EFFECTIVENESS MONITORING OF STOLTZ BLUFF STABILIZATION WORKS, COWICHAN RIVER
Final Report

Prepared for

BC Conservation Foundation

and

Pacific Salmon Commission

Prepared by

LGL Limited

and

BC Conservation Foundation

June 2012

EFFECTIVENESS MONITORING OF STOLTZ BLUFF STABILIZATION WORKS, COWICHAN RIVER
Final Report

Prepared for

BC Conservation Foundation
3-1200 Princess Royal Ave.
Nanaimo, BC V9S 3Z7

and

Pacific Salmon Commission
(Southern Endowment Fund)
#600 - 1155 Robson Street
Vancouver, BC V6E 1B5

Prepared by

Marc Gaboury
Dave Robichaud
LGL Limited
environmental research associates
2459 Holyrood Drive
Nanaimo, British Columbia, V9S 4K7

and

J. Damborg
BC Conservation Foundation
3-1200 Princess Royal Ave.
Nanaimo, BC V9S 3Z7

June 2012

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

LIST OF APPENDICES

ACKNOWLEDGMENTS

Several people participated in one way or another in the completion of this project. Craig Wightman of the BC Conservation Foundation (BCCF) managed the contract and provided clear monitoring objectives for this project. Mel Sheng of Fisheries and Oceans Canada (DFO) provided input on project objectives and assistance with monitoring site selection, pipe incubator design and deployment, and hydraulic sampling. Margaret Wright (DFO) provided input on project objectives and shared data and information from previous water quality assessments on the river. Gary Horncastle collected water samples for lab analysis and assisted with field work. Brian Houle (Catalyst Paper, Crofton) provided real-time turbidity data for water extracted at their intake in Duncan. Shane Johnson, Shawn Stenhouse and Kevin Pellett (BCCF) and Doug Poole (DFO) also assisted with various aspects of the field work. The support of all these individuals is greatly appreciated.

Funding for the project was provided by NRCan (Natural Resources Canada), Pacific Salmon Commission (Southern Boundary Restoration and Enhancement Fund) and BCCF/Living Rivers.

INTRODUCTION

The impact of fine sediments on salmonid egg incubation habitat in the Cowichan River has been an ongoing concern among members of the Cowichan Stewardship Roundtable. The concern relates to the impact of fine sediments, typically generated from excessive bank erosion, infiltrating the interstices of the riverbed spawning gravel and reducing egg-to-fry survival. Although sediment inputs from naturally eroding banks are apparent along the mainstem, several sites stand out as generating large volumes of fine sediments to the river. For example, Stoltz Bluff has been identified as the most significant single source of fine sediments to the river (LGL and KWL 2005; KWL 2005). The sediment contribution from Stoltz Bluff was estimated at ~10,000-28,000 m^3 annually between 1993 and 2004. Suspended sediment from Stoltz Bluff also represented from 35-45% of the total suspended load measured at Vimy Road, ~15 km further downstream. To address this significant sediment source, rehabilitation measures were constructed at Stoltz Bluff in 2006 to stabilize the toe of the Bluff thereby reducing sediment inputs from this chronic erosion site. Two key rehabilitation objectives for the Stoltz Bluff stabilization project were:

1. To reduce the erosion and the generation of sediment loads from Stoltz Bluff to the lower river; and
2. To improve salmon egg-to-fry survival in spawning habitats downstream of Stoltz Bluff.

This final report presents results of a two year study of the effectiveness of rehabilitation works constructed at Stoltz Bluff to determine if these rehabilitation objectives are being met.

Project Goal and Objectives

The goal of this project is to report back to the Stoltz Bluff rehabilitation project funding partners, Cowichan Stewardship Roundtable and Cowichan Watershed Board on the status of fish habitat (particularly spawning conditions), following successful implementation of a major sediment control project (i.e., capital cost >$1M). The project objectives were:

1. Develop an appropriate experimental design that will produce repeatable and testable results at the 0.05 level of significance.
2. Establish a series of water quality, substrate permeability, test egg incubator and hydraulic egg sampling sites on the Cowichan River, downstream of Lake Cowichan, closely matching those conducted in baseline years, prior to Stoltz Bluff remediation. The sites will most likely include Greendale (control), Riverside Cabins (control), Greendale Trestle (control), ~200 m above Stoltz Bluff (control), Stoltz Bluff side channel (control), Wildwood, Stoltz Pool, Sandy Pool and the Catalyst Paper mill pump house. Sampling targeted August 2010 to March 2012.
3. Measure substrate permeability with standpipe piezometers using a constant gradient test at four of the above sites, where suitable salmon spawning habitat presently exists.

4. Continuously measure in situ turbidity using YSI 600 OMS meters at 5 sites embracing both control and treated (impacted) reaches from October to March. Additional turbidity data to be provided by Catalyst Paper from water extracted at their intake site in Duncan.
5. Collect turbidity and TSS water samples at up to six sites. The focus will be on ascending limbs of the seasonal flood hydrograph from November to February. Standard chemical analysis will be conducted at a certified water analysis laboratory.
6. Install approximately 50 standpipe incubators of DFO (M. Sheng) design with ~60 eyed Chinook eggs at 4 sampling sites (~5-15 incubators/site) with five incubators remaining in the hatchery to act as controls.
7. Conduct hydraulic sampling at salmon egg incubation sites. Approximately 10-15 samples will be obtained at each of up to ~5 sites.
8. Prepare interim 2010-11 and final 2011/12 reports incorporating assessment results, conclusions and recommendations.

METHODS

Hydrology

Historical and real-time river discharge information was obtained from two existing Water Survey of Canada (WSC) gauging stations: Cowichan River near Duncan (WSC gauge 08HA011) and Cowichan River at outlet of Cowichan Lake (WSC gauge 08HA002) (http://www.wateroffice.ec.gc.ca/text_search/search_e.html?search_by=p&region=BC). Both stations have long term periods of record as follows:

- Cowichan River near Duncan (08HA011) (active station):
  - period of record – 1960-2009;
  - instantaneous peak flows – data for 33 yrs;
  - mean daily peak flows – data for 49 yrs;

- Cowichan River at outlet of Cowichan Lake (08HA002)) (active station):
  - period of record – 1913-2009;
  - instantaneous peak flows – data for 65 yrs;
  - mean daily peak flows – data for 74 yrs.

Permeability

Permeability tests were conducted to provide a relative measure of water movement in spawning gravel. The test is based on Darcy's Law (Wickett 1954) which relates the flow of water through a porous media as a measure of gravel permeability.

A minimum of seven and a maximum of 14 permeability tests were completed at each of four sites: River Cabins, ~200 m upstream of Stoltz Bluff, Stoltz Pool, and Sandy Pool (Figure 1; Table 1). Methodology for the permeability tests was modified after Sweeten (2005). Gravel permeability was measured in standpipes using a constant 25 mm (1 in) gradient that was established using a vacuum pump and suction pipe assembly. The flow of water was measured in ml/sec. The maximum permeability measurable with the equipment described below was ~200 ml/sec.

Mark IV standpipes 1.18 m in length and constructed from 3.7 cm inside diameter stainless tubing with a mild steel point welded on one end were used for the tests (Photo 1). Each standpipe had a ~5.5 cm wide band of holes (6 rows with 8 holes per row) located ~8.5 cm from the welded tip. Each hole was 3.2 mm in diameter and set 45° apart from the next hole. The holes were countersunk to prevent plugging by sand during increased flows. Each row of holes was set 9.5 mm apart and offset by 22.5°.

A pounding bar was used to drive the standpipes into the gravel to depths of 25 and 40 cm. The two depths represented the range of depths where salmon egg deposition occurs. Standpipes were driven a 1 m minimum distance apart into suitably-sized substrates on currently dry gravel bars and in wetted channels at known salmon spawning areas.
A vacuum pump was used to withdraw any water that entered the standpipe after the 25 mm (1 in) gradient (i.e., water level in standpipe during pumping was maintained 25 mm lower than static water level prior to pumping) had been established. The vacuum source was a gas powered Honda GX110 with a 2 to 1 reduction motor coupled to a Gast 1065 vane vacuum pump (Photo 2). The large capacity vacuum pump was used to maintain a continuous 71 cm (28 in) (Mercury) of vacuum. A 0.04 m^3 (10 gal) vacuum reservoir was also attached to maintain a constant vacuum during the permeability test. The hose from the vacuum pump was connected to a ~1 m long by 12.5 mm OD copper suction tube. Water was sucked through the copper tube, and collected and measured in a 1000-ml Nalgene graduated cylinder (Photo 3). Suction occurred over measured time periods and was terminated when ≥500 ml of water had been collected or when the water level in the graduated cylinder remained relatively static.

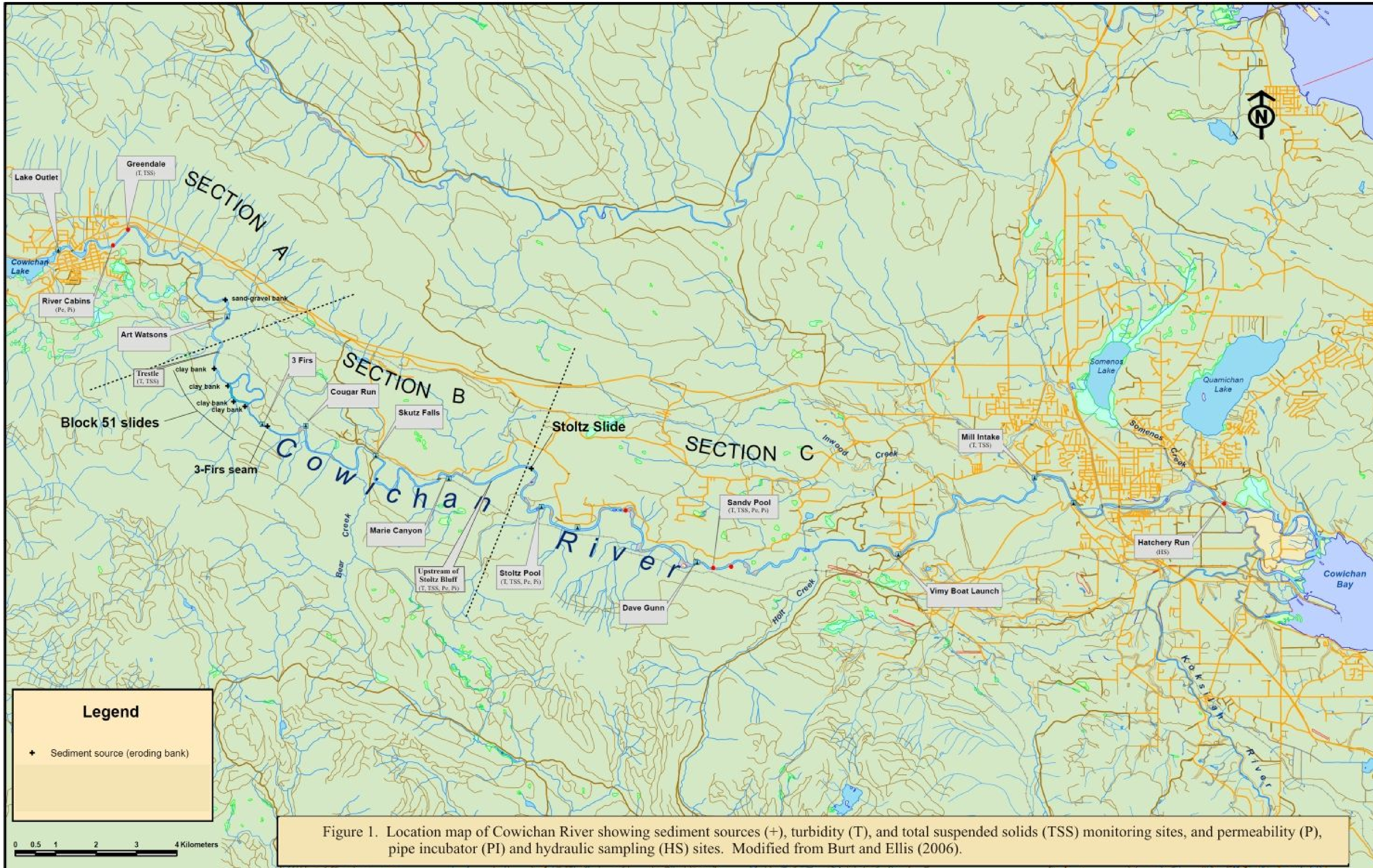

Figure 1. Location map of Cowichan River showing sediment sources (+), turbidity (T), and total suspended solids (TSS) monitoring sites, and permeability (Pe), pipe incubator (Pi) and hydraulic sampling (HS) sites.

Table 1. Summary of survey design for effectiveness monitoring of Stoltz Bluff stabilization works.

Sites	Spawning Gravel Permeability Test (P)	Egg Survival: Hydraulic Sampling (HS)	Egg Survival: Pipe Incubators (PI)	Water Quality: Turbidity (T)	Water Quality: T + TSS
Greendale (G)				1	1
River Cabins (RC)	1	1	1 (5 pipes)		
70. 2 Mile Trestle (MT)				2 (Side Channel)	2
Upstream of Stoltz Bluff (USB)	2	2	2 (15 pipes)	3 (Side Channel)	3
Stoltz Pool (St)	3	3	3 (15 pipes)	4 (Wildwood)	4
Sandy Pool (SP)	4	4	4 (12 pipes)	5	5
Catalyst Mill Intake (CM)				6	6
Hatchery Run (HR)		5			
Cowichan River Hatchery (CR)			5 (5 pipes)		
Frequency & Timing	Once: September	Once: March	late Nov to Jan-Feb	Continuous: mid-Oct to mid-March; Manual in situ water samples: Nov-March	Weekly: Oct to late-March
Initial Egg Density	-	-	60 eggs/pipe	-	-
Sampling Intensity	~10 piezometers/site	10 redds/site	5-15 pipes / site	-	one sample / site
Total Number of Samples	10 piezometers/site x 4 sites = 40 samples	10 redds/site x 4 sites x 1 sample = 40	45 pipes + 5 pipes in hatchery	-	5 x 1 x ~10 = 50
Collection Method	DFO piezometers (T. Sweeten)			Continuous: YSI - Sonde meter (sites 1-5), Catalyst Paper Corp. turbidity meter (site 6); In situ water samples with lab analyses (sites 1-6)	Water sample with lab analysis
TEST for:	Gravel permeability using constant head test (following methodology of Sweeten 2005)	Live vs Dead: Eggs & Alevins; incubation survival rate	Live vs Dead: Eggs & Alevins; incubation survival rate	Turbidity (NTU)	Turbidity + Total Suspended Solids (TSS) (mg/L)

Photo 1. Mark IV standpipe used in permeability tests. Reproduced from Sweeten (2005).

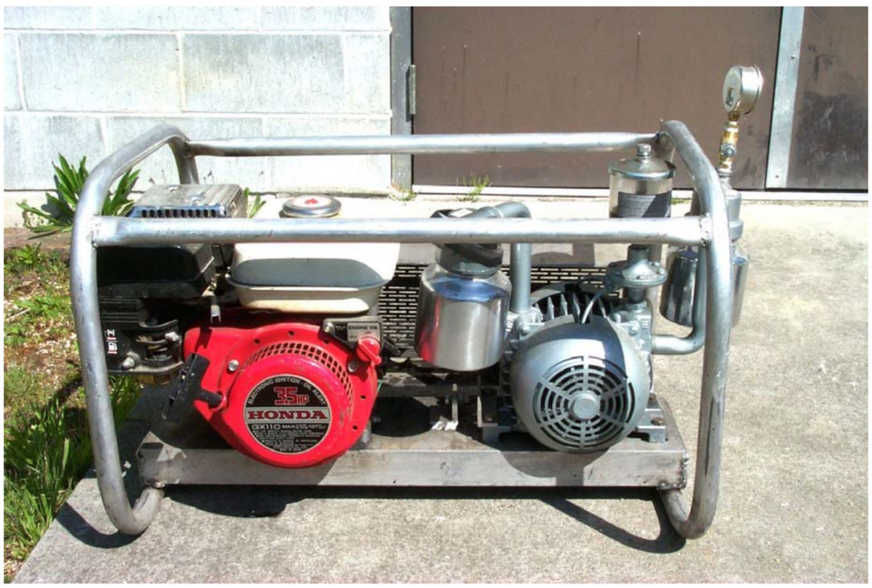

Photo 2. Gas powered vacuum pump used in permeability tests. Reproduced from Sweeten (2005).

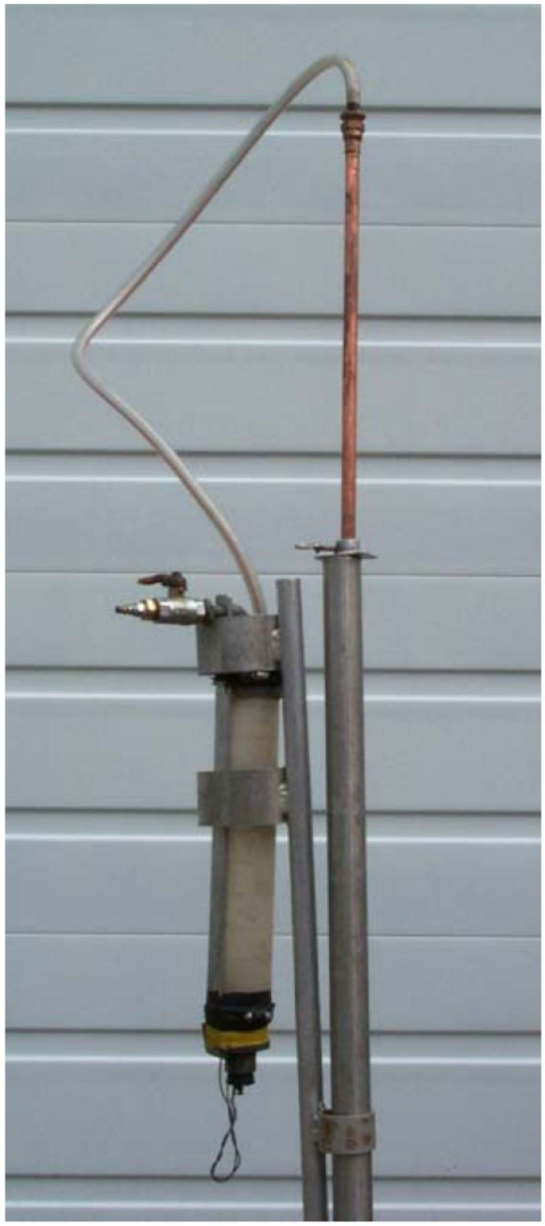

Photo 3. Graduated cylinder and suction pipe coupled to Mark IV standpipe. Reproduced from Sweeten (2005).

Turbidity and Total Suspended Solids

Six water quality sites were established on the Cowichan River, downstream of Lake Cowichan, matching those sampled in baseline years prior to Stoltz Bluff remediation (Figure 1; Table 1). Real-time turbidity as nephlometric turbidity units (NTUs), conductivity and temperature were measured continuously (1 hr interval) at five sites with YSI 600 OMS V2 multi-parameter water quality Sonde meters, each with an attached Optix X - turbidity 6136 probe. Real-time turbidity was also measured continuously (1 hr interval) for water extracted by Catalyst Paper from the Cowichan River in Duncan.

In situ water samples were collected manually from six sites during the ascending limb of the hydrograph for larger flood events (>~150 cms at Duncan WSC 08HA011). Sampling occurred between November and March in 2010/11 and 2011/12. Samples were analyzed by North Island Laboratories (Courtenay, BC) for turbidity (detection limit 0.5 NTUs) and total suspended solids (TSS in mg/l; detection limit 5 mg/l). Statistical relationships for the data were developed between total suspended solids and turbidity measurements.

TSS values were calculated from real-time turbidity measurements using the equations developed by Burt (2008) for the three sections of the Cowichan River. The equation for Section A was used for Trestle Channel and the equation for Section B and C was used for Upstream of Stoltz Bluff, Wildwood, Sandy Pool and Catalyst Intake sites.

The equations are as follows:

Section A $TSS_{Calculated} = 1.23 + 0.58 \times Turbidity^{0.85}$

Section B and C $TSS_{Calculated} = 3.35 + 0.69 \times Turbidity^{1.06}$

TSS load estimates were calculated using equations modified from Burt (2008). The modified equations are as follows:

$$SSL_{Hourly} = TSS_{Calculated} \times Q_{site} \times 3600 \times 10^{-6}$$

Where:

SSL_{Hourly} = hourly suspended sediment load (tonnes/hour)

Q_{site} = mean daily discharge estimate for the site (cms)

10^{-6} = conversion factor for mg to tonnes and cubic metres per second (cms) to litres (L)

$$Q_{site} = Q_{HA002} \div Area_{HA002} \times Area_{Site} \times (1-CP_{Site}) + Q_{HA011} \div Area_{HA011} \times Area_{Site} \times CP_{Site}$$

Where:

Q_{HA002} Q_{HA011} = hourly discharge from WSC records

$Area_{HA002}$ $Area_{HA011}$ = drainage area for each WSC station

$Area_{Site}$ = drainage area for each site

CP_{Site} = drainage area of site as cumulative proportion of total drainage area to Catalyst Intake

Egg Incubation Success

Pipe Incubators

Chinook egg incubation success was measured using pipe incubators. The pipe incubators were modified from designs used previously by Burt et al (2005) and Burt and Ellis (2006). Each pipe incubator consisted of a 2.6 cm outside diameter by 24 cm long perforated stainless steel cylinder with flow-through openings of ~2 mm in diameter (Photo 4). Masonry drill bits were welded onto their ends to allow them to be drilled into river substrates using a rechargeable drill. Sixty (2010) or forty (2011) eyed Cowichan River Chinook eggs were placed in each incubator separated by layers of aquarium pea stone (2010) or round plastic beads (2011). Incubators were then buried so that the perforated section was located between 15 and 39 cm below the streambed elevation. Pipes were deployed on 29-30 November 2010, and retrieved on 5 January 2011 or 1 February 2011, for total soak times of 36 (River Cabins, Sandy Pool and CR Hatchery) to 64 (Upstream of Stoltz Bluff and Stoltz Pool) days. Pipes were deployed on 17-18 November 2011, and retrieved on 20-21 December 2011, for total soak times of 32 (River Cabins and Sandy Pool) to 33 (Upstream of Stoltz Bluff, Stoltz Pool and CR Hatchery) days.

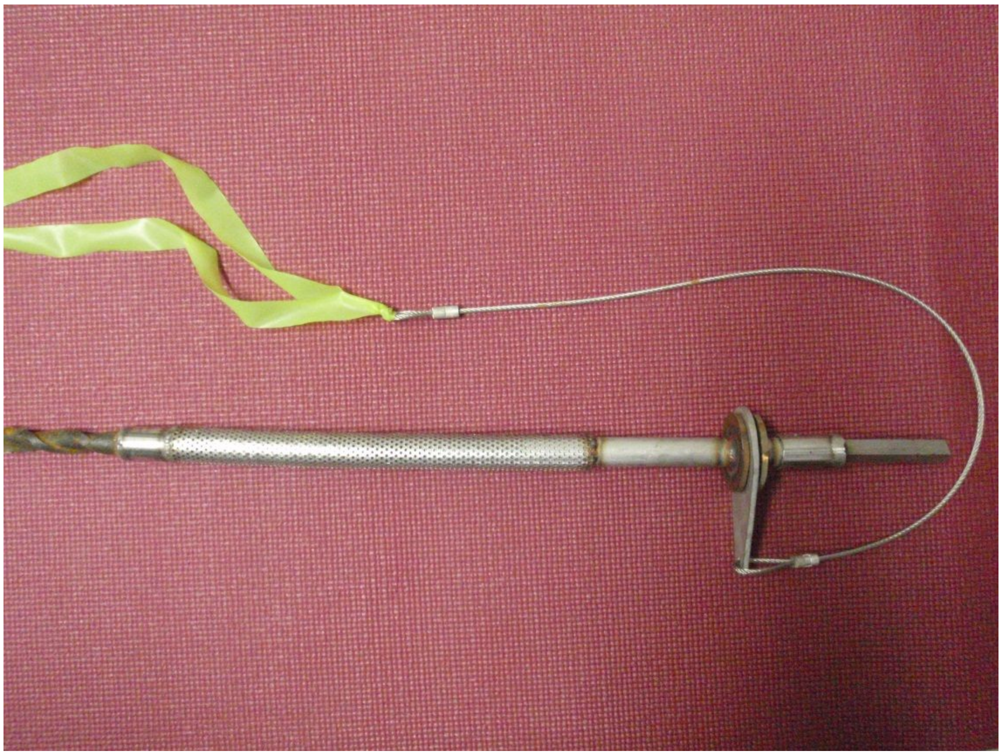

Photo 4. Pipe incubators used in egg incubation study.

An experimental design of the incubation study using pipe incubators was developed to produce repeatable and testable results at the 0.05 level of significance. Simulations were run to determine how the number of pipe incubators at control and treatment sites affects the probability of finding a statistically significant difference, assuming in the trials true differences of 10%, 20% and 30% between the control and treatment survivals. The analysis also assumed that the mean and variability at the real control and the real treatment sites will be similar to those in this simulation. Based on these assumptions, the plot shown in Figure 2 illustrates the effect of increasing or decreasing the number of pipes per site on the probability of finding a significant difference between control and treatment survivals. The plot shows that:

At 10 pipes per site, you can expect to find a significant difference:

- 20% of the time when the true difference between control and treatment is 10%;

- 60% of the time when the true difference between control and treatment is 20%;
- 90% of the time when the true difference between control and treatment is 30%; and

At 20 pipes per site, you can expect to find a significant difference:
- 36% of the time when the true difference between control and treatment is 10%;
- 90% of the time when the true difference between control and treatment is 20%;
- 100% of the time when the true difference between control and treatment is 30%.

