Hill Creek Spawning Channel - 2006 Scarification Monitoring and Suspended Sediment Assessment

Prepared for
Fish and Wildlife Compensation Program
- Columbia Basin

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EXECUTIVE SUMMARY

During 2006 the kokanee and rainbow trout spawning gravels at the Hill Creek Spawning Channel (HCSC) were restored by the mechanical removal of fine sediments or scarification.

Integrated Ecological Research prepared this report for Fish and Wildlife Compensation Program in order to document: (1) the procedures that were used to clean settling ponds and restore spawning gravel at HCSC in August 2006 (2) the effect of scarification on levels of induced turbidity; (3) changes in particle sizes and embeddedness of the Hill Creek stream bed downstream of the spawning channel; (4) the total amount of fine material removed from the spawning channel, and (5) evaluate the effect of re-suspended sediment on fish and fish habitat within the channel and Hill Creek downstream of the channel.

Machine scarification was an effective and affordable technique for cleaning the spawning gravel.

Peak levels of suspended sediments during scarification were well below lethal levels for juvenile salmonids. Short-term exposure to suspended sediment in scarification effluent may cause temporary minor to moderate physiological stress to juvenile fish.

Transect sampling showed a post-scarification increase in fines downstream of the spawning channel that may have detrimental effects on kokanee spawning and late summer insect production. However, the enhanced spawning in the channel clearly provides a net benefit for kokanee spawning, and losses to insect production may be mitigated by the positive influence of kokanee carcass inputs in September.

The HCSC has an important net benefit for kokanee and rainbow trout spawning. It helps sustain the Upper Arrow Reservoir kokanee abundance and provides a forage base for bull trout and rainbow trout. These fish stocks contribute to an important sport fishery with economic benefits.

A number of recommendations were made to optimize scarification operations and sediment management techniques in order to mitigate possible impacts.

This report and Thompson (2006) are intended to provide a basis for further discussion of sediment management options in the spawning channel.

KEY WORDS

Hill Creek Spawning Channel, scarification, turbidity, suspended sediments, deposited sediment, Kokanee, Rainbow Trout

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ACKNOWLEDGEMENTS

Steve Arndt of the Fish and Wildlife Compensation Program carried out the project initiation, sediment sampling design, data collection and aspects of the reporting.

Brian Barney of Kingfisher Sivilculture, on contract to the FWCP, collected data, and supervised the scarification and Hill Creek Spawning Channel operations.

Darcie Quamme of Integrated Ecological Research conducted data analysis and reporting.

The FWCP is a joint initiative between BC Hydro, the Ministry of Environment and Fisheries & Oceans Canada to conserve and enhance fish and wildlife populations affected by the construction of BC Hydro dams in Canada's portion of the Columbia Basin.

1 INTRODUCTION

Integrated Ecological Research prepared this report for the Fish and Wildlife Compensation Program (FWCP) to document the effect of scarification on the levels of induced fine sediment and its dispersal at the Hill Creek Spawning Channel (HCSC).

1.1 Background

The HCSC was constructed in 1981 in an effort to replace the production of fish lost as a result of the creation of the Revelstoke Dam. Annual fish losses from the construction of Revelstoke Dam were estimated to be five hundred thousand for kokanee, one thousand for rainbow trout and four thousand for bull trout (Martin 1976). The objective of HCSC is to increase the abundance of kokanee and rainbow trout in the Arrow Reservoir through improved spawning habitat and compensate for habitat lost due to the construction of Revelstoke Dam. The operation and maintenance of HCSC is funded by a joint initiative of the provincial government and BC Hydro under the FWCP.

The HCSC is located 53 km north of Nakusp at the north end of Upper Arrow Lake (Figure 1). The spawning channel is supplied with water from a diversion on Hill Creek and an additional 2.4 km pipeline from nearby MacKenzie Creek. The spawning channel is 3.2 km long with a width of 6.2 m. There are three settling pools upstream of the channel gravel platforms and another located after the rainbow trout section that are designed to collect naturally occurring fines during spring runoff and other high water periods (Figure 2). Downstream of the settling pools, there are 54 spawning riffles separated by resting pools (Figure 3). The spawning channel was constructed so that the upper 751 m^2 of the channel is rainbow trout spawning habitat with gravel sizes ranging 6 - 51 mm and a depth of 0.6 m. Downstream of this area, there is 14,137 m^2 of kokanee spawning habitat that has smaller gravel sizes of 6 - 38 mm and a shallower depth of 0.41 m. HCSC has a theoretical capacity of 100 - 140 thousand kokanee. The kokanee spawning area also serves as rearing habitat for juvenile rainbow trout (Lindsay 1982, Porto and Arndt 2006).

Throughout the year, natural suspended sediment settles and accumulates in the HCSC because the low gradient design of the channel reduces water velocities compared to the upstream natural channel. In addition, flow control structures within the channel reduce discharge during peak flows. These aspects of the spawning channel design result in the deposition of suspended sediment in the interstitial spaces of the spawning gravel during most of the year, with the gravel acting as a vertical filter (Mundie and Crabtree 1997).

In order to maintain the gravel quality for spawning and kokanee egg-to-juvenile survival, it is necessary to clean the gravels annually. This is done for a short period in late summer using a machine scarification process that dislodges and re-suspends the fines so that they are carried downstream of the channel.

The Department of Fisheries and Oceans (DFO) requested that an assessment of the effects of fine sediment (resulting from the scarification process) on fish habitat in HCSC and Hill Creek below the channel be conducted during the 2006 scarification. As a result, a number of monitoring studies were conducted in 2006 to estimate possible adverse effects and recommend mitigation options.

1.2 Monitoring Objectives

The objectives of the 2006 program were to:

- Document the procedures that were used to clean settling ponds and restore spawning gravel at HCSC in July/August 2006.
- Monitor the effect of scarification on levels of induced turbidity.
- Estimate the total amount of fine material removed from the spawning channel.
- Observe any changes in particle sizes and embeddedness of the Hill Creek streambed downstream of the spawning channel before and immediately after cleaning of spawning gravels.
- Evaluate the effects of the re-suspended sediments on fish habitat and fish in the spawning channel and Hill Creek downstream of the channel.

The following report provides a compilation and interpretation of the 2006 effluent data, transects of the Hill Creek streambed, and a summary of juvenile rainbow trout trapping data.

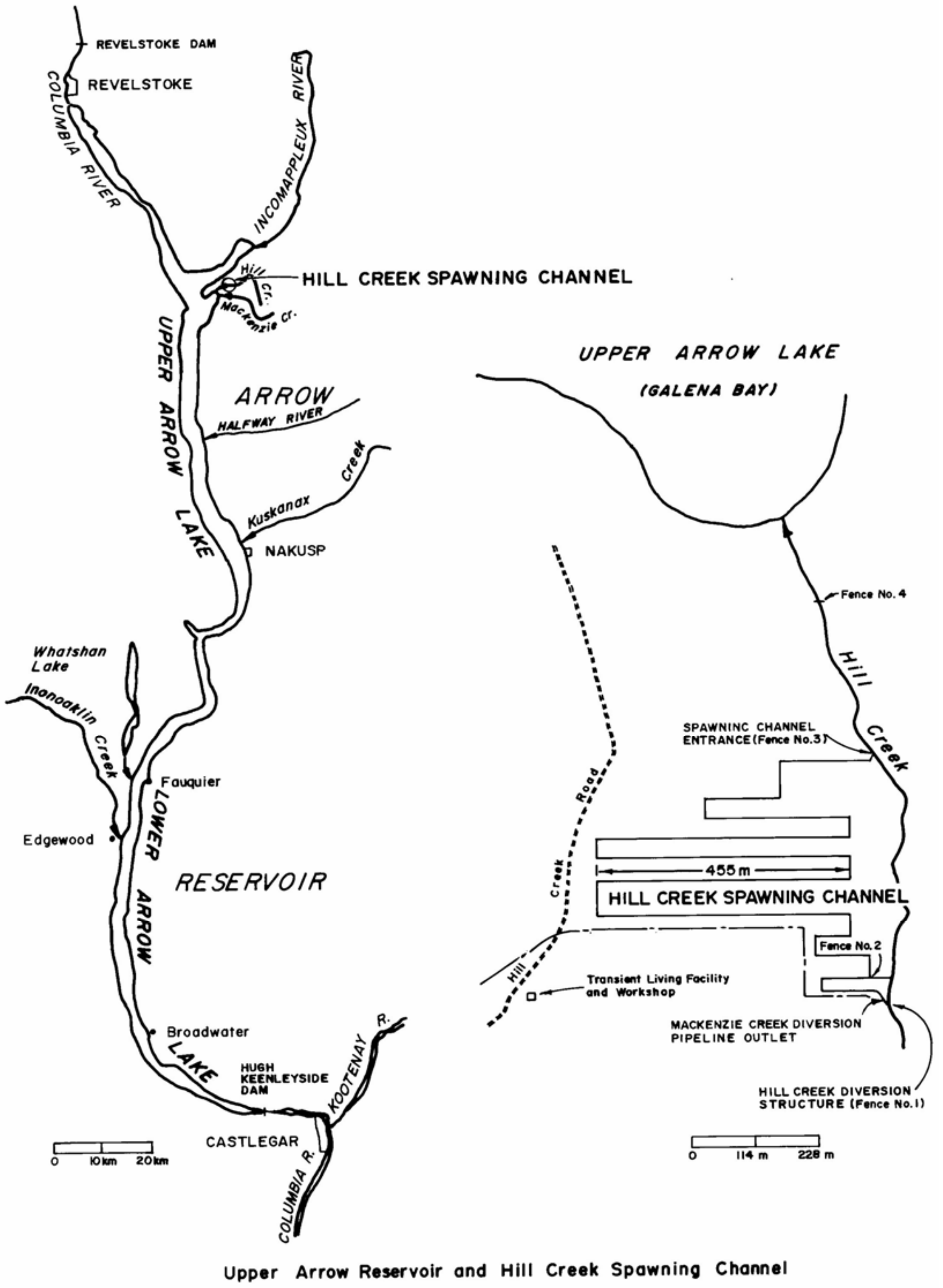


Figure 1. Location of Hill Creek Spawning Channel and overview of the channel, depicting four fences and stream outlet to upper Arrow Lakes Reservoir (Manson et al. 2005).

