Meadow Creek Spawning Channel - Scarification Monitoring and Suspended Sediment Assessment 2003-2007

Prepared for
Fish and Wildlife Compensation Program, Nelson, BC

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EXECUTIVE SUMMARY

The spawning gravels of the Meadow Creek Spawning Channel (MCSC) are cleaned and redistributed annually using a D6 Caterpillar to dislodge fine sediments (machine scarification). Integrated Ecological Research prepared this report for the Fish and Wildlife Compensation Program in order to: (1) document the procedures that were used to clean settling ponds and restore spawning gravel at MCSC from 2003-2007; (2) determine the effect of scarification on levels of induced turbidity during this time; (3) estimate the total tonnage of sediment removed from the channel; (4) evaluate the effect of re-suspended sediment on fish and fish habitat within the channel and the possible effects on the biological community in Meadow Creek downstream of the channel; and (5) review previous work on gravel studies.

Machine scarification was identified as a cost efficient and effective method for cleaning the spawning gravel. Possible increases in fines within the streambed downstream of the spawning channel following scarification may have negative effects on kokanee spawning habitat. However, scarification occurs before kokanee enter the spawning channel so there is minimal direct effect on adults or incubating eggs.

The enhanced spawning habitat in the channel clearly provides a net benefit to kokanee populations for the Meadow Creek system as a whole. The increased spawning habitat helps sustain Kootenay Lake kokanee, which in turn create a prey base for bull trout and rainbow trout. In addition, a healthy kokanee population generates sport fisheries for these stocks with important financial gains to the surrounding area.

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

KEY WORDS

Meadow Creek Spawning Channel, scarification, turbidity, suspended sediments, deposited sediment, kokanee

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Jeff Burrows from the Ministry of Environment, Kootenay Fish and Wildlife, collected suspended sediment data and summarized the metering, laboratory data in 2003 and made recommendations on scarification procedures in a previous memo (Burrows 2003).

Darcie Quamme of Integrated Ecological Research carried out data analysis and reporting. John Boulanger, Integrated Ecological Research, gave statistical advice.

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 gravel scarification at the Meadow Creek Spawning Channel (MCSC) on the levels of induced fine sediment and its dispersal in the Meadow Creek system downstream of the spawning channel.

1.1 Background

The Meadow Creek spawning channel (Figure 1) was constructed in 1967 in order to partially replace kokanee production and spawning habitat lost when the Duncan River was impounded during the construction of the Duncan Dam (Acara 1970). Kokanee, bull trout, and rainbow trout spawning habitat was impacted by the creation of the dam. Annual fish losses from the construction of the dam were estimated to be 2.8 million kokanee from the Duncan River (Bull 1965). Before flooding Meadow Creek supported 346,128 spawners in 1964 and 116,095 spawners in 1965 (Acara 1970). This was 7.6% (1964) and 10.8% (1965) of the total Lardeau-Duncan River system escapement. After the Duncan River was blocked in 1966, the escapement to Meadow Creek then comprised a larger proportion (46.0% in both 1967 and 1968) of the total escapement to the Lardeau-Duncan River system (Bull 1965; Acara 1970).

The objective of the MCSC is to increase the abundance of kokanee in Kootenay Lake by providing high quality spawning habitat and increased kokanee production through improved egg to fry survival. The operation and maintenance of the spawning channel is funded by a joint initiative of the Ministry of Environment and BC Hydro under the auspices of the FWCP.

The MCSC is located 45 km north of Kaslo at the north end of Kootenay Lake (Figure 1). The spawning channel is supplied with water from diversions on Meadow Creek and John Creek. The spawning channel is 2.9 km long and on average 9.1 m wide with 26,390 m^2 of spawning habitat. The theoretical capacity of the channel is 350,000 spawning kokanee with an annual deposition of 45-50 million eggs. It produces between 15-20 million fry annually, with a target egg-to-fry survival rate of greater than thirty-five percent.

Throughout the year, naturally occurring fine suspended sediment accumulates in the MCSC due to the low gradient (approximately 0.02%) and reduced water velocities of the channel compared to the natural stream. Also flow control structures within the channel reduce discharge during peak flows. These aspects of the channel design result in the deposition of suspended sediment in the interstitial spaces of the spawning gravel (Mundie and Crabtree 1997). Sediment sources occur, in particular, in John Creek, and directly contribute to the spawning channel (Taylor et al. 1972). An upstream settling pond (approximately

113 m by 13-30 m) was constructed in 1987 to remove some sediment from the water column before it enters the channel.

In order to maintain the quality of spawning gravel and high kokanee egg-to-fry survival, it is important to scarify the gravels annually. This is carried out during a five to six day period in late summer using a Caterpillar D-6 with a push blade that dislodges and re-suspends the fines so that the sediment is flushed downstream of the channel.

The Department of Fisheries and Oceans (DFO) requested that the levels and effects of suspended sediment from the scarification process be summarized. In addition, continuous monitoring of turbidity in 2007 was carried out in order to document possible adverse impacts to fish and recommend mitigation options. This report also provides a record of spot checks of turbidity from 2003-07 during the peak levels of turbidity.

1.2 Monitoring Objectives

The objectives of the review were to:

- Document recent procedures that are used to clean settling ponds and restore spawning gravel at the Meadow Creek Spawning Channel.
- Monitor the effect of scarification on levels of turbidity.
- Estimate the total amount of fine material removed from the spawning channel.
- Evaluate the effects of the re-suspended sediments on fish habitat and fish in the spawning channel and Meadow Creek downstream of the channel.
- Review previous work on gravel studies within the spawning channel before and immediately after cleaning of spawning gravels.