Based on this analysis, the number of pipe incubators installed at the four sites varied between 5 and 15 (Table 1). Incubators were installed in substrates, depths and velocities typically favoured by spawning salmon.

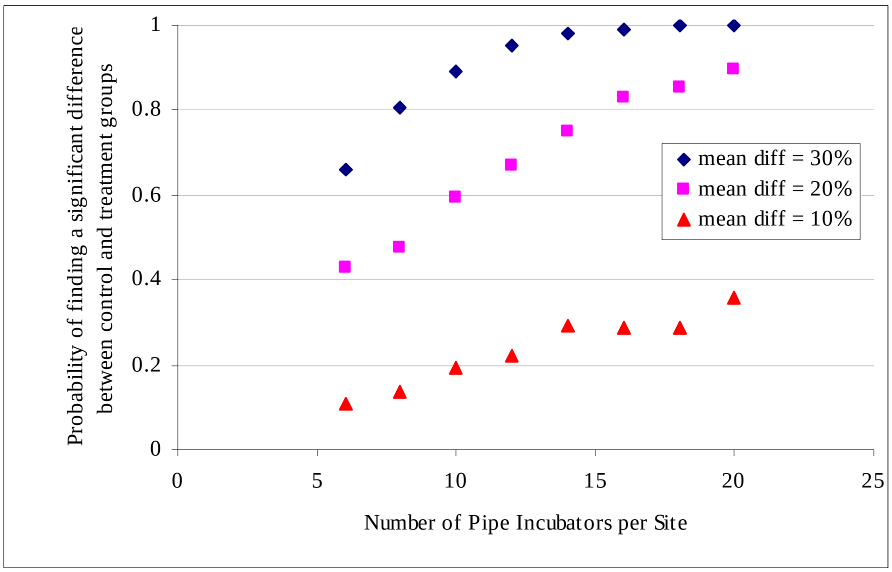

Figure 2. Results of analysis to determine an appropriate number of pipe incubators per site required to find an acceptable significant difference between control and treatment groups with mean differences in survival of 10, 20 and 30%.

Results from the study were compared statistically between the four sites and between the two study years. Comparisons were also made to incubation survival data obtained from the baseline period 2004 to 2006 (Burt et al. 2005; Burt and Ellis 2006).

In 2010/11, non-parametric statistical analyses were employed to look for statistically significant differences in egg survival between locations upstream versus downstream of Stoltz Bluff. The analyses included the Kruskal-Wallis (for comparing more than two groups) and Mann-Whitney (for comparing two groups) tests, which are analogous to the parametric ANOVA and t-test, respectively. Non-parametric tests were appropriate in this study because the data (survival proportions) were not normally distributed and the parametric model assumptions about error-structure were violated. For statistical comparisons involving more than two groups, Kruskal-Wallis tests were initially used, and when statistical significance was obtained, post-hoc pair-wise comparisons were performed using Mann-Whitney tests with controlled (i.e., Bonferroni-adjusted) experiment-wise alpha levels.

The purpose of the analysis was to look for statistically significant differences in egg survival between locations upstream vs. downstream of Stoltz Bluff. Each of the five sites were assigned to a 'location' category, depending on whether they were upstream (River Cabins, Upstream Stoltz) or downstream (Stoltz Pool, Sandy Pool, CR Hatchery) of Stoltz Bluff. Given the assumed continual mortality in the pipe incubators, incubators should all be deployed on the same day, and should all be retrieved at or around the same time.

In 2011/12, comparisons of egg survival among sites were performed using general linear models (GLMs), and assuming a binomial error structure (with a logit link function). This model form is ideally suited for 'success or failure' type data, such as analyses of the number of surviving eggs, given the number deployed. Two analyses were conducted on this year's data: one using site as the explanatory variable, and one using the 'location' category. If a statistically significant effect of site was detected, then Tukey tests would be used to compare survival rates among them.

Comparisons with the results from pipes deployed in 2010 were problematic. In 2010/11, river conditions did not allow synoptic recovery of the pipe incubators. Pipes at three sites (River Cabins, Sandy Pool, and CR Hatchery) were retrieved after 36 days of soak, whereas those at two sites (Upstream Stoltz, Stoltz Pool) soaked for 64 days. In this report, comparisons of egg survival between the 2010 and 2011 deployments were restricted to the River Cabins, Sandy Pool, and CR Hatchery, as soak times for these sites were similar between years. For these analyses, site and year were included as explanatory variables, along with a site x year interaction term[1]. If a statistically significant interaction was detected, then separate analyses would be conducted for each site.

Analyses for this report were performed in R (version 2.13.2; R Development Core Team 2011), using the 'multcomp' package (Hothorn et al. 2008). Box-plots were prepared in R, using the 'ggplot2' package (Wickham 2009).

Hydraulic Sampling

The hydraulic sampler was modified after McNeil (1964) and consisted of a sampling probe, catch net and high-pressure water pump. Sampling was planned for five sites during March 2011 (Table 1). Due to high flows in 2011, hydraulic sampling was restricted to one occurrence at Hatchery Run in March 2011. No hydraulic sampling was conducted in 2012.

[1] In last year's report, non-parametric statistical analyses were employed. However, because of the increased complexity associated with the two-way analysis (i.e., examining the effects of site and year), a change in approach was needed. General linear models, although more difficult to work with, provide the flexibility to define non-normal error structures (such as the binomial distribution), allowing survival data to be analyzed parametrically.

RESULTS

Hydrology

Year 2010-2011

Between October 2010 and March 2011, Cowichan River flows at the outlet of Cowichan Lake (WSC gauge 08HA002) ranged from 40.04 to 180.43 cms with a mean discharge of 95.09 cms (Figure 3). An instantaneous peak discharge of 174.76 cms occurred on 27 Dec 2010 during this period. This is equivalent to a ~50% or ~2 yr event based on the flood frequency for this gauging station (Figure 4).

Between October 2010 and March 2011, Cowichan River flows near Duncan (WSC gauge 08HA011) ranged from 40.54 to 284.74 cms with a mean discharge of 103.36 cms. An instantaneous peak discharge of 284.74 cms occurred on 12 Dec 2010 during this period. This is equivalent to a ~54% or ~1.8 yr event based on the flood frequency for this gauging station (Figure 5).

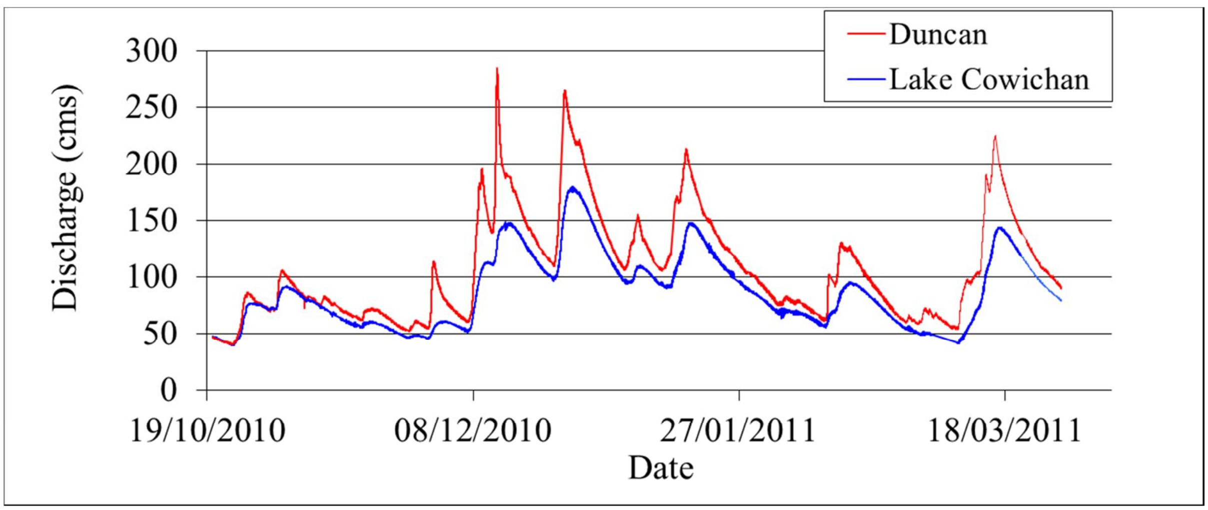

Figure 3. Hydrographs for Cowichan River from October 2010 to March 2011 measured at Cowichan River near Duncan (WSC gauge 08HA011) and Cowichan River at outlet of Cowichan Lake (WSC gauge 08HA002).

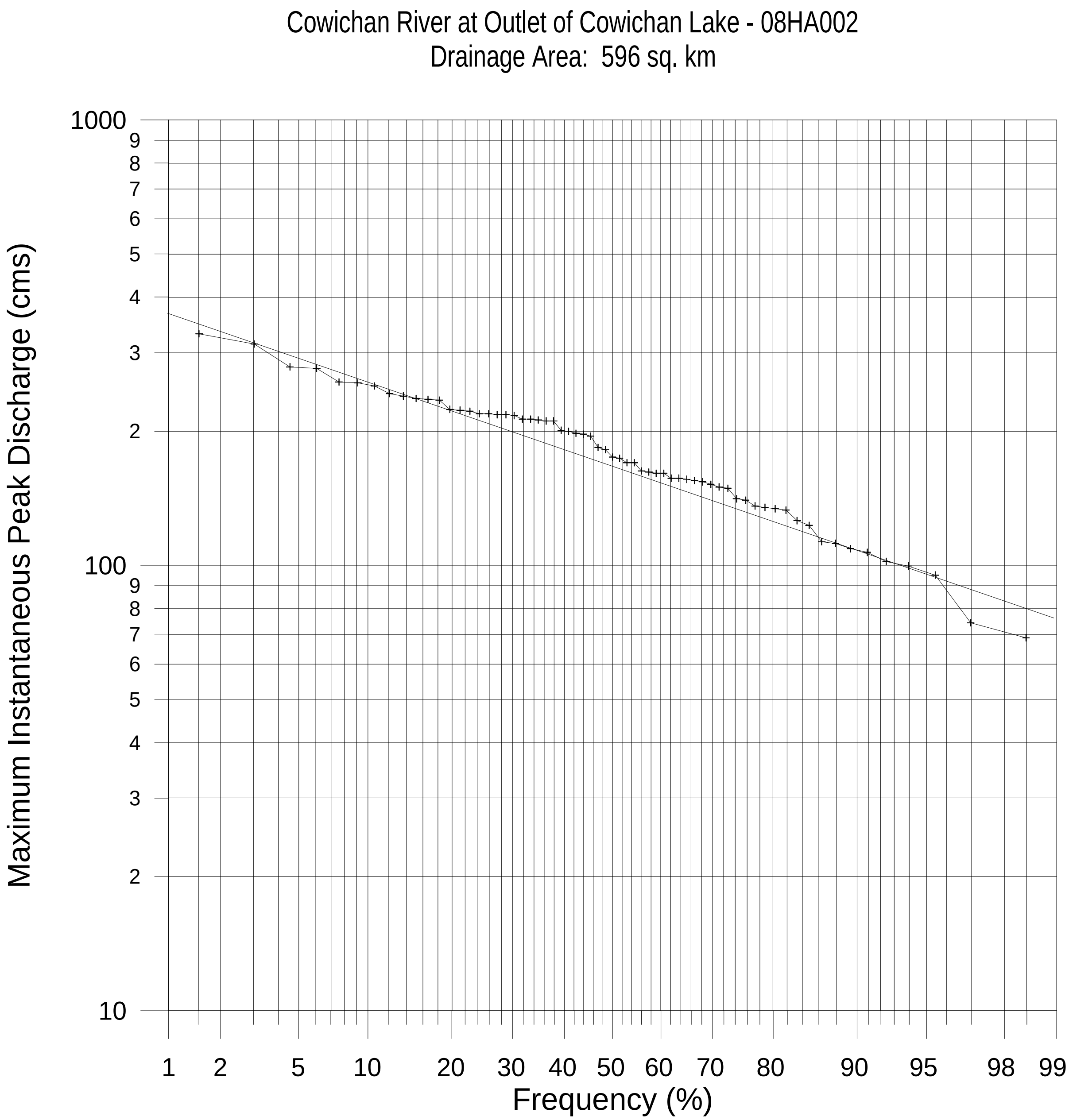

Figure 4. Flood frequency plot of maximum instantaneous peak discharges for Cowichan River at outlet of Cowichan Lake, WSC gauge 08HA002, 1913-2009.

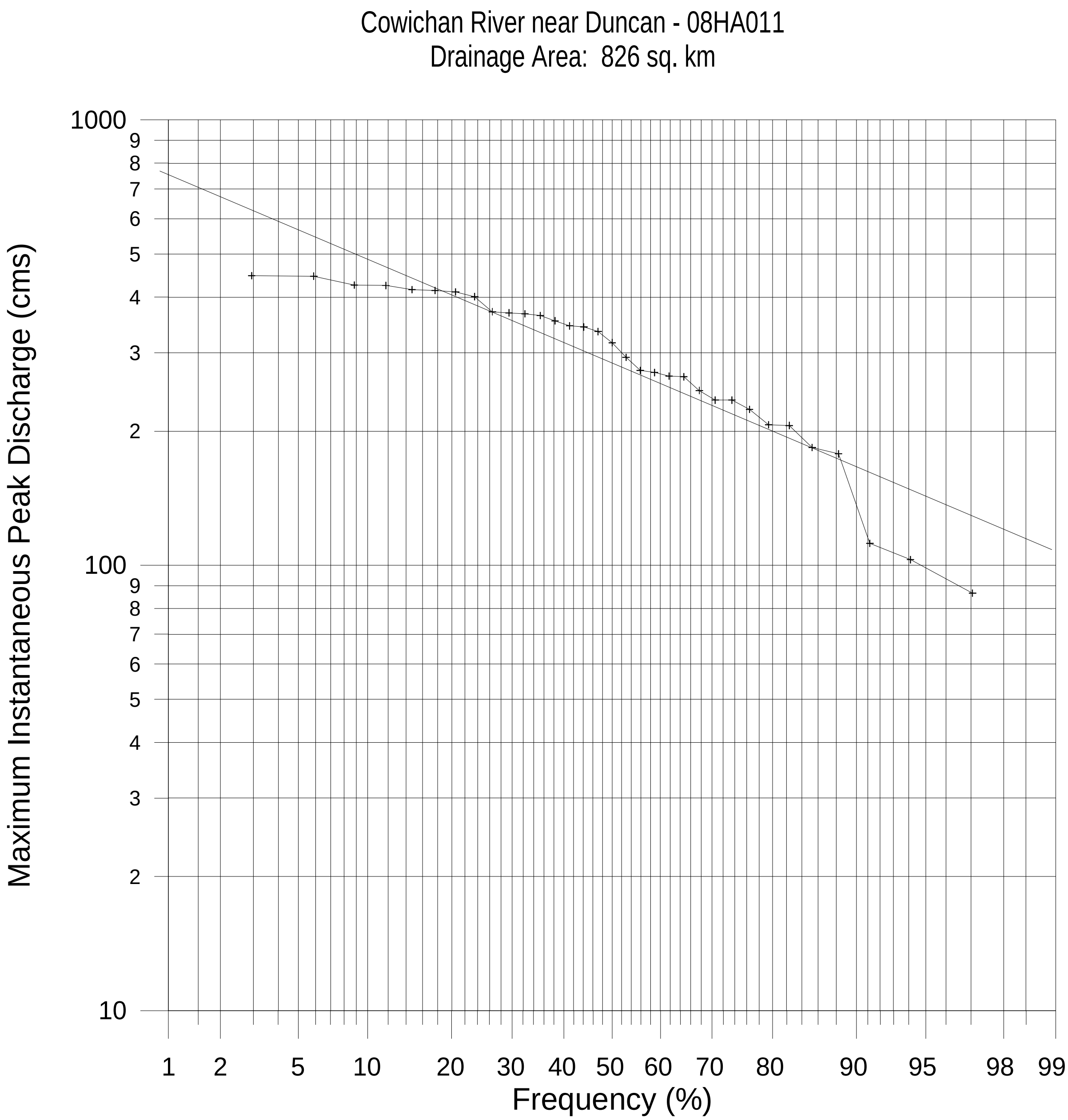

Figure 5**. Flood frequency plot of maximum instantaneous peak discharges for Cowichan River near Duncan, WSC gauge 08HA011, 1960-2009.**

Year 2011-2012

Between October 2011 and March 2012, Cowichan River flows at the outlet of Cowichan Lake (WSC gauge 08HA002) ranged from 31.33 to 147.13 cms with a mean discharge of 77.57 cms (Figure 6). An instantaneous peak discharge of 147.13 cms occurred on 6 Jan 2012 during this period. This is equivalent to a ~61% or ~1.6 yr event based on the flood frequency for this gauging station (Figure 4).

Between October 2011 and March 2012, Cowichan River flows near Duncan (WSC gauge 08HA011) ranged from 34.00 to 252.61 cms with a mean discharge of 86.11 cms. An instantaneous peak discharge of 252.61 cms occurred on 5 Jan 2012 during this period. This is equivalent to a ~65% or ~1.5 yr event based on the flood frequency for this gauging station (Figure 5).

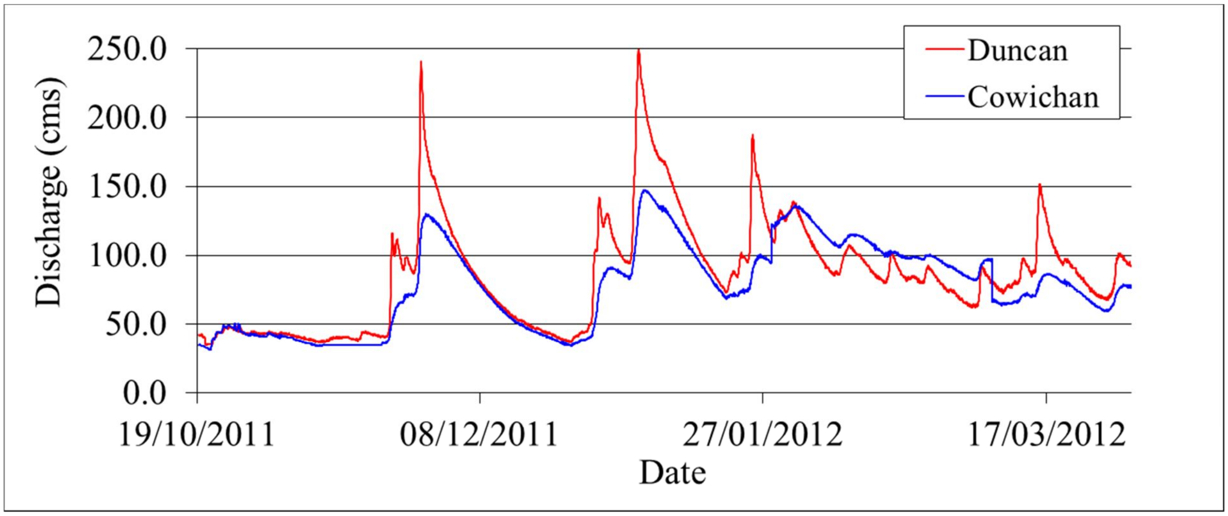

Figure 6. Hydrographs for Cowichan River from October 2011 to March 2012 measured at Cowichan River near Duncan (WSC gauge 08HA011) and Cowichan River at outlet of Cowichan Lake (WSC gauge 08HA002).

Permeability

Permeability tests were conducted in 2010 and 2011 to provide more quantitative evidence of gravel quality with respect to egg/alevin survivals. Water movement through the redd governs the rate of oxygen exchange and thus egg and alevin survival. This flow is directly proportional to permeability and so is a relative measure of this parameter.

Year 2010-2011

Mean permeabilities for all samples ranged from 2.1 to 16.2 ml/sec in 2010 (Table 2; Appendix A to Appendix D). Permeability of gravel bar substrates was generally similar to the wetted channel with the exception of Stoltz Pool where a very compacted silt layer was encountered at ~20 cm below the substrate surface in the wetted channel (Figure 7). When the piezometer was driven to the 40 cm depth in the wetted channel at this site, the water level in the piezometer did not return to the static river water level because of the compacted silt layer. As a result, the permeability was recorded at 0 ml/sec.

Permeabilities at River Cabins and Upstream of Stoltz Bluff were lower at the 40 cm depth than at the 25 cm depth in the wetted channel but the reverse when these depths were compared for gravel bars. At Sandy Pool, permeability was lower at 40 cm depth than at 25 cm on gravel bars but slightly higher in the wetted channel.

Table 2. Mean and standard deviation (S.D.) of permeability measurements for Cowichan River, 2010.

Location	No. of Sites	Statistic	All Samples			Gravel Bar		Wetted Channel	
			Permeability (ml/sec) all data	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm
River Cabins	10	Mean	12.1	11.7	12.6	9.0	19.3	11.4	9.7
		S.D.	6.6	5.3	7.6	3.5	8.6	5.2	4.8
Upstream of Stoltz	14	Mean	14.3	16.2	12.3	7.5	11.8	19.7	12.5
		S.D.	11.1	14.1	6.1	2.5	5.5	15.3	6.3
Stoltz Pool	7	Mean	4.1	2.9	2.1	-	7.2	2.9	0
		S.D.	2.3	1.3	3.3	-	0.3	1.3	0
Sandy Pool	10	Mean	7.0	7.3	6.7	7.9	5.1	7.1	7.4
		S.D.	3.4	2.2	4.2	1.6	2.2	2.4	4.7
Overall Mean			9.4	9.5	8.4	8.1	10.9	10.3	7.4

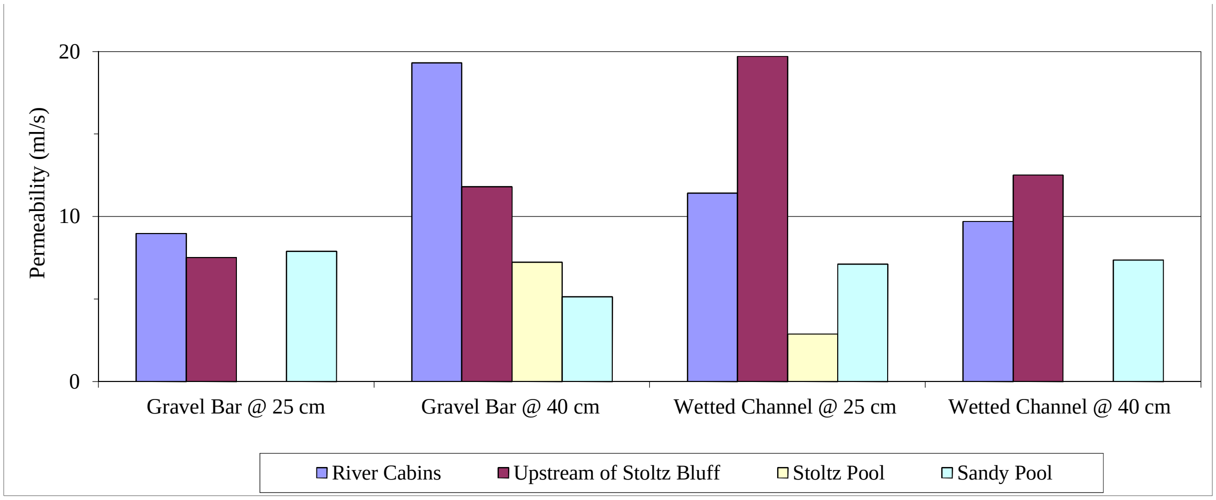

Figure 7. Permeabilities measured for gravel bars and wetted channels at four locations in Cowichan River, 2010.

Year 2011-2012

Permeability measurements were taken at the same sites as in 2010, except for Stoltz Pool which was re-located ~200 m upstream of the 2010 site. Mean permeabilities for all samples ranged from 24.4 to 45.9 ml/sec (Table 3; Appendix E to Appendix H). Permeabilities at Upstream of Stoltz Bluff and Stoltz Pool were slightly lower at the 40 cm depth than at the 25 cm depth in the wetted channel but the reverse when these depths were compared for gravel bars (Figure 8). At Sandy Pool and River Cabins, permeability was higher at 40 cm depth than at 25 cm in both gravel bars and wetted channels.

Table 3. Mean and standard deviation (S.D.) of permeability measurements for Cowichan River, 2011.

