during peak discharges scour at the redd is a minimum depiction. (Seg. 3, R.P. 0+00 m)

Fall 2000 to Late Winter 2001

Chinook redd digging released 3 balls (12 cm scour) from one monitor and 1 ball (4 cm scour) from a monitor 1 m away. The redd incurred no peak discharge scour. Aggradation (7 cm) visible at the redd site in Figure 22 may have been due to extensive coho spawning throughout the fall to early winter at, and immediately upstream of this location. Scour from flow events did not occur this year, and the egg impact depth remained undisturbed. See Figure 24.

Segment 3 Cross-section GW#2

Fall 1997 to Fall 2000

Figure 25 shows the profiles from the four fall surveys. As with GW#1, the major profile change documented occurred fall to late winter 1998 to 1999 along with the largest flow event of the study. The center of the channel aggraded as much as 22 cm and lateral pools / pool tailouts present on both sides of the channel widened and deepened.

Fall 1997 to Late Winter 1998

Two adjoining chinook redds were built on the cross-section. These redds cumulatively spread across 5 scour monitors. One monitor had 0 balls released, 1 had 1 ball released (4 cm of digging depth), 1 had 2 balls (8 cm of digging depth), and 2 had 4 balls (16 cm of digging depth). Because the areas dug during spawning are also refilled during spawning, any further balls released during a peak flow must have the refilled depth additionally scoured before they can be reached. Only one other ball was released by flow related scour at the redd locations.

However, 3 of 5 monitors not at redds had scour of 8 cm from a peak flow event making it likely that the redd sites also incurred undocumented scour. During this incubation period, the scour level remained above the chinook egg impact depth. A portion of the cross-section on one side of the channel increased in elevation, while an area located on the opposite side of the channel degraded. This information is shown in Figure 26.

Fall 1998 to Late Winter 1999

Major profile changes occurred during this time-frame. In addition, scour monitor data indicated the minimum scour depth was deeper than the 15 cm chinook egg impact depth across the spawning habitat at the cross-section. These data are shown in Figure 27.

Fall 1999 to Late Winter 2000

Figures 28A-B and 29 are photos of this location. Figure 30 is the graphed profile. The average elevation for the cross-section showed an increase of 3 cm between fall and late winter measurements. The profile shows this aggradation in the pool and pool tail-out zones on both sides of the channel. In the channel center, scour reached the chinook egg impact depth.

Fall 2000 to Late Winter 2001

During this low flow year, we found no scour from flow. The chinook egg impact depth remained intact. Coho spawned at 4 of 9 monitor locations along the cross-section. This spawning only triggered the release of one ball (4 cm depth). Figure 31 shows this cross-section.

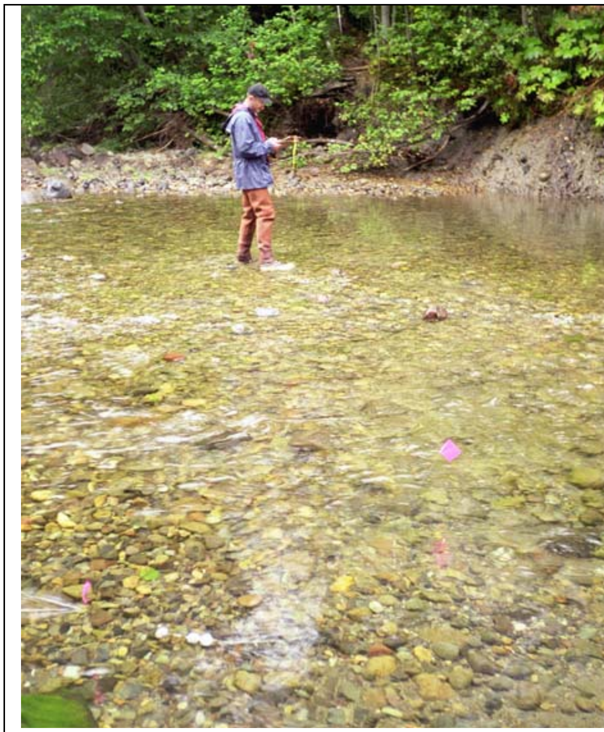


Figure 23A. Greenwater cross-section #1. Taken 10/7/99. View of scour monitors. Pink flags surround a chinook redd providing protection during data collection. Two scour balls were released during redd construction.

Figure 23B. Greenwater cross-section #1. Taken 3/3/2000. View of exposed scour monitors along the cross-section. The orange disk is located on a chinook redd mound.

Figures 23A-B Greenwater River cross-section #1.

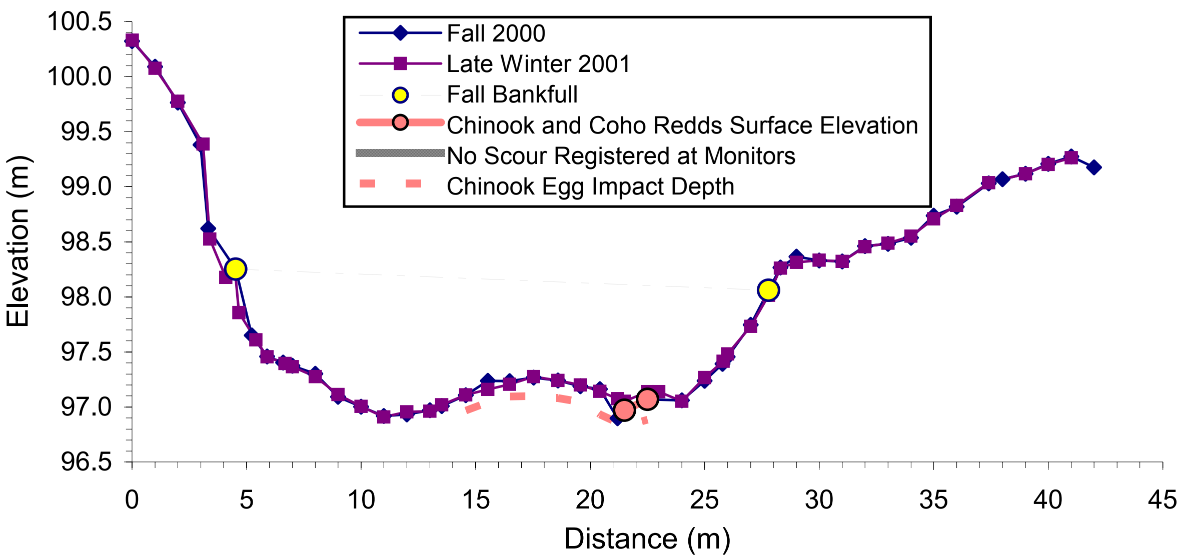


Figure 24. Greenwater cross-section #1 profiles for the 2000 chinook incubation period. (Seg. 3, R.P.0+00 m)