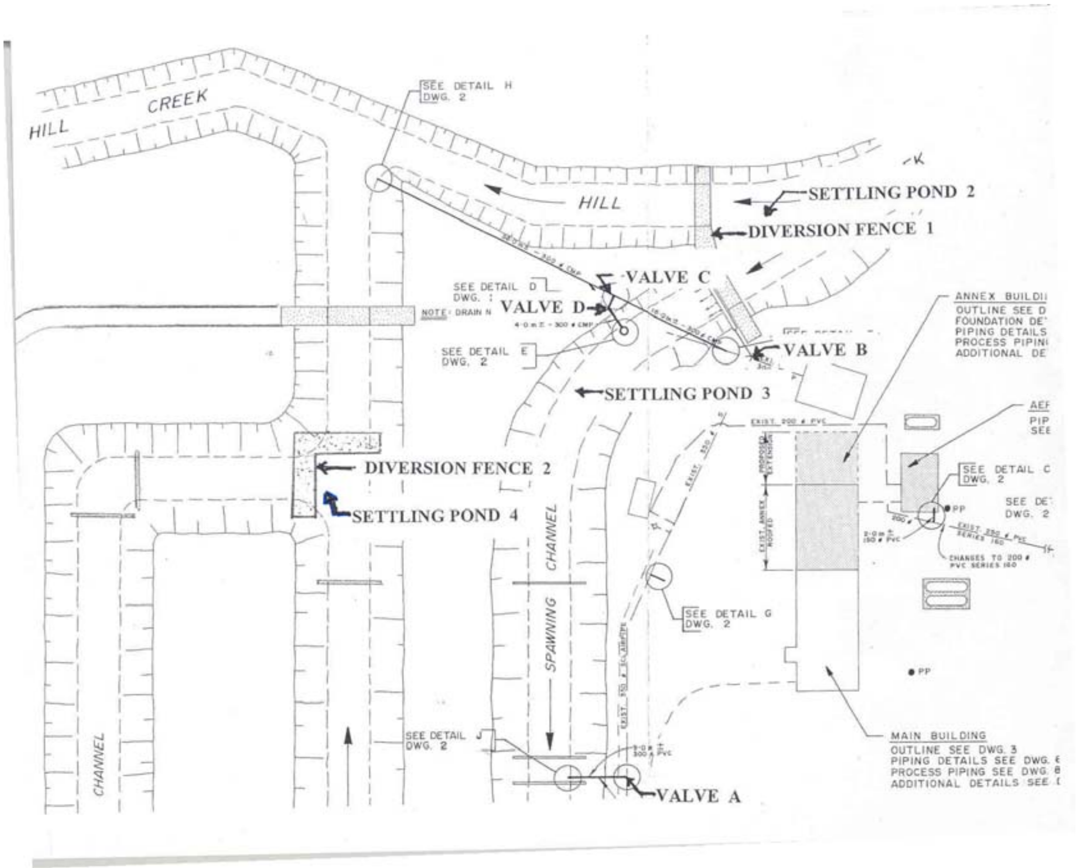


Figure 2. Location of settling ponds, diversion fences, and valves at the Hill Creek Spawning Channel (Manson et al. 2005).

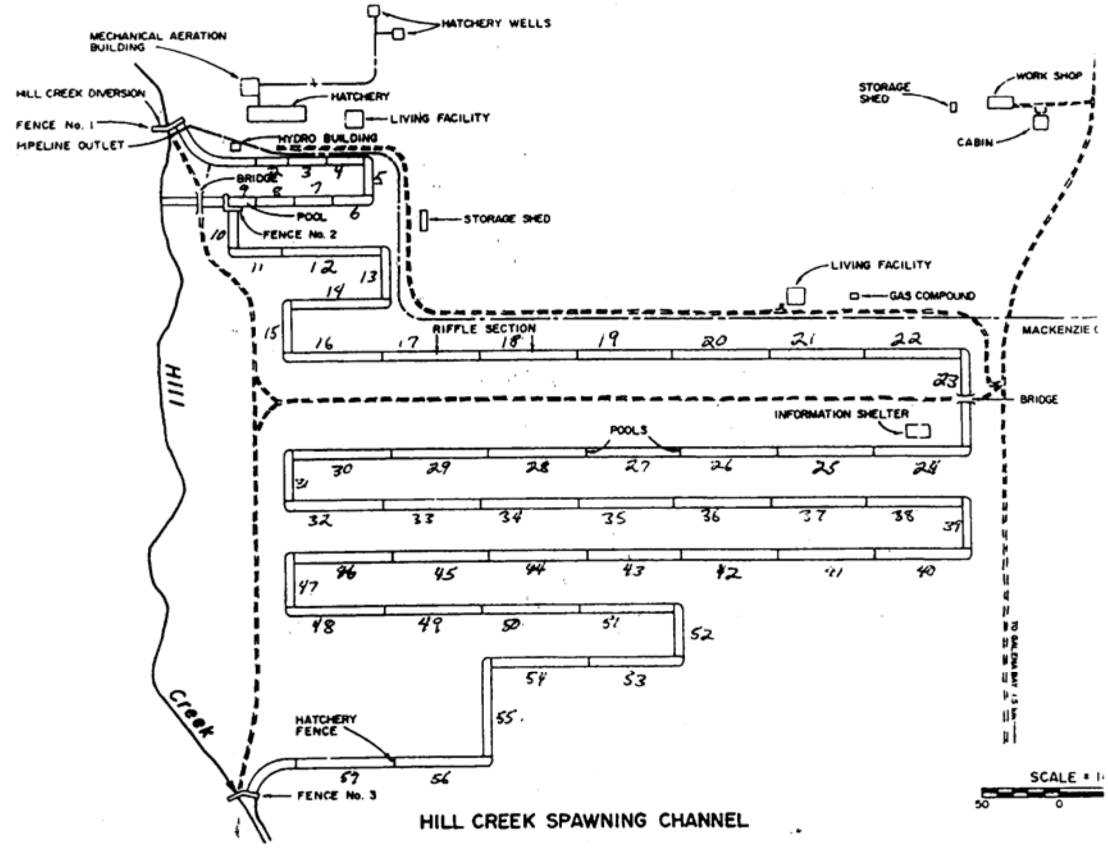


Figure 3. Schematic of the Hill Creek spawning channel showing numbered cells (Manson et al. 2005).

2 METHODS

2.1 Scarification Procedures

In 2006, Hamling Lakes Contracting Ltd. carried out the HCSC scarification procedures under the direction of Kingfisher Silviculture.

Scarification began on July 29 following completion of rainbow fry emergence. Scarification started with the cleaning of Settling Pool #1. Effluent water from cleaning of the settling ponds was diverted away from the spawning channel to the overflow/old streambed. During this time, the spawning gravels were watered using discharge from MacKenzie Creek.

Settling Pool #2 was cleaned on July 30 and Settling Pool #3 was cleaned on July 31. Settling Pool #2 had not been cleaned in three years. Effluent from cleaning Pool #2 was diverted in part to the overflow/old streambed channel at Fence 2. The remaining effluent discharged to the spawning channel was diluted with water from MacKenzie Creek. Large amounts of silt and debris were removed from the settling ponds using an excavator (Samsung SE210LC3) and hauled to dumpsites in a tandem gravel truck. For example, 18 tandem axle gravel truckloads of material were removed from Pool #2. Pool #2 was over 10 feet deep after cleaning.

Scarification of the 57 cells (Figure 2) of the main channel began on August 1 and took 15 days to complete. Initially, Kingfisher Siviculture removed overhead vegetation along each cell so as not to interfere with scarification. However, escape cover for rainbow juveniles was not disturbed at this time. Also, scarification was not carried out within 0.5 m of each spawning channel bank in order to minimize juvenile mortality and avoid disturbance of preferred trout habitat. Machine operators were advised not to push gravel against the banks, as well.

A small excavator (Link-Bell Spin Ace 80) dug and recast the spawning channel gravel. Three passes with the excavator were made on the main spawning channel cells 1 - 48 of the spawning channel. A bulldozer (Cat TD 8-E) then levelled the cleaned gravel.

Cells 19 and 20 were found to have heavy amounts of silt. In order to improve silt removal in these cells, the excavator recast the spawning gravel, and then windrowed the gravel. The bulldozer then rolled the windrow to remove silt once again before levelling. Cells #24 - 26 were found to require new gravel.

Cleaning of cells #49 - 57 was time constrained and limited by the in-stream work permit. As a result a much quicker cleaning technique was adopted compared to the upstream cells. Intensive hand raking of these cells was also done in order to aid the gravel cleaning.

The excavator and bulldozer took ten-minute breaks each hour so as to reduce turbidity levels for short periods over the scarification workday. A half-hour lunch break was also taken as well as the 12-hour period overnight during which turbidity levels were visibly reduced.

2.2 Turbidity Monitoring

2.2.1 Portable field meter

The spawning channel operator took spot check turbidity measurements with a Lamotte Model 2020 portable turbidity meter (resolution ±2% 0 - 100 NTU, ±3% above 100 NTU, detection limit 0.5 NTU).

“Spot checks” were taken upstream of the gravel cleaning operations and various distances downstream of the scarification process. The portable field meter was calibrated with 10 Nephelometric Turbidity Units (NTU) solutions before daily measurements at each new location. The purpose of these measurements was to provide an indication of the rate of reduction in turbidity as the water moved downstream, and a backup in case the Analite NEP495 continuous recorder failed (Section 2.2.2). All “spot check” turbidity values reported here were a mean of two consecutive measurements.

2.2.2 Continuous recorder

Turbidity levels during the scarification were monitored using an Analite NEP495 microprocessor turbidity probe (McVan Instruments Ltd., Australia) installed at the downstream end of the spawning channel (at the Hatchery Fence) on 13 July. Turbidity values were recorded until 18 August (Figure 1 and Figure 3). The Analite NEP 495 has a resolution of ±0.01 at 40 NTU, ±0.02 at 100 NTU, ±0.1 at 400 NTU, and ±0.2 at 1000 NTU for turbidity and is designed to operate where build-up from sediment is likely.

The meter was re-calibrated internally and upgraded at the factory in June 2006. The recorder was calibrated prior to installation, with solutions provided by the distributor (Geo Scientific Ltd., Vancouver, BC).

It was set to log a turbidity measurement once every 15 minutes, and wipe the sampling window once every 6 hours. Wipe frequency was less than the measurement frequency to ensure that the battery would not expire during the sampled period. Additionally, the Analite NEP 495 logged continuous temperature measurements every 15 minutes (resolution ±0.1 from -10 to 50^{o}C).

2.3 Sediment Load in Spawning Channel Effluent

Sediment loads were calculated by first converting continuous turbidity values in NTU to total suspended sediment (TSS, mg/L). The equation for this was obtained from Thompson (2005):

$$\text{TSS} = 0.56*(\text{Turbidity})^{1.2}.$$

Suspended sediment load was calculated using the equation:

$$\text{Suspended load} = \text{TSS (mg/L)}*\text{Discharge (m}^3\text{/s)}*1{,}000\ \text{L/m}^3.$$

This equation was then multiplied by the number of seconds in fifteen minutes because the continuous turbidity meter recorded turbidity every fifteen minutes. The fifteen-minute periods were added over 24 hours to calculate load on a daily basis and milligrams were converted to metric tons.