Location	No. of Sites	Statistic	All Samples: Permeability (ml/sec) all data	All Samples: Rate of Volume Change (ml/sec) @ 25 cm	All Samples: Permeability (ml/sec) @ 40 cm	Gravel Bar: Permeability (ml/sec) @ 25 cm	Gravel Bar: Permeability (ml/sec) @ 40 cm	Wetted Channel: Permeability (ml/sec) @ 25 cm	Wetted Channel: Permeability (ml/sec) @ 40 cm
River Cabins	10	Mean	37.2	28.5	45.8	27.7	45.9	29.1	45.8
		S.D.	13.4	8.4	11.7	7.0	2.6	9.2	14.9
Upstream of Stoltz Bluff	10	Mean	26.3	25.9	26.8	25.8	36.3	25.9	24.4
		S.D.	12.3	11.8	12.7	12.8	20.3	11.5	8.5
Stoltz Pool	11	Mean	39.5	40.4	38.5	34.2	37.6	43.9	39.1
		S.D.	16.0	14.7	17.3	5.8	10.9	17.0	20.4
Sandy Pool	10	Mean	37.3	29.4	45.2	34.6	43.8	25.9	40.7
		S.D.	24.2	16.2	27.9	14.4	37.6	16.4	22.0

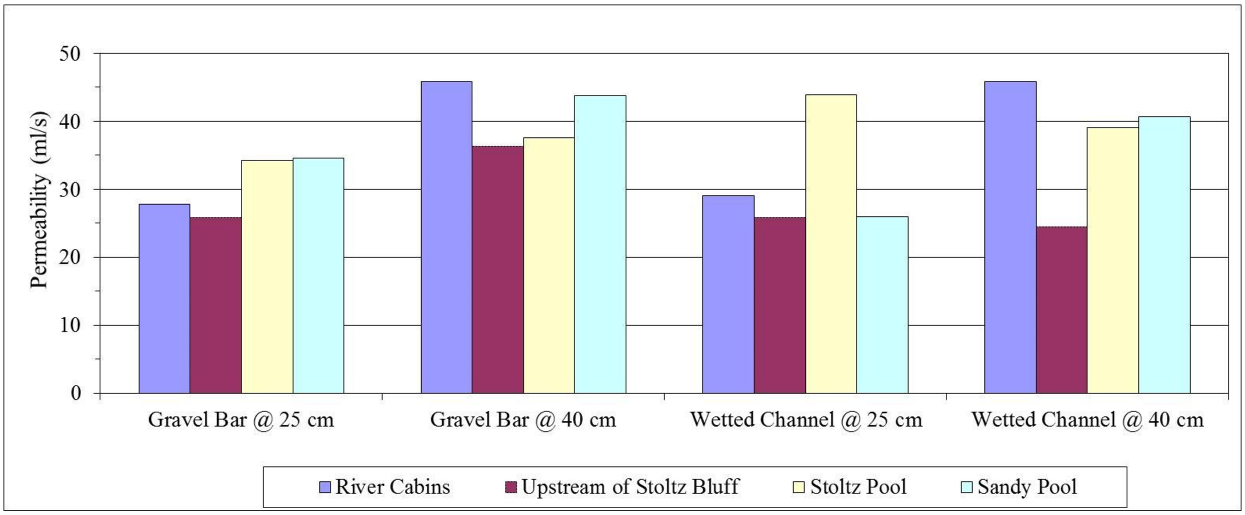

Figure 8. Permeabilities measured for gravel bars and wetted channels at four locations in Cowichan River, 2011.

Turbidity and Total Suspended Solids

Year 2010-2011

Real-time turbidity measurements, recorded continuously at six sites in the Cowichan River, were evaluated for 12 storm events that occurred between 19 October 2010 and 20 March 2011 (Figure 9 to Figure 11). For a given event, turbidities typically increased from the upstream to downstream sites with the lowest values recorded at Greendale and the highest turbidities at the Catalyst Intake site. Turbidities typically peaked on the ascending limb of the flood hydrograph and turbidity values generally varied temporally with the fluctuation in flow for the hydrometric station closest to the site. The highest turbidity values for most sites occurred during the largest flow event on 12 December 2010 (Figure 10). On this date, the maximum turbidity recorded for all sites was 80.6 NTUs at the Catalyst Intake site. Also, the greatest change in turbidity occurred between the Wildwood and Sandy Pool sites (difference of 30.4 NTUs) followed by the Trestle Channel and Upstream of Stoltz Bluff sites (difference of 29.2 NTUs). The difference between Upstream of Stoltz Bluff and Wildwood sites was only 14.3 NTUs on 12 December suggesting that suspended sediment contributions from Stoltz Bluff were relatively minor.

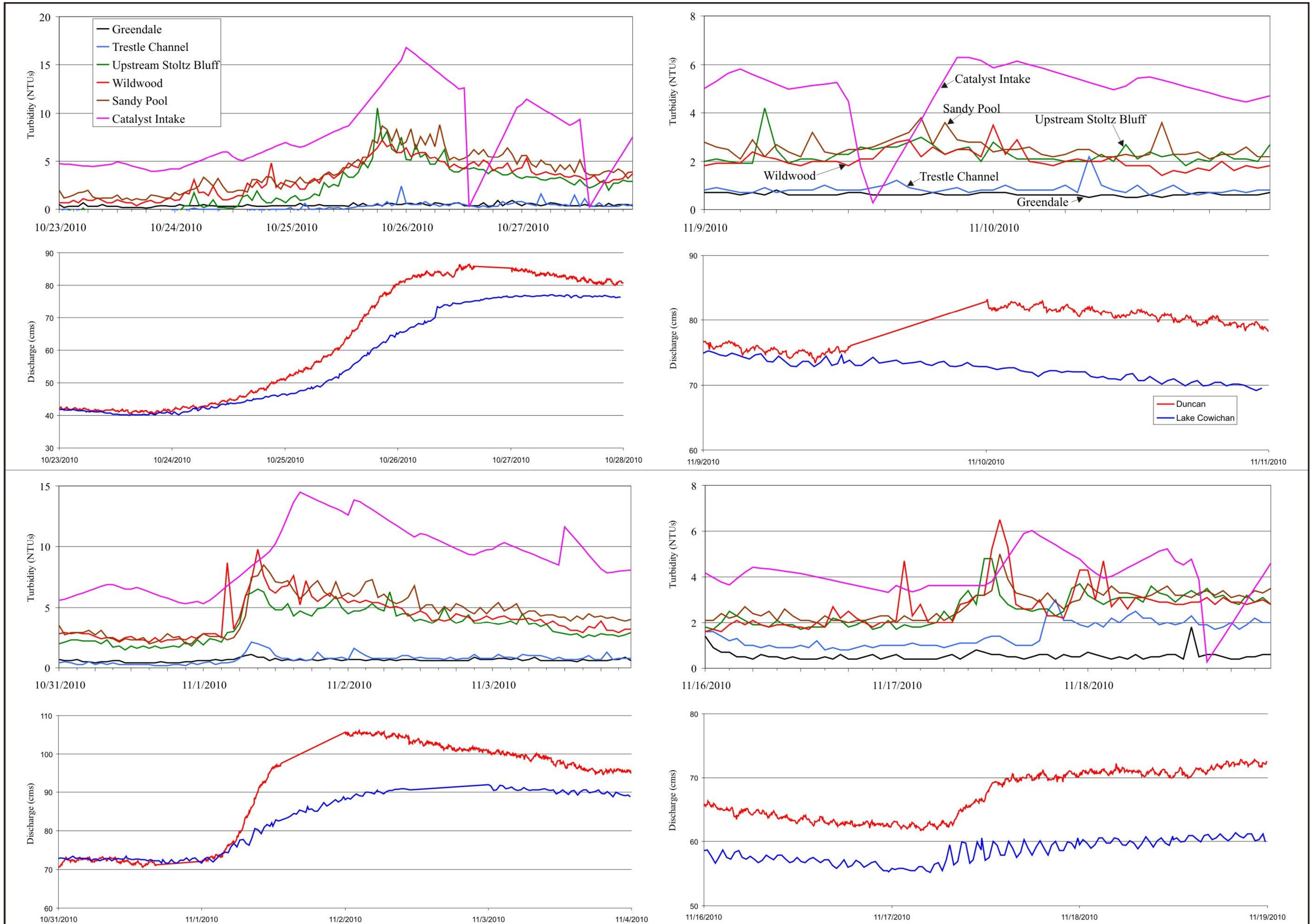

Figure 9. Turbidity at six sites in Cowichan River during high discharge events in October and November 2010.

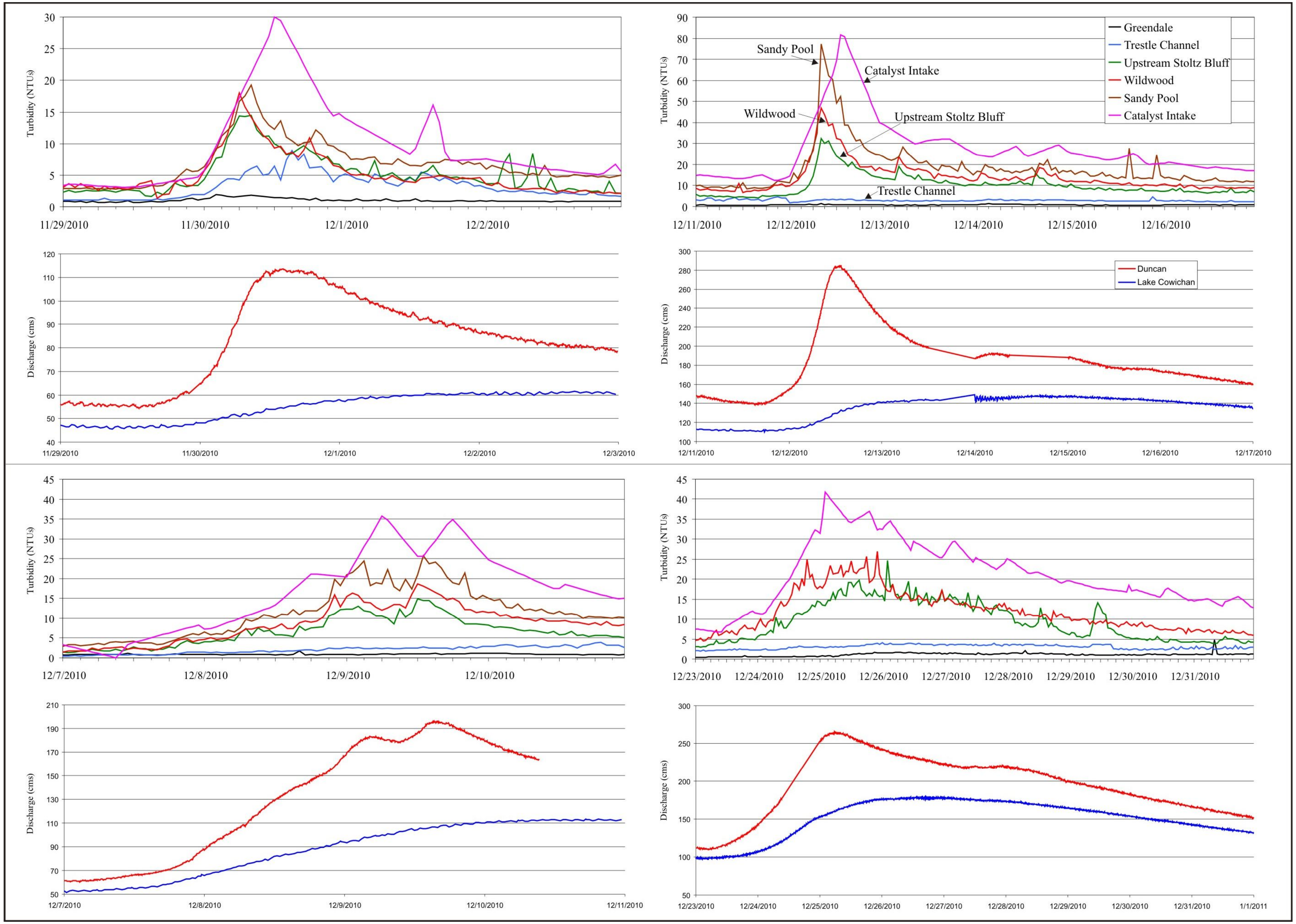

Figure 10. Turbidity at six sites in Cowichan River during high discharge events in November and December 2010.

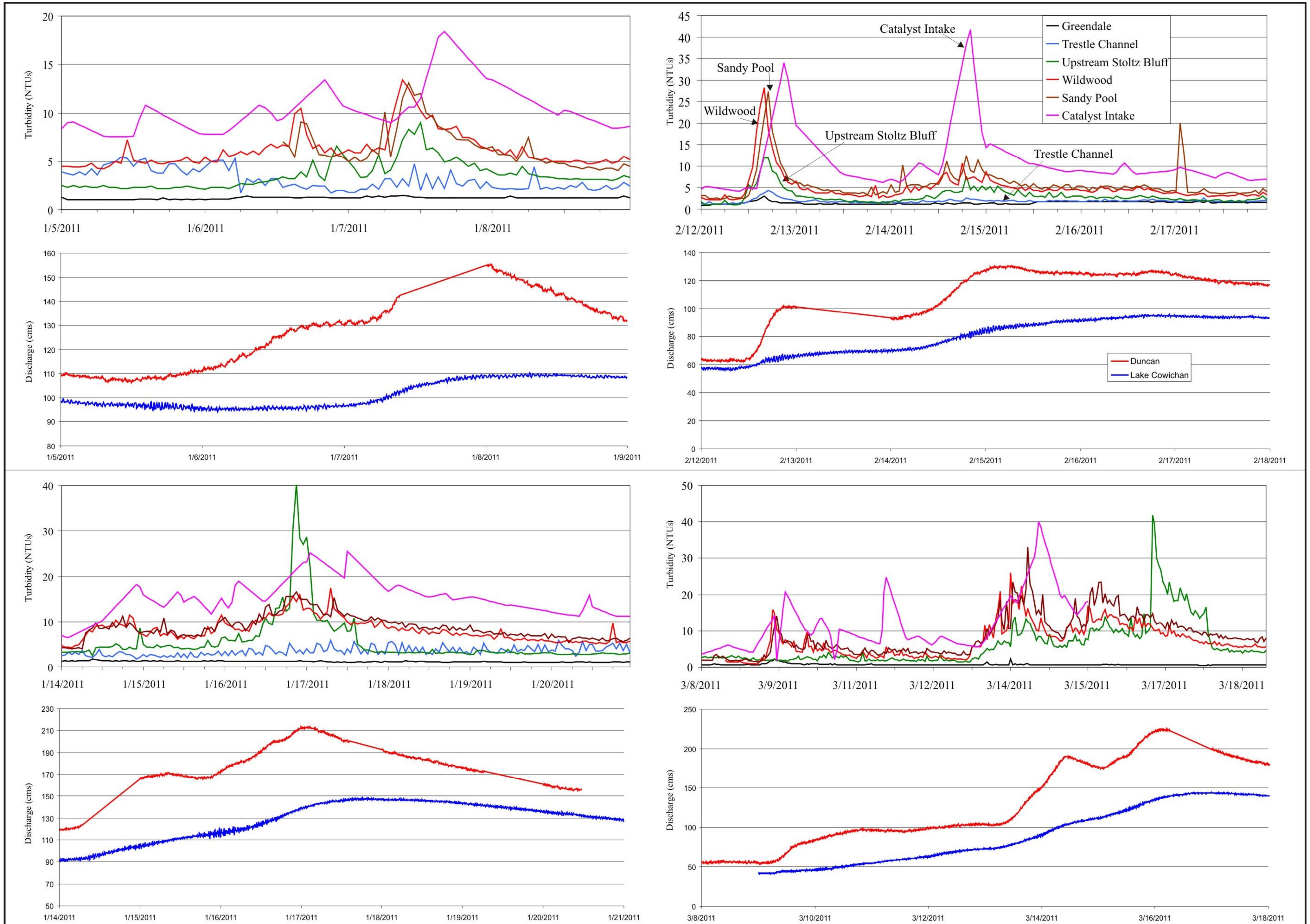

Figure 11. Turbidity at six sites in Cowichan River during high discharge events in January, February and March 2011.

Total suspended solids (TSS) values were calculated for all sites from the real-time turbidities measured continuously with the instream meters. TSS values were then plotted for the higher discharge events that occurred between October 2010 and March 2011 (Figure 12 to Figure 14). Between 23 October and 19 November 2010 when discharges at the Duncan WSC station were <110 cms, TSS values increased greatly between Trestle Channel and Upstream of Stoltz Bluff and between Sandy Pool and Catalyst but showed little to no increases between Upstream of Stoltz Bluff to Sandy Pool. For event periods with >100 cms, there was generally increasing TSS values between the Upstream of Stoltz Bluff to Sandy Pool sites but the greatest increases between successive stations proceeding downstream still occurred between Trestle Channel and Upstream of Stoltz Bluff and between Sandy Pool and Catalyst Intake sites. These changes in TSS are also observed in the comparison of mean turbidity and mean TSS values for each high discharge event (Figure 15 and Figure 16). In addition, it is apparent that after 7 December 2010 there are incremental gains in TSS at successive sites proceeding downstream for most event periods with >100 cms.

TSS load estimates for the 12 event periods ranged from a total of 1,260 tonnes at Trestle Channel to 13,037 tonnes at Catalyst Intake (Table 4). The estimated TSS load for the period 20 October 2010 to 23 March 2011 ranged from 2,426 tonnes at Trestle Channel to 19,155 tonnes at Catalyst Intake. However, an incomplete turbidity dataset for the Sandy Pool site prevented an accurate TSS estimate for this period. Nevertheless, it is apparent that the contribution from Stoltz Bluff to the TSS load estimate at the Catalyst Intake site was ~3% during this period, with contributions for individual event periods ranging from 0 to 17% (Table 5). In comparison, the contribution from Block 51 was estimated at ~39% of the estimated TSS load at the Catalyst Intake.

TSS yields (tonnes/river km) for the 20 October 2010 to 23 March 2011 period were highest for the Sandy Pool to Catalyst Intake section (10.7 river km) at 893, followed by the Trestle Channel to Upstream of Stoltz Bluff section (12.3 river km) at 607. The TSS yield in the Upstream of Stoltz Bluff to Wildwood section (3.3 river km) was 167. In comparison, the TSS yield for the 12 event periods was higher from the Upstream of Stoltz Bluff to Wildwood section than from the Trestle Channel to Upstream of Stoltz Bluff section.

The low sediment contribution from Stoltz Bluff in 2010/11 is substantiated by the effectiveness of the constructed sediment retention area at the toe of the Bluff in reducing the volume of sediments delivered from the Bluff to the river. Since completion of the rehabilitation project in 2006, the retention basin has captured ~19,270 m^3 of fine sediment (C. Sutherland, Kerr Wood Leidal unpubl. data), estimated at >95% of the total volume that has sloughed from the Bluff (J. Craig, BCCF pers. comm.) (Figure 17). Sediment volumes are based on topographic surveys of the sediment retention area.

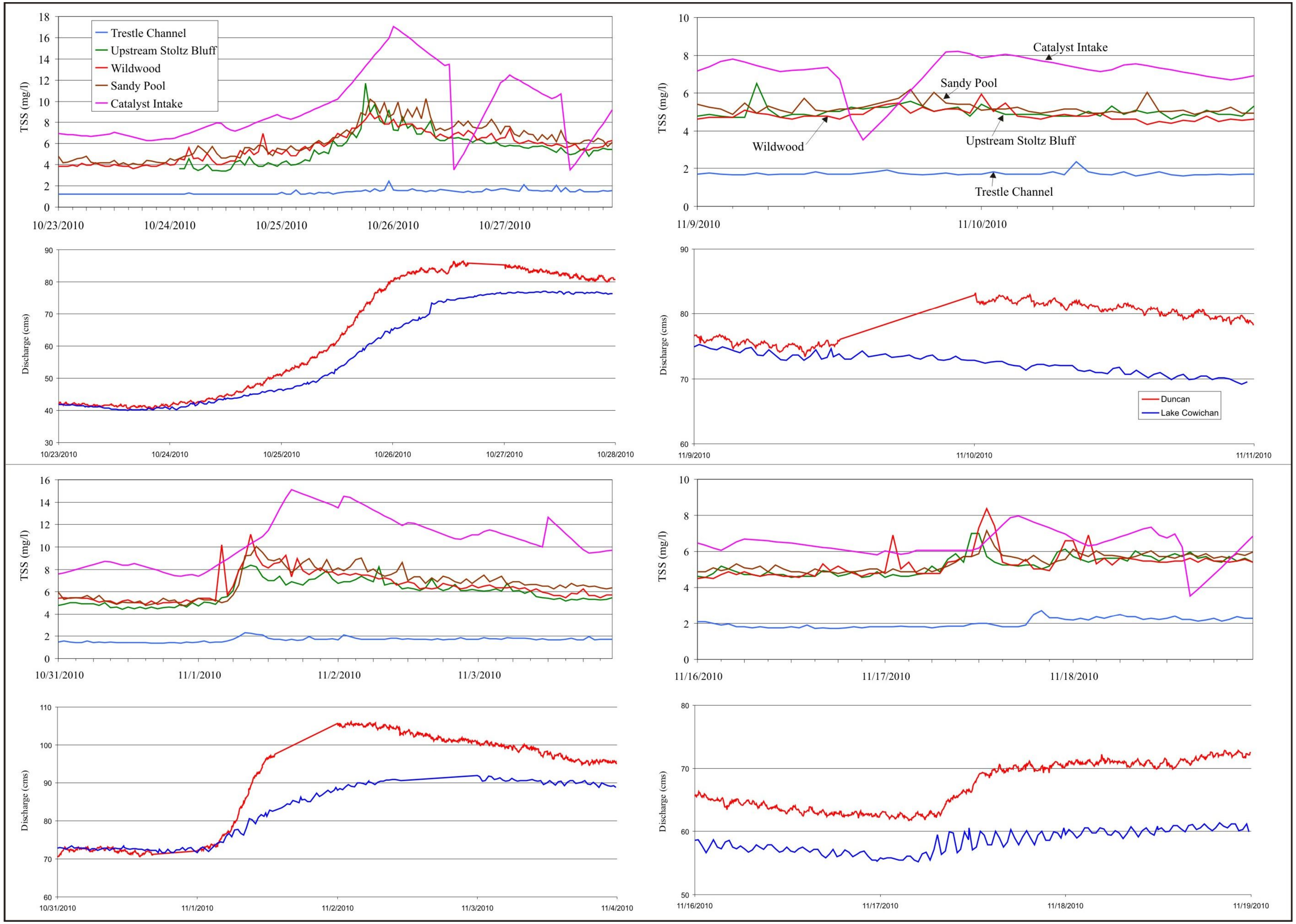

Figure 12. Calculated Total Suspended Solids (TSS) concentrations at six sites in Cowichan River during high discharge events in October and November 2010.

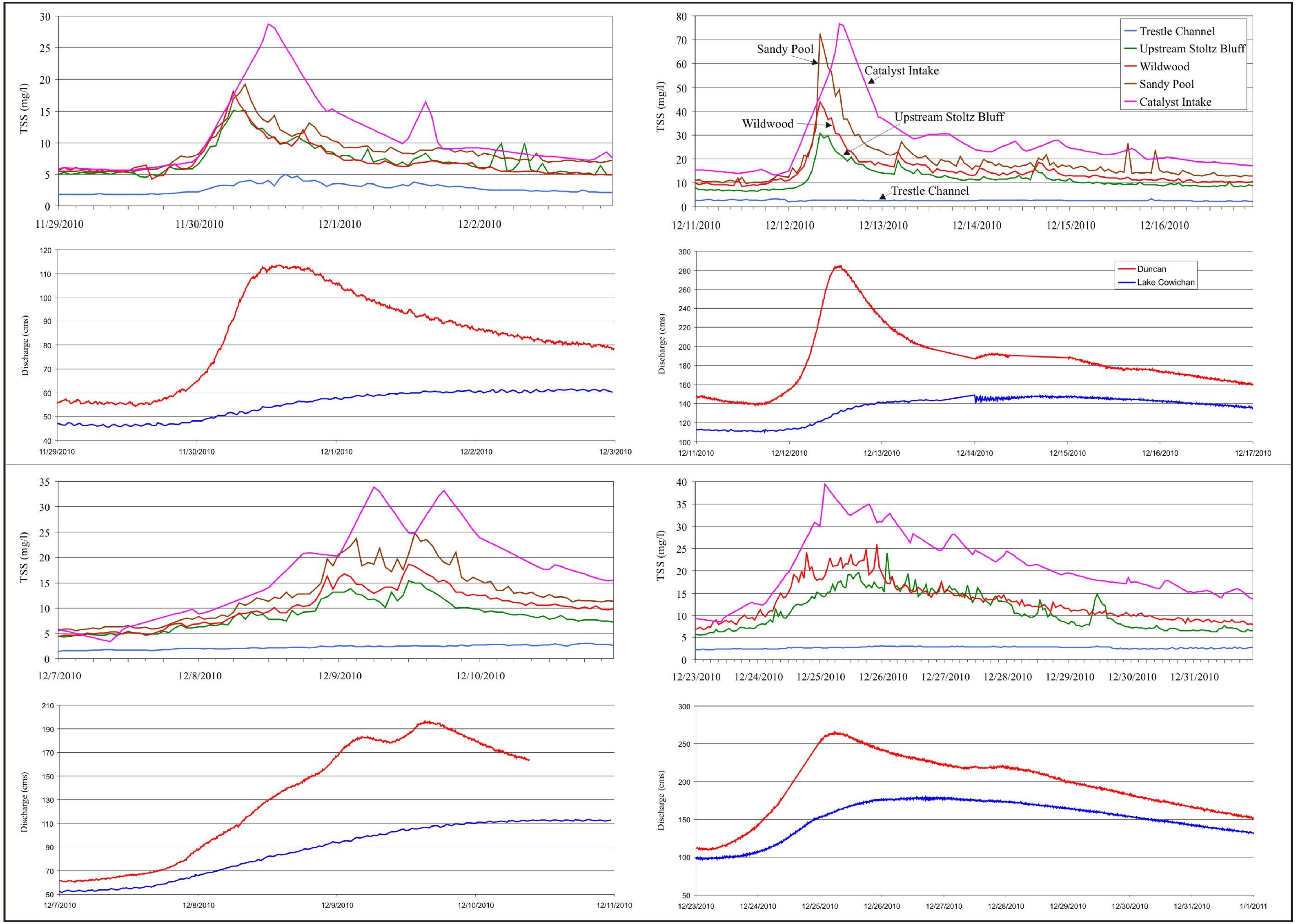

Figure 13. Calculated Total Suspended Solids (TSS) concentrations at six sites in Cowichan River during high discharge events in November and December 2010.