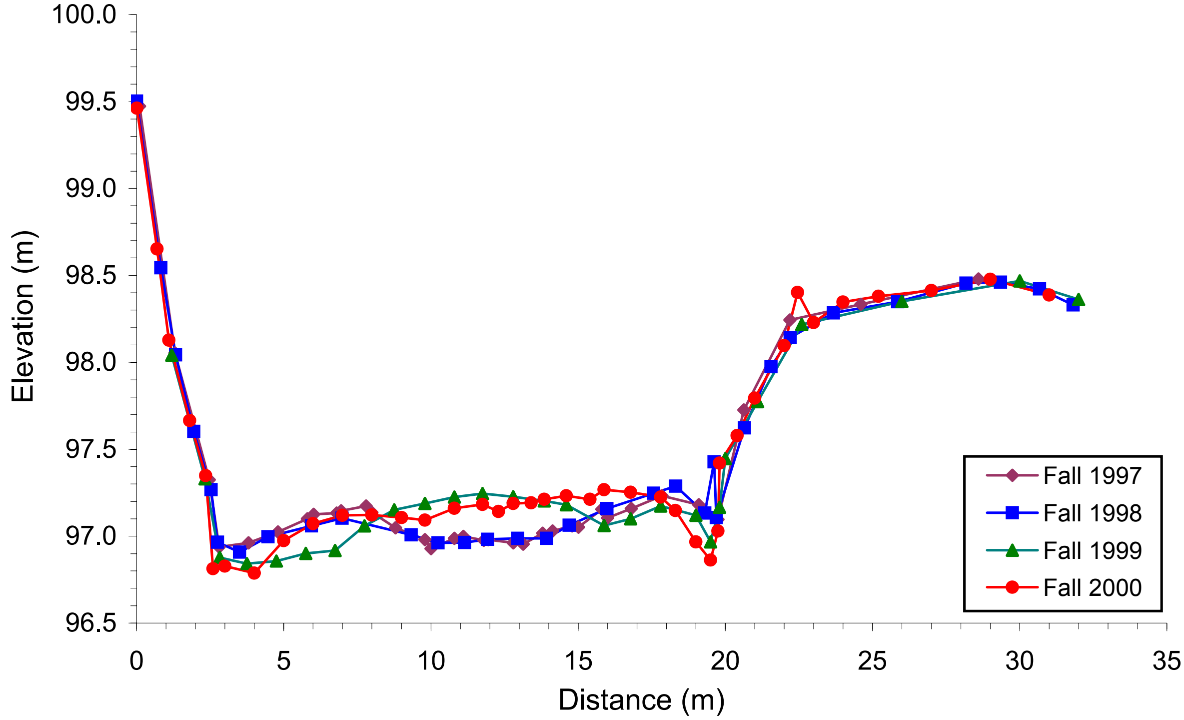


Figure 25. Greenwater cross-section #2 profiles for the falls of 1997 through 2000. (Seg. 3, R.P. 14+41 m)

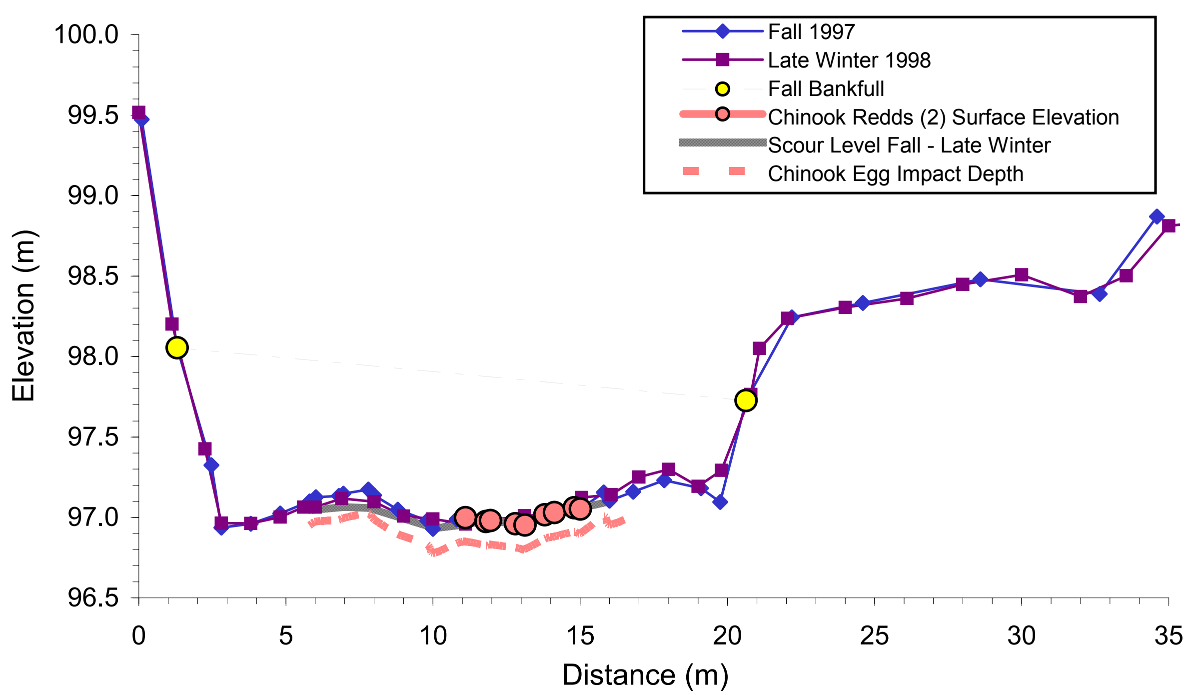


Figure 26. Greenwater cross-section #2 profiles for the 1997 chinook incubation period. Note the intact chinook egg impact depth and the location of chinook redds along the cross-section. (Seg. 3, R.P. 14+41 m)