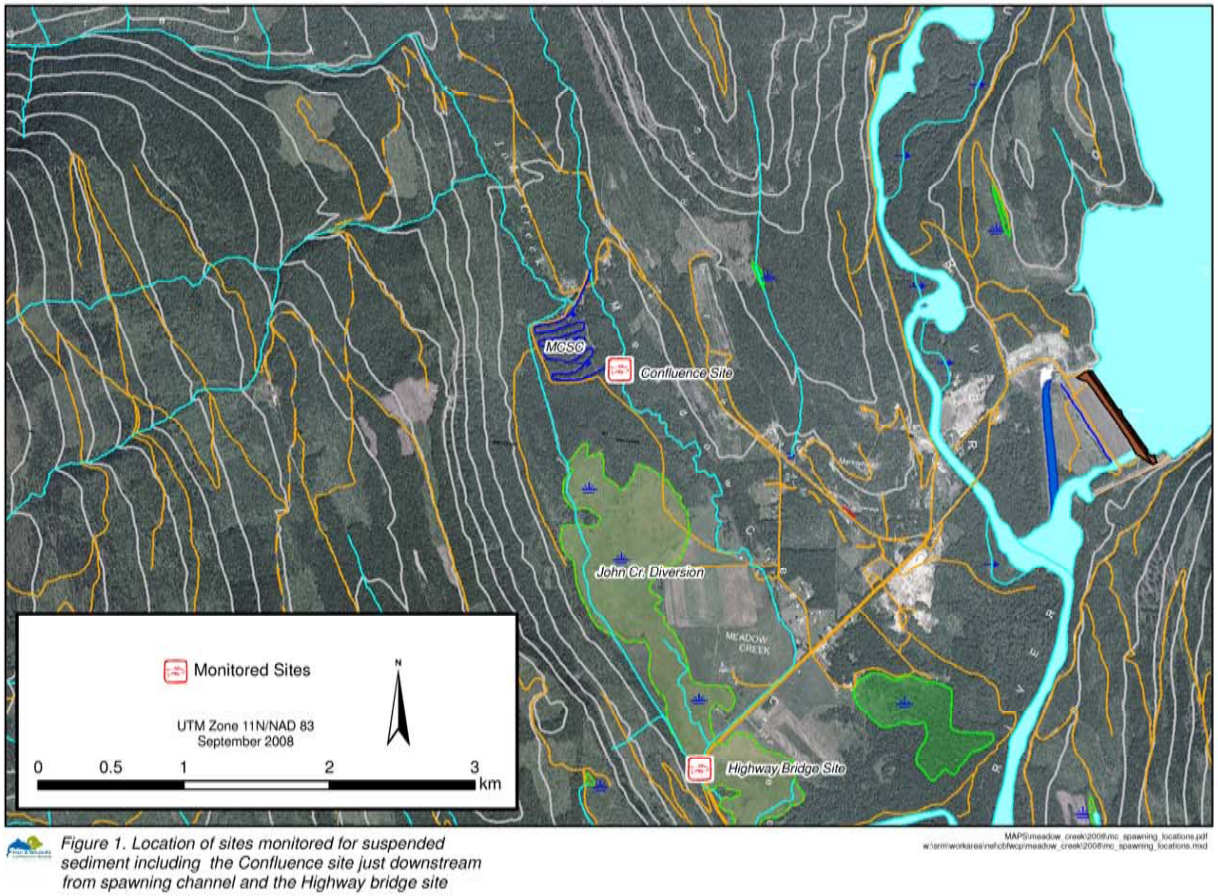


Figure 1. Location of the Meadow Creek Spawning Channel and overview of the spawning channel.

2 METHODS

2.1 Scarification Procedures

In the first week of August (2004-2007) during the instream work window, Stan Baker Trucking carried out the MCSC scarification procedures under the direction of Murray Pearson, the channel manager (Table 1).

Maintenance operations were initiated each year with the removal of suspended bed load that settles in Meadow Creek in the area near the hatchery. Following this, the flow control gate that diverts water to the spawning channel from Meadow Creek was shut down. The gravel berm that develops in front of the settling basin was then removed and the area levelled.

Then in order to dewater and clean the large settling pool upstream of the spawning channel, the flow from the John Creek diversion was redirected to the spawning channel below the settling pond. Typically, 200-700 m^3 of sediment are removed from the pond over a period of 3-5 days.

Afterwards, maintenance took place upstream of the spawning channel in John Creek (approximately 100 m upstream of the John Creek diversion fence) where debris accumulated in front of the water diversion. Typically, 60-100 m^3 of material were removed from this area.

Finally, scarification of the spawning channel commenced once suspended sediment levels in both John and Meadow creeks returned to baseline levels. In addition, flow through the spawning channel was increased in order to help flush sediment out of the channel. Scarification of the channel typically took five to six days to complete.

Overhead vegetation was removed along each portion of the channel so as not to interfere with scarification. In the channel, the small bulldozer (CAT D6) was used to turn and recast the spawning channel gravel while working from the top of the channel to the bottom each year. The bulldozer then evenly distributed the cleaned gravel.

The bulldozer typically took short breaks of 5-25 minutes every one to two hours so as to reduce turbidity levels for short periods over the scarification workday (Table 1). A 30-40 minute lunch break was also usually taken, as well as the 12-hour period overnight, during which turbidity levels were reduced daily.

From 2003-2007, spot check turbidity monitoring was done during scarification just below the channel outlet (confluence site) and 4 km downstream (highway bridge site) in order to capture the increased turbidity levels resulting from the procedure (Figure 1). In 2007 a continuous monitor was also put in place at the confluence site to monitor turbidity levels throughout the whole scarification process.

Table 1. Timing of final scarification operations at the Meadow Creek Spawning Channel by year during peak turbidity levels during scarification of the lower channel.

Year	Date	Timing of scarification		Break (min)
		Start	End	
2004	Aug. 7	18:18	19:03	None
2004	Aug. 8	7:42	10:32	5
		10:37	12:14	5
		12:19	18:13	end
2004	Aug. 10	6:20	8:10	10
		8:20	8:45	23
		9:08	11:10	40
		11:50	13:50	10
		14:00	14:40	15
		14:55	15:15	25
		15:40	17:05	end
2005	Aug. 2	10:30	12:30	20
		12:50	1:15	15
		1:30	17:00	10
		17:10	17:30	end
2006	Aug. 6	7:30	9:45	15
		10:00	10:15	15
		11:00	12:30	30
		13:00	13:30	10
		13:40	14:00	5
		14:05	15:00	15
		15:15	16:10	10
		16:20	17:00	end
2007	Aug. 8	7:00	8:50	10
		9:10	11:30	40
		12:10	13:40	10
		13:50	15:05	5
		15:15	17:00	end
2007	Aug. 9	7:00	8:50	10
		9:00	10:10	end

2.2 Turbidity Monitoring

2.2.1 Portable field meter

From 2003-2007, the spawning channel operator took spot check turbidity measurements each hour with a Lamotte Model 2020 portable turbidity meter during periods of peak turbidity (resolution ±2% 0-100 Nephelometric Turbidity Units (NTU), ±3% above 100 NTU, detection limit 0.5 NTU). Quality assurance/Quality control (QA/QC) of the turbidity meter was carried out in 2003 (Appendices 1-4).

Monitoring took place just below the confluence of the channel outlet and Meadow Creek (confluence site) and 4 km downstream (highway bridge site) in order to capture the increased turbidity levels resulting from the procedure (Figure 1; Table 2). The portable field meter was calibrated with solutions of 10 NTU before daily measurements at each new location.

2.2.2 Continuous recorder

In 2007, turbidity levels during the scarification were monitored using an Analite NEP495 microprocessor turbidity probe (McVan Instruments Ltd., Australia). The meter was installed downstream of the spawning channel below the confluence of the spawning channel with Meadow Creek (Figure 1, Table 2) on July 13th and turbidity values were recorded until August 18th. The Analite NEP495 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 in conditions where there are high levels of suspended sediment. The recorder was calibrated prior to installation with solutions provided by the distributor (Geo Scientific Ltd., Vancouver, BC).

The meter was set to log a turbidity measurement once every 20 minutes, and wipe the sampling window prior to each measurement. Additionally, the Analite NEP495 logged a temperature measurement every 20 minutes (resolution ±0.1 from -10 to 50^{o}C).

Data from the Analite NEP495 continuous turbidity meter was higher in thirty-one of the thirty-four paired samples measured using the Lamotte 2020 portable turbidity meter (Appendix 4). As a result, continuous turbidity data was calibrated to the portable field meter for comparison to previous annual monitoring.

2.3 Sediment Load in Spawning Channel Effluent

Hourly sediment loads for 2003-2007 were estimated from spot checks of turbidity using the portable field meter (Lamotte 2020) measured during periods of peak turbidity. Daily and total loads for 2007 were estimated from the automated turbidity metered every 20 minutes using the NEP495. The continuous data turbidity was also calibrated to the Lamotte 2020 meter using the equation found in Appendix 4 prior to load calculations. This was done so that turbidity values measured in 2007 could be compared to data from past years collected with the portable meter.