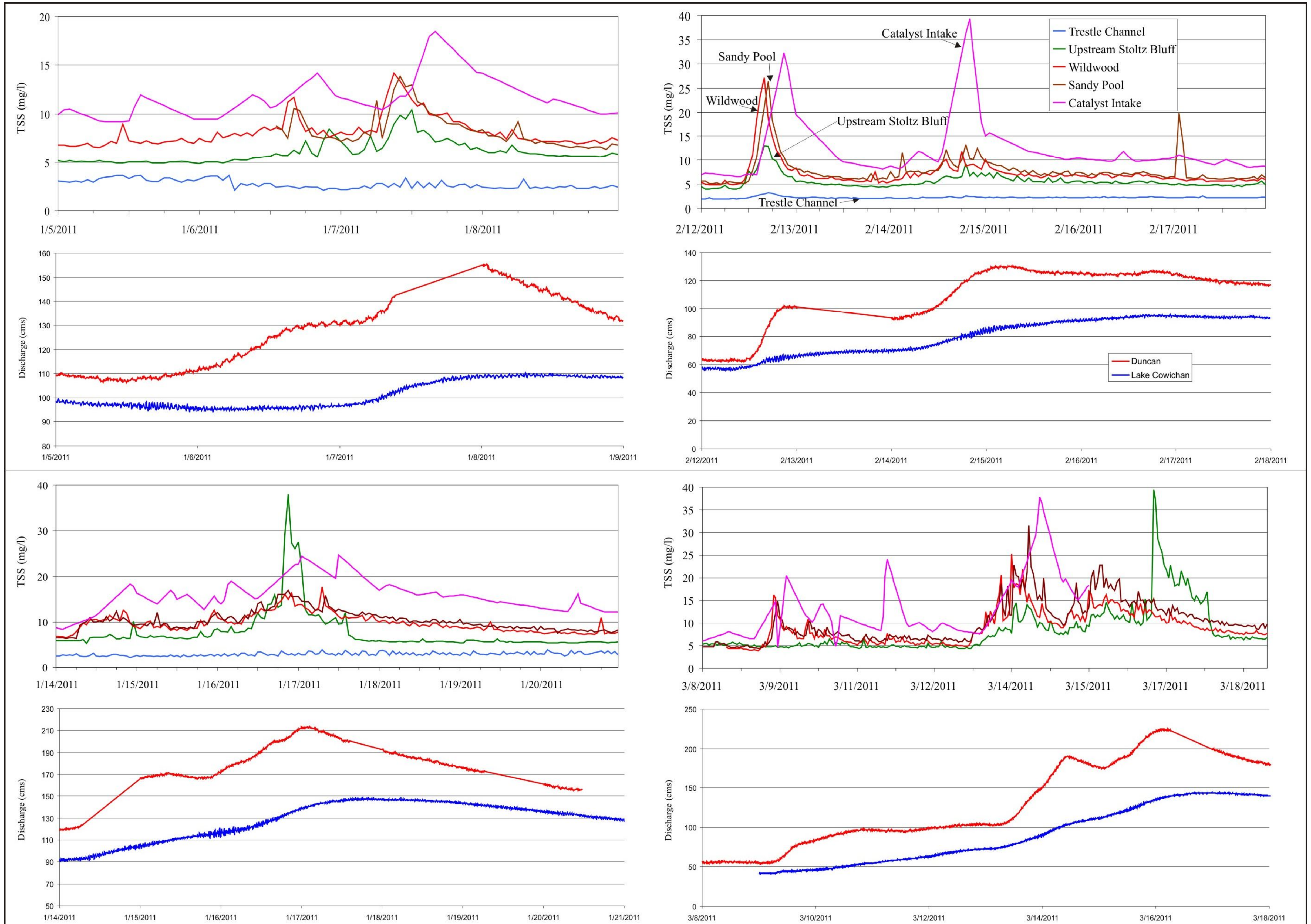

Figure 14. Calculated Total Suspended Solids (TSS) concentrations at six sites in Cowichan River during high discharge events in January, February and March 2011.

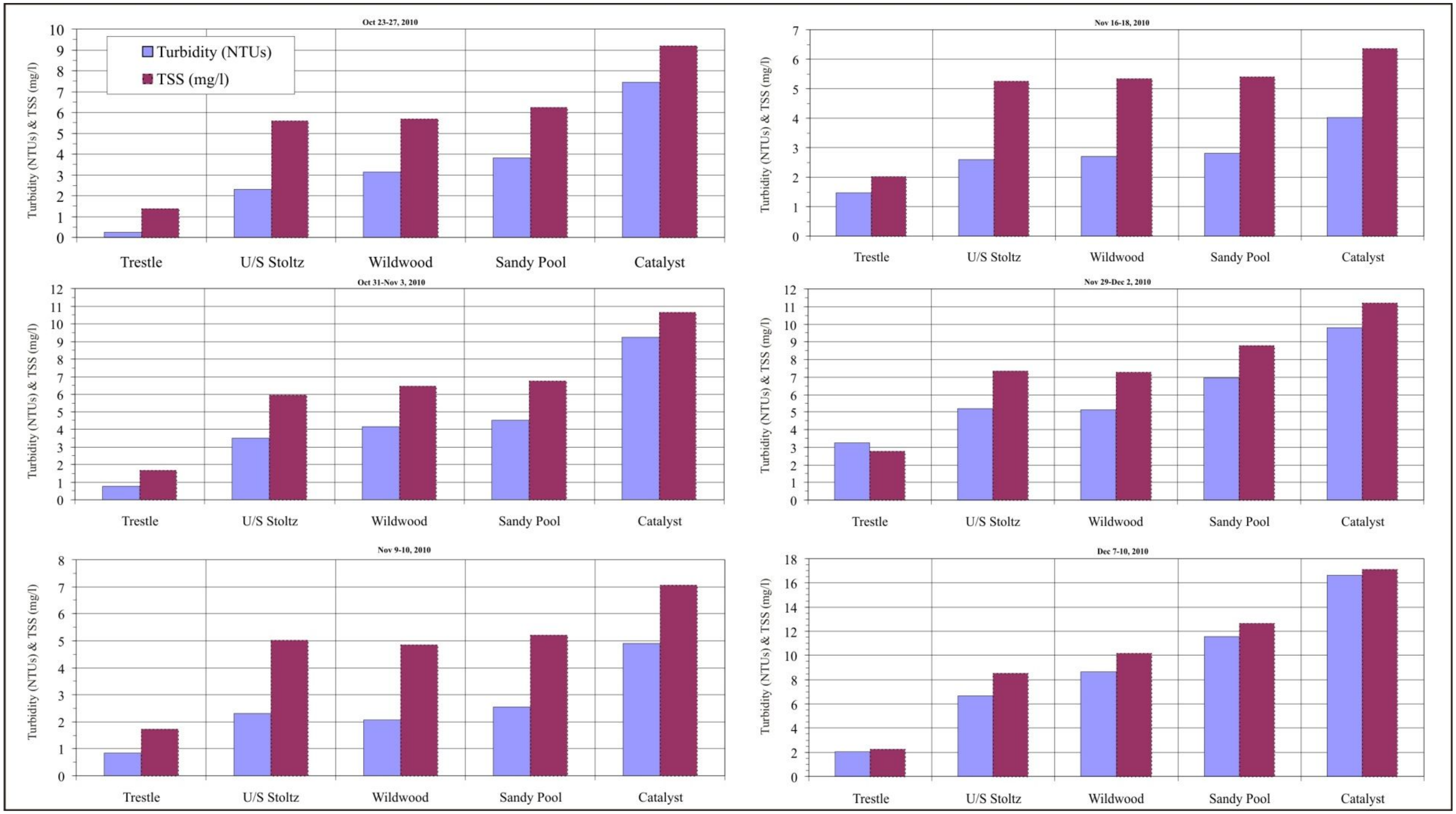

Figure 15. Comparison of mean turbidity and TSS values for six high discharge events between December 2010 and March 2011.

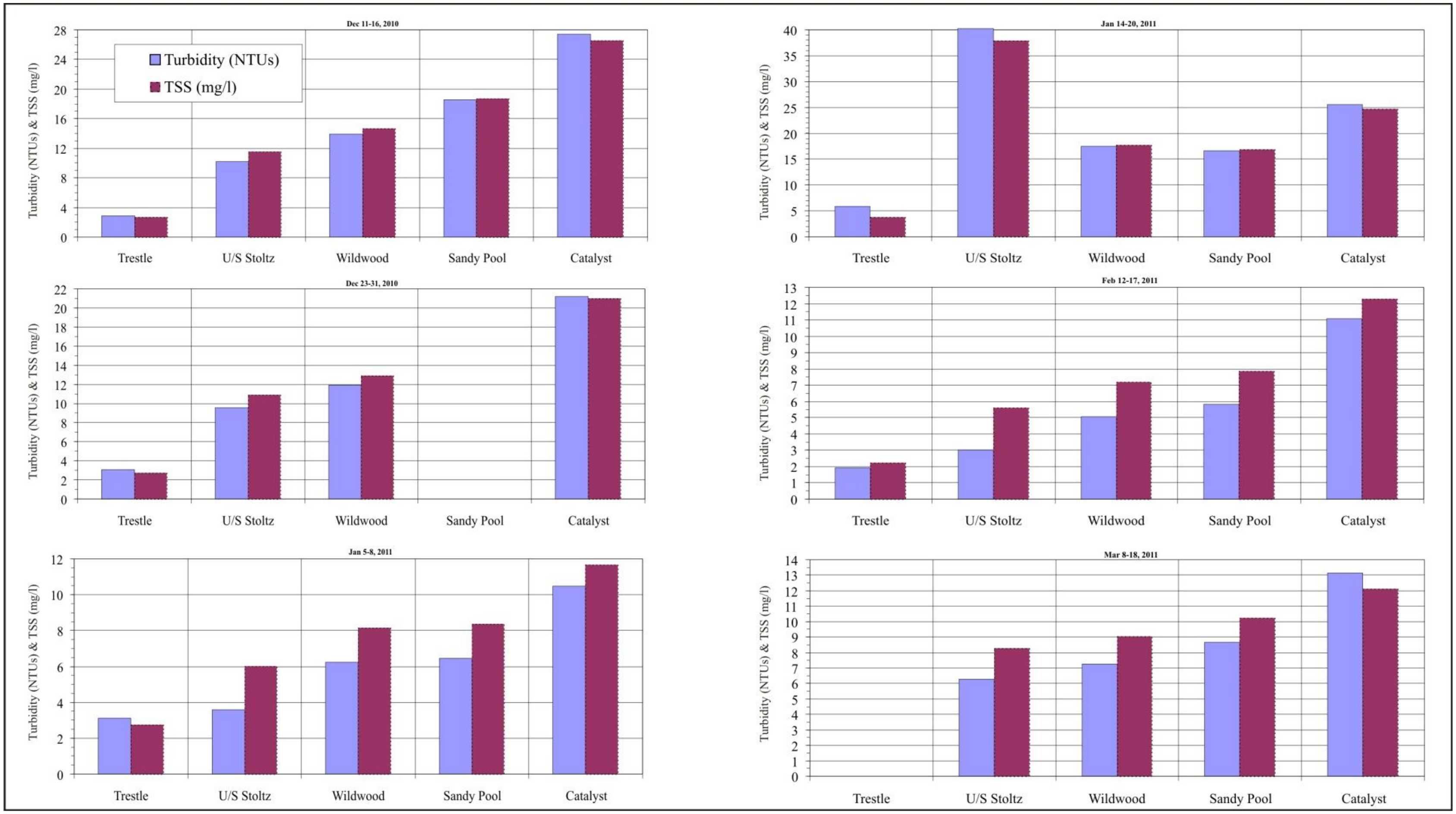

Figure 16. Comparison of mean turbidity and TSS values for six high discharge events between December 2010 and March 2011.

Table 4. Estimated total suspended sediment load in 2010/11 for each of six sites in the Cowichan River.

	Total Suspended Sediment Load to Site (tonnes)				
Date	Trestle Channel	Upstream of Stoltz Bluff	Wildwood	Sandy Pool	Catalyst Intake
Oct 23-27, 2010	37	131	158	175	264
Oct 31- Nov 3, 2010	50	184	200	211	340
Nov 9-10, 2010	22	66	64	69	96
Nov 16-18, 2010	32	86	88	90	111
Nov 29-Dec 2, 2010	59	174	175	216	347
Dec 7-10, 2010	79	343	424	540	913
Dec 11-16, 2010	200	975	1255	1639	2739
Dec 23-31, 2010	341	1529	1806	-	3311
Jan 5-8, 2011	100	239	326	**217**	520
Jan 14-20, 2011	241	699	890	952	1661
Feb 12-17, 2011	99	269	348	387	697
Mar 8-18, 2011	**-**	1017	**1030**	1242	2039
Total of 12 periods	**1260**	5714	**6764**	**5739**	13037
Oct 20/10 - Mar 23/11	**2426**	9885	**10435**	**9599**	19155

Note: incomplete datasets shown in bold and missing datasets with dash

Table 5. Estimated total suspended sediment load (tonnes) and yield (tonnes/km) in 2010/11 contributed by each section of the Cowichan River.

	Blk 51 Contribution	Stoltz Bluff Contribution		
Date	Trestle to Upstream of Stoltz Bluff	Upstream of Stoltz Bluff to Wildwood	Wildwood to Sandy Pool	Sandy Pool to Catalyst
Oct 23-27, 2010	94	27	17	89
Oct 31- Nov 3, 2010	134	16	11	129
Nov 9-10, 2010	44	-2	5	26
Nov 16-18, 2010	54	2	2	21
Nov 29-Dec 2, 2010	115	1	42	131
Dec 7-10, 2010	264	81	116	373
Dec 11-16, 2010	775	279	384	1101
Dec 23-31, 2010	1188	277	-	-
Jan 5-8, 2011	139	86	**-**	**303**
Jan 14-20, 2011	458	192	61	709
Feb 12-17, 2011	170	78	39	311
Mar 8-18, 2011	-	**13**	**212**	797
Total of 12 periods (tonnes)	**3436**	**1050**	**889**	**3988**
TSS yields (tonnes/km) for 12 periods	279	318	83	373
Oct 20/10 - Mar 23/11 (tonnes)	**7460**	**550**	**-836**	**9556**
TSS yields (tonnes/km) for Oct 20/10 to Mar 23/11	607	167	-78	893

Note: incomplete datasets shown in bold and missing datasets with dash

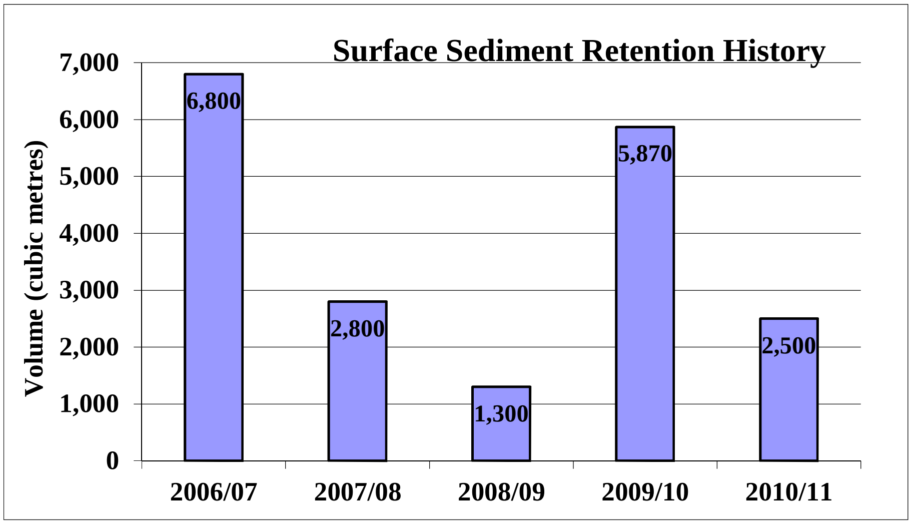

Figure 17. Estimated volume of sediment captured in the constructed retention area at the toe of Stoltz Bluff (C. Sutherland, KWL unpubl. data).

Laboratory analysis of water samples collected from six sites in the Cowichan River showed a generally increasing trend in turbidity and TSS from upstream to downstream sites (Table 6; Figure 18; Figure 19). The laboratory values of turbidity from collected water samples were generally lower than the measurements obtained from the continuously recording meters installed at the six sites (Table 7). With the exception of the December 12 discharge, turbidities were ≤16 NTU at all sites where water samples were collected. During the largest discharge event in the study period that occurred on 12 December 2010, the highest turbidities for all sites except Greendale were recorded. Similarly, total suspended solids (TSS) concentrations were highest on 12 December 2010 for Upstream of Stoltz Bluff, Wildwood, Sandy Pool and Catalyst Pumphouse.

A comparison of the Wildwood and Upstream of Stoltz Bluff sites indicated that no pronounced spike in turbidity or TSS as a consequence of Stoltz Bluff sediment inputs was evident. However, there was noticeable increase in TSS between Wildwood and Sandy Pool in the December 12 and 24 samples. Also, there was a noticeable increase in turbidity and TSS between the Trestle Channel and Upstream of Stoltz Bluff sites during the large flood event on December 12.

Table 6. Laboratory analysis results of turbidity (NTUs) and TSS (mg/l) for water samples collected in 2010/11 in Cowichan River.

	Greendale		Trestle Channel		Upstream of Stoltz Bluff		Wildwood		Sandy Pool		Catalyst Intake		Clear Creek	
Date	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity
30-Nov-10	<5.0	-	9.5	-	18	-	14	-	19	-	-	-	-	-
9-Dec-10	<5.0	1.5	5.3	2.8	21	7.9	22	8.7	29	5.5	43	10.2	230	252
12-Dec-10	<5.0	1.9	<5.0	4.6	60	16.9	64	22.7	110	26.9	120	29.5	1600	103.9
24-Dec-10	<5.0	0.6	6	1.3	16	4.1	23	8.3	47	7	30	4.9	1000	2230
7-Jan-11	<5.0	2.3	<5.0	1.1	10	4.4	14	6.2	18	6.7	28	6.4	1400	1550
15-Jan-11	<5.0	0.6	<5.0	1	5	3.5	14	3.5	12	4	18	6.5	170	136
15-Feb-11	<5.0	0.8	<5.0	0.7	8.5	3.2	7	3.1	23	3.2	11	4.3	270	148
14-Mar-11	<5.0	<0.5	<5.0	1.4	25	7.9	31	8.8	40	6.5	56	15.9	970	1160

Note: Detection limits are 5 mg/L for TSS and 0.5 NTUs for Turbidity

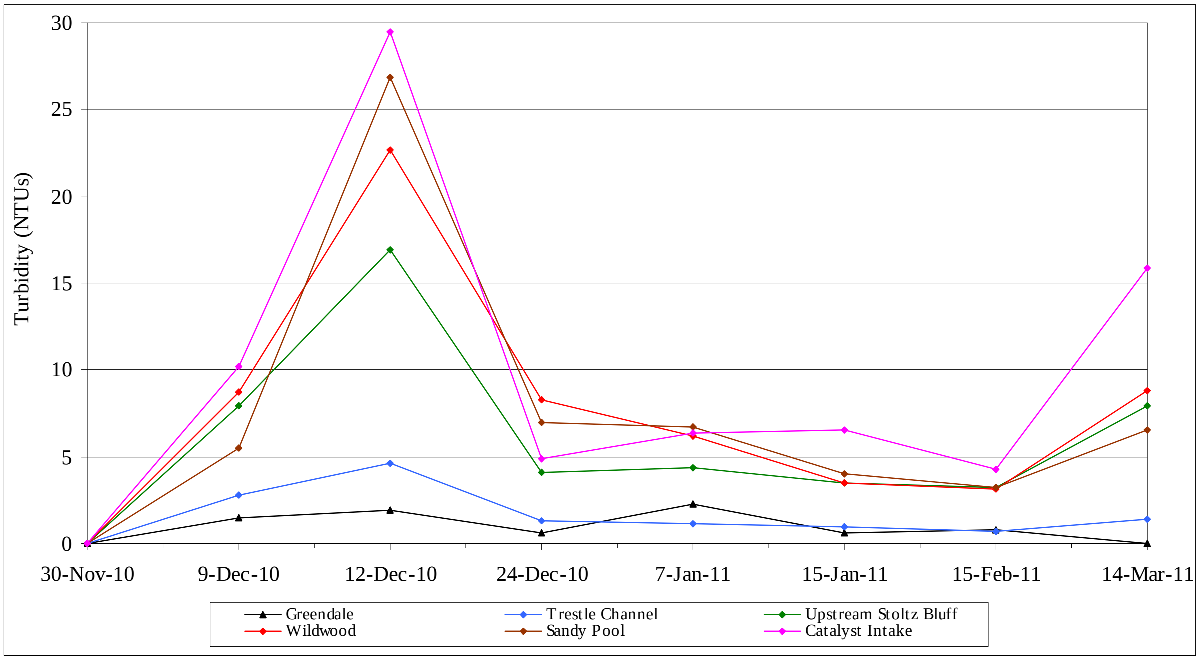

Figure 18. Turbidity measurements based on lab analysis of water samples collected at six sites in Cowichan River.

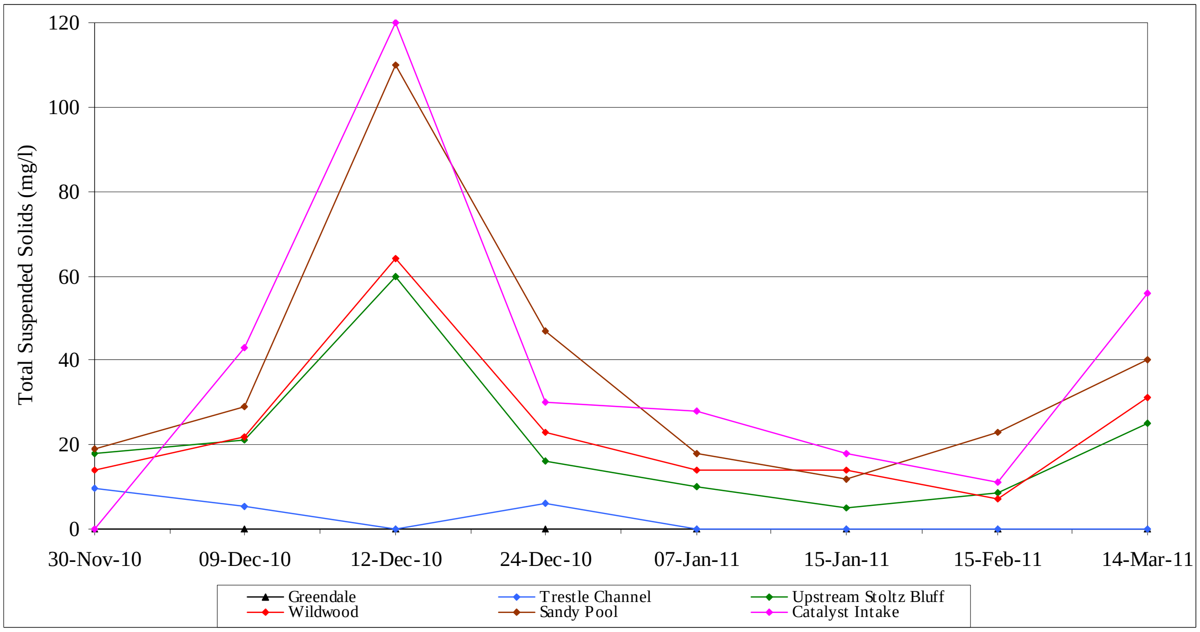

Figure 19. Total suspended solids concentrations based on lab analysis of water samples collected at six sites in Cowichan River.

Table 7. Comparison of turbidity (NTUs) measurements obtained from continuous recording meter and laboratory analysis of water samples in 2010/11.