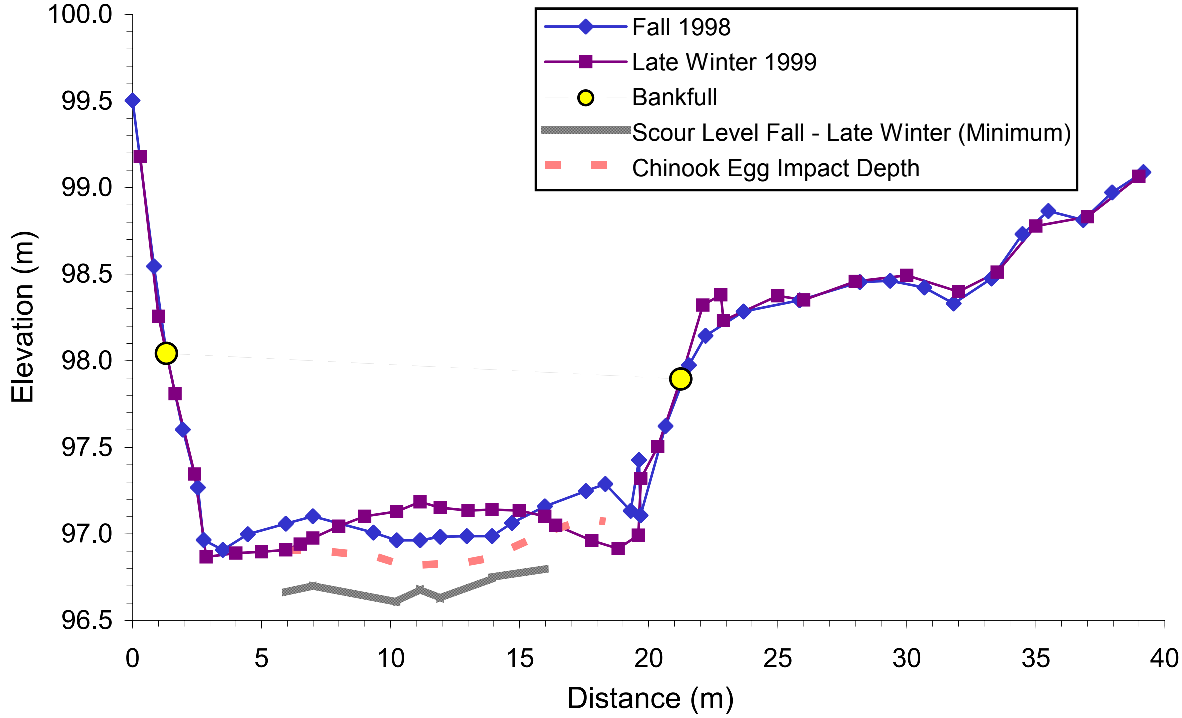


Figure 27. Greenwater cross-section #2 profiles for the 1998 chinook incubation period. Scour for the profile was deeper than the egg impact depth this year. (Seg. 3, R.P. 14+41 m)

Figure 28A. View of Greenwater cross-section #2, viewing towards the right bank. Taken: 10/1/98.

Figure 28B. View looking upstream from Greenwater cross-section #2. Taken 10/1/98.

Figure 28A-B. Photos of Greenwater cross-section #2.

Figure 29. Panorama viewing downstream to Greenwater cross-section #2. Taken 3/2/00. The left side of this photo is the right side of the profile in Figures 25, 26, 27, 30 and 31.

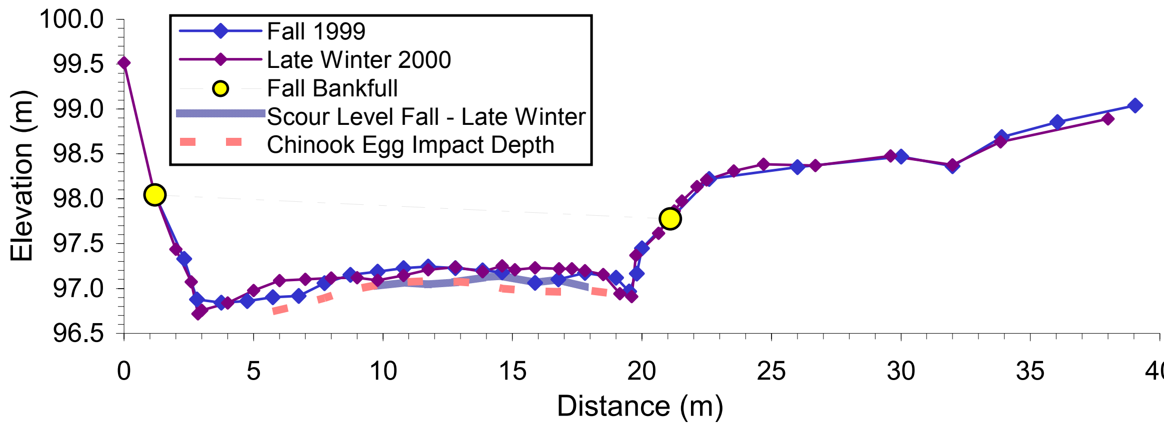


Figure 30. Greenwater #2 profiles for the 1999 chinook incubation period. (Seg. 3, R.P. 14+41 m)

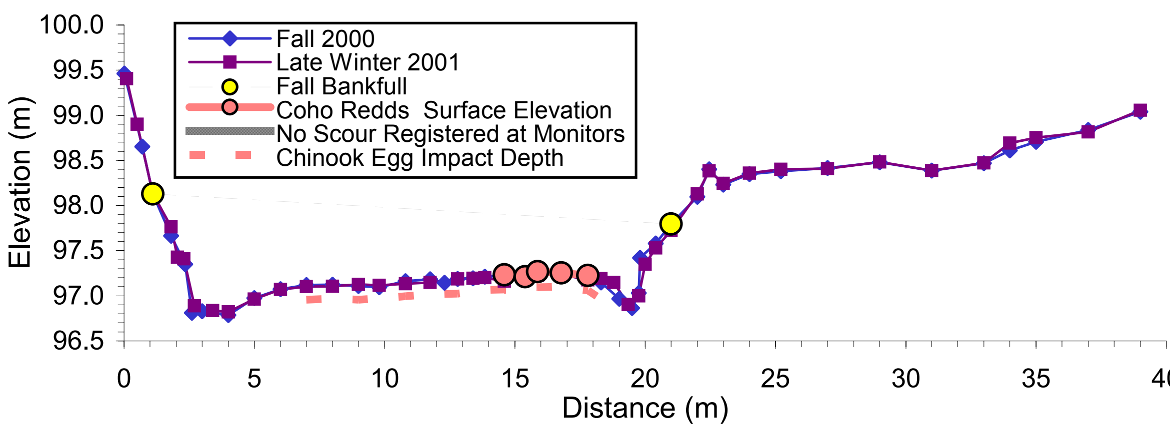


Figure 31. Greenwater #2 profiles for the 2000 chinook incubation period. (Seg. 3, R.P. 14+41 m)

Segment 8 Cross-section GW#3

Fall 1997 to Late Winter 1998

One side of the channel aggraded 30 cm, while the other side deepened 23 cm. Scour monitor data indicates that scour as deep as 36 cm occurred in this location, going well below the 15 cm chinook egg impact depth. Figure 32 shows this cross-section profile, and Figure 33A is a photo showing the scour monitors along the cross-section at the time of installation.