Sediment loads were calculated by converting turbidity values in NTU to total suspended sediment (TSS, mg/L) using linear regression of the data from Burrows (2003). See Appendices 1-4 for raw data and quality control.

An inspection of the linear regression of turbidity versus TSS indicated that the intercept value was not significantly different from zero ($p=0.64$, $n=14$). When the intercept was included it was negative and thus not possible. In addition, there was minimal data to estimate an intercept because at least twenty data points are required to support an intercept plus slope-term model based on recommendations by Tabachnick, and Fidell. (1996). As a result, the intercept was dropped from the model and the regression was forced through zero on the assumption that when turbidity is below detection (<0.1 NTU), TSS is also near detection (4 mg/L). The confidence intervals for this model widely encompassed the zero value and these detection limits (Appendix 1).

A quadratic term was also tested but was not significant ($p=0.60$). There was not enough data to support a model with a non-linear term. In addition, laboratory verification of the portable meter at high turbidities was limited to two data points (Appendix 1). Paired TSS-turbidity data across the full range of turbidities is required to test for non-linearity. Previous work by Lewis (1996) also indicates that regressions of suspended sediment concentration versus turbidity are often linear with low variance. As a result, TSS was estimated from the equation below:

$$\mathbf{TSS = 6.44 \times (Turbidity)} \quad \mathbf{(r^2 = 0.95, p<0.0001)}$$

Suspended sediment load was calculated using the equation:

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

Load was computed on an hourly, daily or total period basis and milligrams were converted to metric tons.

However, daily discharge data was lacking for 2007 at the monitoring sites and as a result possible ranges in sediment load were estimated based on Meadow Creek flow only and Meadow Creek plus John Creek. Discharge from Meadow Creek was used as a minimum estimate of flow at this site. Also, an unknown percent of flow from John Creek was diverted through the spawning channel. As a result, the discharge of Meadow Creek plus John Creek was used as a maximum range.

Discharge at the confluence of the spawning channel outlet and Meadow Creek (confluence site) was estimated using continuous discharge data from Duhamel and Lemon creeks (Water Survey of Canada archived data). Drainage area ratios (Duhamel:Meadow and Lemon:Meadow creeks) were used to estimate discharge at the confluence site. The drainage areas and August discharges for Duhamel and Lemon creeks were obtained from Water Survey of Canada records (Table 2).

The drainage areas for the confluence and highway bridge sites were obtained from Water Survey of Canada records (1968-1973 only) by adding drainage areas for Meadow Creek (upstream of John Creek) and for John Creek (just upstream of Meadow Creek) to obtain an estimate of 97.4 km^2 (Table 2). The WSC site, Meadow Creek upstream of John Creek, is located 1.61 km upstream from the confluence of the spawning channel outlet and Meadow Creek. The WSC site, John Creek just upstream of Meadow Creek, is approximately about 680 m northwest of the confluence of the spawning channel outlet and Meadow Creek or 300 m upstream of the location where water from the John Creek Diversion can be redirected through the spawning channel.

Using the 97.4 km^2 drainage area gave a slight underestimate of discharge and load for the confluence of the spawning channel outlet and Meadow Creek because the site Meadow Creek above John Creek was 1.6 km upstream from this site.

Table 2. Water Survey of Canada (WSC) sites used to estimate discharge and the location of the suspended sediment monitoring sites.

Site	WSC Station ID /Study Site	Latitude	Longitude	Gross Drainage Area (km^2)	Period Of Record Obtained
Meadow Ck above John Ck	08NH124	50°16'2''N	116°59''1''E	62.7[1]	1968-1973
John Ck at Meadow Ck	08NH125	50°15'32''N	116°59''7''E	34.7[2]	1968-1973
Duhamel Ck	08NJ026	49°35'44''N	117°14'42''E	52.9	2003-2007
Lemon Ck	08NJ160	49°41'52''N	117°27'00''E	178.0	2003-2007
Confluence of MCSC outlet & Meadow Ck	confluence site	50°15'14'.83'N	116°59'37.20''E	97.4[3]	NA
Highway Bridge -below confluence of John Ck Diversion & Meadow Ck	highway bridge site	50°15'14'.83'N	116°59'37.20''E	------	NA

[1] 689 m upstream of confluence of Meadow Creek and spawning channel outflow, [2]1.6 km upstream of confluence of spawning channel outlet and Meadow Creek,[3] Estimated from adding gross drainage areas of Meadow Creek above John Creek and John Creek at Meadow Creek.

3 RESULTS

3.1 Turbidity

3.1.1 Portable field metering of turbidity downstream of spawning channel

During the years of monitoring (2003-2007) the confluence site (below the confluence of spawning channel water and Meadow Creek), the peak turbidity levels observed in 2004 (2100 NTU) and 2007 (1069 NTU) were the highest of the period (Figure 2). Lower values were observed in 2006 (850 NTU), and 2005 (257 NTU).

As expected further downstream, peak turbidity levels at the highway bridge site (1.5 km downstream of spawning channel) were generally lower than upstream levels at the confluence site (Figure 2). But again, peak levels were highest in 2004 (632 NTU) and 2007 (308 NTU), with lower levels in 2005 (244 NTU), and 2006 (160 NTU). The maximum turbidity level observed on each day often occurred during the afternoon scarification (Figure 2).

In 2003, monitoring was carried out post-scarification each evening (16:08-20:05) after turbidity returned to baseline to demonstrate that turbidity levels had decreased. As a result the maximum turbidity level in 2003 was much lower (38.7 NTU) at the confluence site and at the highway bridge (38.4 NTU) than in other years

3.1.2 Continuous turbidity measurements of spawning channel effluent 2007

In 2007, the maximum daily turbidity levels during scarification increased from 31.2 NTU to a peak of 637.9 NTU over the course of the nine-day scarification period as the machine worked from the top of the channel downstream (Figure 3, Table 3).

Median daily turbidity levels during scarification ranged from 2.8–40.9 NTU with an overall median of 5.0 NTU (Table 3). The interquartile range for the daily values during scarification varied from 1.6–110.5 NTU with an overall value of 14.7 NTU (Table 3). As the bulldozer worked on the upper legs of the spawning channel fine sediments were flushed downstream with the current. Fines then accumulated in the middle and lower spawning channel.

Efforts were made to decrease the duration of high turbidity levels throughout the workday in order to reduce potential impacts to aquatic life. An example of this is given in Figure 4 for August 8, 2007 in which the machine operators took the following breaks; 8:50-9:10, 11:30-12:10, 13:40-13:50 and 15:05-15:15. As well the 12- to 14-hour period overnight period reduced turbidity to near base levels.