2.4 Sediment Transects

Sediment transect sampling was done at three sites in Hill Creek downstream of the spawning channel (Figure 4). Site 1 was located immediately downstream of the channel outlet, Site 2 at the Koucheck Road bridge (~ 1 km downstream), and Site 3 just upstream of Fence 4, approximately 1.5 km downstream of the spawning channel and 0.5 km from the lake. Sampling was not conducted at the mouth of Hill Creek because of private land access restrictions.

At each of the sites, two habitat types were sampled, a riffle, and either a run or pool tailout. Depth and turbulence prevented sampling of pool habitats. For each habitat type within a site, three to five transects were sampled across the stream width. The first transect was located near the downstream end of the habitat type (e.g., riffle) and remaining transects were located upstream of the first using distances taken from a random number table. Transect locations were marked with rebar stakes and flagging tape so that the same transect could be sampled before and after scarification. Sampling before scarification took place on 13 and 18 July, and immediately after scarification on 17 August 2006. Stream discharge decreased between July and August so that the edges of some transects were above the wetted width at the second sampling. Only points that were still inside the wetted width were included for before/after comparisons (i.e., potentially usable by fall spawning fish).

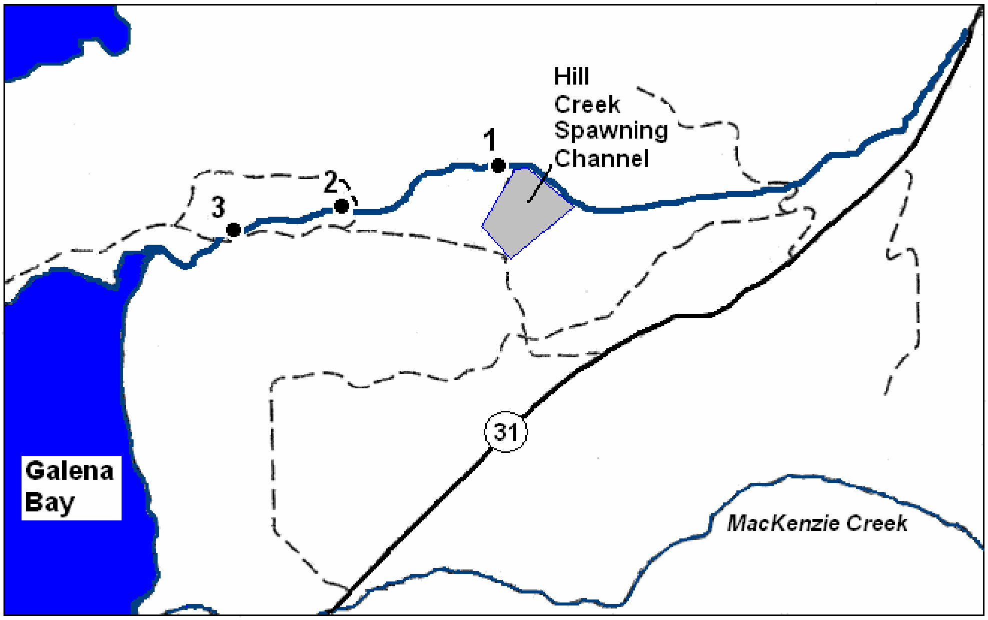


Figure 4. Location of three sites used for sediment transects sampling downstream of Hill Creek Spawning Channel in 2006.

Two methods were used to compare substrate particle size and sediment quantity before and after scarification. Surface substrate size was classified using the Wentworth scale (Table 1) with measurements taken at each boot length as the sampler walked heel-to-toe across a transect. The sampler reached down at the end of his boot for each step and measured the size of the particle his finger touched. Size of particles was determined by measuring across the median length of the particle, or visually estimated (for particles less than 1 cm).

The number of points in each size category along each transect was summarized as a percent of the total points assessed per transect. Percentages from replicate transects were averaged to calculate the "mean percent of measurement points" for various particle sizes.

Table 1. Modified Wentworth classification for substrate particle sizes (McMahon et al. 1996.)

Classification	Particle size range (mm)
Boulder	>256
Cobble	64 – 256
Pebble	16 – 64
Gravel	2 – 16
Sand	0.0625 – 2
Silt/clay	< 0.0625

The second method, substrate embeddedness, is a measure of the degree to which larger particles (cobble, pebble, gravel) are surrounded or covered by fine sediment (Platts et al. 1983). The percentage of the perimeter of larger particles covered by fine sediment was estimated visually at intervals of 20 or 30 cm across each transect. The shorter length interval was used on shorter transects to obtain a minimum of 9 points per transect. These observations were made through a length of plastic tube (10 cm diameter) covered with clear plastic on the bottom to eliminate the effects of surface turbulence on vision.

The number of points in each embeddedness category along each transect were summarized as a percent of the total points assessed per transect. Percentages from replicate transects were averaged to calculate the "mean percent of measurement points" at various categories of embeddedness.

3 RESULTS

3.1 Turbidity

3.1.1 Field metered turbidity measurements at various locations

Maximum daily levels of turbidity increased over the course of the scarification period (Figure 5). As the excavator and bulldozer worked on the upper cells of the spawning channel fine sediments were flushed downstream with the current. Fines then accumulated in the middle and lower spawning channel.

Daily peaks in turbidity increased from 0.05 NTU on July 29 to 649 NTU on August 14 monitored at the Hatchery Fence (at the downstream end of the spawning channel). At Fence 4 (1.5 km downstream from the spawning channel), maximum daily turbidity increased from 0.7 on July 29 to 332.0 NTU on August 11.

Peak turbidity levels were usually observed in the afternoon during active cleaning. Overnight the levels of turbidity declined to low levels. Turbidity was monitored prior to starting work every morning. Pre-work turbidity levels varied from 0 NTU on July 29 to 9.9 NTU on August 14 at the Hatchery Fence. Pre-work turbidity levels varied from 0 NTU on July 29 to 7.2 NTU on August 14 at Fence 4.

Peak turbidity (649 NTU), monitored in 2006 at the Hatchery Fence, was higher than the peak value in 2005 (514.0 NTU) but lower than the peak turbidity level in 2004 (834.0 NTU) (Table 2).

A similar trend in turbidity levels by year was observed at Fence 4 (1.5 km downstream of the spawning channel). Peak turbidity value (332.0 NTU) in 2006 at Fence 4 was higher than the maximum level in 2005 (227.5 NTU) but lower than the maximum turbidity value observed in 2004 (624.0 NTU) (Table 2).

The turbidity levels in MacKenzie Creek water remained relatively low (0 - 2.2 NTU in 2006) during scarification (Figure 5). In 2006 there was a peak value of 2.2 NTU on August 11 corresponding to a rain event on August 10 and 11. The turbidity remained low and varied from 0 - 0.1 NTU on other dates during gravel cleaning.

At Fence 1 in Hill Creek upstream of scarification, the turbidity levels remained relatively low (0 – 47.0 NTU in 2006) from July 29 to August 15 (Figure 5). In 2006 there was a peak value of 47.0 NTU on July 30 that may have been affected by cleaning of the upstream settling pools although most of the water is by-passed to the overflow channel. No corresponding rain event was noted on this date. A rain event was observed on August 10 and 11 during which the turbidity level rose to 5.5 NTU (August 11). The turbidity remained low and varied from 0 - 0.2 NTU during the rest of the scarification period. Maximum turbidity levels at Fence 1 were 5.6 NTU in 2005 and 8.2 in 2004.

Table 2. Turbidity levels (NTU) at various locations from 2004 - 06.

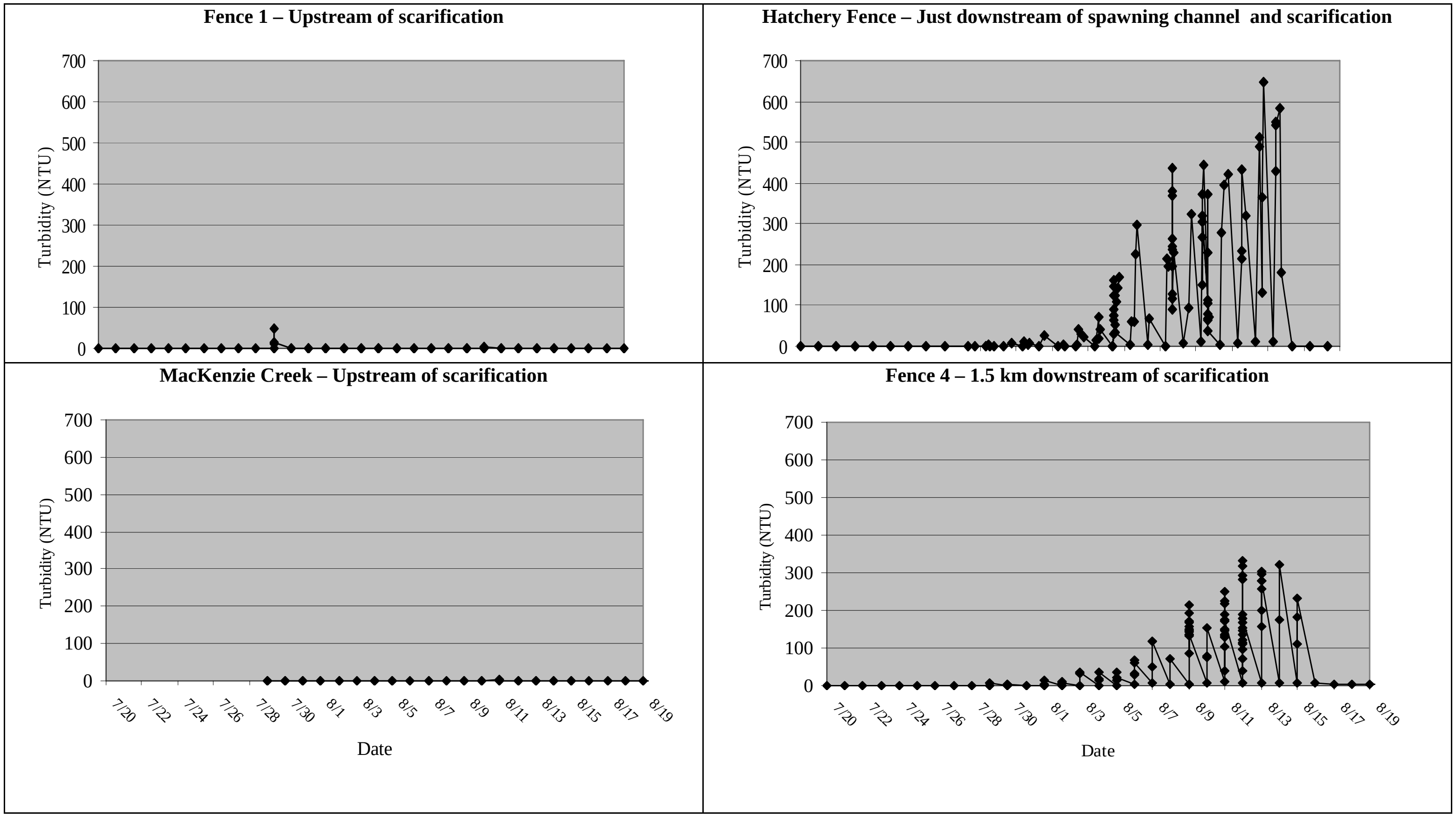
				NTU	
Site	**Location**		**2004**[1]	**2005**[2]	**2006**
MacKenzie Creek	Upstream of scarification				
		Min	--	--	0
		Max	--	--	2.2
Fence 1-SC	Upstream of scarification				
		Min	0.1	0.0	0.0
		Max	8.2	5.6	47.0
Hatchery Fence-SC	Spawning channel at downstream end of kokanee spawning gravels				
		Min	0.2[3]	0.0	0
		Max	834[3]	514.0	649.0
Fence 4-HC	Hill Creek 1.5 km below spawning channel				
		Min	0.9	0.1	0
		Max	624.0	227.5	332.0

SC=spawning channel, HC=Hill Creek,

[1] Manson et al. 2005,

[2] Porto 2006,

[3] These values were actually sampled at Fence 3 in the spawning channel within a few 100m of Hatchery Fence-SC.