Fall 1998 to Late Winter 1999

The pool formed the previous year deepened 69 cm between fall and late winter. Figure 34 shows this profile change. Between fall 1997 and late winter 1999 a total deepening of 89 cm was measured. This cross-section was not measured during the rest of the study.

Segment 8 Cross-section GW#4

Fall 1999 to Late Winter 2000

Figures 33B and 35 show this cross-section, which was measured for one incubation period. Minor changes in elevation occurred across the profile, but measured scour did not go below the chinook egg impact depth.

Segment 8 Cross-section GW#5

Fall 1999 to Late Winter 2000

Also measured for one incubation period, this cross-section profile deepened below the 15 cm chinook egg impact depth across most of its width. Figures 36 and 37A depict this cross-section.

Segment 8 Cross-section GW#6

Fall 1997 to Late Winter 1998

Only minor elevation changes occurred and no scour was registered at the monitors. Figure 38 shows this cross-section.

Fall 1998 to Late Winter 1999

Concurrent with the December 1998, 10-year-plus peak flow event, the cross-section incurred deep scour and formation of a scour pool. At it’s deepest point the profile deepened 78 cm. Whereas roughly one-half of the primary wetted channel area sustained scour, the other one-half had aggradation of up to 55 cm. Within the aggraded area, all but one scour monitored had also scoured; two of the monitors scoured to a level below the 15 cm top of egg pocket depth. This cross-section was not measured during the rest of the study. Figures 37B and 39 are of this cross-section.

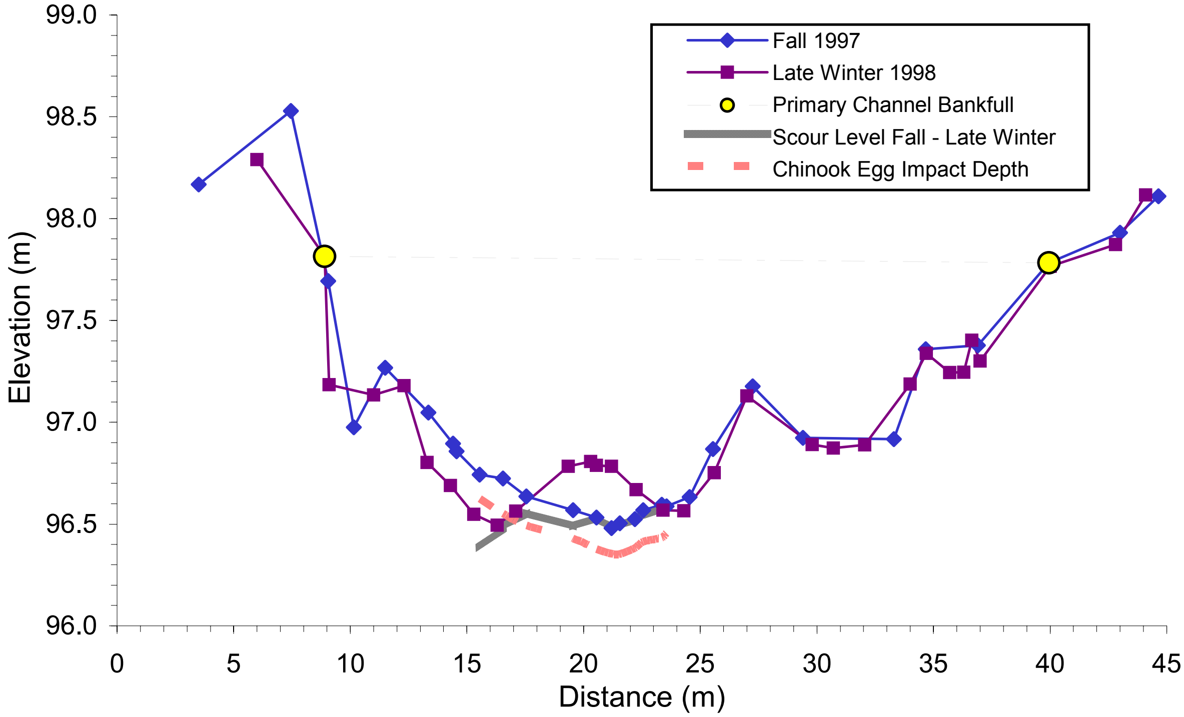


Figure 32. Greenwater #3 profiles for the 1997 chinook incubation period. The left side channel is not shown. (Seg. 8, R.P. 1+24 m)

Figure 33A. View of Greenwater cross-section #3 and scour monitors. Taken 9/3/97.

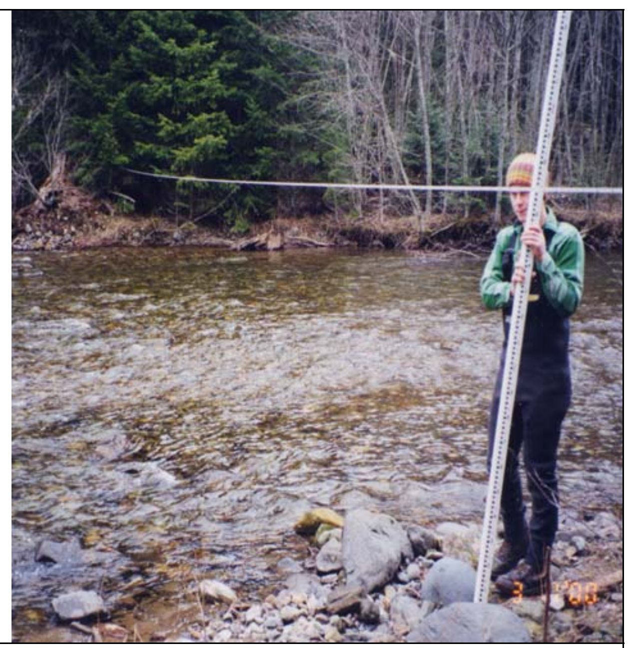


Figure 33B. View of Greenwater cross-section #4. Taken 3/1/2000.

Figures 33A-B. Views of Greenwater River cross-sections #3 and #4.