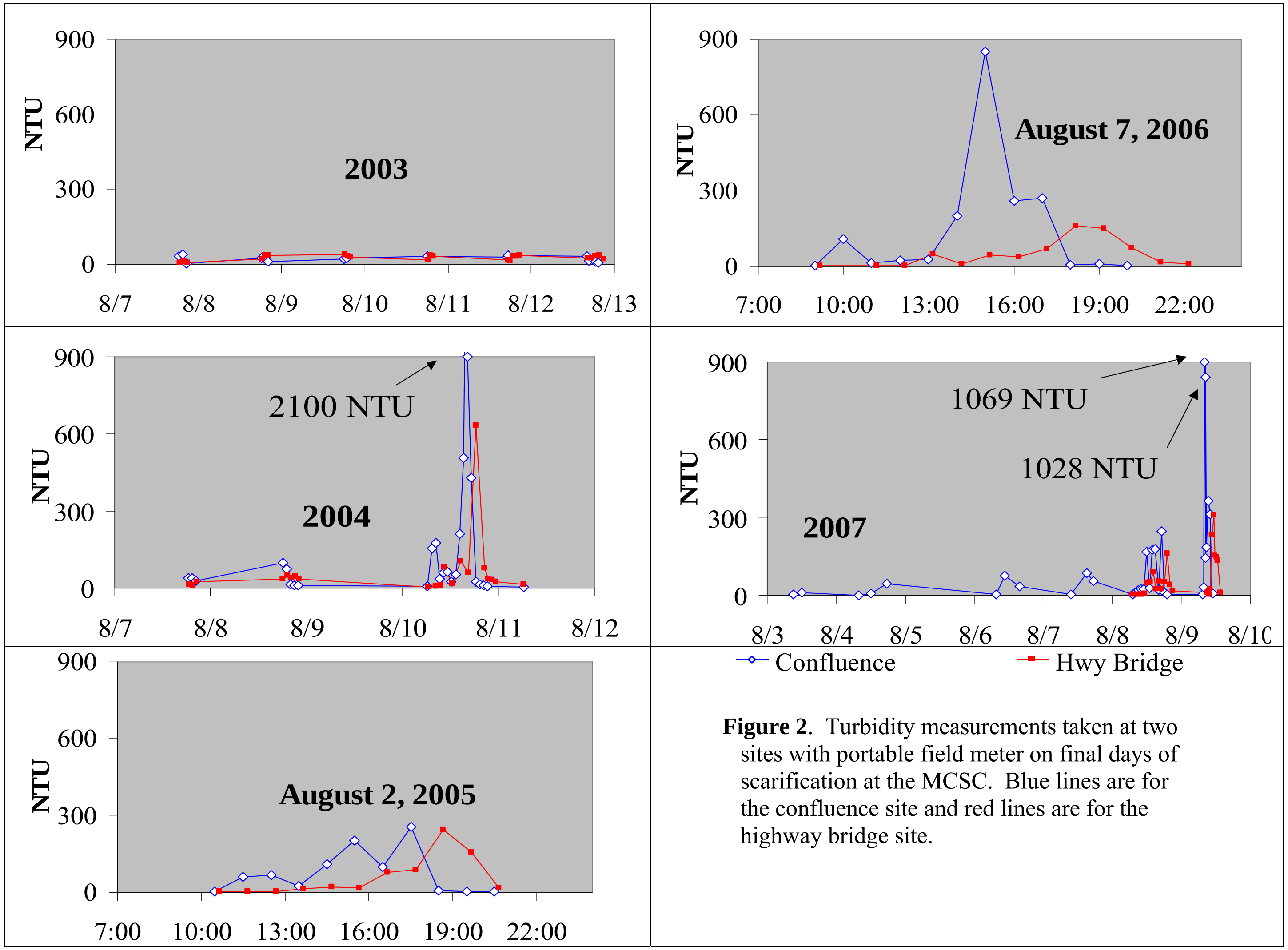


Figure 2. Turbidity measurements taken at two sites with portable field meter on final days of scarification at the MCSC. Blue lines are for the confluence site and red lines are for the highway bridge site.

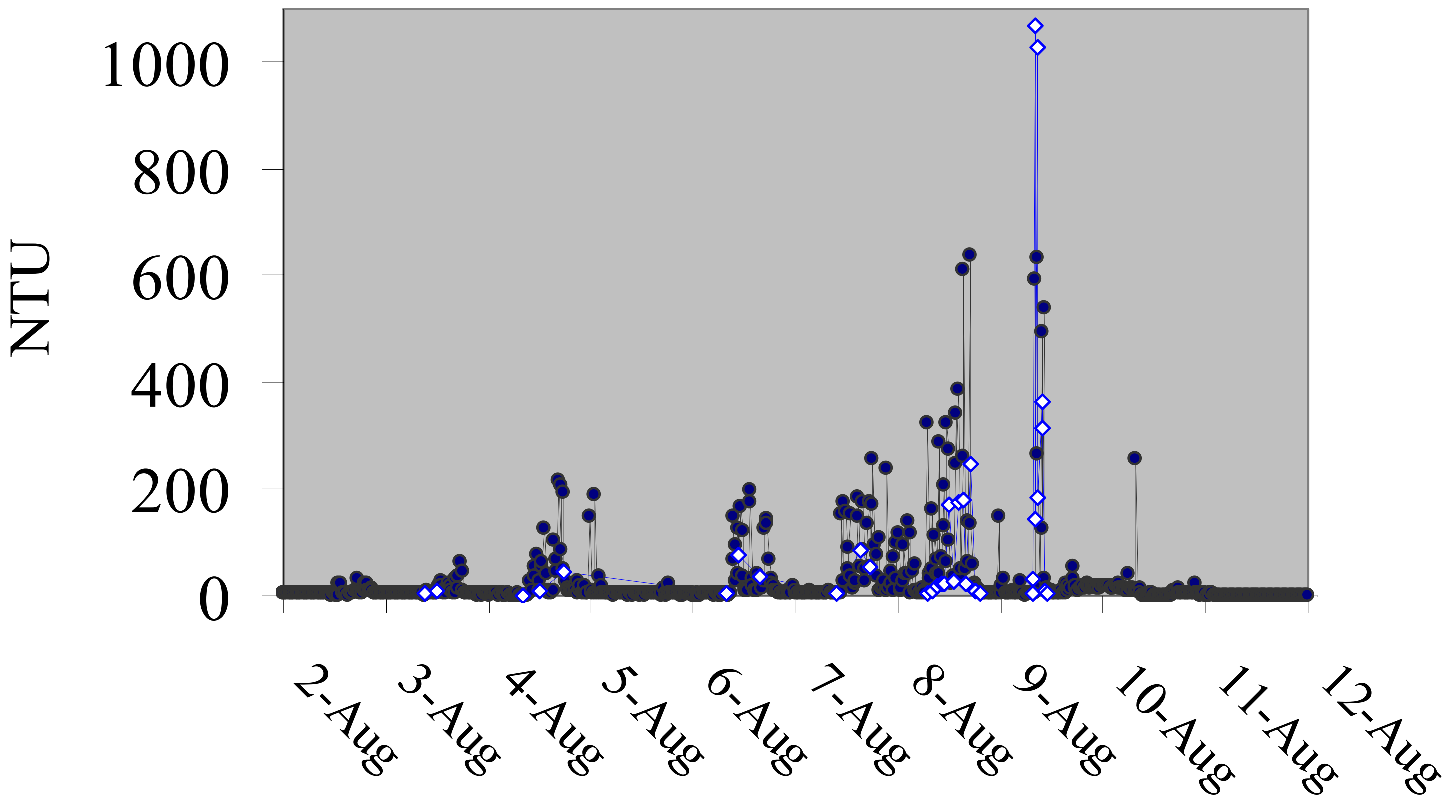


Figure 3. Continuous (blue circles/grey line) and portable field metered (white diamonds/blue line) turbidity measurements in 2007 recorded at the confluence site, downstream of spawning channel outlet and confluence with Meadow Creek.