Fence 1 – Upstream of scarification

Hatchery Fence – Just downstream of spawning channel and scarification

MacKenzie Creek – Upstream of scarification

Fence 4 – 1.5 km downstream of scarification

Figure 5. Turbidity measurements taken with portable field meter by location. Scarification occurred from July 29 - August 15.

3.1.2 Continuous turbidity measurements at Hatchery Fence

Water samples measured by the Analite NEP498 continuous turbidity meter were screened and found to be higher than paired samples measured by the Lamotte 2020 portable turbidity meter (Appendix I). The portable meter was previously used to develop a turbidity-total suspended solids relationship for the channel (Thompson 2005). Thus, the continuous turbidity data was corrected by the linear equation:

$$y = 0.59*x.$$

The slope parameter of the linear regression was significant ($t=23.56$, $df=1$, $p<0.0001$, $r = 0.99$).

Higher values measured by the continuous recorder compared to the field meter are likely due to a build-up of sediment on the optics of the sensor. This could have resulted from the fact that the wiper was set to swipe only every six hours to save on battery power.

Additionally, continuous turbidity data was not valid on August 16 - 17 (post scarification) and possibly due to bubbles or debris on the optics of the sensor or parking of the wiper assembly. This data was eliminated from the data set and field meter data for these dates was used instead.

Maximum daily turbidity levels increased from 2.2 - 605.1 NTU over the course of the scarification period as the machines worked from the top of the channel downstream (Figure 6, Table 3). Turbidity levels were lower on August 8 due to machine failure. As a result, gravel-cleaning operations on August 8 were halted temporarily.

Median daily turbidity levels ranged from 0.4 - 27.8 NTU with an overall median of 8.5 NTU during the entire scarification period (Table 3). The interquartile range for the daily values varied from 0.6 - 468.7 NTU with an overall interquartile range of 38.5 for the whole (Table 3) period.

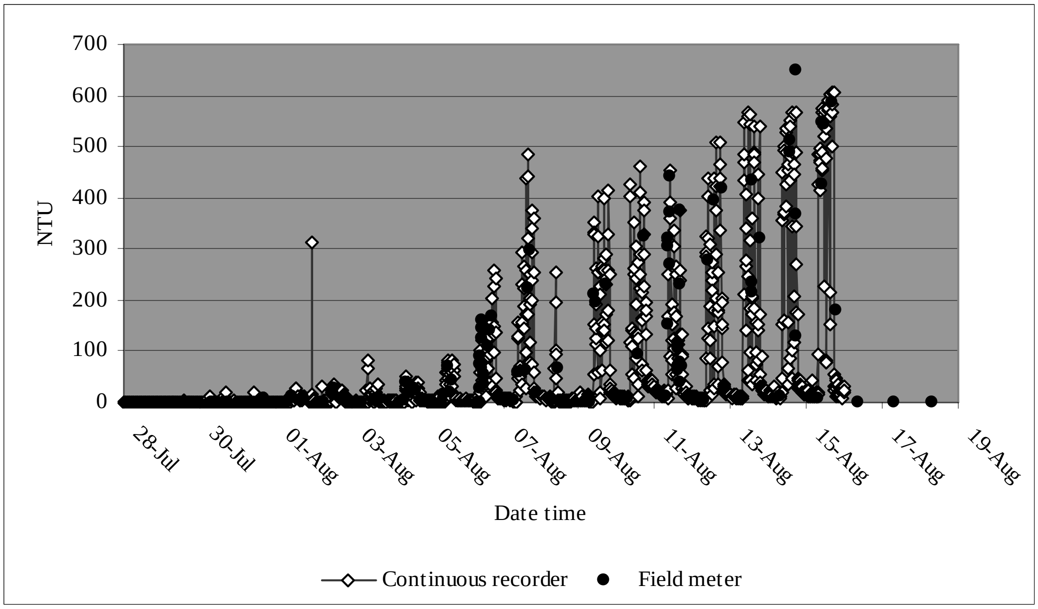


Figure 6. Corrected continuous turbidity measurements and field metered turbidity recorded just downstream of spawning channel (Hatchery Fence 4). Scarification occurred from July 29 - August 15.

Table 3. Corrected daily turbidity levels (NTU) at the Hatchery Fence just downstream from the spawning channel during scarification.

Scarification Date	Median	Min	Max	90th percentile	IQR[1]
07/29/06	0.4	0.0	2.2	1.0	0.6
07/30/06	0.7	0.2	19.9	1.7	0.7
07/31/06	0.5	0.0	20.4	1.5	0.3
08/01/06	3.6	0.2	314.7	11.2	7.5
08/02/06	2.1	0.1	35.1	22.7	13.8
08/03/06	1.8	0.8	81.0	19.0	3.4
08/04/06	4.1	0.0	49.9	26.2	12.1
08/05/06	4.1	0.0	83.9	61.1	11.2
08/06/06	9.9	0.0	259.7	137.4	78.0
08/07/06	15.2	0.0	483.7	261.7	146.4
08/08/06	3.5	0.0	253.6	10.2	4.7
08/09/06	18.1	0.0	413.1	274.1	169.6
08/10/06	39.9	4.3	462.4	290.1	150.9
08/11/06	21.2	8.1	453.5	253.9	97.2
08/12/06	22.0	3.0	508.6	355.8	187.9
08/13/06	29.1	7.0	567.1	477.4	191.1
08/14/06	29.7	8.1	568.1	490.3	331.7
08/15/06	27.8	9.7	605.1	573.1	468.7
Total period	**8.5**	**0.0**	**605.1**	**250.6**	**38.5**

[1] IQR = Interquartile range

An effort was made to decrease the duration of exposure to high turbidity levels throughout the ten-hour workday in order to reduce potential impacts to fish health. The machine operators took ten-minute breaks each hour. A half-hour lunch break was also taken, as well as the 12 to 14-hour period overnight during which turbidity levels were reduced to near base levels. An example of this is given in Figure 7 for August 15, a day on which some of the highest turbidity levels were observed.

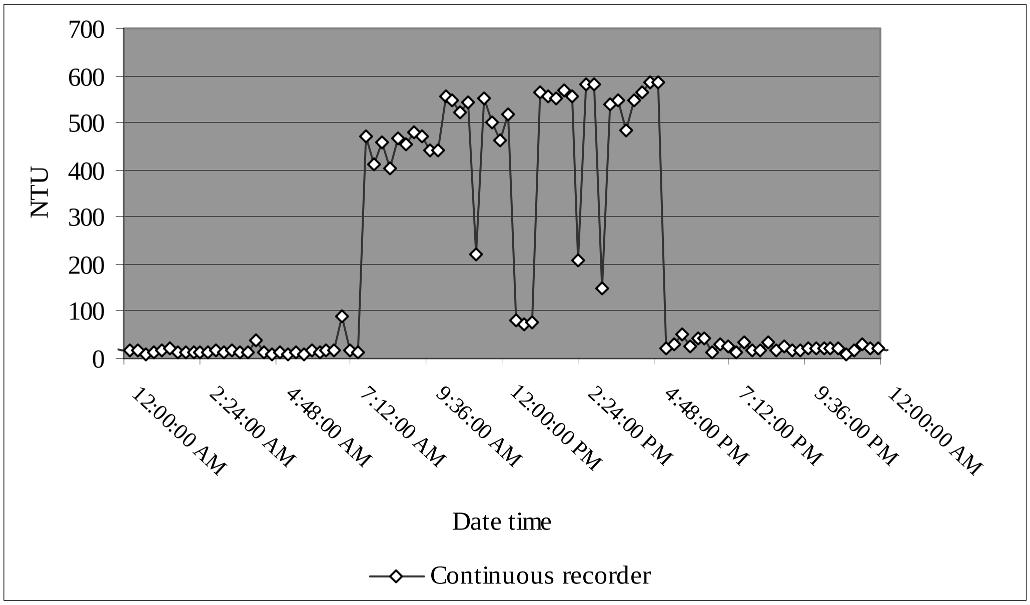


Figure 7. Corrected continuous turbidity measurements recorded on August 15 (24 hour period) just downstream of spawning channel (Hatchery Fence 4).

3.2 Sediment Load in Spawning Channel Effluent

The total sediment load removed from the spawning channel effluent was 74.71 metric tons over the entire scarification period from July 29 to August 15, 2006. This represents the total amount of sediment, previously deposited in the channel, that was re-suspended and flushed downstream of the channel during the gravel cleaning process. It does not include the amount of sediment directly removed by the excavator from the upstream settling ponds.

Daily sediment load increased over the scarification period because gravel cleaning began at the upstream end of the channel and slowly worked downstream. Some of the sediment from the upper channel settled at the bottom of the channel and required further remobilization. On August 8 gravel-cleaning operations were halted due to equipment failure and as a result there is a decrease in the sediment load on this date (Figure 8).

Discharge levels were fairly constant from July 29 to August 15. Discharge varied from 0.30 - 0.58 m^3/s. Rain events occurred on August 10 and 11.