	Greendale		Trestle Channel		Upstream of Stoltz Bluff		Wildwood		Sandy Pool		Catalyst Intake	
Date	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab
9-Dec-10	1.0	1.5	2.5	2.8	10.3	7.9	13.4	8.7	17.0	5.5	31.0	10.2
12-Dec-10	0.9	1.9	3.6	4.6	31.3	16.9	43.8	22.7	70.3	26.9	49.3	29.5
24-Dec-10	0.6	0.6	2.6	1.3	7.8	4.1	13.2	8.3	-	7.0	17.2	4.9
7-Jan-11	1.2	2.3	2.0	1.1	7.8	4.4	12.5	6.2	13.1	6.7	10.0	6.4
15-Jan-11	1.2	0.6	2.9	1.0	4.0	3.5	6.1	3.5	6.5	4.0	15.7	6.5
15-Feb-11	1.5	0.8	2.0	0.7	2.9	3.2	5.0	3.1	5.4	3.2	12.0	4.3
14-Mar-11	0.7	<0.5	-	1.4	12.6	7.9	16.2	8.8	21.6	6.5	29.0	15.9

Year 2011-2012

Real-time turbidity measurements, recorded continuously at up to six sites in the Cowichan River, were evaluated for 10 storm events that occurred between 19 October 2011 and 31 March 2012 (Figure 20 to Figure 22). For a given event, turbidities typically increased from the upstream to downstream sites with the lowest values recorded at Greendale and the highest turbidities at the Catalyst Intake site. However, turbidities at the Wildwood site (station downstream of Stoltz Bluff) were higher than those at the Sandy Pool site for 27-29 December 2011 and between 21 January and 29 March. Turbidities typically peaked on the ascending limb of the flood hydrograph and turbidity values generally varied temporally with the fluctuation in flow for the hydrometric station closest to the site. The highest turbidity values for most sites occurred during a high flow event on 27-28 November 2011 (Figure 20). On this date, the maximum turbidity recorded was 67.7 NTUs at the Catalyst Intake site. The change in turbidity was similar between successive stations, with a difference of 19 NTUs between the Trestle Channel and Upstream of Stoltz Bluff sites, 20 NTUs between Upstream of Stoltz Bluff and Wildwood sites, and 22 NTUs between Wildwood and Catalyst Intake sites. Discharges were slightly higher at both WSC stations on 5-6 January 2012 but turbidities were lower at all of the sampling sites. It's important to note for the discharge events between 28 January and 6 March 2012 that provisional discharge data from the WSC real-time hydrometric stations indicated that discharges were greater at the station near Cowichan Lake outlet than at the Duncan station. It is expected that these discharges will be adjusted once WSC reviews and verifies the datalogs. Adjustments to the higher than expected discharges at Cowichan Lake outlet will affect calculated TSS values. Consequently, TSS values in this report for 2011/12 would need to be re-calculated once WSC data have been verified.

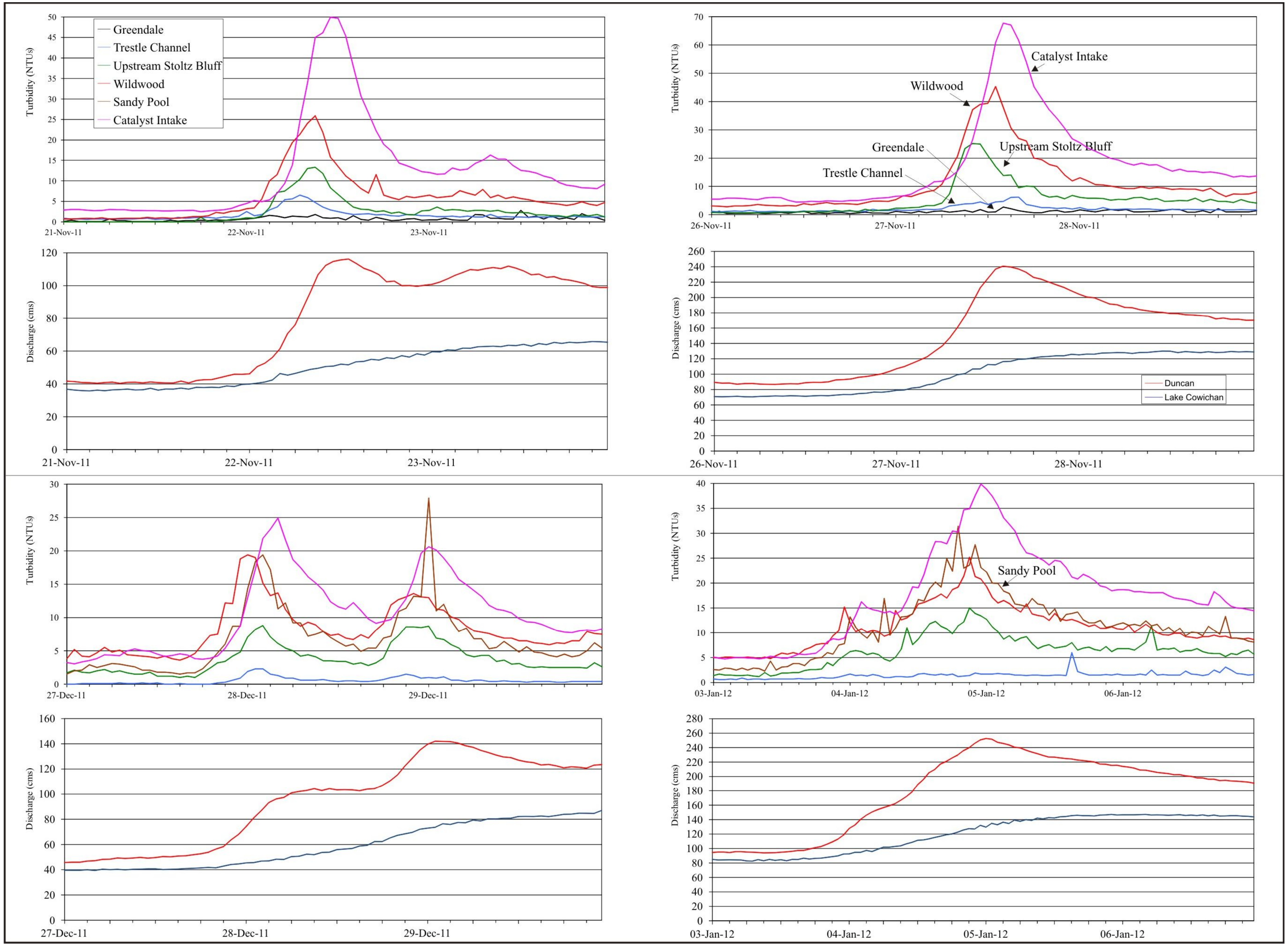

Figure 20. Turbidity at six sites in Cowichan River during high discharge events in November 2011 to January 2012.

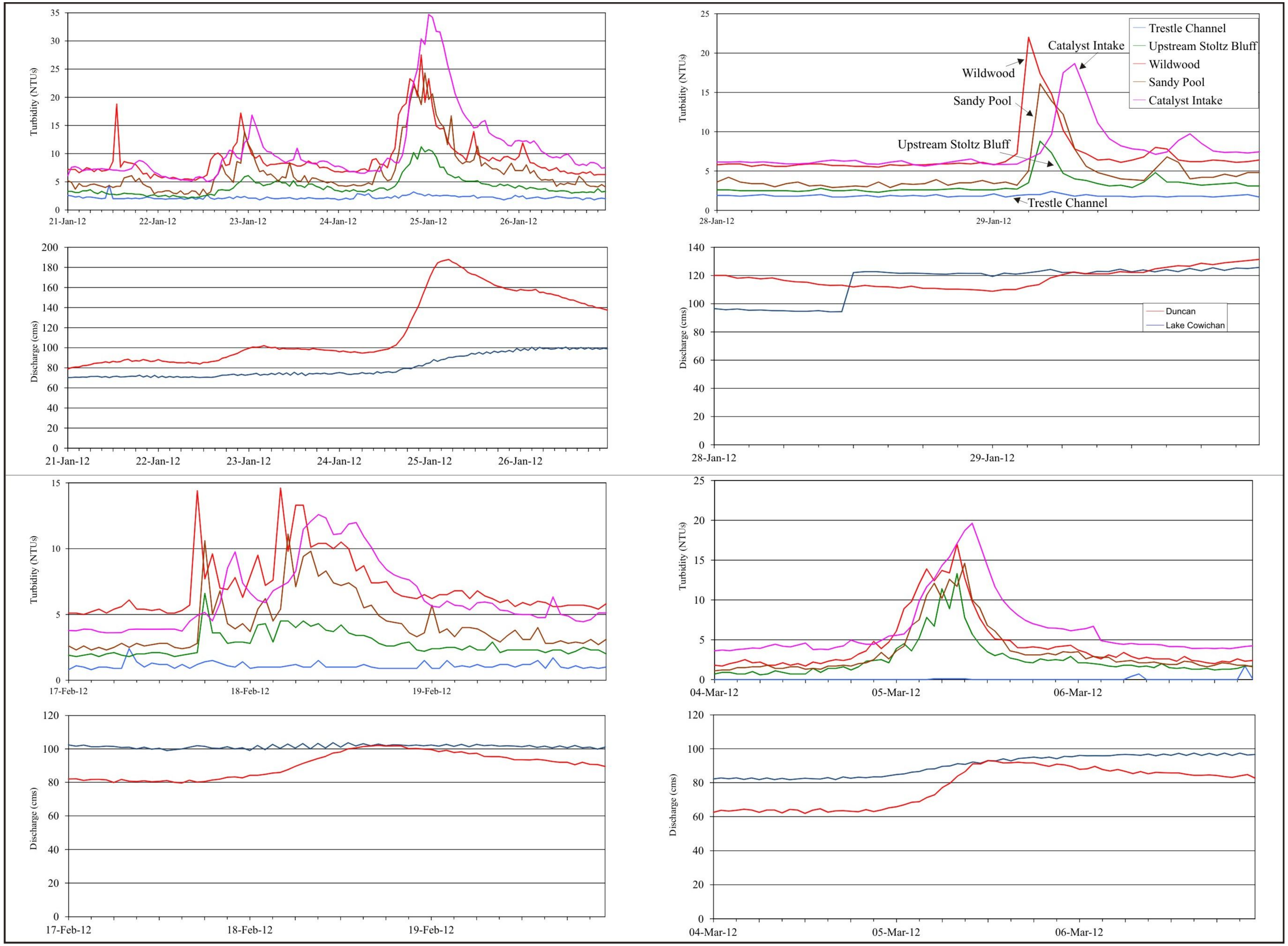

Figure 21. Turbidity at five sites in Cowichan River during high discharge events in January to March 2012.

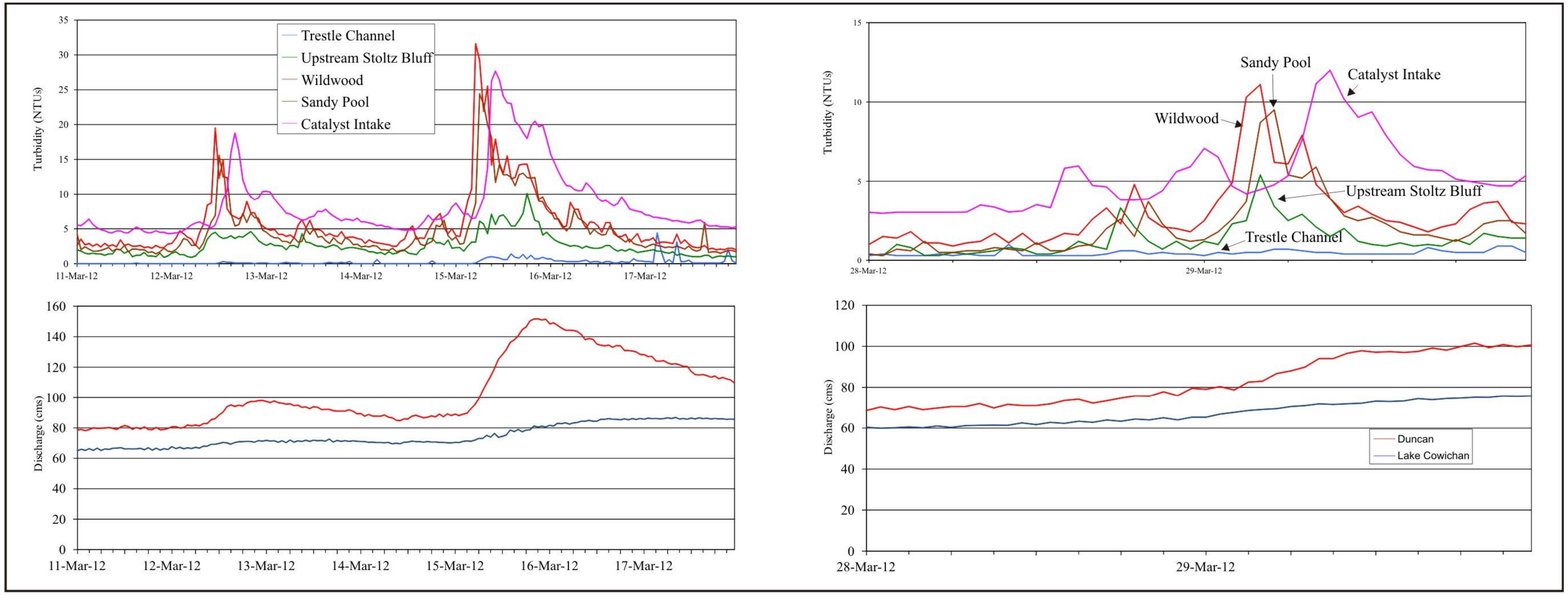

Figure 22. Turbidity at five sites in Cowichan River during high discharge events in March 2012.

Total suspended solids (TSS) values were calculated for all sites from the real-time turbidities measured continuously with the instream meters. TSS values were then plotted for the higher discharge events that occurred between October 2011 and March 2012 (Figure 23 to Figure 25). The TSS plots closely reflect the turbidity plots described above. A decrease in TSS and turbidity from the Wildwood site to Sandy Pool site is clearly evident in the comparison of mean turbidity and mean TSS values for the high discharges events on 27-29 December 2011 and between 21 January and 29 March (Figure 26 and Figure 27).

TSS load estimates for the 10 event periods ranged from a total of 475 tonnes at Trestle Channel to 4,326 tonnes at Catalyst Intake (Table 8). The estimated TSS load for the period 20 October 2011 to 31 March 2012 ranged from 2,151 tonnes at Trestle Channel to 11,570 tonnes at Catalyst Intake. The contribution from Stoltz Bluff to the TSS load estimate at the Catalyst Intake site averaged 21% for the 10 high discharge events, with contributions for individual event periods ranging from 0 to 46% (Table 9). In comparison, the contribution from Block 51 averaged 28% and ranged between 16 and 51% of the estimated TSS load at the Catalyst Intake.

TSS yields (tonnes/river km) for the 20 December 2011 to 31 March 2012 period were highest for the Upstream of Stoltz Bluff to Wildwood section (3.3 river km) at 637, followed by the Sandy Pool to Catalyst Intake section (10.7 river km) at 245. The TSS yield in the Trestle Channel to Upstream of Stoltz Bluff section (Block 51; 12.3 river km) was 243 tonnes/river km. The TSS yield for the 10 event periods was also markedly higher for the Upstream of Stoltz Bluff to Wildwood section than for the Sandy Pool to Catalyst Intake section. The high TSS yields from the Stoltz Bluff reach may be attributed in part to the relatively high TSS from Clear Creek. TSS values for Clear Creek ranged from 200 to 2100 in the five sampling events in 2011/12 (Table 10). Clear Creek drains water off the valley wall behind Stoltz Bluff and, during its descent to the Cowichan River, captures sediment laden waters from the sediment retention area of Stoltz Bluff. During all high discharge events when water quality samples were collected, Clear Creek was overtopping the constructed ford crossing at Stoltz Bluff and discharging into the river.

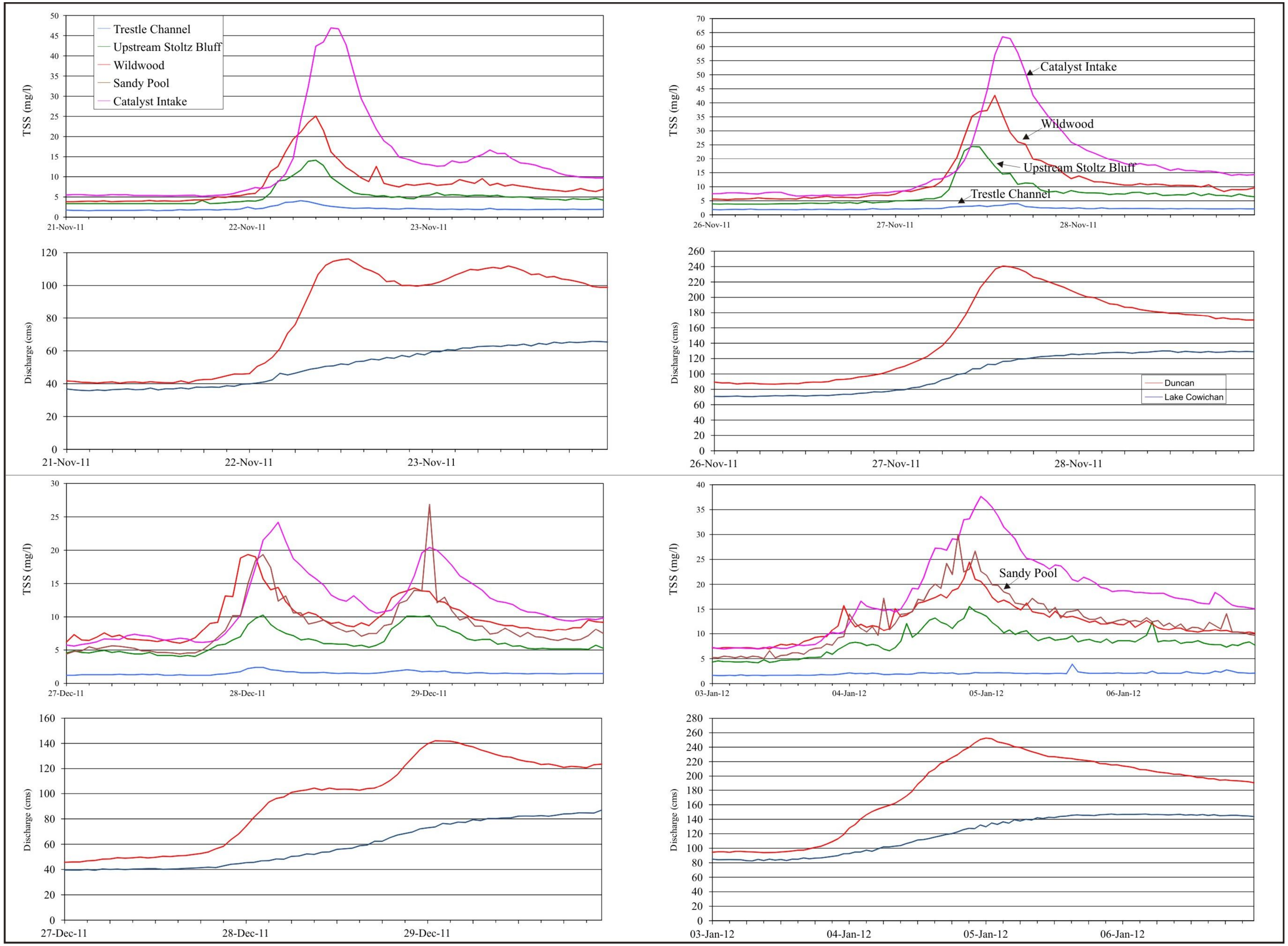

Figure 23. Calculated Total Suspended Solids (TSS) concentrations at five sites in Cowichan River during high discharge events in November 2011 to January 2012.

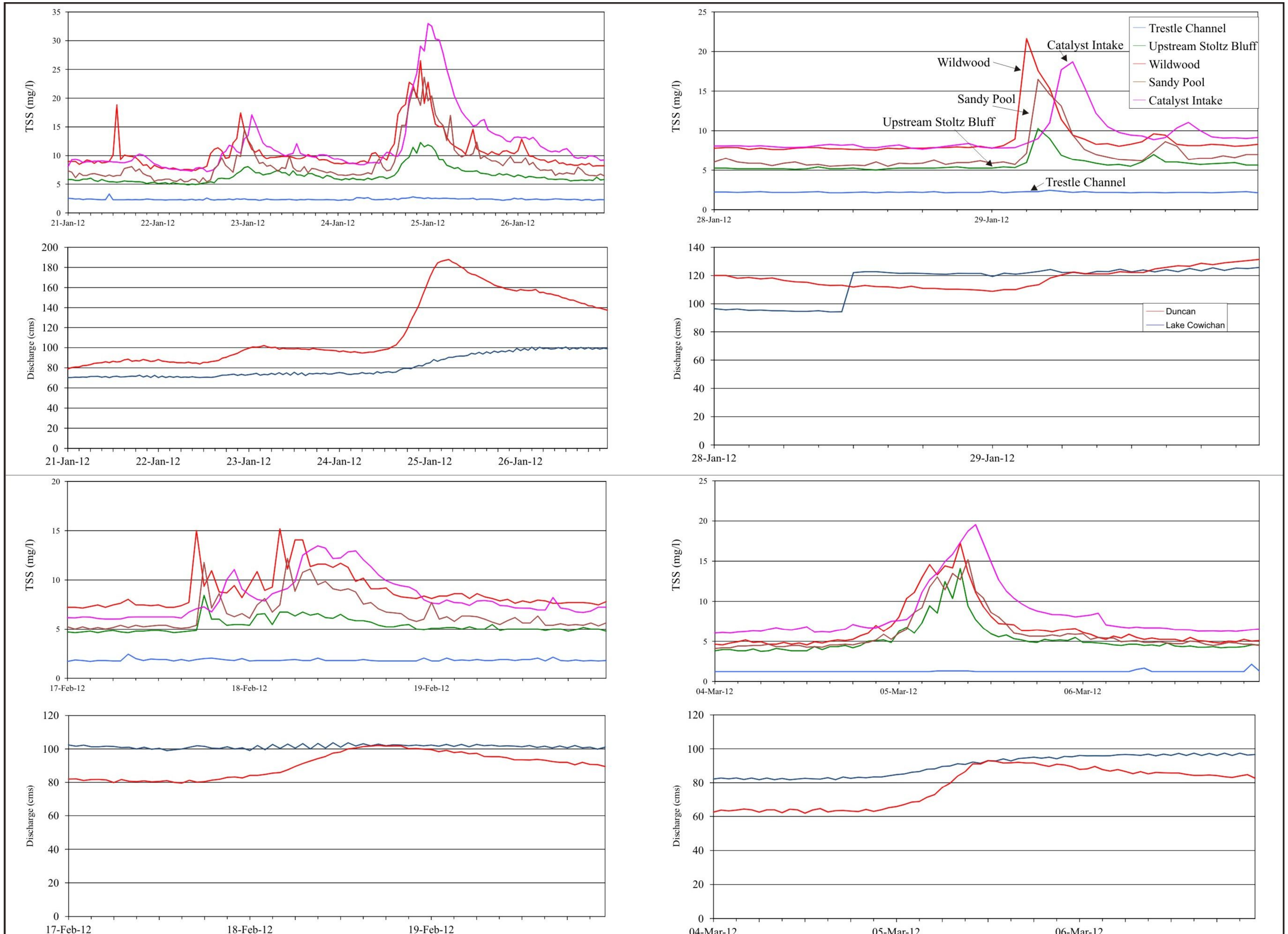

Figure 24. Calculated Total Suspended Solids (TSS) concentrations at five sites in Cowichan River during high discharge events in January to March 2012.

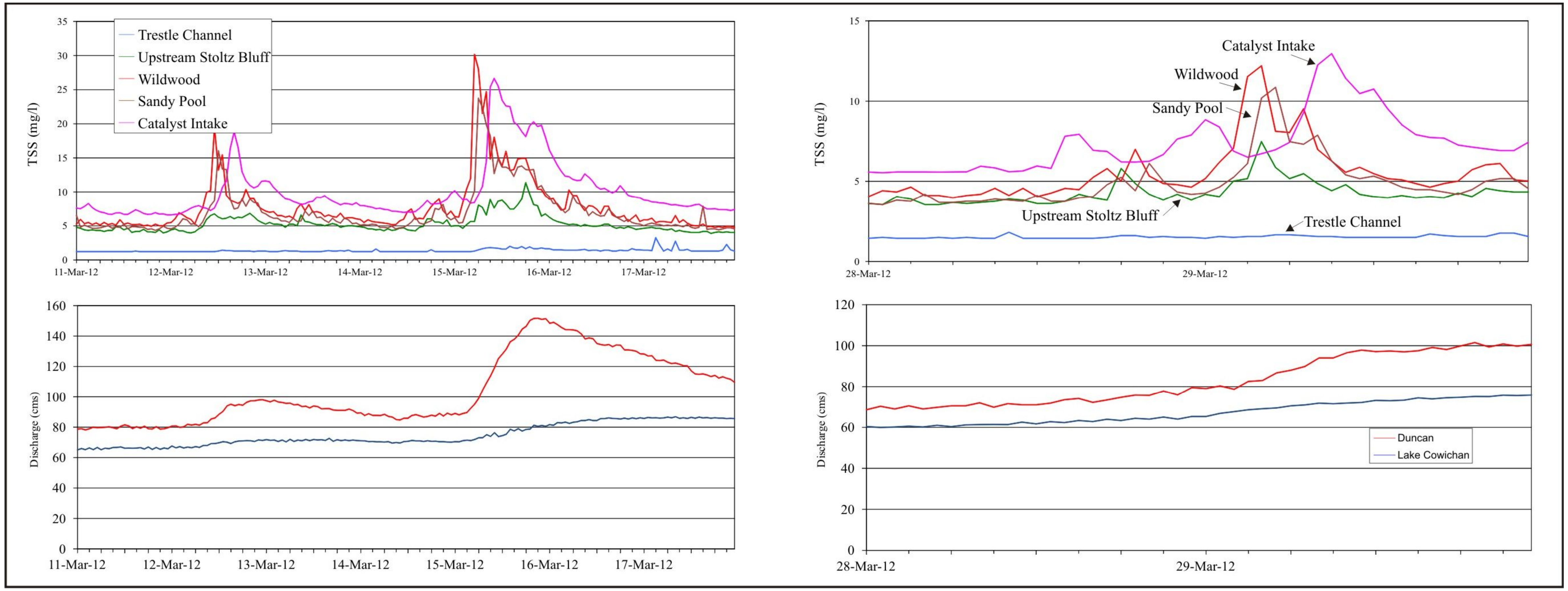

Figure 25. Calculated Total Suspended Solids (TSS) concentrations at five sites in Cowichan River during high discharge events in March 2012.