Table 3. Summary of continuous turbidity measurements (NTU) in 2007 measured at confluence site during scarification.

Date	Median	Min	Max	90th percentile	IQR[1]
07/31/07	3.0	0.1	4.1	3.7	0.7
08/01/07	3.0	1.9	5.9	3.9	0.9
08/02/07	3.6	1.9	31.2	9.8	2.7
08/03/07	3.1	1.7	63.0	18.0	1.9
08/04/07	6.6	1.4	215.5	75.3	24.4
08/05/07	2.8	1.9	190.4	5.7	1.6
08/06/07	6.4	1.5	198.5	124.4	28.0
8/07/07	13.9	2.8	254.1	156.3	67.1
08/08/07	40.9	3.2	637.9	271.4	110.5
08/09/07	11.9	2.2	633.8	33.3	13.7
08/10/07	3.5	0.8	256.0	16.6	11.0
08/11/07	1.2	0.5	3.1	1.9	0.6
08/12/07	0.9	0.3	2.4	1.7	0.5
08/13/07	1.0	0.5	4.4	1.7	0.6
08/14/07	0.7	0.1	8.6	1.5	0.6
08/15/07	1.0	0.2	4.2	2.2	1.0
During Scarification	**5.0**	**0.8**	**637.9**	**76.4**	**14.7**
Total period	**3.0**	**0.1**	**637.9**	**34.4**	**5.6**

[1] IQR = Interquartile range, Shaded dates indicate period of scarification

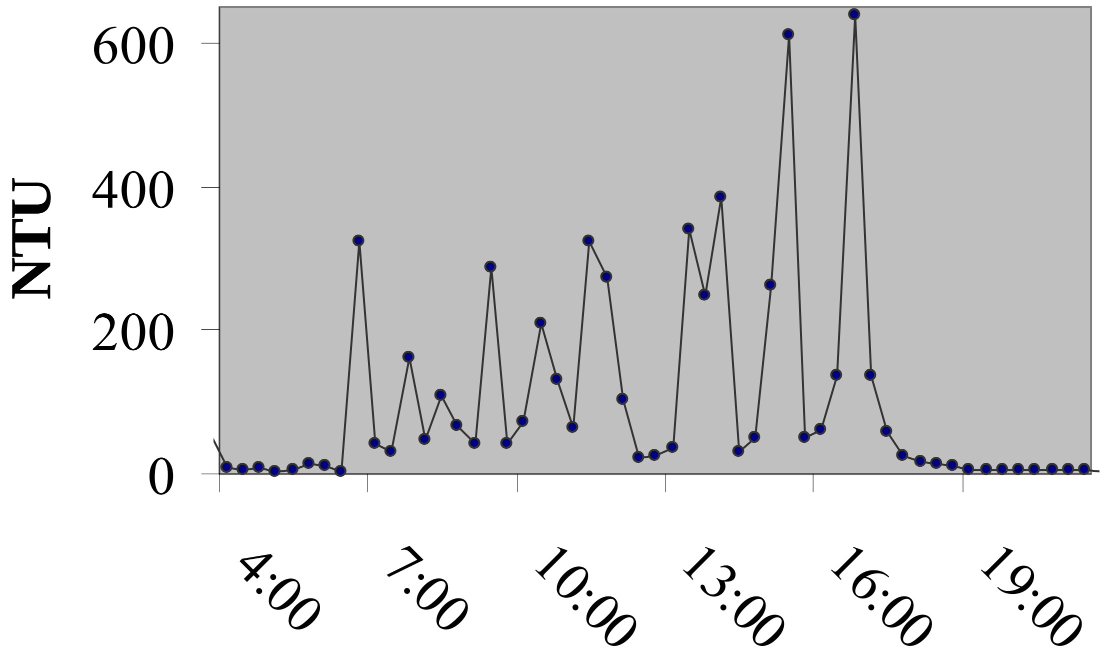


Figure 4. Continuous turbidity measurements recorded on August 8, 2007 (during scarification operations) at confluence site just downstream of spawning channel and confluence with Meadow Creek.

3.2 Sediment Load

3.2.1 Hourly sediment load based on portable turbidity monitoring

Hourly loads of suspended sediment were estimated from turbidity levels measured with the portable field meter at the confluence site (downstream of the spawning channel outflow and Meadow Creek) (Figure 5). Hourly loads (including background levels) were calculated in order to examine annual differences in load but were not used to estimate daily loads because of limited monitoring. Continuous discharge data from Duhamel and Lemon creeks were prorated by drainage area ratios to obtain daily discharge for this site used in loading calculations.

The highest hourly loads were observed in 2004 downstream of the confluence of John Creek and Meadow Creek (46.3 and 41.4 metric tons estimate based on discharge prorated from Duhamel and Lemon creeks, respectively). Peak hourly loads in 2007 (23.1 and 17.6 metric tons), 2006 (17.9 and 16.4 metric tons), and 2005 (8.7 and 8.2 metric tons) were lower than 2004.

In 2003, monitoring was carried out in the later part of the day (16:32-20:05) to demonstrate that suspended sediment levels dropped after scarification was completed each day. As a result, peak levels in 2003 were much lower (0.19 and 0.21 metric tons based on Duhamel and Lemon creeks, respectively) than in other years.

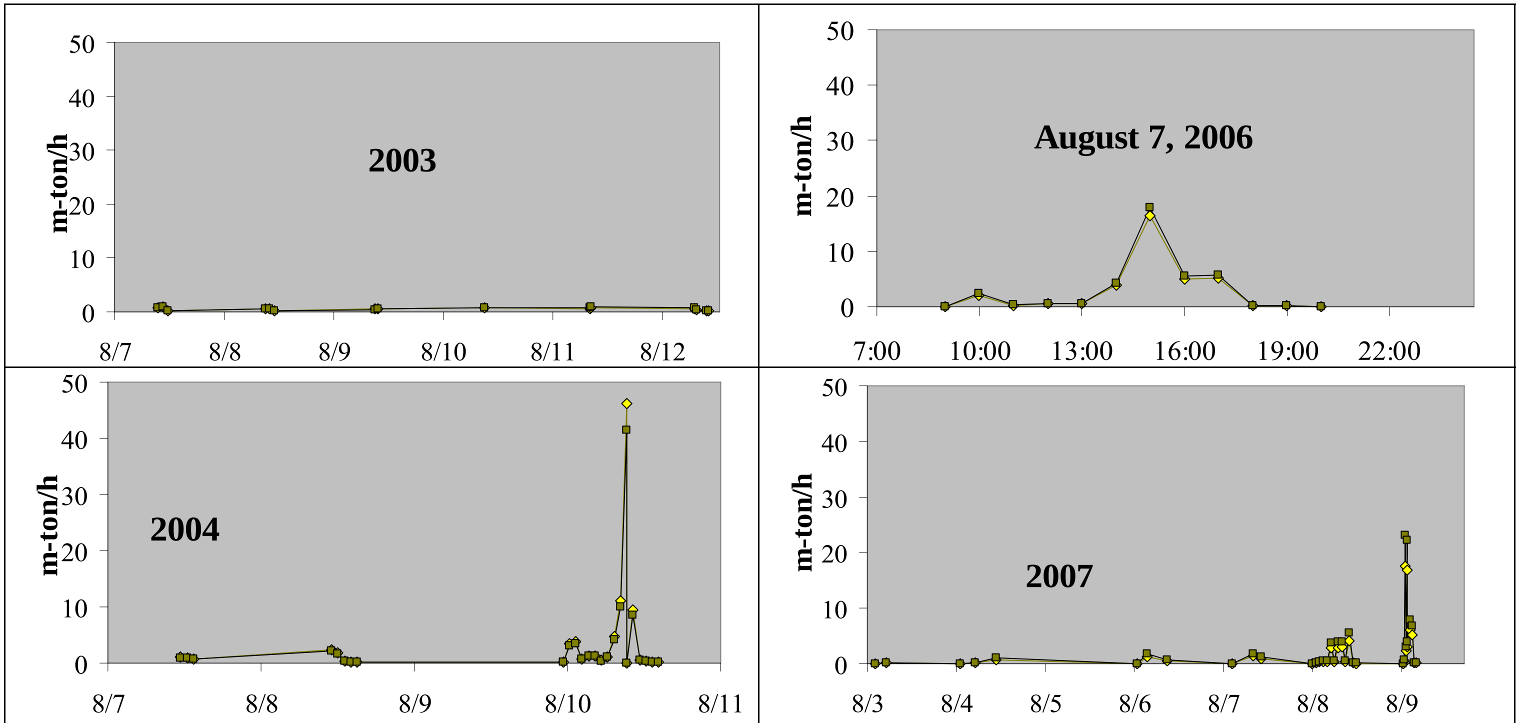
3.2.2 Daily and total sediment load based on continuous meter