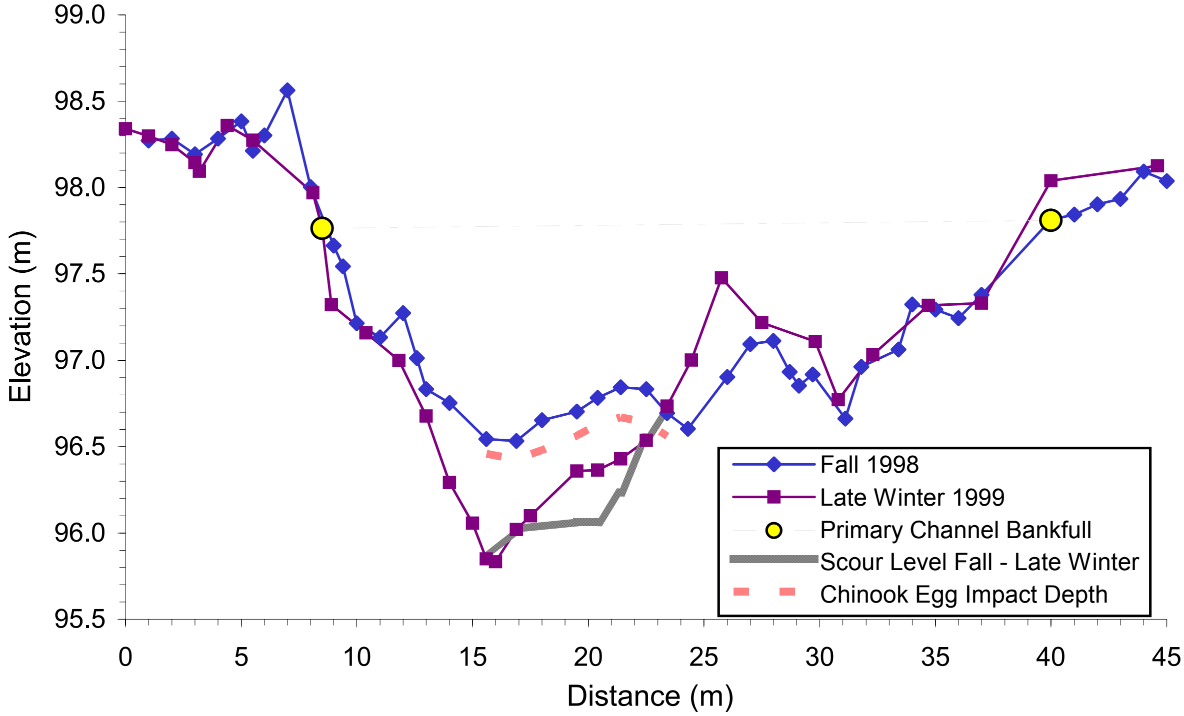


Figure 34. Greenwater #3 profiles for the 1998 chinook incubation period. The left side-channel is not shown. (Seg. 8, R.P. 1+24 m)

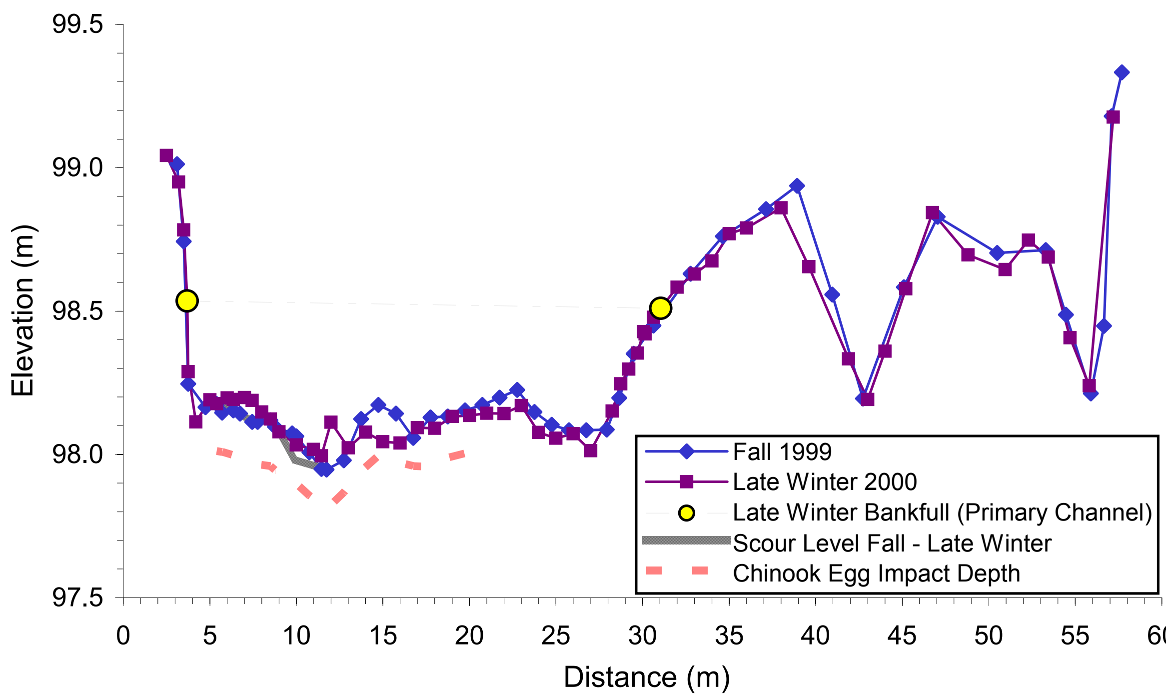


Figure 35. Greenwater #4 profiles for the 1999 chinook incubation period. (Seg. 8, R.P. 6+70 m)