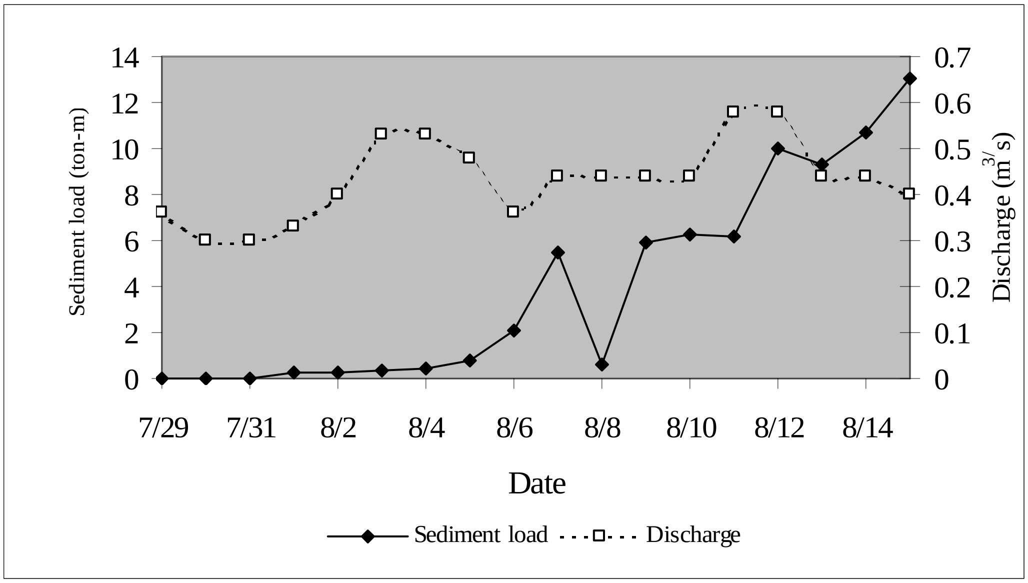


Figure 8. Daily sediment load (metric tons) just downstream of the spawning channel (at Hatchery Fence 4) and discharge (m^3/s) at Fence 2 over the scarification period.

3.3 Sediment Transects

Transect sampling took place before scarification on 13 and 18 July, and immediately after scarification on 17 August 2006. The last day of scarification took place on August 15. The transect data, thus, represents two “snap shots” of stream bed conditions before and immediately after gravel cleaning.

3.3.1 Substrate particle size

The dominant substrate type was pebble (size 16 - 65 mm) at all transect sites (Figures 9 - 11). This substrate type comprised 38 - 70% of the measurement points along transects at all sites before and after scarification. Gravel (2 - 16 mm) was less prevalent but comprised 0 - 19% of the measurement points along transects at all sites (Figures 9 - 11) before and after gravel cleaning. These substrate sizes include the sizes of particles that are considered ideal for spawning kokanee and rainbow trout (6 - 51 mm according to the spawning channel design specifications).

Sand and clay/silt are the particle size categories mobilized during the scarification process. Sand (0.0625 - 2.00 mm) was common at 0 - 21% of the measurement points along transects at all sites and clay/silt (<0.0625 mm) predominated at 0 - 20% of the sites before and after scarification (Figures 9 - 11).

Following scarification, the percent clay/silt increased at all sites except the riffle at Site 3 (Figure 12). The largest increases occurred at Site 1 just downstream from the spawning channel. At this site the percent clay/silt increased from zero before scarification in both the riffle and tailout to 15% in the riffle and 20% in the tailout. Site 2 (1 km downstream of channel) also showed increases in the percent clay/silt after gravel cleaning. Here, the percent clay/silt increased from zero before scarification in both the riffle and tailout to 5% in the riffle and 10% in the tailout. The riffle at Site 3 furthest from the spawning channel (1.5 km downstream) showed a slight decrease in percent clay/silt from 10% to 8% after scarification while the run at Site 3 had an increase from 4% to 11%.

The percent pebbles decreased after scarification at Sites 1 and 2 in all habitat types but this trend was not observed at Site 3 (Figure 12). At Site 1 the percent pebble decreased from 70% to 40% in the riffle and 62% to 53% in the tailout. At Site 2 the percent pebble decreased from 67% to 61% in the riffle and 51% to 38% in the tailout. The riffle at Site 3 showed no change (55%) in percent pebble before and after scarification while the run at Site 3 had an increase from 53% to 68%.

The changes, observed at Site 1 and Site 2, were due to in filling of pebble-dominated habitat along the margins of the stream with clay/silt immediately after scarification (see below Section 3.2.2). These sediments will be dispersed downstream over time and will ultimately be distributed to Arrow Lake in the following spring freshet.

There were no consistent changes in the percent gravel or sand before or after scarification at any of the sites (Figure 12).

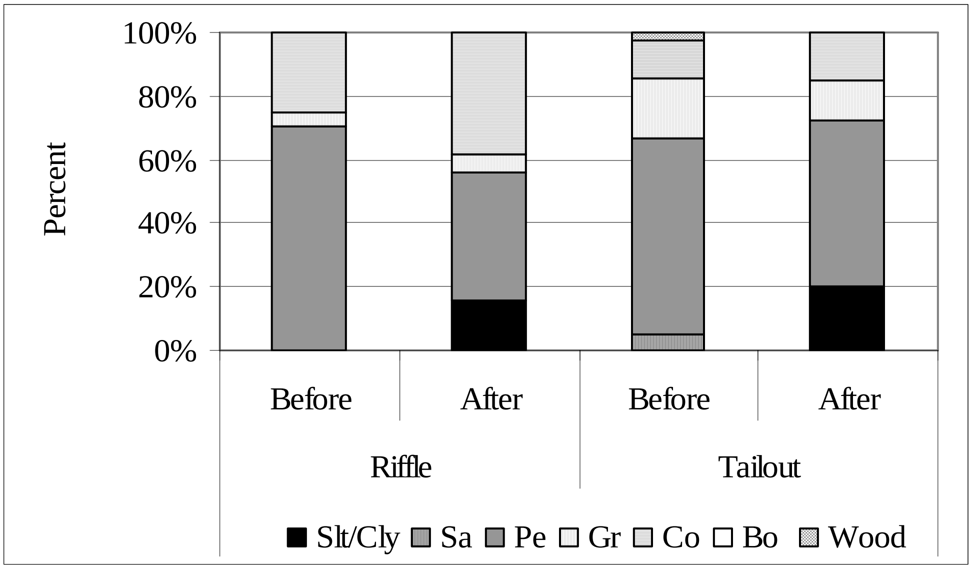


Figure 9. The mean percent points along a transect with various particle sizes at Site 1 (just downstream of channel). Particle size categories are indicated by the following abbreviations; Pe (Pebble), Co (Cobble), Gr (Gravel), Sa (Sand), Bo (Boulder), Slt/Cly (Silt/Clay).

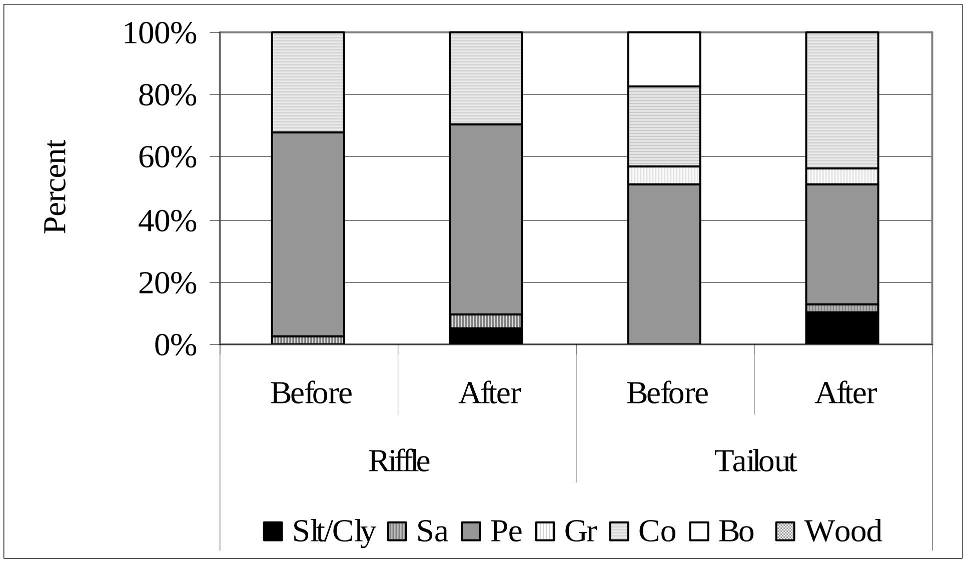


Figure 10. The mean percent points along a transect with various particle sizes at Site 2 (Middle Bridge, 1 km downstream of the spawning channel). Particle size categories are indicated by the following abbreviations; Pe (Pebble), Co (Cobble), Gr (Gravel), Sa (Sand), Bo (Boulder), Slt/Cly (Silt/Clay).

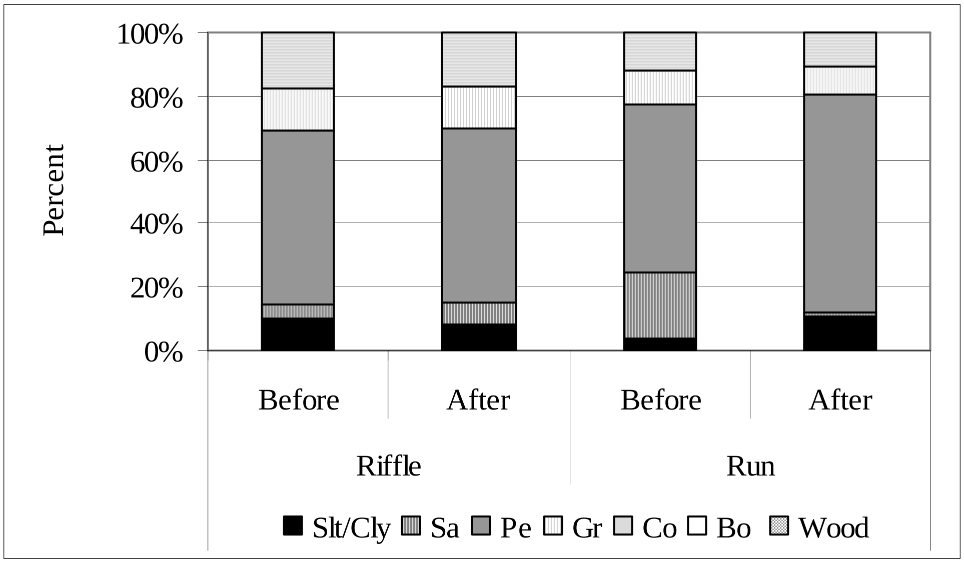


Figure 11. The mean percent points along a transect with various particle sizes at Site 3 (Fence 4, 1.5 km downstream of the spawning channel). Particle size categories are indicated by the following abbreviations; Pe (Pebble), Co (Cobble), Gr (Gravel), Sa (Sand), Bo (Boulder), Slt/Cly (Silt/Clay).