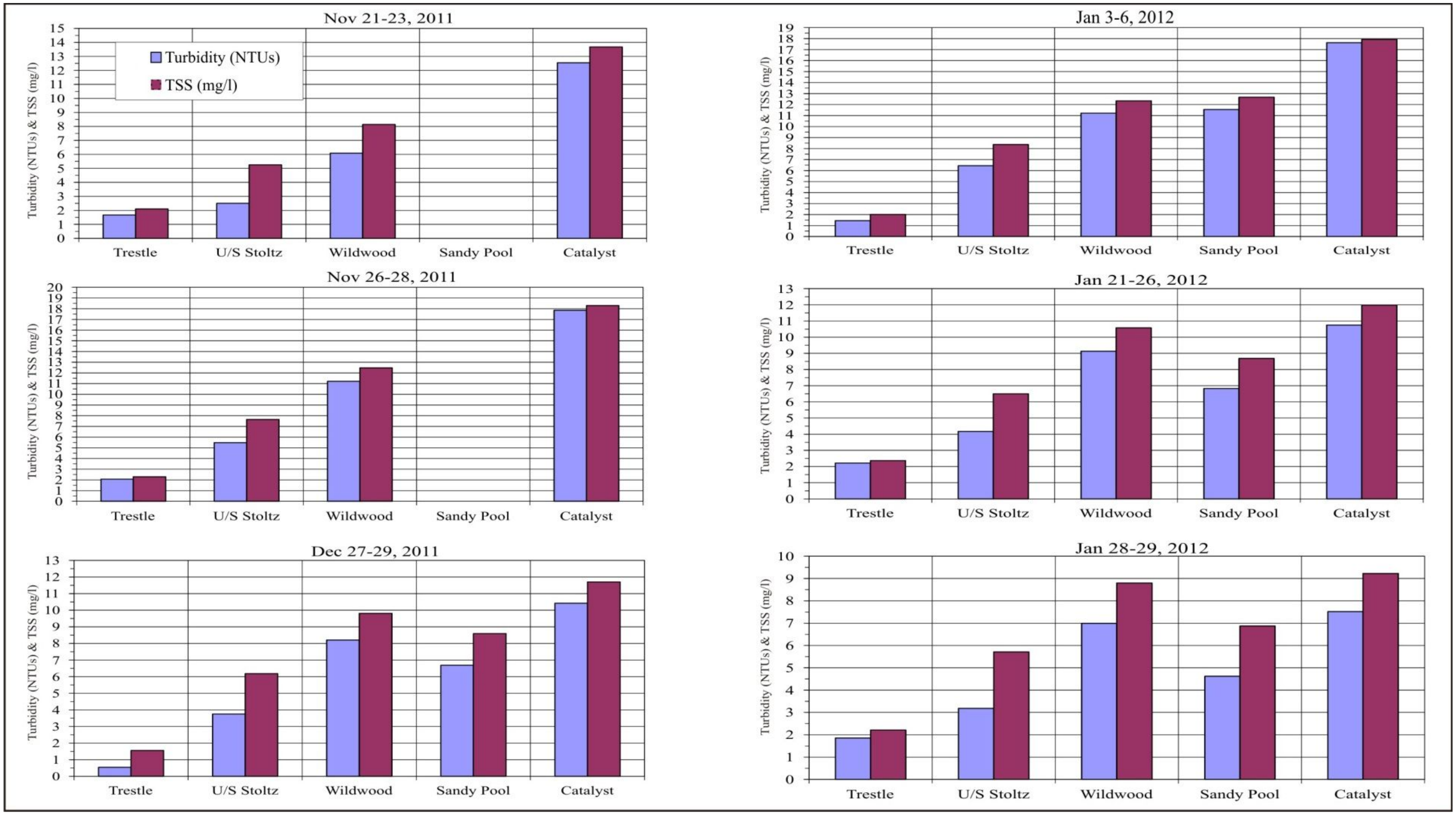

Figure 26. Comparison of mean turbidity and TSS values for six high discharge events between November 2011 and January 2012.

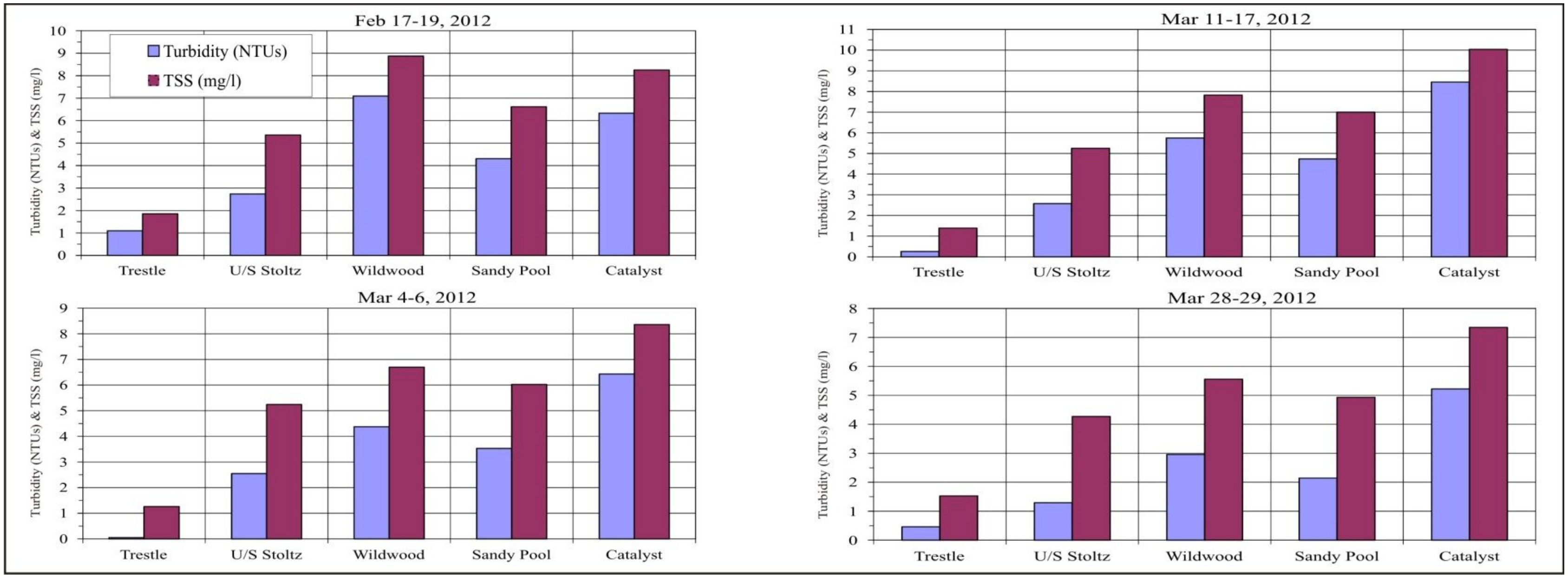

Figure 27. Comparison of mean turbidity and TSS values for four high discharge events between February 2012 and March 2012.

Table 8. Estimated total suspended sediment load in 2011/12 for each of five sites in the Cowichan River.

	Total Suspended Sediment Load to Site (tonnes)				
Date	Trestle Channel	Upstream of Stoltz Bluff	Wildwood	Sandy Pool	Catalyst Intake
Nov 21-23, 2011	22	71	119	-	303
Nov 26-28, 2011	68	269	456	-	865
Dec 27-29, 2011	27	123	197	180	308
Jan 3-6, 2012	93	445	661	707	1221
Jan 21-26, 2012	107	331	547	464	780
Jan 28-29, 2012	45	119	183	144	190
Feb 17-19, 2012	49	139	229	171	198
Mar 4-6, 2012	21	92	118	107	139
Mar 11-17, 2012	24	60	61	112	215
Mar 28-29, 2012	19	43	44	66	107
Total of 10 periods	475	1692	2615	**1949**	4326
Oct 20/11 - Mar 23/12	2077	5925	8712	**-**	11214
Dec 20/11 - Mar 31/12	1555	4543	6644	5707	8329

Note: incomplete datasets shown in bold and missing datasets with dash

Table 9. Estimated total suspended sediment load (tonnes) and yield (tonnes/km) in 2011/12 contributed by each section of the Cowichan River.

Date	Blk 51 Contribution Trestle to Upstream of Stoltz Bluff	Stoltz Bluff Contribution Upstream of Stoltz Bluff to Wildwood	Wildwood to Sandy Pool	Sandy Pool to Catalyst Intake
Nov 21-23, 2011	49	48	-	-
Nov 26-28, 2011	201	187	-	-
Dec 27-29, 2011	96	74	-17	128
Jan 3-6, 2012	352	216	46	514
Jan 21-26, 2012	224	216	-83	316
Jan 28-29, 2012	74	64	-40	46
Feb 17-19, 2012	90	90	-59	27
Mar 4-6, 2012	71	26	-11	32
Mar 11-17, 2012	36	1	51	103
Mar 28-29, 2012	25	0	22	41
Total of 10 periods (tonnes)	1217	924	**-91**	1208
TSS yields (tonnes/km) for 10 periods	99	280	-17	113
Oct 20/11 - Mar 23/12 (tonnes)	3848	2787	-	-
TSS yields (tonnes/km) for Oct 20/11 to Mar 23/12	313	845	-	-
Dec 20/11 - Mar 31/12 (tonnes)	2988	2101	-937	2622
TSS yields (tonnes/km) for Dec 20/11 to Mar 31/12	243	637	-180	245

Note: incomplete datasets shown in bold and missing datasets with dash

Laboratory analysis of water samples collected from six sites in the Cowichan River showed a generally increasing trend in turbidity and TSS from upstream to downstream sites (Table 10; Figure 28; Figure 29). The laboratory values of turbidity from collected water samples were generally similar to the measurements obtained from the continuously recording meters installed at Trestle and Upstream of Stoltz Bluff sites (Table 11; Figure 30). Field readings with meters at the Wildwood, Sandy Pool and Catalyst Intake sites were consistently greater than laboratory measurements. The large deviation between continuous and lab turbidity readings for the Catalyst Intake site may be due to: 1) the location of the meter, located at Catalyst Mill and not at the river, 2) the discrepancy between the timing of the meter readings versus the time of water sample collection, or 3) imprecise calibration of the Catalyst turbidity meter.

In a comparison of sediment loads from high discharge events in the various river sections for 2010/11 and 2011/12, it is apparent that the sediment load contribution (tonnes) from Stoltz Bluff in both sampling years lies between the contributions estimated for Trestle to Upstream of Stoltz Bluff and Sandy Pool to Catalyst Intake sections (Figure 31). In 2011/12, measured turbidities at Sandy Pool were lower than at the Wildwood site resulting in a calculated decrease in sediment load for the Wildwood to Sandy Pool section.

Comparing high discharge event periods in the study, relative sediment load and yield from Stoltz Bluff decreased from 2010/11 to 2011/12. Sediment load contribution from Stoltz Bluff was 1050 tonnes in 2010/11 versus 924 tonnes in 2011/12 (Table 5; Table 9). At these sediment load values, sediment yield from Stoltz Bluff was 318 tonnes/km in 2010/11 versus 280 tonnes/km in 2011/12. A consistent TSS load from Stoltz Bluff in both survey years resulted in a higher percent contribution of sediment in 2011/12 because the TSS load estimated at Catalyst Intake had declined. The high TSS concentration in Clear Creek during storm events in both survey years may be the single most important factor that raises the contribution attributable to Stoltz Bluff.

Table 10. Laboratory analysis results of turbidity (NTUs) and TSS (mg/l) for water samples collected in 2011/12 in Cowichan River.

	27-Nov-11		28-Dec-11		04-Jan-12		25-Jan-12		16-Mar-12	
Date	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity	TSS	Turbidity
Greendale	2.7	0.7	5.0	0.7	4	0.6	2	0.6	4.5	<0.5
Trestle Channel	13	5.4	12	1.5	7	1.5	2	0.7	4	<0.5
Upstream of Stoltz Bluff	68	23.7	11	3.4	19	6.3	13	3.3	12	1.9
Wildwood	77	26.0	8.5	3.8	23	7.4	17	7.1	9.5	2.2
Sandy Pool	92	26.0	11	3.8	75	6.7	16	5.4	12	2.5
Catalyst Intake	75	24.0	15	4.8	26	9.6	17	6.7	13	3.7
Clear Creek	311	500	200	167	2100	1400	1600	1134	1100	5400

Notes:

1. Detection Limits are 5 mg/L for TSS and 0.5 NTUs for Turbidity for Upstream of Stoltz Bluff, Wildwood, Sandy Pool, & Catalyst Intake
2. Detection Limits are 1 mg/L for TSS and 0.5 NTUs for Turbidity for Greendale & Trestle Channel
3. Clear Creek is located in the downstream section of Stoltz Bluff.

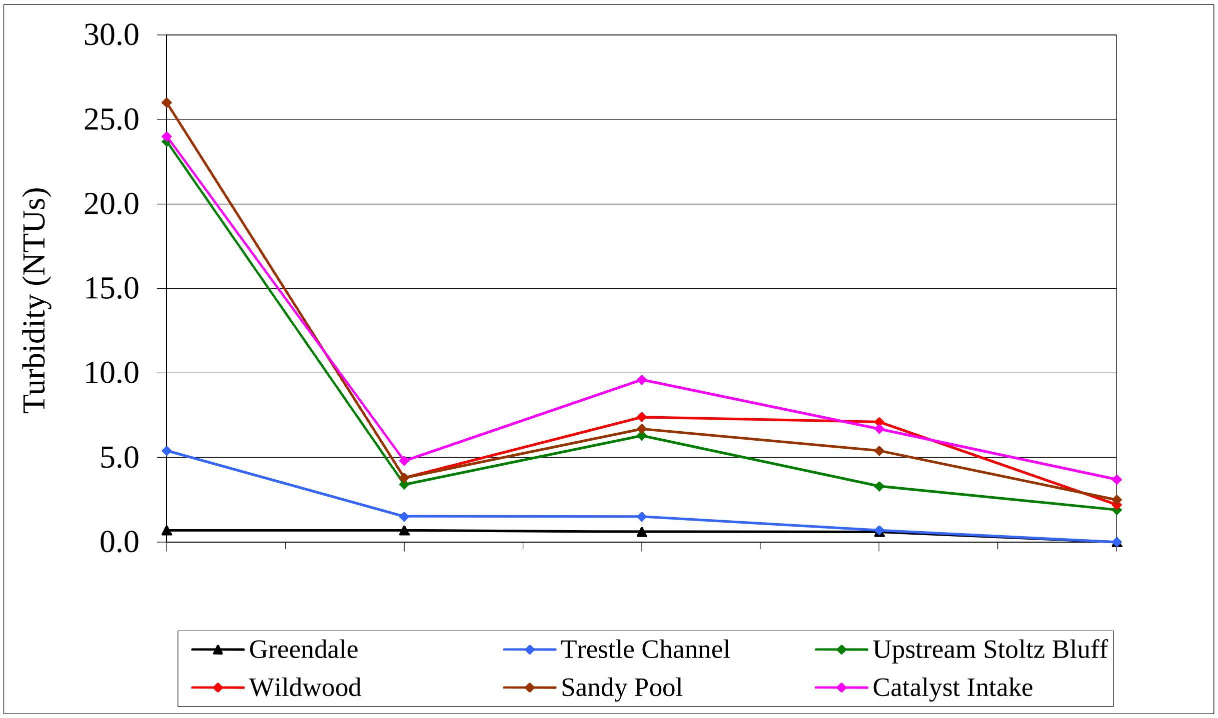

Figure 28. Turbidity measurements based on lab analysis of water samples collected at six sites in Cowichan River.

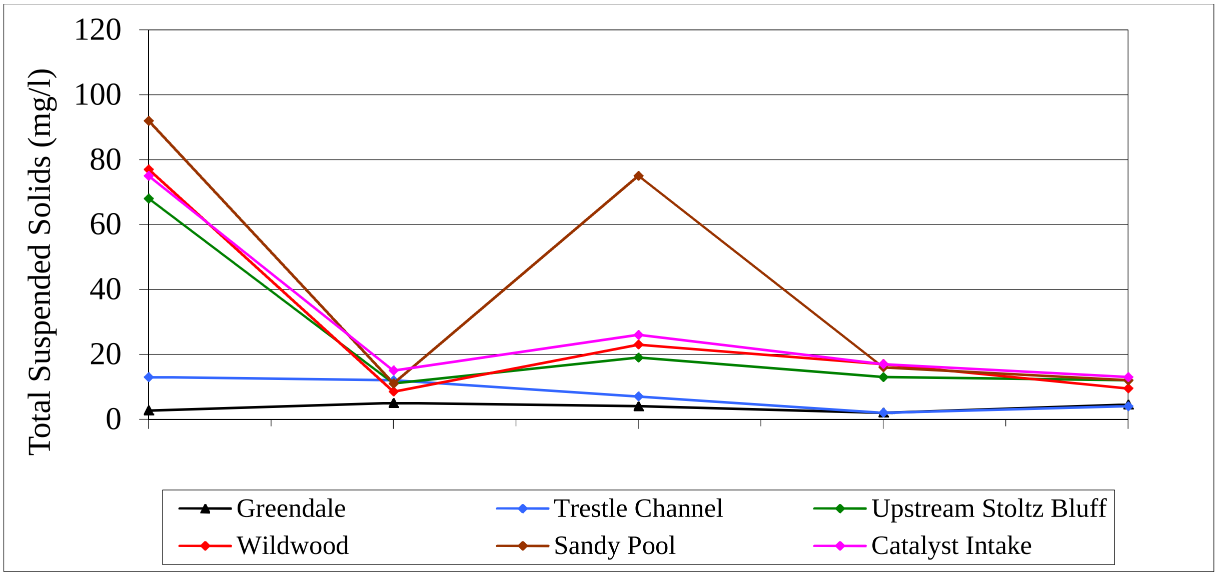

Figure 29. Total suspended solids concentrations based on lab analysis of water samples collected at six sites in Cowichan River.

Table 11. Comparison of turbidity (NTUs) measurements obtained from continuous recording meter and laboratory analysis of water samples.

	Greendale		Trestle Channel		Upstream of Stoltz Bluff		Wildwood		Sandy Pool		Catalyst Intake	
Date	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab	Continuous	Lab
27-Nov-11	0.9	0.7	4.5	5.4	25.2	23.7	29.0	26.0	-	26.0	15.2	24.0
28-Dec-11	-	0.7	0.5	1.5	3.5	3.4	7.9	3.8	7.9	3.8	16.1	4.8
4-Jan-12	-	0.6	1.2	1.5	7.6	6.3	13.0	7.4	13.3	6.7	13.7	9.6
25-Jan-12	-	0.6	2.4	0.7	5.1	3.3	8.8	7.1	8.2	5.4	19.0	6.7
16-Mar-12	-	<0.5	0.3	<0.5	2.2	1.9	5.9	2.2	4.2	2.5	11.1	3.7

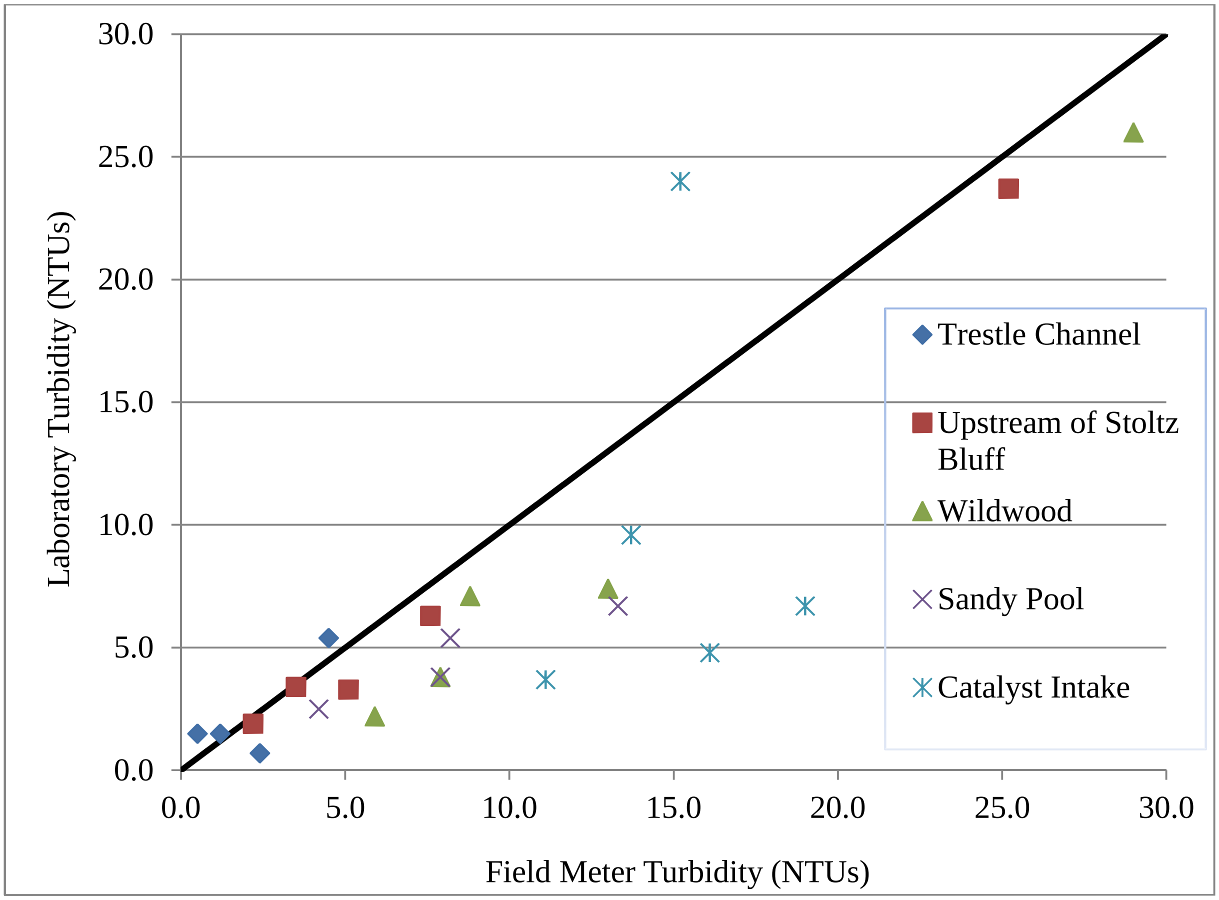

Figure 30. Comparison of 2011/12 turbidity measurements from field and laboratory meters.

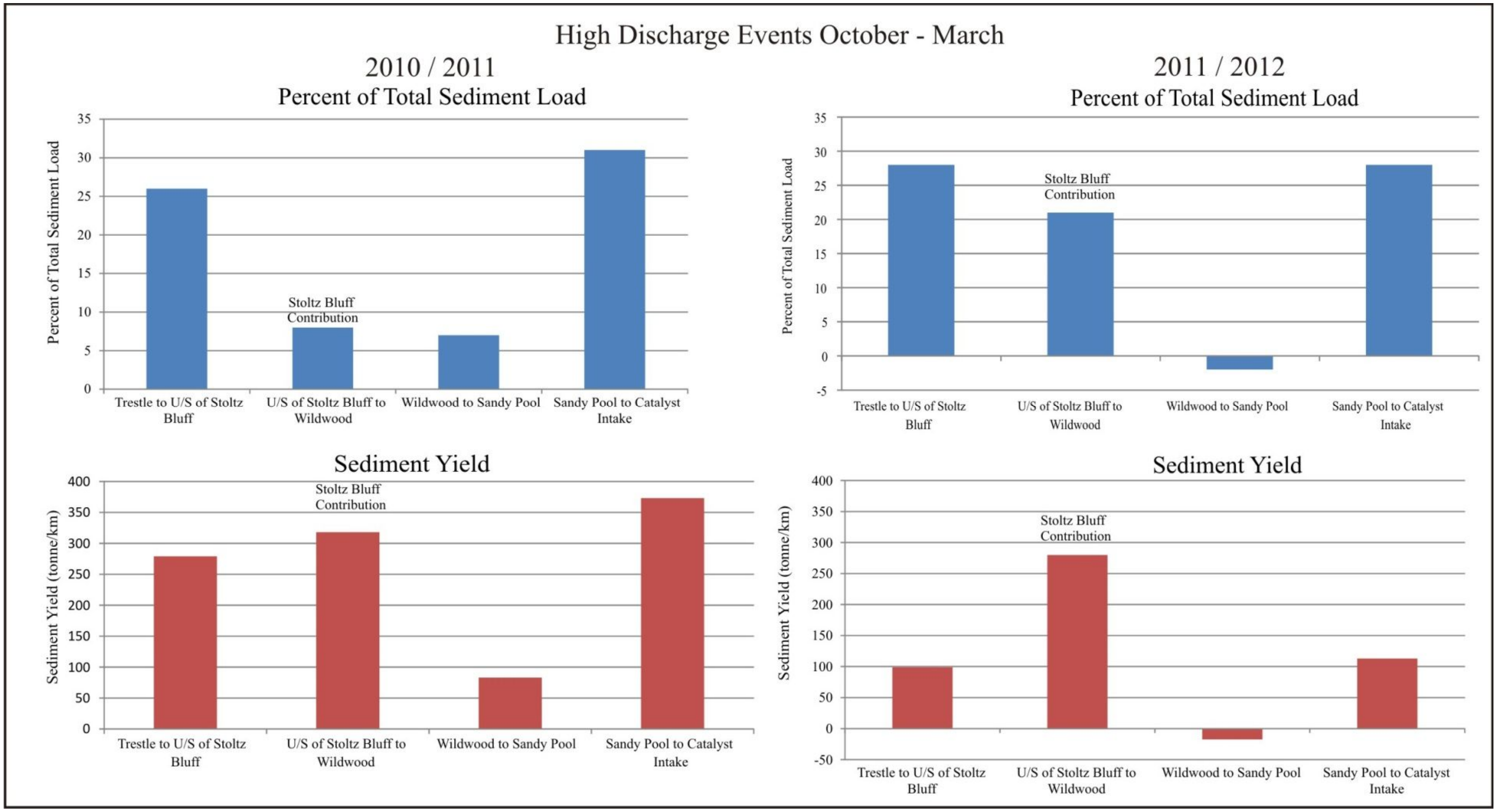

Figure 31. Comparison of sediment loads and yields in 2010/11 and 2011/12.