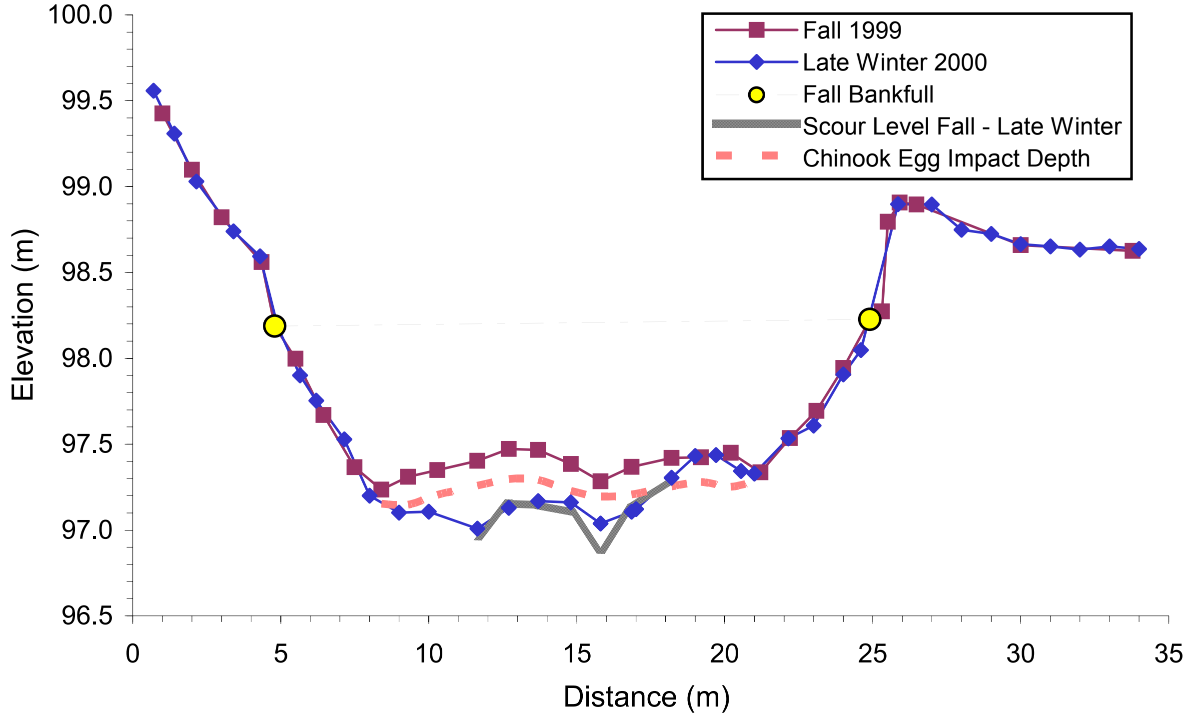


Figure 36. Greenwater #5 profiles for the 1999 chinook incubation period**.** This cross-section incurred the most extensive overall channel degradation. (Seg. 8, R.P. 15+29 m)

Figure 37A. Photo view of Greenwater cross-section #5, taken 3/1/00.

Figure 37B. Greenwater cross-section #6, taken 3/5/99. View of aggraded gravel bar (covered by snow) and pool.

Figures 37A-B. Greenwater River cross-sections #5 and #6.

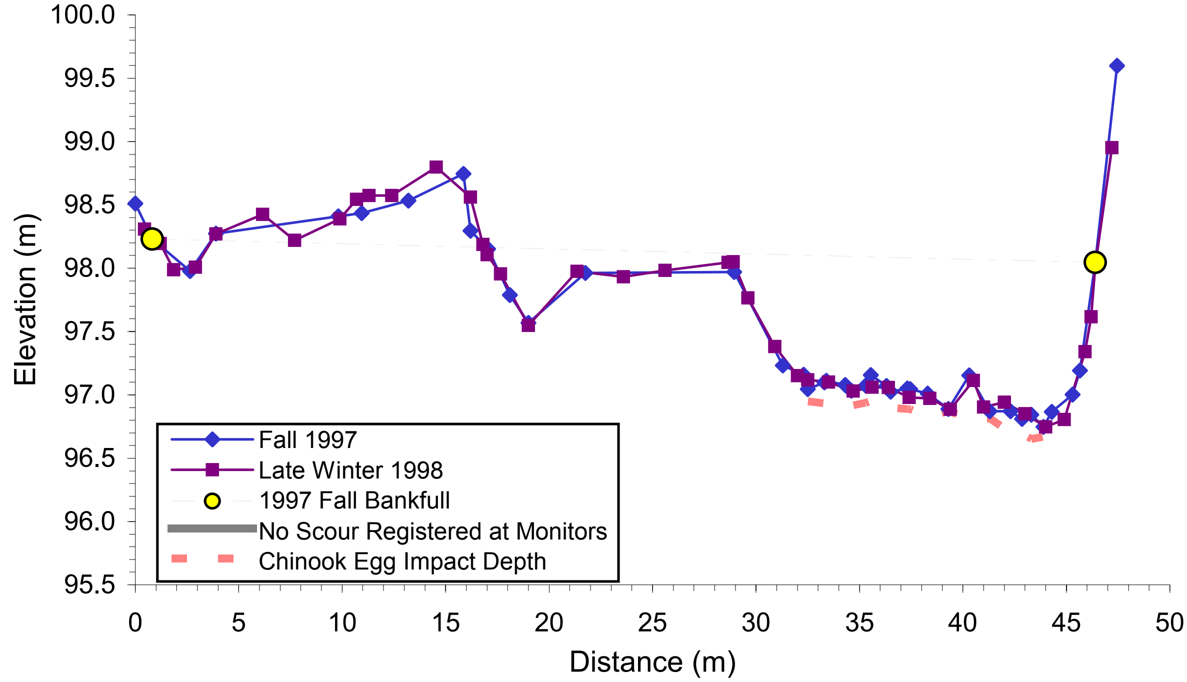


Figure 38. Greenwater #6 profiles for the 1997 chinook incubation period. (Seg. 8, R.P. 18+40 m)

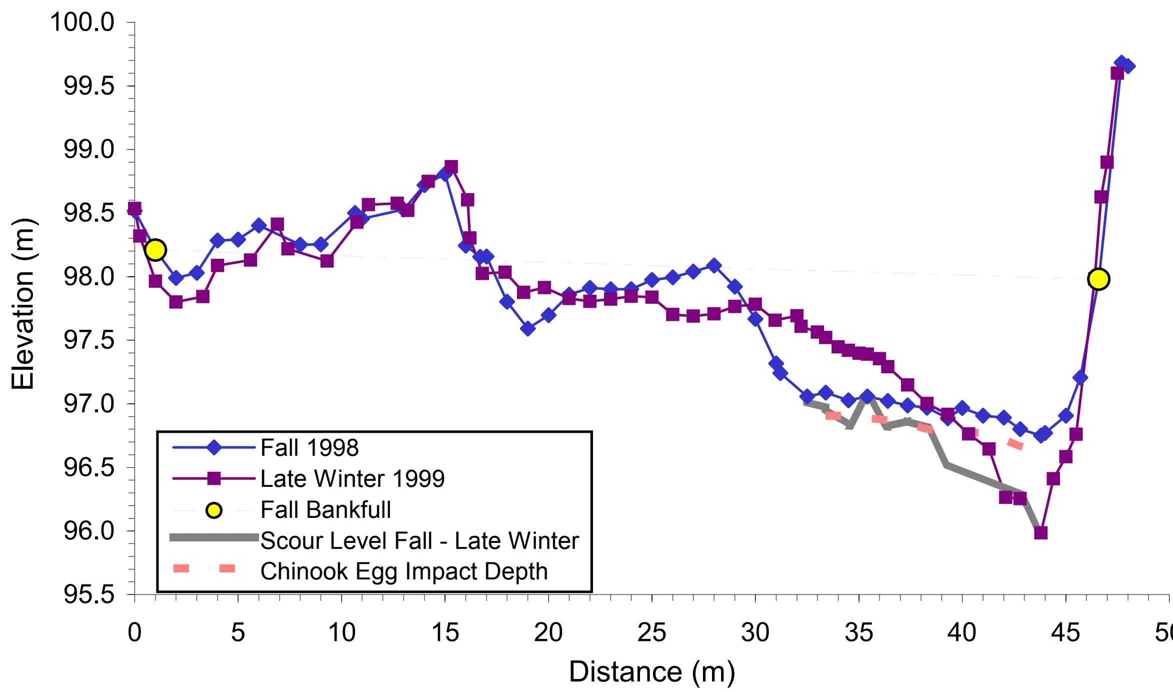


Figure 39. Greenwater #6 profiles for the 1998 chinook incubation period. (Seg. 8, R.P. 19+40 m)

APPENDIX C: Upper White Watershed Redd Photos and Data

This appendix contains photos (Figures 40 to 42), that illustrate chinook redds monitored in the Clearwater, White and Greenwater rivers. It also includes the chinook survival to emergence analysis table for individual redds (Table 20).