Possible ranges in daily and total sediment load were estimated based on Meadow Creek flow only (minimum) and Meadow Creek plus John Creek (maximum) (Figure 6). Estimates of load were based on the discharge of Meadow Creek (minimum) and discharge of Meadow Creek plus John Creek (maximum) because an unknown amount of flow from John Creek was diverted to the turbidity monitoring location. Load was also estimated using discharge (equation, Section 2.3) from Lemon Creek to prorate the discharge for Meadow Creek from a drainage-area ratio.

The estimated peak daily sediment load occurred on August 8, 2007 was 21.8-134.2 metric tons (including background levels). The peak sediment load removed from the spawning channel effluent (above background) was 21.4 - 33.6 metric tons on August 8.

The estimated total sediment load from August 2-10, 2007 was 67.7-106.3 metric tons (including background levels). The total sediment load removed from the spawning channel effluent (minus background) was 64.2-100.9 metric tons over the entire scarification period. The background suspended sediment load was based on monitoring carried out pre-scarification (August 1) and after levels returned to baseline (August 11-14).

The total load represents the amount of sediment, naturally deposited in the channel, that was re-mobilized and flushed downstream of the channel during scarification. It does not include the amount of sediment directly removed by the excavator from the settling pond. 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 mid to bottom portions of the channel and required further scarification of the gravels.



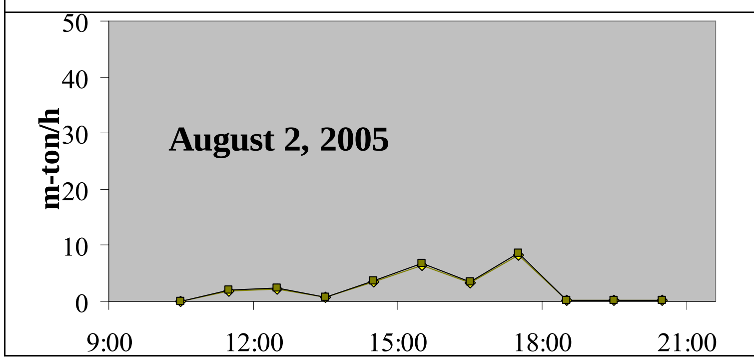


Figure 5. Estimates of hourly sediment load (metric tons) at the confluence site based on the portable meter (including background levels). Brown squares indicate that load was estimated using discharge (equation, Section 2.3) from Duhamel Creek to prorate the discharge for Meadow Creek from a drainage-area ratio. Yellow diamonds indicate discharge from Lemon Creek was used.

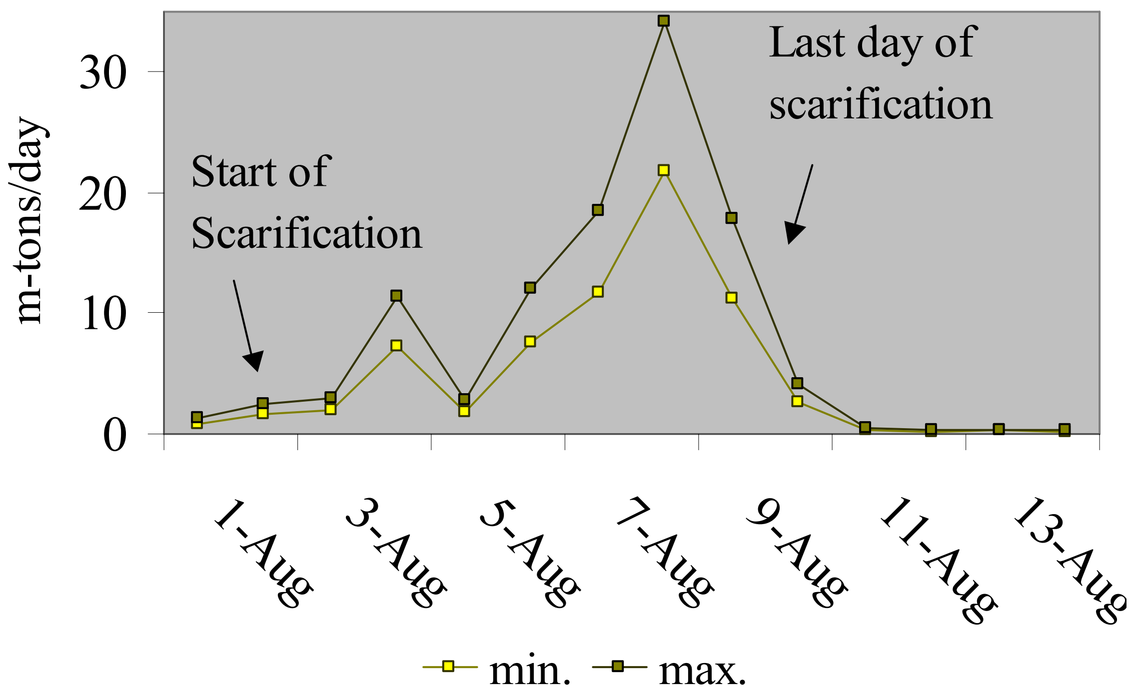


Figure 6. Estimates of daily sediment load (metric tons) removed from the Meadow Creek Spawning Channel in 2007 (above background). Yellow squares indicate estimates of load (min.) that use the discharge of Meadow Creek to calculate load. Brown squares indicate (max.) estimates of load based on the discharge of Meadow Creek plus John Creek.

3.3 Previous Gravel Studies

The overall spawning habitat quality data described in Porto (2006) for Meadow Creek spawning channel (data in Appendix 5) met BC water quality guidelines for streambed substrate composition (MoE 2008) and recommendations for benthic sediment found in the literature (Chapman 1988 and Kondolf 2000).