Egg Incubation Success

Pipe Incubators

Year 2010-2011

Chinook egg incubation survivals in 2010/11 ranged from 1.3% to 84.7% for the incubation pipes placed in the Cowichan River and hatchery (Table 12; Appendix I). The pipe incubators were installed primarily in the gravel bar substrates evaluated in the gravel permeability tests as described above under Permeability. Survival in Cowichan River substrates was highest at River Cabins in the upper reaches and lowest at Stoltz Pool immediately downstream of Stoltz Bluff. However, survivals in the incubators appeared to decline with time which complicated survival comparisons among sites. For example, survivals in the "control" zone upstream of Stoltz Bluff were 48.7% (River Cabins) after 36 days and 6.2% (Upstream of Stoltz Bluff) after 64 days. Similarly, downstream of Stoltz Bluff survivals declined from 35.9% at Sandy Pool after 36 days to 1.3% at Stoltz Pool after 64 days. In almost all cases there were fewer eggs and alevins present in a retrieved incubator than were placed initially (60 eggs) inside the incubator pipe.

The purpose of the analysis of 2010/11 survival data was to look for statistically significant differences in egg survival between locations upstream versus downstream of Stoltz Bluff. Given the assumed continual mortality in the pipe incubators, incubators should all be deployed on the same day, and should all be retrieved at or around the same time. However, river conditions in January 2011 did not allow synoptic recovery of the pipe incubators installed in December 2010. Thus, the only valid comparisons that could be made were among the pipe incubators that were retrieved together. In this case, comparisons were made among pipe incubators retrieved on 5 Jan 2011 (River Cabins vs Sandy Pool vs Cowichan River Hatchery (CR)), and between pipe incubators retrieved on 1 Feb (Upstream (U/S) of Stoltz vs Stoltz Pool).

The average egg survival in pipe incubators retrieved on 5 Jan (Table 12) differed significantly among sites ($\chi^2 = 11.5$; df = 2; $P = 0.0032$). Post-hoc pair-wise comparisons showed that egg survival at CR Hatchery was significantly higher than that at both River Cabins and Sandy Pool ($\chi^2 > 6.9$; df = 1; $P < 0.0088$) (Table 13). Differences in egg survival between River Cabins and Sandy Pool were not statistically significant ($\chi^2 = 0.6$; df = 1; $P = 0.43$).

The average egg survival in pipe incubators retrieved on 1 Feb (Table 13) differed significantly among sites ($\chi^2 = 4.1$; df = 1; $P = 0.042$). Survival of eggs in incubators deployed upstream of Stoltz Bluff (U/S Stoltz Bluff) was significantly higher than that at Stoltz Pool. However, high gravel bedload at Stoltz Pool may have reduced egg and alevin survival considerably. Gravel depth over top of the pipe incubators on 1 February 2011 was ~0.6 m.

Comparing the 2010/11 results to the 2005/06 pipe incubation study (Burt and Ellis 2006), mean survivals were similar at Sandy Pool at 36% and 38%, respectively, but lower at River Cabins at 49% and 77%, respectively.

Table 12. Summary of mean survivals for Chinook eggs placed in incubation pipes in 2010.

Site	Installation Date	Retrieval Date	Days in River	Number of Incubators Retrieved	Mean Survival	Standard Deviation
CR Hatchery	30-Nov-10	5-Jan-11	36	5	84.7%	7.8%
River Cabins	30-Nov-10	5-Jan-11	36	5	48.7%	17.5%
Upstream of Stoltz Bluff	29-Nov-10	1-Feb-11	64	15	6.2%	5.5%
Stoltz Pool	29-Nov-10	1-Feb-11	64	5	1.3%	1.4%
Sandy Pool	30-Nov-10	5-Jan-11	36	10	35.9%	22.0%

Table 13. Summary of statistical analysis of egg incubation success from pipe incubators in 2010.

Duration in River (days)	Site 1		Site 2	Chi Square	*P*
36	River Cabins	=	Sandy Pool	0.6	0.43
36	River Cabins	<<	CR Hatchery	6.9	0.0088
36	Sandy Pool	<<	CR Hatchery	10.0	0.0016
64	U/S Stoltz	>>	Stoltz Pool	4.1	0.042

Year 2011-2012

Chinook egg incubation survivals during November/December 2011 ranged from 48.5% to 75.9% for the incubation pipes placed in the Cowichan River and hatchery (Table 14; Appendix J). In 2011, survival in the Cowichan River substrates was highest at Stoltz Pool, immediately downstream of Stoltz Bluff, and lowest at River Cabins, in the upper reaches. Except for Stoltz Pool, the pipe incubators were installed in the same locations as in 2010. The 2011 incubators at Stoltz Pool were installed ~200 m upstream of the 2010 location. Incubators were deployed on either November 17 or 18 and retrieved on either December 20 or 21 for a total incubation time of 32 or 33 days.

Table 14. Summary of mean survivals for Chinook eggs placed in incubation pipes in 2011.

Site	Installation Date	Retrieval Date	Days in River	Number of Incubators Retrieved	Mean Survival	Standard Deviation
CR Hatchery	18-Nov-11	21-Dec-11	33	5	75.5%	9.9%
River Cabins	18-Nov-11	20-Dec-11	32	5	48.5%	16.8%
Upstream of Stoltz	17-Nov-11	20-Dec-11	33	15	72.7%	11.9%
Stoltz Pool	17-Nov-11	20-Dec-11	33	15	75.9%	16.6%
Sandy Pool	18-Nov-11	20-Dec-11	32	12	60.0%	11.2%

The pipe incubator egg survival rates differed significantly among sites (Figure 32, Dev = 74.0, $P < 0.0001$). Post-hoc pair-wise comparisons showed that egg survival at River Cabins was significantly lower than that at all other sites ($|z| \geq 2.7$; $P \leq 0.045$). Egg survival at Sandy Pool was significantly lower than all other sites ($|z| \geq 3.8$; $P \leq 0.001$) except River Cabins. No other differences among sites were statistically significant ($|z| \leq 1.2$; $P \geq 0.73$). The site differences did not translate into a treatment effect. When sites were pooled into 'locations', it was found that egg survival did not differ significantly upstream versus downstream of Stoltz Bluff (Figure 33, Dev = 2.5, $P = 0.12$).

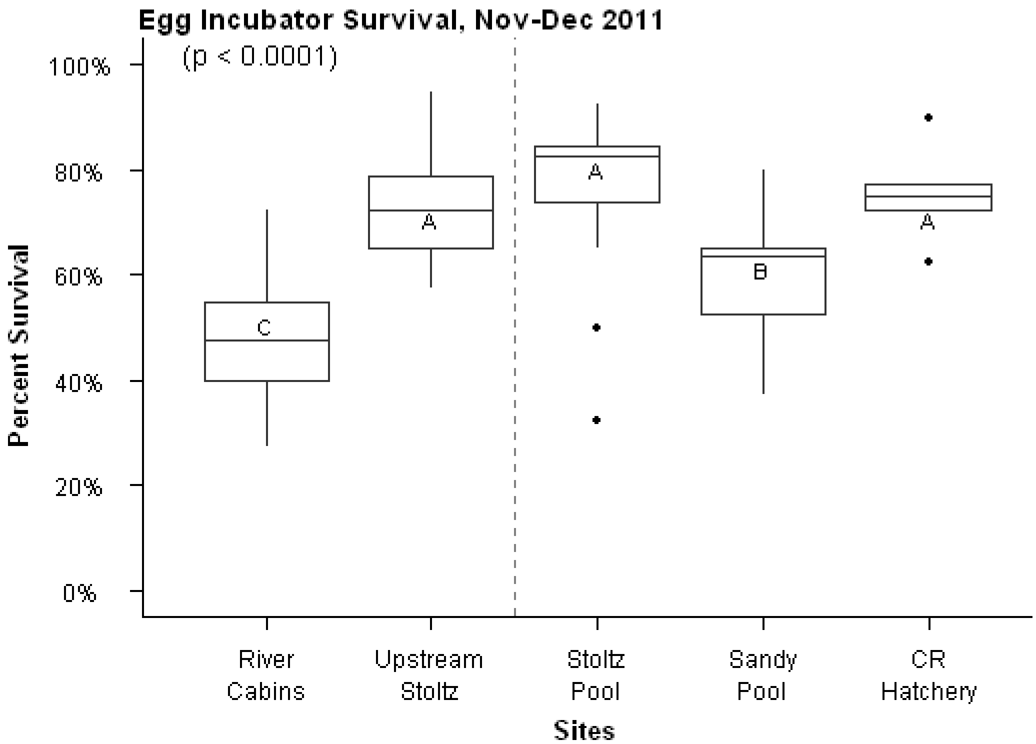

Figure 32. Distribution of egg survival values, by site, for incubator pipes deployed in November 2011, and recovered in December 2011. Letters are shown next to median values to indicate statistically significant differences (i.e., sites that share a letter in common are not significantly different). Boxes enclose the 25th and 75th percentile values, and the horizontal lines within each box indicate the median value. Vertical 'whiskers' extend to last point that is less than 1.5 × the interquartile range and values outside that range are shown as dots. A dotted vertical line divides the sites that are upstream of Stoltz Bluff (to the left of line), from those that are downstream.

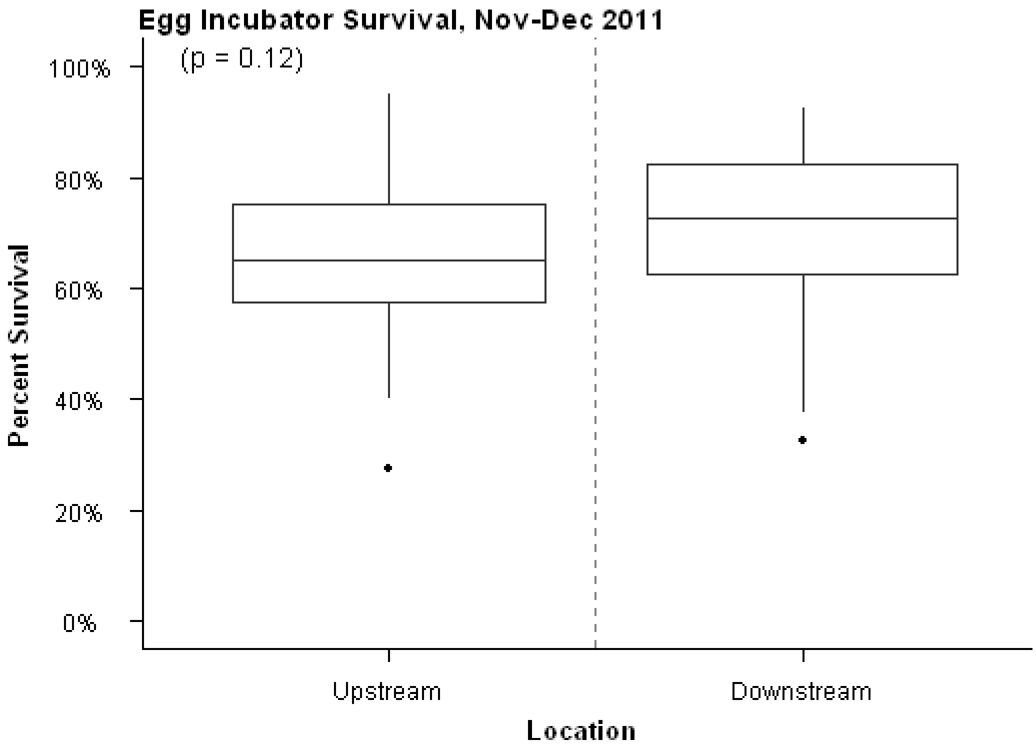

Figure 33. Distribution of egg survival values for incubator pipes deployed in locations upstream and downstream of Stoltz Bluff. Pipes were deployed in November 2011, and recovered in December 2011. Boxes enclose the 25th and 75th percentile values, and the horizontal lines within each box indicate the median value. Vertical 'whiskers' extend to last point that is less than 1.5 × the interquartile range and values outside that range are shown as dots.

For comparisons with the incubator pipes deployed in 2010, analyses were restricted to three sites (River Cabins, Sandy Pool, and CR Hatchery). A two-way GLM showed a statistically significant interaction between year and site (Figure 34, Dev = 42.9; $P < 0.0001$). The effects of year were therefore examined separately for each site.

Egg survival at Sandy Pool was significantly lower in 2010 (37%), as compared to 2011 (60%; Dev = 61.9; $P < 0.0001$). In contrast, egg survival at CR Hatchery was significantly higher in 2010 (85%), as compared to 2011 (76%; Dev = 6.4; $P = 0.011$). There were no significant effects of year on egg survival at River Cabins (49% in both years; Dev = 0.001; $P = 0.97$).

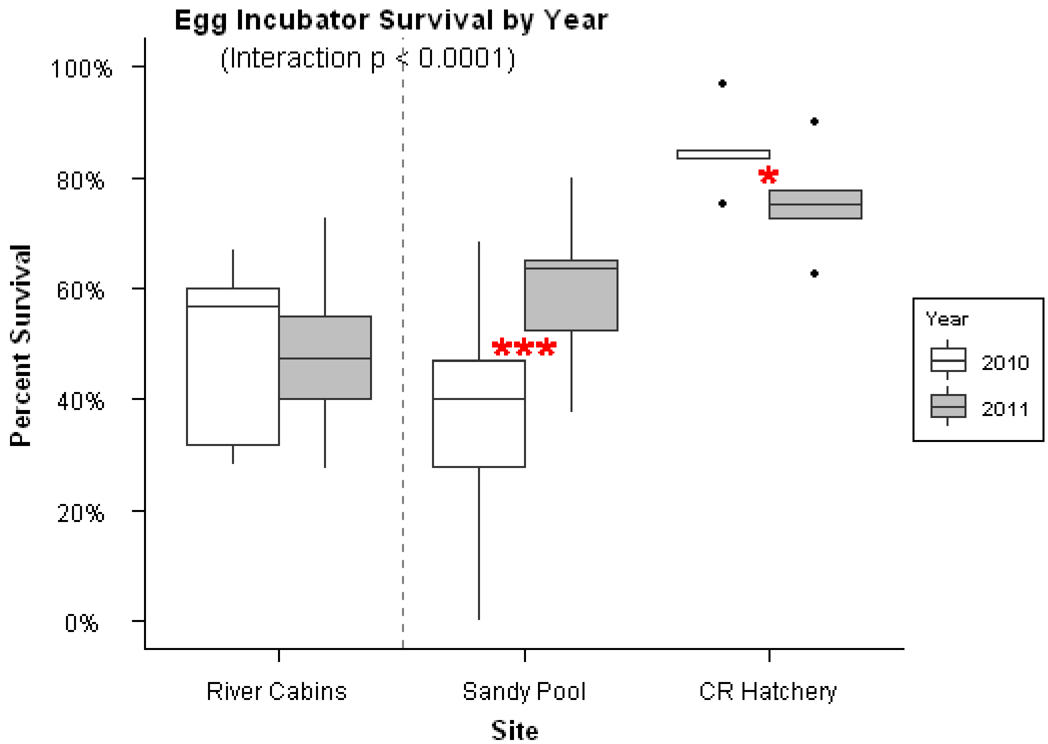

Figure 34. Distribution of egg survival values, by site and year. In 2010, pipes were deployed in late November 2010, and recovered after 36 days. In 2011, pipes were deployed in mid-November, and recovered after 32-33 days. Stars indicate where site-specific survival differed significantly between years (* $p = 0.011$; *** $p < 0.0001$). Boxes enclose the 25th and 75th percentile values, and the horizontal lines within each box indicate the median value. Vertical 'whiskers' extend to last point that is less than 1.5 × the interquartile range, and values outside that range are shown as dots. A dotted vertical line divides the site that is upstream of Stoltz Bluff (to the left of line), from those that are downstream.

Hydraulic Sampling

Hydraulic sampling was conducted at Hatchery Run (Figure 1) by DFO and BCCF personnel on 4 March 2011. Chum and Coho alevins were primarily captured. Survival estimates for the samples were high ranging from 98 to 100% and averaging 99.7% (Table 15). D. Poole (DFO, pers. comm.) commented that the gravel substrates were of higher quality in 2011 and not covered with a hard crusted surface of fine silts and sands as he observed in previous hydraulic sampling events in 2005. In comparison to previous hydraulic sampling results in 2005 and 2006 (Burt and Ellis 2006), mean survivals at Hatchery Run in 2011 had increased slightly from 2006 but both 2006 and 2011 results were considerably higher than the mean survival in 2005 (Table 16).

Table 15. Summary of hydraulic sampling at Hatchery Run, 4 March 2011 (data provided by M. Sheng, DFO).

Site	No. Dead Eggs	No. Live Eggs	No. Dead Alevins	No. Live Alevins	Total Dead	Total Live	Total	% Survival	Comments
1	0	0	0	240	0	240	240	100	alevins 3/4 buttoned -up
2	0	0	0	225	0	225	225	100	alevins 3/4 buttoned -up
3	0	0	0	105	0	105	105	100	alevins 3/4 buttoned -up
4	2	0	0	98	2	98	100	98	alevins 3/4 buttoned -up
5	1	0	0	184	1	184	185	99.5	92 chum buttoned-up; 122 coho full yolk sacs
6	0	0	0	93	0	93	93	100	71 chum buttoned-up; 2 coho alevins
7	0	0	0	21	0	21	21	100	chum 3/4 buttoned-up
8	0	0	0	8	0	8	8	100	chum 3/4 buttoned-up

Table 16. Comparison of 2011 hydraulic sampling results to previous surveys (Burt and Ellis 2006). Results by year indicate percent egg/alevin survival (primarily for Coho and Chum salmon).

Site	2005	2006	2011
Greendale	86.2		
River Cabins		89.3	
Sandy Pool	3.4	55.4	
Hatchery Run	6.8	93.1	99.7

SUMMARY AND CONCLUSIONS

The conclusions based on two years of post-construction effectiveness monitoring of the Stoltz Bluff stabilization works are as follows:

1. In 2010 gravel permeabilities were generally higher at River Cabins and Upstream of Stoltz Bluff than at Stoltz Pool and Sandy Pool. In 2011, permeabilities were generally similar at all four sites. Note: Stoltz Pool site was re-located further upstream in 2011.
2. The 2011 study on Chinook egg incubation success in pipe incubators found that egg survival did not differ significantly upstream versus downstream of Stoltz Bluff when sites were pooled into ‘locations’.
3. Egg survival at Sandy Pool was significantly lower in 2010 (37%), as compared to 2011 (60%). In contrast, egg survival at CR Hatchery was significantly higher in 2010 (85%), as compared to 2011 (76%). There were no significant effects of year on egg survival at River Cabins (49% in both years).
4. Hydraulic sampling at Hatchery Run found high Chum and Coho alevin survivals and a reduction in the surface crusting of the spawning substrate suggesting survival rates and spawning gravel condition have improved from pre-restoration conditions. In comparison to previous hydraulic sampling results in 2005 and 2006 (Burt and Ellis 2006), mean survivals at Hatchery Run in 2011 had increased slightly from 2006 but

both 2006 and 2011 results were considerably higher than the low mean survival found in 2005.

5. Currently, the primary sources of suspended sediment are generated between Trestle Channel and Stoltz Bluff (12.3 river km; includes Block 51 section) and between Sandy Pool and Catalyst Intake (10.7 river km).
6. For the high flow events, total suspended sediment loads estimated at the Catalyst Intake site were 13,037 tonnes in 2010/11 and 4,326 tonnes in 2011/12.
7. For the high flow events, the contribution from Stoltz Bluff to the TSS load estimate at the Catalyst Intake site was ~8% in 2010/11 and ~21% in 2011/12.
8. For the high flow events, the contribution of suspended sediment from the Block 51 section of the river was ~26% (2010/11) and ~28% (2011/12) of the total TSS load estimate at the Catalyst Intake site.
9. TSS yields (tonnes/river km) for the high discharge events between October 2010-March 2011 period were highest for the Sandy Pool to Catalyst Intake section (10.7 river km) at 373, followed by the Upstream of Stoltz Bluff to Wildwood section (3.3 river km) at 318. In comparison, the TSS yield in 2011/12 was highest for Upstream of Stoltz Bluff to Wildwood section at 280, followed by Sandy Pool to Catalyst Intake section at 113.
10. In a comparison of sediment loads from high discharge events in the various river sections for 2010/11 and 2011/12, it is apparent that the sediment load contribution (tonnes) from Stoltz Bluff in both sampling years is less than the contributions estimated for Trestle to Upstream of Stoltz Bluff (i.e., Block 51) and Sandy Pool to Catalyst Intake sections.
11. The contribution of suspended sediment from Stoltz Bluff during high flow events between late fall (October) and the following spring (March) has declined from a pre-restoration estimate of 15,000-22,000 tonnes (1 Oct to 31 March; Burt 2008) to an estimated 1050 tonnes (2010/11) and 924 tonnes (2011/12). At these sediment load values, sediment yields from Stoltz Bluff were 318 tonnes/km in 2010/11 versus 280 tonnes/km in 2011/12. The apparent reduction in downstream sediment loads after stabilization of Stoltz Bluff is corroborated by TSS sampling results from Obee and Epps (2011) where mean TSS concentrations downstream of Stoltz Bluff after its stabilization (Fall 2008) were 8-20% of the concentrations prior to stabilization (Fall 2002 and 2003).
12. Our results indicate that the reduction in sediment loads, and presumably sediment deposition, after Bluff stabilization appears to have improved salmon egg incubation success downstream of Stoltz Bluff. Further improvement in spawning habitat quality and egg incubation success downstream of Stoltz Bluff should occur over time as floodwaters continue to scour previously deposited fine silts and sands.

RECOMMENDATIONS

Recommendations for remedial works and future monitoring are as follows:

1. Assess the outlet area of Clear Creek and develop structural designs to reduce the re-suspension of sediments from the toe of Stoltz Bluff.
2. Assess the reach between Stoltz Bluff and the Wildwood site to identify any chronic bank or bed erosion sites, or small streams that may be contributing significant suspended sediments. Develop rehabilitation designs for chronic erosion / sediment contribution sites as appropriate.
3. Provisional discharge data from the WSC real-time hydrometric stations between 28 January and 6 March 2012 indicated that discharges were greater at the station near Cowichan Lake outlet than at the Duncan station. It is expected that these discharges will be adjusted once WSC reviews and verifies the datalogs. Adjustments to the higher than expected discharges at Cowichan Lake outlet will affect calculated TSS values. Consequently, TSS values in this report for 2011/12 would need to be re-calculated once WSC data have been verified.
4. In five years, repeat the collection of continuous, real-time turbidity measurements at the six sites studied in 2010/11.
5. In five years, repeat the gravel permeability assessment using piezometers and the pipe incubation study to determine if Chinook egg survival is improving.

REFERENCES

Burt, D.W. 2008. Suspended sediment in the Cowichan River before and after rehabilitation of Stoltz Bluff (2004-2007). Prepared for BC Conservation Foundation, TimberWest Forest Corporation, and Catalyst Paper Corporation. 28 pp.

Burt, D.W. and E. Ellis. 2006. Cowichan River Chinook salmon incubation assessment, 2005-2006. Report prepared for Pacific Salmon commission, Vancouver, BC. 31 pp.

Burt, D.W., Wright, M. and M. Sheng. 2005. Cowichan River Chinook salmon incubation assessment, 2004-2005. Report prepared for Pacific Salmon commission, Vancouver, BC. 28 pp.