40A. Fall view of Clearwater River chinook redd 1996 #5. Redd pit is in front of Dave Adams, the mound is in the photo's bottom left quarter. Late winter results indicated good likelihood of embryo survival. Photo taken 10/10/96.

40C. Fall view of Greenwater River chinook redd 1996 #9, shown in the photo's center. Aggradation of 9 cm occurred fall to late winter; likelihood of embryo survival and emergence was good. Photo taken 10/3/96.

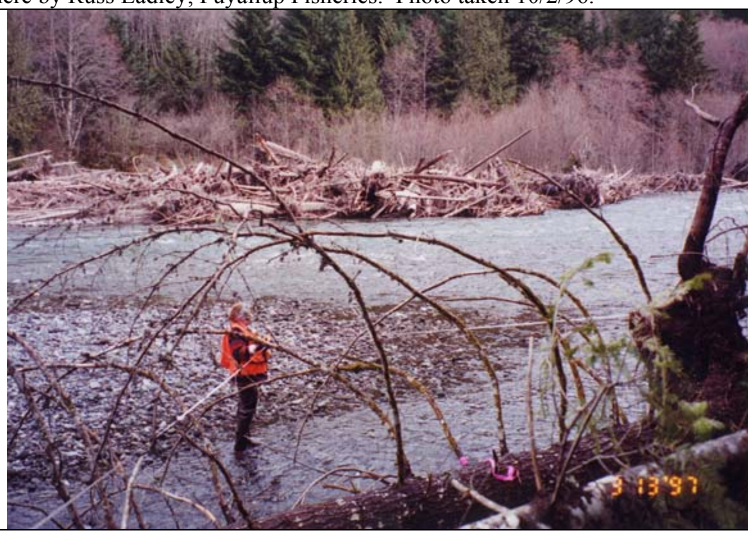
40C. Fall view of Clearwater chinook redd 1996 #3, (center of photo). Late winter results found 60 cm of aggradation on the mound, a channel shift from single strand to braided, and a new thalweg. Survey results indicated poor likelihood of embryo survival. Photo taken 10/10/96.

40D. Winter view of Greenwater River chinook redd 1996 #3. Redd is under the survey rod. The late winter survey measured 12 cm of surface scour at the redd site. Photo taken 3/5/97.

Figures 40A-D. Clearwater and Greenwater 1996 chinook redds.

41A. Fall view of White River chinook redd(s) 1996 #1. Redd is at the location where the two tapes cross each other. Two radio-tagged females were found here by Russ Ladley, Puyallup Fisheries. Photo taken 10/2/96.

41B. Fall view of the location of White River chinook redd #3. Redd mound is under the rod. This site was too deep to be resurveyed late winter. Photo taken 10/2/96.



41C. Repeat view of 41A for White River chinook redd 1996 #1. Late winter results found 88 cm of agradation over the redd mound. Photo taken 3/13/1997.

41D. Late winter view off White River chinook redd 1996 #2. The rod is located on the redd site. This redd incurred 115 cm of aggradation on top of the mound.

Figures 41A-D. White River 1996 chinook redds.

42A. Greenwater redd 1999 #17. Photo taken 10/6/99.

42B. Greenwater redd 2000 #4. This redd spanned a pool tailout, riffle-crest feature in side-channel. Photo taken 10/5/2000.

42C. Repeat view of photo 42A for Greenwater redd 1999 #17. Surface scour of 19 cm occurred between the October and March surveys. Photo taken 3/2/00.

42D. Repeat view of photo 42B at end of incubation for Greenwater redd 2000 #4. Pool tailout has been filled, and habitat is now riffle. Photo taken 3/7/2001.

Figures 42A-D. Greenwater River 1999 and 2000 redds.

Table 20. Survival to fry emergence for individual chinook redds in the Upper White watershed. Analysis is based on surface elevation changes, surface flow characteristics, and habitat changes during incubation years 1996 to 2000.

River, Segment and River Miles	**Year and Redd #**	**Surface Elevation Change at Redd**				**Surface Flow at End of Incubation**		**Habitat Type Beginning and End of Incubation**			**Likelihood of Survival to Fry Emergence**			**Foot Notes**
		Scour		Aggradation										
		<15 cm	≥15 cm	0 to <10 cm	≥10 cm	Present	Absent	Same	Changed	Major Change	Good	Uncertain	Poor	[2]
Clearwater Segment 1 (part), River Miles 0.7 – 0.9														
	1996 #1				–	+				–			X	[3]
	1996 #2				–	+				–			X	[2]
	1996 #3				–	+				–			X	[2]
	1996 #4	+				+		+			X			
	1996 #5	+				+		+			X			
	1996 #6	+				+		+			X			
	1996 #7		–			+		+					X	
	1996 #8		–			+		+					X	
	1996 #9		–			+		+					X	
	1996 #10	+				+			+/–			X		[4]
White River, River Miles 41.9 – 42.2														
	1996 #1				–	+				–			X	[5]
	1996 #2				–		–			–			X	[6]
	1996 #3	?	?	?	?	+				–			X	[7]

[2] Scour data in this table is from the assumed natural bed surface; this is the height of the mound minus 7 cm. Redds registering measurements of between 1 and 7 cm scour are included in the less than 15 cm category.

[3] Habitat changes included a change from single strand stream to braided, a thalweg location change, and in addition for redd #3, aggradation of 60 cm measured in late winter..

[4] This redd sustained scour of 12 cm and habitat change was a shift to the channel thalweg.

[5] Redd site sustained 88 cm aggradation, habitat shifted from primary to secondary channel.

[6] Redd site aggraded 115 cm, habitat shifted from a riffle in a secondary channel, to an exposed bar, dewatered to 15 cm.