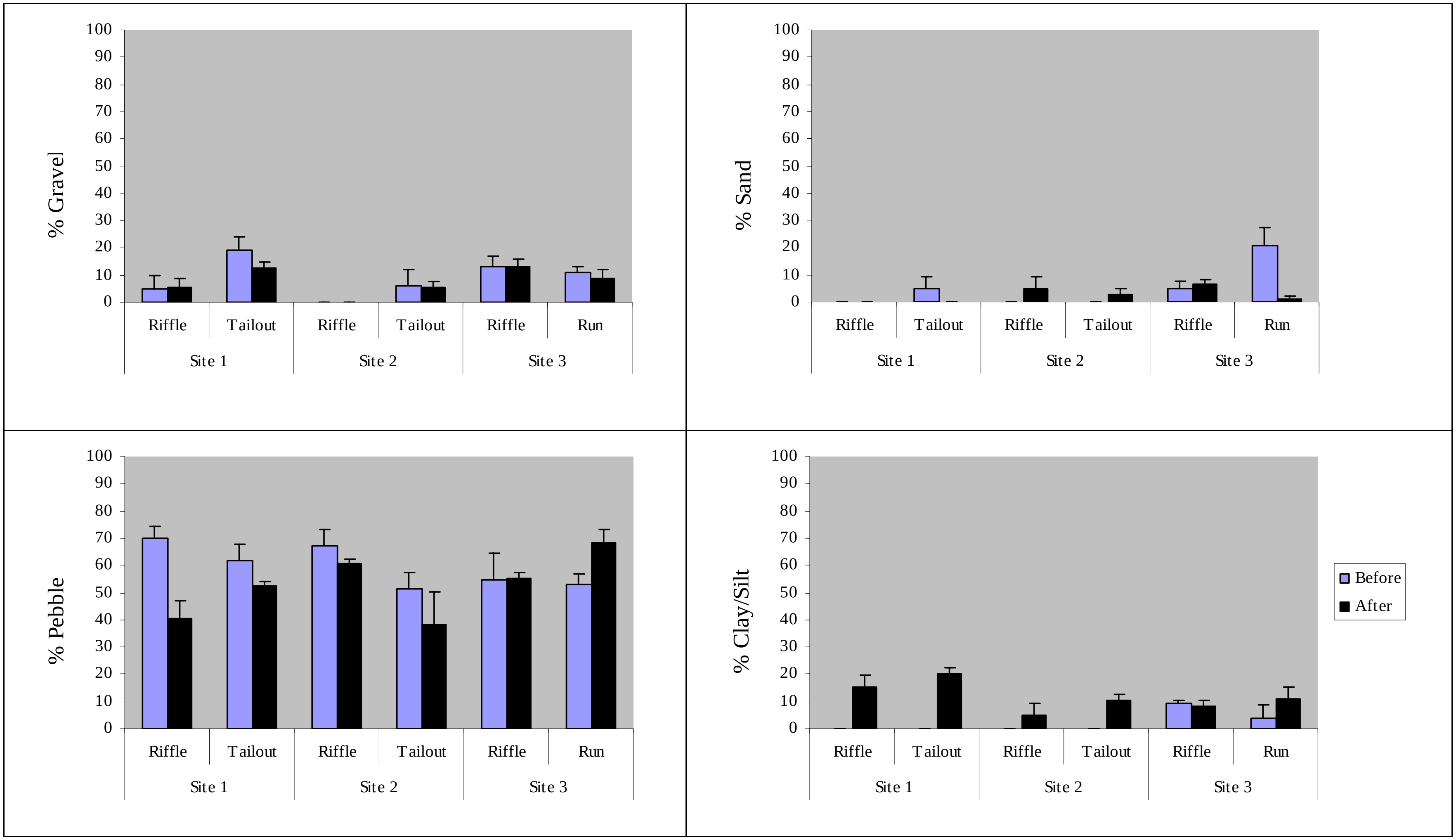


Figure 12. The mean percent particle size at each site by habitat type before and after scarification. Error bars indicate standard error among replicate transects. No particles were recorded at sites indicated by blanks.

3.3.2 Embeddedness

The lowest embeddedness rating, *0 - 10% of perimeter covered*, was the most commonly occurring category before and after scarification at all habitat types and locations. Before scarification the embeddedness rating of *'0 - 10% Covered'* varied in occurrence from 89 - 95% before scarification at all sites. After scarification, habitat with embeddedness ratings of *'0 - 10% Covered'* varied in occurrence from 46 - 91% at all sites (Figures 13 - 15).

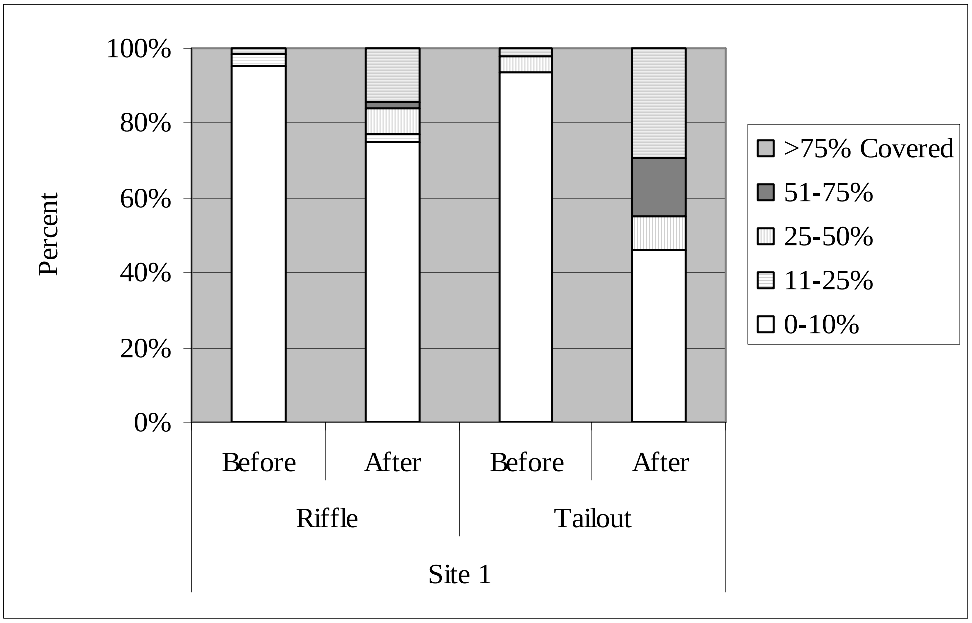


Figure 13. The mean percent of points along transects (n = 3 - 5) with various categories of embeddedness ratings (% of perimeter covered by fines) before and after scarification at Site 1.

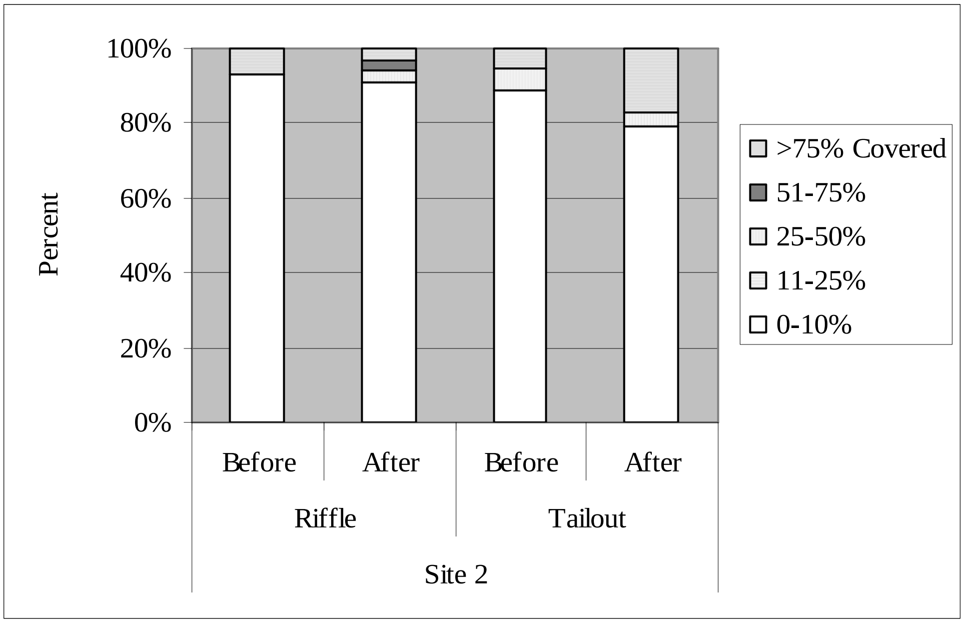


Figure 14. The mean percent of points along transects (n = 3 - 5) with various categories of embeddedness ratings (% of perimeter covered) before and after scarification at Site 2.

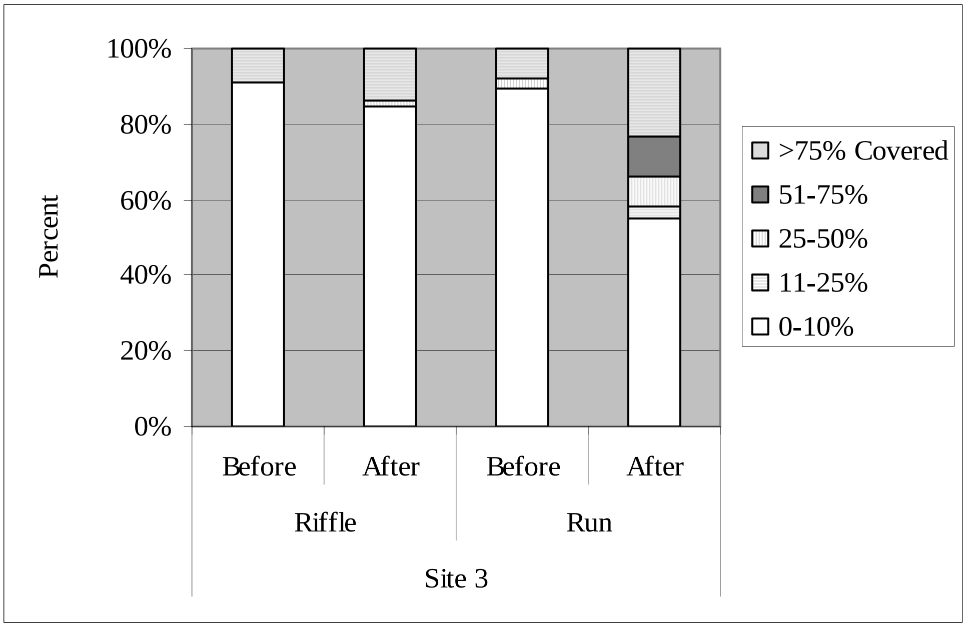


Figure 15. The mean percent of points along a transect (n = 3 - 5) with various categories of embeddedness ratings (% of perimeter covered) before and after scarification at Site 3.