KWL. 2005. Cowichan River sediment management. Final Report, April 2005. Prepared by Kerr Wood Leidal Associates Ltd., Victoria, BC for Cowichan Treaty Office, Duncan, BC.

Hothorn, T., F. Bretz, and P. Westfall. 2008. Simultaneous inference in general parametric models. Biometrical Journal 50: 346-363.

LGL and KWL. 2005. Preliminary sediment management review – Stoltz Slide and Block 51. Prepared for the BC Conservation Foundation, Nanaimo, BC. Prepared by LGL Limited and Kerr Wood Leidal Associates Ltd. 26 p.

McNeil, W.J. 1964. A method of measuring mortality of pink salmon eggs and larvae. U.S. Dep. Int., Fish Wildl. Serv., Fish. Bul. 63 (3): 575-588.

Obee, N., and D. Epps. 2011. Water quality assessment and objectives for the Cowichan and Koksilah rivers: first update. BC Environmental Protection Division and BC Environmental Sustainability & Strategic Policy Division.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Sweeten, T. 2005. Gravel sampling methods used in the assessment of spawning channels at the Big Qualicum and Little Qualicum facilities on Vancouver Island, British Columbia. Fisheries and Oceans Canada, Vancouver, BC. 25 pp.

Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Bd. Can. 11(6): 933-953.

Wickham, H. 2009. ggplot2: elegant graphics for data analysis. Springer New York.

Appendices

Appendix A. Permeability tests at River Cabins site on Cowichan River, 21 September 2010.

			Initial Conditions			Constant Head Test		All Samples			Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Permeability (ml/sec) all data	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm
River Cabins	1	25	-	87.8		510	26.53	19.2	19.2		19.2			
d/s	1	40	-	73.2		520	22.8	22.8		22.8		22.8		
	2	25	-	88		365	66.66	5.5	5.5		5.5			
	2	40	-	74.5		310	41.31	7.5		7.5		7.5		
	3	25	-	88.3		500	40.13	12.5	12.5		12.5			
	3	40	-	75.2		515	18.67	27.6		27.6		27.6		
	4	25	74.6	73.7	0.036	500	41.5	12.0	12.0				12.0	
	4	40	57.1	57.5	-0.01	30	84.91	0.4		0.4				0.4
	5	25	74.2	73.1	0.044	500	57.54	8.7	8.7				8.7	
	5	40	59.8	60.2	-0.01	310	49.58	6.3		6.3				6.3
	6	25	66.8	65.8	0.04	510	47.12	10.8	10.8				10.8	
	6	40	52.8	53.2	-0.01	350	36.34	9.6		9.6				9.6
	7	25	68.7	68.2	0.02	520	22.07	23.6	23.6				23.6	
u/s	7	40	52.1	51.5	0.015	490	38.35	12.8		12.8				12.8
u/s	8	25	75.2	73.7	0.06	310	45.27	6.8	6.8				6.8	
	8	40	58.8	59.1	-0.0075	500	35.47	14.1		14.1				14.1
	9	25	71.3	69.7	0.064	330	36.12	9.1	9.1				9.1	
	9	40	54	54.6	-0.015	530	34.62	15.3		15.3				15.3
	10	25	62.5	61.5	0.04	300	34.01	8.8	8.8				8.8	
d/s	10	40	48.2	47.8	0.01	505	53.51	9.4		9.4				9.4
							Mean	12.1	11.7	12.6	9.0	19.3	11.4	9.7
							SD	6.6	5.3	7.6	3.5	8.6	5.2	4.8
Free Water Test						980	3.75	261.3						

Appendix B. Permeability tests at site upstream of Stoltz Bluff on Cowichan River, 22 September 2010.

			Initial Conditions			Constant Head Test		All Samples			Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Permeability (ml/sec) all data	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm
U/S of Stoltz	1	25	69	69.2	-0.008	560	9.87	56.7	56.7				56.7	
u/s	1	40	51.4	51.4	0	300	18.44	16.3		16.3				16.3
	2	25	68.6	68	0.024	310	41.99	7.4	7.4				7.4	
	2	40	53.8	53.3	0.0125	135	32.78	4.1		4.1				4.1
	3	25	60.8	60.1	0.028	300	38.75	7.7	7.7				7.7	
	3	40	49.4	50.8	-0.035	340	13.28	25.6		25.6				25.6
	4	25	69.5	69.5	0	230	53.82	4.3	4.3				4.3	
	4	40	?	54.4		310	18.41	16.8		16.8				16.8
d/s	5	25	67.7	66.9	0.032	370	24.62	15.0	15.0				15.0	
	5	40	49.4	49.7	-0.0075	340	25.57	13.3		13.3				13.3
	6	25	66.2	65.4	0.032	400	19.78	20.2	20.2				20.2	
	6	40	52.2	51	0.03	300	21.46	14.0		14.0				14.0
	7	25	79.3	79.3	0	480	14.48	33.1	33.1				33.1	
	7	40	63.8	62.3	0.0375	340	22.46	15.1		15.1				15.1
	8	25	74.7	75	-0.012	390	16.37	23.8	23.8				23.8	
	8	40	61.7	61.3	0.01	200	29.62	6.8		6.8				6.8
	9	25	82	82	0	460	19.66	23.4	23.4				23.4	
	9	40	65.8	65	0.02	190	23.3	8.2		8.2				8.2
	10	25	79	78.1	0.036	190	36	5.3	5.3				5.3	
	10	40	63.4	63.4	0	160	32.37	4.9		4.9				4.9
	11	25	-	87.4		170	42.87	4.0	4.0		4.0			
	11	40	-	72.3		175	30.93	5.7		5.7		5.7		
	12	25	-	82.5		220	20.51	10.7	10.7		10.7			
	12	40	-	69.4		210	28.26	7.4		7.4		7.4		
	13	25	-	83.1		190	27.57	6.9	6.9		6.9			
	13	40	-	67.5		280	19.03	14.7		14.7		14.7		
	14	25	-	85.5		210	24.8	8.5	8.5		8.5			
	14	40	-	68.5		320	16.51	19.4		19.4		19.4		
							Mean	14.3	16.2	12.3	7.5	11.8	19.7	12.5
							SD	11.1	14.1	6.1	2.5	5.5	15.3	6.3
Free Water Test						980	3.75	261.3						

Appendix C. Permeability tests at Stoltz Pool site on Cowichan River, 22 September 2010.

Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Initial Conditions			Constant Head Test		All Samples			Gravel Bar		Wetted Channel	
			Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Permeability (ml/sec) all data	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm
Stoltz Pool	1	25	51	51.7		270	52.94	5.1	5.1				5.1	
d/s	1	40	38.5	71.8		0				0.0				0.0
	2	25	58.6	58		240	67.03	3.6	3.6				3.6	
	2	40	43.7	45.8		0				0.0				0.0
	3	25	61.3	61		180	80.12	2.2	2.2				2.2	
	3	40	44.9	44.5		0				0.0				0.0
	4	25	63.6	62.4	0.048	160	78.78	2.0	2.0				2.0	
	4	40	48.2	49.1	-0.0225	0				0.0				0.0
	5	25	58.2	57.2	0.04	110	79.38	1.4	1.4				1.4	
u/s	5	40	42.1	77.1	-0.875	0				0.0				0.0
	6	48	-	100.03	-	225	32.74	6.9		6.9		6.9		
	7	47	-	98	-	220	29.07	7.6		7.6		7.6		
							Mean	4.1	2.9	2.1		7.2	2.9	0.0
							SD	2.3	1.3	3.3		0.3	1.3	0.0

Appendix D. Permeability tests at Sandy Pool site on Cowichan River, 21 September 2010.

			Initial Conditions			Constant Head Test		All Samples			Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Permeability (ml/sec) all data	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm	Permeability (ml/sec) @ 25 cm	Permeability (ml/sec) @ 40 cm
Sandy Pool	1	40	63	63	0.000	210	91.34	2.3		2.3				2.3
	1	25				410	91.08	4.5	4.5				4.5	
	2	25	75.4	74	0.056	500	56.84	8.8	8.8				8.8	
	2	40	60.7	60	0.018	210	40.3	5.2		5.2				5.2
	3	25	66.6	65	0.064	390	86.15	4.5	4.5				4.5	
	3	40	49.5	50	-0.013	200	74.37	2.7		2.7				2.7
	4	25	76.6	75.1	0.060	530	52.75	10.0	10.0				10.0	
	4	40	69.2	67.7	0.038	350	26.43	13.2		13.2				13.2
	5	25	74.4	73	0.056	390	77.84	5.0	5.0				5.0	
	5	40	59.4	60	-0.015	210	36.44	5.8		5.8				5.8
	6	25	72.6	71.4	0.048	500	48.79	10.2	10.2				10.2	
	6	40	60	59.6	0.010	225	32.85	6.8		6.8				6.8
	7	25	74.6	73	0.064	500	75.35	6.6	6.6				6.6	
	7	40	61	61.9	-0.023	315	20.42	15.4		15.4				15.4
	8	25	-	89.6		310	30.78	10.1	10.1		10.1			
	8	40	-	74.3		300	47.21	6.4		6.4		6.4		
	9	25	-	90.8		300	44.39	6.8	6.8		6.8			
	9	40	-	75.3		310	44.25	7.0		7.0		7.0		
	10	25	-	92.8		295	43.38	6.8	6.8		6.8			
	10	40	-	78.5		200	98.24	2.0		2.0		2.0		
							Mean	7.0	7.3	6.7	7.9	5.1	7.1	7.4
							SD	3.4	2.2	4.2	1.6	2.2	2.4	4.7
Free Water Test						850	3.64	233.5						

Appendix E. Permeability tests at River Cabin site on Cowichan River, 20 September 2011.

			Initial Conditions			Constant Head Test					Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Rate of Volume Change (ml/sec) all data	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm
River Cabins	1	25	82	82.3	-0.012	590	34.38	17.2	17.2				17.2	
u/s	1	40	66.3	67	-0.0175	675	24.56	27.5		27.5				27.5
	2	25	42.8	43.1	-0.012	700	16.92	41.4	41.4				41.4	
	2	40	29.8	30.5	-0.0175	610	15.86	38.5		38.5				38.5
	3	25	39.6	40.8	-0.048	580	27.77	20.9	20.9				20.9	
	3	40	23.4	25.4	-0.05	700	10.7	65.4		65.4				65.4
	4	25	69.1	69.7	-0.024	630	17.63	35.7	35.7				35.7	
	4	40	50.5	51.3	-0.02	710	14.08	50.4		50.4				50.4
	5	25	71	71.8	-0.032	685	18.61	36.8	36.8				36.8	
	5	40	52.6	53.3	-0.0175	675	10.73	62.9		62.9				62.9
	6	25	-	70		610	27.24	22.4	22.4				22.4	
d/s	6	40	56.2	57.7	-0.0375	595	19.72	30.2		30.2				30.2
u/s	7	25	-	63		630	31.49	20.0	20.0		20.0			
	7	40	-	50.9		670	14.59	45.9		45.9		45.9		
	8	25	-	65.2		590	15.18	38.9	38.9		38.9			
d/s	8	40	-	52.6		630	14.64	43.0		43.0		43.0		
u/s	9	25	-	90.9		630	22.61	27.9	27.9		27.9			
	9	40	-	74.8		740	14.77	50.1		50.1		50.1		
	10	25	-	64.1		585	24.13	24.2	24.2		24.2			
d/s	10	40	-	47.3		625	14.04	44.5		44.5		44.5		
							Mean	37.2	28.5	45.8	27.7	45.9	29.1	45.8
							SD	13.4	8.4	11.7	7.0	2.6	9.2	14.9

Appendix F. Permeability tests at site upstream of Stoltz Bluff on Cowichan River, 20 September 2011.

			Initial Conditions			Constant Head Test					Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Rate of Volume Change (ml/sec) all data	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm
U/S of Stoltz	1	25	32.2	32.6	-0.016	625	16.53	37.8	37.8				37.8	
u/s	1	40	18	19.2	-0.03	685	22.23	30.8		30.8				30.8
	2	25	-	87.1		685	17.73	38.6	38.6		38.6			
	2	40	-	71.2		720	12.72	56.6		56.6		56.6		
	3	25	-	89.1		470	36.3	12.9	12.9		12.9			
	3	40	-	74.5		550	34.36	16.0		16.0		16.0		
	4	25	77.6	78.3	-0.028	560	31.6	17.7	17.7				17.7	
	4	40	61.5	63	-0.0375	590	30.11	19.6		19.6				19.6
d/s	5	25	84	85	-0.04	325	56.01	5.8	5.8				5.8	
	5	40	64.1	66.3	-0.055	480	32.63	14.7		14.7				14.7
u/s	6	25	64.8	66.2	-0.056	740	29.27	25.3	25.3				25.3	
	6	40	48.2	49.9	-0.0425	665	21.06	31.6		31.6				31.6
	7	25	66	66.8	-0.032	825	17.61	46.8	46.8				46.8	
	7	40	53.8	53.8	0	720	18.85	38.2		38.2				38.2
	8	25	64.7	66	-0.052	600	24.78	24.2	24.2				24.2	
	8	40	50.9	52.9	-0.05	750	26.11	28.7		28.7				28.7
	9	25	34	34.6	-0.024	730	28.07	26.0	26.0				26.0	
d/s	9	40	19.9	22.1	-0.055	605	32.98	18.3		18.3				18.3
u/s	10	25	74.7	74.7	0	645	27.73	23.3	23.3				23.3	
	10	40	62	62.3	-0.0075	440	32.5	13.5		13.5				13.5
							Mean	26.3	25.9	26.8	25.8	36.3	25.9	24.4
							SD	12.3	11.8	12.7	12.8	20.3	11.5	8.5
Free Water Test						1000	4	250.0						

Appendix G. Permeability tests at Stoltz Pool site on Cowichan River, 19 September 2011.

			Initial Conditions			Constant Head Test					Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Rate of Volume Change (ml/sec) all data	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm
Stoltz Pool	1	25	79.8	84.2	-0.176	540	26.5	20.4	20.4				20.4	
u/s	1	40	63.2	69.4	-0.155	630	21.53	29.3		29.3				29.3
	2	25	47.2	50.1	-0.116	665	11.71	56.8	56.8				56.8	
	2	40	35.4	38.9	-0.0875	620	23.82	26.0		26.0				26.0
	3	25	43.7	45.7	-0.08	650	10.2	63.7	63.7				63.7	
	3	40	28.6	33.1	-0.1125	690	15.67	44.0		44.0				44.0
	4	25	41.1	43.2	-0.084	680	10.3	66.0	66.0				66.0	
	4	40	21.3	26.4	-0.1275	700	8.55	81.9		81.9				81.9
	5	25	74.6	79.8	-0.208	565	13.81	40.9	40.9				40.9	
	5	40	59.9	64.8	-0.1225	640	19.75	32.4		32.4				32.4
	6	25	78	78.8	-0.032	580	20.49	28.3	28.3				28.3	
	7	25	83.1	84.2	-0.044	645	20.66	31.2	31.2				31.2	
d/s	7	40	69.7	71.4	-0.0425	690	33.2	20.8		20.8				20.8
u/s	8	25	-	97.1		710	17.52	40.5	40.5		40.5			
	8	40	-	81.7		680	23.33	29.1		29.1		29.1		
	9	25	-	98		650	22.99	28.3	28.3		28.3			
	9	40	-	83.2		720	14.32	50.3		50.3		50.3		
	10	25	-	65.2		715	18.09	39.5	39.5		39.5			
	10	40	-	48.7		700	15.11	46.3		46.3		46.3		
	11	25	-	59.3		680	23.86	28.5	28.5		28.5			
d/s	11	40	-	45.6		680	27.57	24.7		24.7		24.7		
							Mean	39.5	40.4	38.5	34.2	37.6	43.9	39.1
							SD	16.0	14.7	17.3	5.8	10.9	17.0	20.4

Appendix H. Permeability tests at Sandy Pool site on Cowichan River, 19 September 2011.

			Initial Conditions			Constant Head Test					Gravel Bar		Wetted Channel	
Location	Site	Piezometer Depth (L in cm): 25 or 40 cm	Distance from Top of Pipe to Water Surface - Outside Pipe (cm)	Distance from Top of Pipe to Water Surface - Inside Pipe (cm)	Vertical Hydraulic Gradient (H/L)	Volume (ml)	Time (sec)	Rate of Volume Change (ml/sec) all data	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm	Rate of Volume Change (ml/sec) @ 25 cm	Rate of Volume Change (ml/sec) @ 40 cm
Sandy Pool	1	25	-	62.5		730	12.81	57.0	57.0		57.0			
	1	40	-	48.9		720	6.75	106.7		106.7		106.7		
	2	25	-	92.1		725	20.22	35.9	35.9		35.9			
	2	40	-	73.7		520	20.57	25.3		25.3		25.3		
	3	25	83.1	83.1	0	630	20.52	30.7	30.7				30.7	
	3	40	67.4	67.4	0	700	11.52	60.8		60.8				60.8
	4	25	-	94.8		630	22.56	27.9	27.9		27.9			
	4	40	-	79.3		670	18.85	35.5		35.5		35.5		
	5	25	50.2	50.2	0	730	12.98	56.2	56.2				56.2	
	5	40	36.1	36.2	-0.0025	750	9.23	81.3		81.3				81.3
	6	25	-	63.3		500	28.28	17.7	17.7		17.7			
	6	40	-	46.9		300	38.93	7.7		7.7		7.7		7.7
	7	25	75.1	75.3	-0.008	580	29.01	20.0	20.0				20.0	
	7	40	58.7	58.6	0.0025	610	16.69	36.5		36.5				36.5
	8	25	48.6	48.5	0.004	670	21.33	31.4	31.4				31.4	
	8	40	33.4	32.8	0.015	640	21.33	30.0		30.0				30.0
	9	25	72.1	73.8	-0.068	305	55.62	5.5	5.5				5.5	
	9	40	58.8	60.6	-0.045	615	15.77	39.0		39.0				39.0
	10	25	63.5	64.9	-0.056	560	47.26	11.8	11.8				11.8	
	10	40	49.0	50.8	-0.045	630	21.32	29.5		29.5				29.5
							Mean	37.3	29.4	45.2	34.6	43.8	25.9	40.7
							SD	24.1801	16.2385	27.9383	14.4	37.6	16.4	22.0
Free Water Test						1000	4	250.0						

Appendix I. Chinook egg incubation survivals for pipe incubators installed in the Cowichan River in 2010.

Site	Pipe Incubator Number	Installed: Time	Installed: Date	Installed: Location	Retrieved: Number	Time	Date	Days in River	Alevins	Live Eggs	Total Live	Dead Eggs	Survival	Mean Survival	Std Deviation
CR Hatchery	37, 52, 51, 22, 44	9:45AM	30-Nov-10	Incubation Trough 6D	22	2:00PM	05-Jan-11	36	51		51	7	85.0%		
					37			36	50		50	1	83.3%		
					51			36	57	1	58	2	96.7%		
					52			36	44	1	45	12	75.0%		
					44			36	49	1	50		83.3%	84.7%	7.8%
River Cabins	32, 17, 14, 34, 19	12:20-12:40PM	30-Nov-10	LB, d/s of fire pit at lodge	32	9:15AM	05-Jan-11	36	19		19	14	31.7%		
					17			36	17		17	7	28.3%		
					34			36	34		34		56.7%		
					19			36	36		36		60.0%		
					14			36	40		40		66.7%	48.7%	17.5%
Upstream of Stoltz	9, 15, 42, 46, 41, 49, 43, 50, 27, 48, 8, 10, 23, 45, 47	12:30PM	29-Nov-10	RB ~200 m upstream of Stoltz Bluff	49	10:30AM	01-Feb-11	64	4		4	4	6.7%		
					46			64	4		4	9	6.7%		
					8			64	0		0	25	0.0%		
					15			64	1		1	11	1.7%		
					23			64	11		11	5	18.3%		
					10			64	3		3	24	5.0%		
					42			64	2		2	2	3.3%		
					48			64	4		4	4	6.7%		
					45			64	3		3	2	5.0%		
					41			64	10		10	8	16.7%		
					43			64	0		0	4	0.0%		
					47			64	5		5	8	8.3%		
					9			64	3		3	6	5.0%		
					50			64	0		0	52	0.0%		
					27			64	6		6	5	10.0%	6.2%	5.5%
Stoltz Pool	24, 2, 29, 5, 6, 25, 1, 4, 7, 30, 26, 12, 3, 21, 28	11:45AM	29-Nov-10	LB just u/s of Stoltz Boat Launch	6	9:00-10AM	01-Feb-11	64	1		1	6	1.7%		
					2			64	2		2	6	3.3%		
					29			64	0		0	7	0.0%		
					24			64	1		1	8	1.7%		
					5			64	0		0	3	0.0%	1.3%	1.4%
Sandy Pool	31, 18, 13, 11, 33, 35, 20, 16, 38, 39, 40, 36	10:40-11:10AM	30-Nov-10	LB, d/s of boat ramp	13	12:00PM	05-Jan-11	36	29		29	14	48.3%		
					36			36	0		0	18	0.0%		
					18			36	18		18	13	30.0%		
					31			36	25		25	26	41.7%		
					16			36	28		28	19	46.7%		
					11			36	20		20	4	33.3%		
					38			36	40		40	8	66.7%		
					33			36	2		2	2	3.3%		
					20			36	13		13	5	21.7%		
					35			36	23		23	8	38.3%		
					40			36	27		27	24	45.0%		
					39			36	41		41	5	68.3%	35.9%	22.0%

Appendix J. Chinook egg incubation survivals for pipe incubators installed in the Cowichan River in 2011.

		Installed			Retrieved												
									Eggs		Alevins		Total				
Site	Pipe Incubator Number	Time	Date	Location	Pipe Incubator Number	Time	Date	Days in River	Dead	Live	Dead	Live	Live Eggs + Live & Dead Alevins	Dead Eggs	Survival (Based on Number of Eggs Initially)	Mean Survival	Std Deviation
CR Hatchery	74,64,68, 52,44	10:40AM	18-Nov-11	Incubation Trough 5D	74	10:00AM	21-Dec-11	33	11		25		25	11	0.625		
					64			33	6		27	4	31	6	0.775		
					68			33	2		36		36	2	0.900		
					52			33	9		30		30	9	0.750		
					44			33	1		29		29	1	0.725	75.5%	9.9%
River Cabins	39,63,62,70,8	1:00-1:30PM	18-Nov-11	LB, d/s of fire pit at lodge	39	3:30PM	20-Dec-11	32	8	10		19	29	8	0.725		
					63			32	14	22			22	14	0.550		
					62			32	25	11			11	25	0.275		
					70			32	18	2	2	12	16	18	0.400		
					8			32	20	6	2	11	19	20	0.475	48.5%	16.8%
Upstream Stoltz	49,31,13,40,5, 35,20,33,43, 22,18,27,6,48, 14	3:30-4:00PM	17-Nov-11	RB ~250 u/s of Stoltz Bluff	49	11:55AM	20-Dec-11	33	10	23		6	29	10	0.725		
					31			33	7	10		16	26	7	0.650		
					13			33	6	17		12	29	6	0.725		
					40			33	5	29		3	32	5	0.800		
					5			33	12	5		21	26	12	0.650		
					35			33	9	15		11	26	9	0.650		
					20			33	6	29		1	30	6	0.750		
					33			33	2	34		4	38	2	0.950		
					43			33	35	1			1	35			
					22			33	9	9	2	12	23	9	0.575		
					18			33	1	38			38	1	0.950		
					27			33	8	20	1	11	32	8	0.800		
					6			33	10			23	23	10	0.575		
					48			33	6	18	2	10	30	6	0.750		
					14			33	11	10	1	14	25	11	0.625	72.7%	11.9%
Stoltz Pool	61,65,66,17, 72,45,11,42, 16,41,36,73, 23,46,10	2:30-3:00PM	17-Nov-11	LB ~120 m u/s of Stoltz Boat Launch	61	2:00PM	20-Dec-11	33	7			32	32	7	0.800		
					65			33	7	2		31	33	7	0.825		
					66			33	10		5	15	20	10	0.500		
					17			33	5			34	34	5	0.850		
					72			33	5	2	1	30	33	5	0.825		
					45			33	1	29		4	33	1	0.825		
					11			33	1	5		30	35	1	0.875		
					42			33	4	14	1	16	31	4	0.775		
					16			33		4		43	47	0			
					41			33	2	25	1	7	33	2	0.825		
					36			33	2	8		28	36	2	0.900		
					73			33	10	1		28	29	10	0.725		
					23			33	11		1	12	13	11	0.325		
					46			33	1	7	1	29	37	1	0.925		
					10			33	7		1	25	26	7	0.650	75.9%	16.6%
Sandy Pool	35,71,34,67, 37,47,19,15, 9,38,35,69	11:30-12:00AM	18-Nov-11	LB, d/s of boat ramp	35	9:30AM	20-Dec-11	32	7	5		21	26	7	0.650		
					71			32	18	15		6	21	18	0.525		
					34			32	14	7		19	26	14	0.650		
					67			32	14	23		3	26	14	0.650		
					37			32	15	4		19	23	15	0.575		
					47			32	3	25		7	32	3	0.800		
					19			32	13	26			26	13	0.650		
					15			32	14	8		11	19	14	0.475		
					9			32	8	4		24	28	8	0.700		
					38			32	9	2		23	25	9	0.625		
					32			32	24	7		8	15	24	0.375		
					69			32	18	6		15	21	18	0.525	60.0%	11.2%