The average percent fines <2 mm from samples collected with a hollow core sampler (McNeil and Ahnell 1964) were lower than BC water quality guidelines of 10% at salmonid spawning sites both before (9.1%) and after (7.3%) scarification. In addition, percent fines <2 mm were less than levels of 12-14 % (<1 mm fines) recommended by Chapman (1988) and Kondolf (2000) to maintain good condition of gravel bed material for egg incubation. Average percent fines <6.4 mm found in the Meadow Creek spawning channel met BC water quality guidelines of not more than 25% before (20.7%) and after (19.8%) scarification.

In addition, Kondolf (2000) has shown that the emergence of fry is reduced if fine sediment of 3-6 mm is greater than 30% of bed material. The percent fines of 2-

6.4 mm in the Porto (2006) survey was on average lower than this criterion including values of 11.6% (before scarification) and 12.6% (after scarification).

Kondolf (2000) also recommends that the percentage of fine sediment in spawning gravels be adjusted downward by 33% for percent fines <1 mm and 42% for fines <4 mm to account for the cleaning effect of the spawning fish. The percent fines in the Meadow Creek spawning channel were below recommended standards even before adjustments for the cleaning effect of redd digging. Thus, gravels of the Meadow Creek channel were thought to be of good quality for spawning with regards to fine materials.

The mean geometric diameter of gravel samples met the BC water quality guideline of at least 12 mm at salmonid spawning sites both before (12 mm) and after scarification (13 mm). The mean geometric diameter (d_g) is a measure of the central tendency that includes larger framework gravels and relates the whole particle size distribution to salmon embryo survival (Rex and Carmicheal 2002).

$$D_g = \sqrt{d_{16} * d_{84}}$$

$d_{16} =$ 16th percentile, $d_{84} =$ 84th percentile of particle diameter

See Appendix 6 for cumulative size distributions curves before and after scarification.

Porto (2006) found that the percent fines measured from gravel samples collected with a hollow core sampler in the channel were not significantly related to scarification, channel location or an interaction between the two variables ($p=0.37$). In the present study, a paired sample t-test and power analysis was conducted on this data to further explain the observed results. The null hypothesis that the mean difference between paired before/after samples was zero (no change) was tested for significance. This was done for fines passing <2 mm and 2-6 mm. A nearly significant decrease occurred with percent fines <2 mm at the Meadow Creek spawning channel ($p=0.06$) and a non-significant increase was observed for percent fines of size 2-6 mm ($p = 0.08$).

A power analysis (Borenstein et al. 1997 and Zar 1984) of the significant case (percent fines <2 mm) concluded that there was low power (19.7%, n=9, for a two tailed test, $\alpha=0.05$) to detect a change with the observed effect size of –1.7 and the level of measurement precision (standard deviation of 6.3). It was also determined that >50 replicates using the hollow core sampler would achieve a desired power level of 0.8 for the paired t-test. The hollow core sampler technique may be more appropriate for detecting greater differences in percent fines with lower standard deviation. See Appendix 7 for the relationship between minimum sample requirements and given differences in percent fines.

As well, the difference in percent fines may vary down the length of the channel if scarification is more effective at the top of the channel compared to the mid to lower sections of the channel (Appendix 6). It would require stratified sampling by distance from the top of the channel to account for this effect. Proper stratification of sampling and analysis of variance and covariance statistical models would increase test power through the efficient modeling of differences in percent fines as a function of distance from the top of channel.

Finally, the hollow core sampler is best used at sites where depth and velocities vary by 10-20% among sites and at depths less than 30 cm to prevent loss of fines (Rex and Carmicheal 2002). Site velocity and depth was not discussed in the Porto (2006) study, however, if some sites sampled varied by more that 10-20% or exceeded 30 cm depth it may account for some of the variation observed. Martin et al. (1980) reported an average depth of 30 cm for the Meadow Creek spawning channel and a range of velocities of 0.43-0.73 m/sec.

Porto (2006) also reported that the Meadow Creek spawning channel had more angular and sub-angular gravels in the middle and lower locations sampled within the spawning channel (Appendix 6). The Meadow Creek spawning channel also had lower overall percent (60%) of angular and sub-angular gravels compared to the Hill Creek spawning channel. Compact angular gravel provide poor habitat for spawners, compared to rounder gravels, which are easier for spawners to move and have larger interstial spaces for better egg and alevin development (Porto 2006).

5 DISCUSSION

5.1 Scarification Effectiveness

The operation target of the Meadow Creek Spawning Channel has an annual target of a kokanee egg-to-fry survival rate of greater than 35%. The spawning channel improves egg-to-fry survival rates from 2-10 % in the natural stream to 20-60% in the spawning channel (Burrows 2003). From 2002-2006, kokanee egg-to-fry survival rate averaged 47% (Spence et al. 2006) in part due to successful scarification techniques, high quality gravels and careful management of the spawning channel operations. The spawning channel is expected to continue to have high egg-to-fry survival rates in the coming years (Spence et al. 2006).

The effective removal of sediments from the spawning channel is essential for achieving kokanee production targets for the facility. Annual machine scarification of gravels and flushing of suspended sediment sufficiently cleans the gravel to allow a high egg-to-fry survival over the following incubation period.

This method is logistically and economically feasible and much less costly than dry screening (Thompson 2006).

The amount of sediment that moved downstream of the channel during scarification was estimated to be 67.7-106.3 metric tons (total including natural background load) and 64.2-100.9 metric tons (above background, remobilized sediment from channel). In addition, typically 200-700 m^3 of sediment and organic material were removed from the upstream settling pond. Estimates of total sediment load in effluent at Meadow Creek spawning channel (channel area 26,390 m^2) bracketed previous values reported by Mundie and Crabtree (1997) for Little Qualicum (82 metric tons, 31,783 m^2) and Quamme and Arndt (2007) for Hill Creek (total load 74 metric tons, 14,888 m^2) spawning channels.

5.2 *Downstream Effects*

The scarification procedure does not add sediment to the creek but changes the timing of movement of sediment through the system. Sediment settles in spawning gravels during most of the year and then is re-mobilized by scarification. The sediments flushed downstream during scarification are part of the annual sediment load carried by Meadow Creek and John Creek. 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. In addition, any sediments settling just downstream of the spawning channel after scarification in late summer will be mobilized and carried downstream by the following spring freshet.

It is possible that scarification may potentially have some effects on downstream populations of resident species of fish such as non-native brook trout, and native bull trout, rainbow trout, and west slope cutthroat trout in Meadow Creek. However, the effects are thought to be minimal because of low quality rearing habitat in Meadow Creek downstream of the channel (Murray Pearson, pers. com.).

Fine sediments resulting from scarification could also potentially have some detrimental effects on incoming kokanee or the few spawning gravels downstream of the channel. However, these detrimental effects are more than compensated for by enhanced egg-to-fry survival in the spawning channel. Thus, there is clearly a net benefit for the overall kokanee population and their spawning habitat.

6 CONCLUSIONS AND RECOMMENDATIONS

The Meadow Creek Spawning Channel clearly compensates for lost kokanee spawning habitat from the construction of Duncan Dam and results in an overall gain in available spawning production. It helps maintain Kootenay Lake kokanee abundance, which provides a forage base for larger predator species including the Gerrard rainbow trout and bull trout. These fish stocks contribute to a popular sport fishery, which has important economic benefits for the local area. Thus, the operation and maintenance of the channel is important for the entire Kootenay Lake ecosystem.