[7] Redds White 1996 #3 and #4 were in water too deep to resurvey at the end of incubation. These locations had been in a secondary channel riffle at the start of incubation, but the mainstem thalweg had shifted to this side of the river by the end of incubation.

River, Segment and River Miles	Year and Redd #	Surface Elevation Change at Redd				Surface Flow at End of Incubation		Habitat Type Beginning and End of Incubation			Likelihood of Survival to Fry Emergence			Foot Notes
		Scour		Aggradation										
		<15 cm	≥15 cm	0 to <10 cm	≥10 cm	Present	Absent	Same	Changed	Major Change	Good	Uncertain	Poor	2
	1996 #4	?	?	?	?	+				–			X	6
Greenwater River, Segment 2 (part), River Miles 1.3 – 1.5														
	1996 #1	?	?	?	?	+				–			X	8
	1996 #2	+				+		+			X			
	1996 #3	+				+		+			X			
Greenwater River, Segment 3, River Miles 1.5 – 2.4														
	1996 #1	+				+		+			X			
	1996 #2	+				+		+			X			
	1996 #3	+				+		+			X			
	1996 #4	+				+		+			X			
	1996 #5			+		+		+			X			
	1996 #6			+		+		+			X			
	1996 #7	+				+		+			X			
	1996 #8	+				+		+			X			
	1996 #9			+		+		+			X			
	1996 #10			+		+		+			X			
	1996 #11				–	+		+					X	
	1996 #12	+				+		+			X			
	1996 #13		–			+			+/–				X	9
	1996 #14		–			+		+					X	

[8] The habitat at this redd changed from a riffle in a side-channel, to a mainstem thalweg which was too deep to resurvey.
[9] Habitat of riffle/shallow pool tail-out changed to a thalweg riffle.

River, Segment and River Miles	Year and Redd #	Surface Elevation Change at Redd				Surface Flow at End of Incubation		Habitat Type Beginning and End of Incubation			Likelihood of Survival to Fry Emergence			Foot Notes
		Scour		Aggradation										[2]
		<15 cm	≥15 cm	0 to <10 cm	≥10 cm	Present	Absent	Same	Changed	Major Change	Good	Uncertain	Poor	
Greenwater River, Segment 3, River Miles 1.5 – 2.4														
	1997 #1	+				+		+			X			
	1997 #2			+		+		+			X			
	1997 #3			+		+		+			X			
	1997 #4	+				+		+			X			
	1997 #5	+				+		+			X			
	1997 #6	+				+		+			X			
	1997 #7	+				+		+			X			
	1997 #8	+				+		+			X			
	1997 #9	+				+		+			X			
	1997 #10	+				+		+			X			
	1997 #11				–	+		+					X	[10]
	1997 #12	+				+		+			X			
Greenwater River, Segment 3, River Miles 1.5 – 2.4														
	1998 #1	?	?	?	?	+		+				X		[11]
	1998 #2		–			+		+					X	[12]
Greenwater River, Segment 8, River Miles 5.5 – 6.8 Coho Redds														
	1998 #1				–	+				–			X	[13]
	1998 #2		–			+				–			X	[14]

[10] Aggradation of 56 cm; redd habitat is a riffle near thalweg and large rootwads.

[11] 300 m long length of left bank erosion at site, visable loss of gravel bar and in-channel wood, tail-pins lost and site not able to be resurveyed.

[12] Scour of 46 cm measured.

[13] This is a coho redd, both 1998 redds in Segment 8 are coho. Aggradation at this redd was 48 cm. Habitat change was from riffle, to riffle secondary channel, a small tree was on the redd at the end of incubation, and a new bar had developed by the redd. Deposition on the redd site is with visually high fines.

[14] This is a coho redd. Scour at the redd site was 31 cm. Habitat change was from riffle-crest to side-of-pool.

River, Segment and River Miles	Year and Redd #	Surface Elevation Change at Redd				Surface Flow at End of Incubation		Habitat Type Beginning and End of Incubation			Likelihood of Survival to Fry Emergence			Foot Notes
		Scour		Aggradation										[2]
		<15 cm	≥15 cm	0 to <10 cm	≥10 cm	Present	Absent	Same	Changed	Major Change	Good	Uncertain	Poor	
Greenwater River, Segment 3, River Miles 1.5 – 2.4														
	1999 #1			+		+		+			X			
	1999 #2			+		+		+			X			
	1999 #3	+				+		+			X			
	1999 #4	+				+		+			X			
	1999 #5	+				+		+			X			
	1999 #6				–	+				–			X	[15]
	1999 #7	+				+				–			X	[16]
	1999 #8		–			+		+					X	[17]
	1999 #9			+		+		+			X			
	1999 #10	+				+		+			X			
	1999 #11	+				+		+			X			
	1999 #12	+				+		+			X			
	1999 #13	+				+		+			X			
	1999 #14			+		+		+			X			
	1999 #15				–	+		+					X	[18]
	1999 #16		–			+		+					X	[19]
	1999 #17	+				+		+			X			
	1999 #18	+				+		+			X			

[15] Redd incurred habitat change from a riffle crest/side-channel, to pool tail-out/side-channel. High fines visable on redd at end of incubation, along with 11 cm of aggradation.
[16] Habitat change at this redd was from riffle crest to pool tail-out. Surface elevation scour was 9 cm.
[17] Scour at the redd site was 37 cm.
[18] Aggradation at redd mound was 16 cm.
[19] Scour at the redd site was 17 cm.

River, Segment and River Miles	Year and Redd #	Surface Elevation Change at Redd				Surface Flow at End of Incubation		Habitat Type Beginning and End of Incubation			Likelihood of Survival to Fry Emergence			Foot Notes
		Scour		Aggradation										[2]
		<15 cm	≥15 cm	0 to <10 cm	≥10 cm	Present	Absent	Same	Changed	Major Change	Good	Uncertain	Poor	
Greenwater River, Segment 3, River Miles 1.5 – 2.4														
	2000 #1			+		+		+			X			
	2000 #2	+				+		+			X			
	2000 #3			+		+		+			X			
	2000 #4			+		+			+/–			X		20
	2000 #5	+				+		+			X			
	2000 #6	+				+		+			X			
	2000 #7	+				+		+			X			
	2000 #8			+		+		+			X			
	2000 #9			+		+		+			X			
	2000 #10	+				+		+			X			
	2000 #11			+		+		+			X			
	2000 #12	+				+		+			X			
	2000 #13			+		+		+			X			

[20] This redd was in a side-channel, pool tail-out in the fall. By late winter the pool tail-out had filled in, changing the habitat to riffle. Coho spawning upstream of the chinook redd was the likely cause of this change.