The categories of 25 - 100% embedded were pooled and termed ’*>25% Covered*’. The pooled embeddedness category of ‘*>25% Covered*’ indicates the percentage of transect where fine sediments accumulated. The rating of ‘*>25% Covered*’ varied in occurrence from 2 - 11% before scarification at all sites. After scarification, the occurrence of this category increased at all sites (9 - 54%). The largest increases in the occurrence of the ‘*>25% Covered*’ category took place just downstream of the spawning channel. At Site 1 riffle habitat there was a 14-fold increase and at the Site 1 tailout there was a 9-fold increase in this category (Figure 16). However, the run at Site 3 also had a 4-fold increase in the embeddedness rating of ‘*>25% Covered*’.

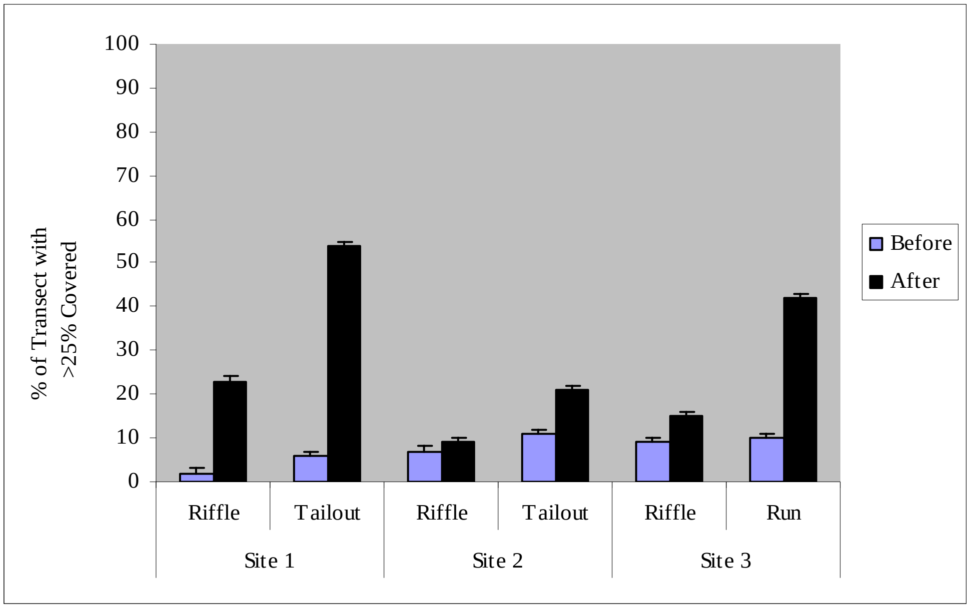


Figure 16. The mean percent of transect with >25% covered before and after scarification. Error bars indicate standard error among replicate transects.

Generally, fine sediments were distributed along the margins of the stream following scarification as indicated by the increase in embeddedness ratings at some sites (for example, see Figure 17).

The fines along the margins of the stream resulting from scarification will move downstream over time during the freshet in the spring of 2007. The transect data collected after gravel cleaning (on August 17, 2006) thus, represents a “snap shot” of stream bed conditions before this occurs. Long-term accumulation of sediments in the natural channel is not expected due to the remobilization that occurs during high water every spring, and no evidence of such accumulation from the previous year was observed during the July 2006 transect sampling.

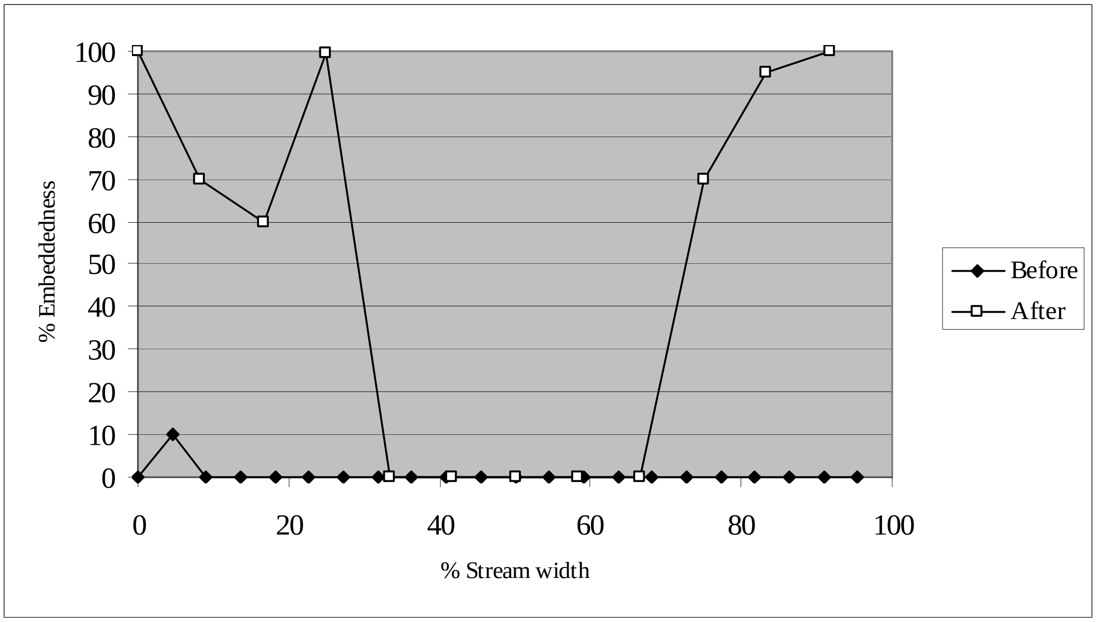


Figure 17. Percent embeddedness versus percent of stream width at Transect Replicate 1 surveyed at the tailout at Site 1.

5 DISCUSSION

5.1 Scarification Effectiveness

HCSC targets a kokanee egg to juvenile survival rate of greater than 30%. In 2006, a kokanee egg to juvenile survival rate of 36% was achieved (Andrusak 2006) due to successful scarification techniques and careful management of HCSC operations. Effective removal of sediments from the spawning channel is essential for achieving kokanee production targets for the facility. Machine scarification of gravels in combination with water flushing has been shown to give acceptable egg to juvenile survivals. This method is logistically and economically feasible and much less costly than dry screening (Thompson 2006).

This year was the first year that a continuous turbidity recorder was used to estimate the total amount of sediment removed from the channel. The amount of sediment removed was 74.71 metric tons over the entire scarification period from July 29 to August 15, 2006. In addition, over 18 tandem axle truckloads of sediment were excavated from upstream settling ponds #1 - 3. Mundie and Crabtree (1997) reported a comparable amount of sediment (82 metric tonnes) removed by scarification in the four kilometre long Little Qualicum Spawning Channel.

Low egg to juvenile survival rates were observed in 2004 (0.08%) and 2005 (2.4%) and caused some concern as to whether the accumulation of silt in the spawning gravels of the channel was a factor (Mansen et al. 2005, Porto 2006). However, in 2006, egg-to-juvenile survival rates were thirty-six percent (Andrusak 2006). Previously low egg-to-juvenile survival rates now are thought to have resulted from sediments deposited in high turbidity rainfall events during egg incubation in these years. Thus, current scarification techniques should continue to meet kokanee egg-to-juvenile survival targets of greater than 30%.

5.2 Downstream Habitat Effects

It is important to recognize that scarification sediments are *part of the annual sediment load* carried by Hill Creek. The channel does not add sediments to the creek but changes the timing of movement through the system (traps sediment in spawning gravels during most of the year and re-mobilizes by scarification). Thus, spawning channels do not add extra sediment load to a stream unlike other impacts such as road building, linear developments, and activities related to agriculture, forestry, mining or urban growth.

Although there is no addition of sediments, the re-suspension of fines in late summer causes a large pulse at a time of year when suspended sediment levels are usually low. Downstream transect sampling allowed an assessment of associated habitat changes *immediately* after the scarification. No long-term habitat effects of scarification are expected because any sediments remaining until the following spring will be mobilized and carried downstream by the freshet.

In the natural Hill Creek streambed, spawning substrates (6 - 51 mm) for kokanee and rainbow were the dominant substrate type (38 - 89%) at all sites and habitats before and after scarification. In addition, the lowest embeddedness rating (0 - 10% Covered) was the most commonly occurring category (29 - 95%) before and after scarification at all habitat types and locations. The prevalence of low embeddedness ratings in riffles and tailouts indicated that there were relatively silt-free spawning gravels available for kokanee spawners entering the stream in August and September.

Transect monitoring of particle size and embeddedness and indicated that fine sediments from scarification were deposited along the margins of the stream. The largest deposition of percent clay/silt was just below the spawning channel as expected (Site 1) when compared to other sites (Site 2 and 3). The embeddedness ratings (of greater than 25% covered) also demonstrated that the largest increases in deposition of fines after scarification occurred at Site 1. Our sampling methods did not assess sediments beneath the surface of the substrate.

Fine sediments resulting from scarification could potentially have detrimental effects on fall spawning gravels that could reduce egg-to-juvenile survival for kokanee spawning in the natural creek downstream of the channel. However, any detrimental effects downstream are more than compensated for by greatly enhanced egg to juvenile survival in the spawning channel (Andrusak 2006), thus for kokanee spawning habitat there is clearly a net benefit with regards to scarification effects. A small number of bull trout also spawn in Hill Creek in the fall, however, observations by the channel operator and investigations in other Arrow Lakes tributaries (Decker and Hagen 2007) suggest that it is unlikely that they would spawn in reaches downstream of the channel. To our knowledge these are the only fall-spawning species in Hill Creek. One juvenile mountain whitefish (*Prosopium williamsoni*) was captured in the creek during electrofishing in 2004 and 2005 (Porto and Arndt 2006). Sculpins (*Cottus* spp.) are present, but sediments are likely transported out of the system prior to their spawning in the spring.

Higher levels of sediment in the creek may negatively affect the abundance or composition of invertebrates in the natural stream (Waters 1995) for the fall and winter period, possibly influencing fish feeding and growth. However, increases in insect drift likely occur during the scarification period (see below) providing additional food availability at the time of scarification. In addition, increased input of kokanee carcasses after spawning (due to the enhanced adult returns from the channel) likely has a positive affect on stream nutrients and invertebrate production (Jauquet et al. 2003, Nakajima and Ito 2003, Reimchen et al. 2003).

In summary, the scarification likely has some detrimental effects on fish spawning and aquatic insect habitat below the channel between late summer and the following spring. However, there is a net benefit to spawning in the creek when the positive contribution of the spawning channel is considered and there may be a net benefit to aquatic and riparian insect production due to the enhanced kokanee returns.

5.3 Potential Fish Effects

Operation of the spawning channel in Hill Creek substantially increases kokanee juvenile production and adult returns. Annual spawning runs to the creek have averaged over 160,000 adult kokanee since the channel was constructed (Andrusak 2007), compared to 10,000 prior to the channel (Lindsay 1982). Rainbow trout also use the channel for spawning and rearing (Porto and Arndt 2006).

Detrimental effects of suspended sediment on fish have been grouped into 3 categories: behavioural, sublethal, and lethal or paralethal (Newcombe and Jensen 1996). Behavioural effects include responses such as turbidity avoidance or abandonment of cover; sublethal effects include reductions in feeding and minor to major physiological stress; and lethal/paralethal effects include direct mortality and reduced growth rates or densities.

Peak levels of suspended sediments in Hill Creek measured during scarification in 2005 and 2006 have been less than 2500 mg/L (Thompson 2005, this report). This is well below lethal levels for juvenile salmonids. Sigler et al. (1989) state that acute lethal levels for older salmonid juveniles are typically over 20,000 mg/l, and Korstrom and Birtwell (2006) exposed juvenile chinook (*O. tshawytscha*) to a concentration of 30,000 mg/l (50,000 NTU) for 48 hours without any mortalities. In Little Qualicum Spawning Channel, coho juveniles are exposed to levels up to 5600 mg/l during scarification without effects on survival (Mundie and Crabtree 1997).

Before/after comparisons of fish densities in the spawning channel based on electrofishing and removal estimates were made in 2004 and 2005 (see Porto and Arndt 2006 for details). The electrofishing data suggest that the scarification does not cause a reduction in rainbow trout densities. Average age-0 densities in August (0.62 and 0.76 fish/m^2 in 2004 and 2005 respectively) were substantially higher than those observed by Ptolemy (1979) for the natural stream (0.47 fish/m^2). Bull trout and sculpin catch decreased in post-scarification samples but these data are not as reliable because electrofishing did not work well as a capture method for sculpins, and bull trout numbers were too low for removal estimates. McPhail and Murray (1979) believed there was a late summer/autumn emigration of bull trout juveniles out of McKenzie Creek (based on otolith analyses) that could cause a natural reduction in density for that species. Scarification did not cause a decrease in densities of coho juvenile in Little Qualicum Spawning Channel (Mundie and Crabtree 1997).

Behavioural or sublethal effects of suspended sediment on fish in the channel and downstream are possible. With respect to physiological stress, Newcombe and Jensen (1996) state that coarse particles of 75 - 250 µm diameter are large enough to cause mechanical gill abrasion. In Hill Creek, about 15% of the particles in scarification effluent is in this category according to the analysis of Thompson (2005). This percentage likely decreases quickly with distance downstream because the larger particles settle quickly, and exposure to larger particles may occur mainly for fish closer to the working machine.

Despite the mechanical disturbance and high turbidity, catches in a juvenile emigration trap at the outlet of the channel showed no evidence of a large-scale emigration (i.e., avoidance of turbidity) during the scarification period in 2006. A total of one rainbow trout and three bull trout juveniles were captured in the trap from August 1 to 11 compared to 149 rainbow trout and 9 bull trout captured from July 14 to 31[1].

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[1] The fry trap sampled approximately 5% or less of the channel discharge. The trap was not functional from August 12-15.

On the last day of scarification when turbidity levels were at their highest, schools of trout juveniles were observed holding in the flowing part of a corner pool a short distance below the working machine. It appeared as though these fish were actively feeding. When the machine stopped working and water began to clear, the trout began to move from the middle of the pool towards the margins to seek cover [S. Arndt and B. Barney observations, August 15; see Gregory and Levings (1998) and Bisson and Bilby (1982) for examples of salmonid juveniles using turbidity to reduce predation risk].

Active feeding under turbid conditions is common in natural streams, especially if the turbidity is associated with an increase in the insect drift (Arndt et al. 2002, White and Harvey 2007). The study of White and Harvey (2007) is of particular interest because they found evidence of increased feeding in juvenile rainbow trout at turbidity of up to 580 NTU during flood events in a California stream. Mundie and Crabtree (1997) documented an 88 - 99% decrease in benthic insects after scarification in Little Qualicum Spawning Channel. This presumably would result in a large pulse of insect drift during the cleaning process.

Additionally, observations at the HSCS show that rainbow trout and bull trout continue to increase in length during scarification procedures. Juvenile rainbow trout age-0 grew an average of 10 mm from late July to late August in 2005; bull trout grew 10 mm in 2004 and 17 mm in 2005 (Porto and Arndt 2006).

Increased returns of kokanee spawners may be a benefit to trout growth in September. Bilby et al. (1998) found that the condition factor of juvenile steelhead increased with the addition of salmon carcasses and that direct consumption of eggs and decomposing carcasses was an important food source.

6 CONCLUSIONS AND RECOMMENDATIONS

The HCSC clearly provides compensation for flooded spawning habitat and has an important net benefit for kokanee and likely rainbow trout spawning. It helps maintain Upper Arrow Reservoir kokanee abundance, which provides a forage base for bull trout and rainbow trout. These fish stocks contribute to a popular recreational fishery, which has important economic benefits.

Machine scarification is an effective and affordable technique for cleaning the spawning gravel. The amount of sediment removed in 2006 was similar to Little Qualicum River Spawning Channel.

Scarification does not add sediments to the creek but changes the timing of movement through the system (traps sediment most of the year and re-mobilizes in late summer).

Temporary exposure to the larger particles in scarification effluent likely results in minor to moderate physiological stress to juvenile fish. The extent of direct exposure within the spawning channel at the time of scarification is unknown because juvenile salmonids may escape to areas of lower turbidity near stream banks or upstream of machine where effluent is not well mixed within channel. Also, available information for fish shows evidence of cover abandonment during periods of high turbidity that may be related to feeding opportunities and reduced risk of predation. Juvenile salmonids downstream of the channel are exposed to decreasing physiological stresses with distance from the scarification activities as turbidity levels are reduced but effluent is well mixed.

Transect sampling showed a post-scarification increase in fines downstream of the spawning channel that may have detrimental effects on kokanee spawning and late summer insect production. However, the enhanced spawning in the channel provides a net benefit for kokanee, and losses to insect production may be mitigated by the positive influence of kokanee carcass inputs in September.

As a result of these possible impacts to fish and fish habitat, the following options for sediment management and mitigation are suggested *for further consideration*.

These include a number of methods to: (1) optimize scarification procedures; (2) decrease sediment inputs to the upper spawning channel throughout the year; (3) decrease sediment delivery to the natural streambed during scarification and (4) improve kokanee and rainbow trout access to spawning gravels (from Barney 2006):

- It would be beneficial to initiate settling pool cleaning in mid July and begin channel scarification by July 25 or sooner so that spawning gravels can be more thoroughly cleaned by higher water flows. This would also likely result in further downstream dispersal of fine sediment and possibly a greater fraction of the fine sediment reaching the upper Arrow Lake instead of settling in the creek. However, starting the scarification earlier increases the risk that late-spawned rainbow trout alevins will still be in the gravel. In recent years, the timing of rainbow trout emergence has been estimated using redd observations and accumulated temperature units with scarification delayed until emergence is judged to be complete.
- A variance for a longer time period on the operating permit for in-stream work would also allow more time to clean the lower spawning channel.
- Increased settling pool capacity on the upper end of the HCSC would trap fine sediments entering the spawning channel. In addition, the rainbow spawning area could be converted into additional settling pool area (see Thompson 2006 for more details).

- Installation of drains at the downstream ends of each of the legs of the spawning channel could allow a portion of high turbidity water to be drained to the overflow/old streambed, rather than progressing the rest of the way through the channel where some of it re-settles.
- Enlargement of an existing settling pool near the bottom of the overflow/old streambed/old streambed in conjunction with drains (above) could trap fine sediments that re-enter Hill Creek during annual low-flow scarification. This might reduce the amount of sediment that enters the creek during scarification, but might result in some stranding of trout juveniles.

As well, continued turbidity monitoring should be carried out using both the continuous turbidity recorder and the portable field meter to carry out spot checks upstream and downstream of the HCSC. The continuous turbidity recorder allows calculation of the amount of sediment removed from the spawning channel and can be used to assess sediment management techniques. Wipe frequency should be increased if battery power allows. Weekly calibration of the continuous turbidity recorder is recommended during the scarification procedure.

Further transect monitoring would also allow assessment of new initiatives in sediment management. Transects could also be carried out at a slightly later date to better assess gravel conditions during the peak of the spawning run.

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8 APPENDICES

Appendix I. Turbidity measured by portable field meter versus continuous meter at Hatchery Fence.

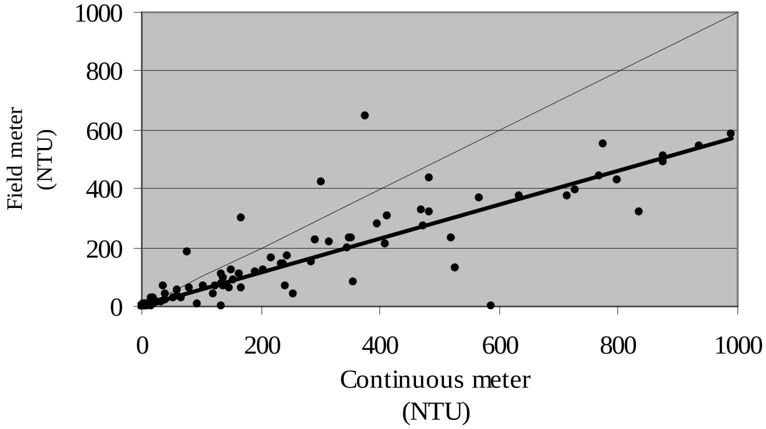

Figure A1. Turbidity measured by Lamotte 2020 portable field meter versus Analite NEP498 continuous meter. Data points represent mean stream samples (n=2) measured within 15 minutes. Continuous metered samples bracket field meter data in time. y = 0.575x. r=0.7771.

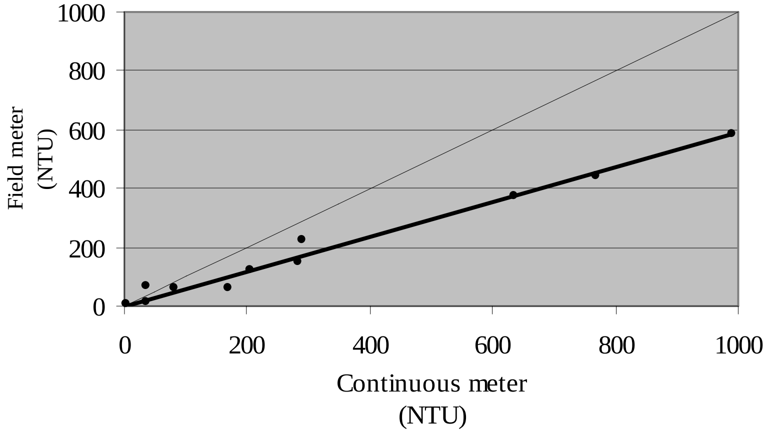

Figure A2. Turbidity measured by Lamotte 2020 portable field meter versus Analite NEP498 continuous meter. Data points represent stream samples (n=1) measured within one minute of each other. y = 0.59x. r=0.9914. p= <0.0001. A quadratic term was tested but was not significant. p=0.3466.