Machine scarification is an effective and affordable technique for annual cleaning of the spawning gravel. In addition, monitoring of fines within the channel (Porto 2006) suggested that gravels of the Meadow Creek channel are of high quality for spawning kokanee. Scarification does not add sediment to the creek but changes the timing of sediment mobilization through the spawning channel and natural stream.

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 Meadow Creek Spawning Channel. 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. Development of a stage-discharge relationship for the spawning channel gauge is recommended during scarification in order to improve sediment load calculations in the effluent.

Quality control procedures for the continuous meter should follow White (1999) and Butcher and Gregory (2006). Quantification of the relationship of TSS versus turbidity is needed across the full range of turbidity on a yearly basis due to possible errors associated with continuous meters (Butcher and Gregory 2006).

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APPENDICES

Appendix 1. Turbidity versus Total Suspended Solids (TSS).

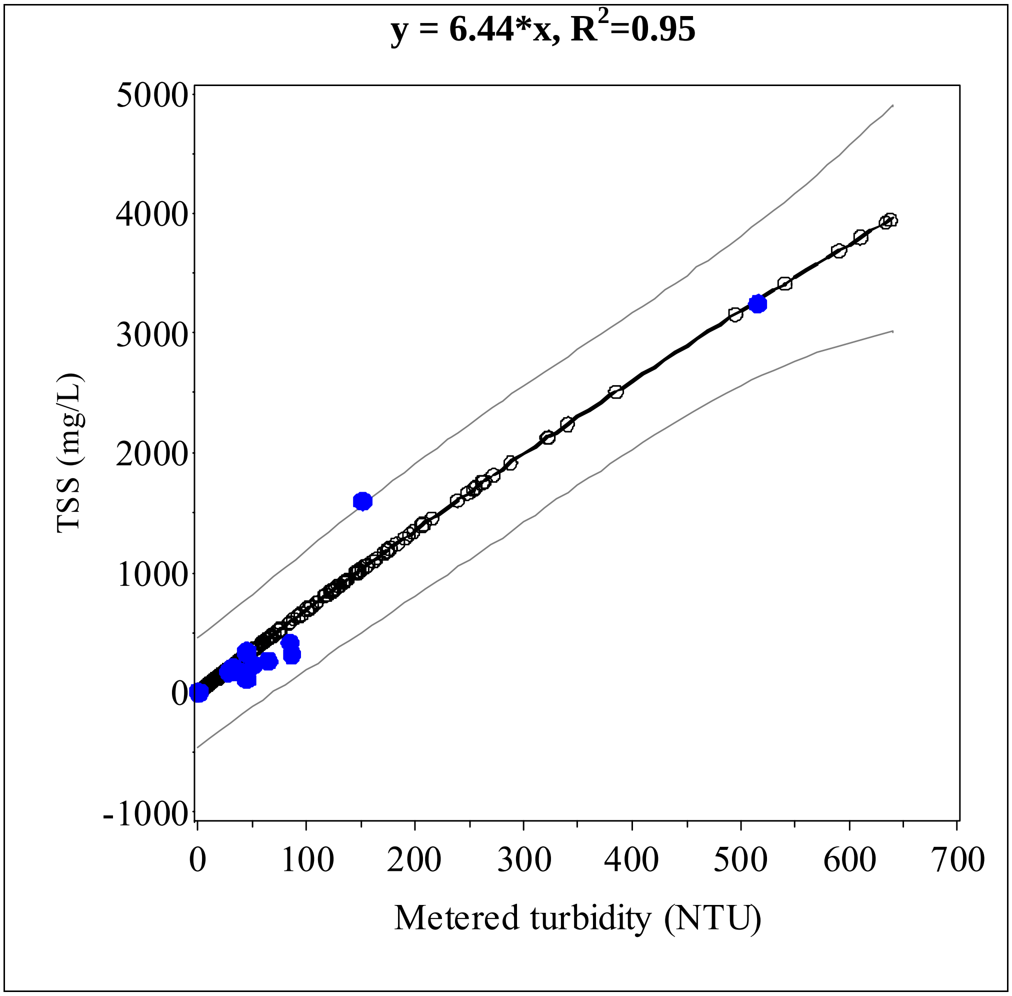

Figure 7. Blue circles indicate the turbidity measured using portable field meter (Lamotte 2020) versus laboratory measurements of TSS from 2003 used to estimate predicted TSS (TSS_P). TSS_P= 6.44 * (Turbidity) (r^2 = 0.95, p<0.001). Black open circles indicate TSS_P based on turbidity from the continuous meter (NEP495) for 2007. .

Appendix 2. Quality assurance and quality control of portable field meter.

Table 4. Percent mean difference between paired turbidity measurements taken with portable field meter in 2003 and laboratory measurements

	Field meter vs lab turbidity (NTU)		
	Field (n=1)	**Lab (n=2)**	**Mean % dif**
	0.380	0.455	
Kokanee	152.000	225.000	18.0
	86.500	62.300	38.7
	52.000	47.050	32.5
	45.000	21.950	10.0
	0.290	0.300	68.9
Redfish	28.700	17.700	3.4
	45.000	38.350	47.4
	85.000	52.450	16.0
	516.000	527.000	47.4
	1.470	4.000	2.1
Meadow	33.000	42.450	92.5
	36.600	39.250	25.0
	65.100	64.300	7.0
	2528.000	2150.000	1.2
			16.2
		Overall mean	**28.4**

Appendix 3. Quality assurance and quality control of laboratory replicates.

Table 5. Percent mean difference between paired turbidity measurements taken in the laboratory from each water sample collected in 2003

	Turbidity NTU		**Mean % dif.**
	Replicate 1	**Replicate 2**	
Kokanee	0.52	0.39	28.6
	190	260	31.1
	55.9	68.7	20.5
	50.8	43.3	15.9
	21.5	22.4	4.1
Redfish	0.33	0.27	20.0
	532	522	1.9
	44.5	60.4	30.3
	35.1	41.6	16.9
	16.1	19.3	18.1
Meadow	0.65	0.64	1.6
	1900	2400	23.3
	69.9	58.7	17.4
	52.8	32.1	48.8
	39.9	38.6	3.3
		Overall mean	**18.8**
Recommended difference when >five times detection (0.5 NTU)[1]			**25%**

[1]Cavanagh et al. 1998

Table 6. Percent mean difference between paired TSS measurements taken in the laboratory from each water sample collected in 2003

	TSS mg/L		Mean % dif.
	Replicate 1	**Replicate 2**	
Kokanee	4	4	0.0
	1370	1830	28.8
	272	368	30.0
	264	197	29.1
	97	120	21.2
Redfish	9	4	76.9
	3020	3470	13.9
	420	411	2.2
	337	336	0.3
	166	180	8.1
Meadow	5	4	22.2
	9440	10000	5.8
	277	250	10.2
	255	172	38.9
	176	184	4.4
		Overall mean	**19.5**
Recommended difference when >five times detection (1 mg/L) [1]			**25%**

[1] Cavanagh et al. 1998

Appendix 4. Paired turbidity measurements from the automated and portable field meters.

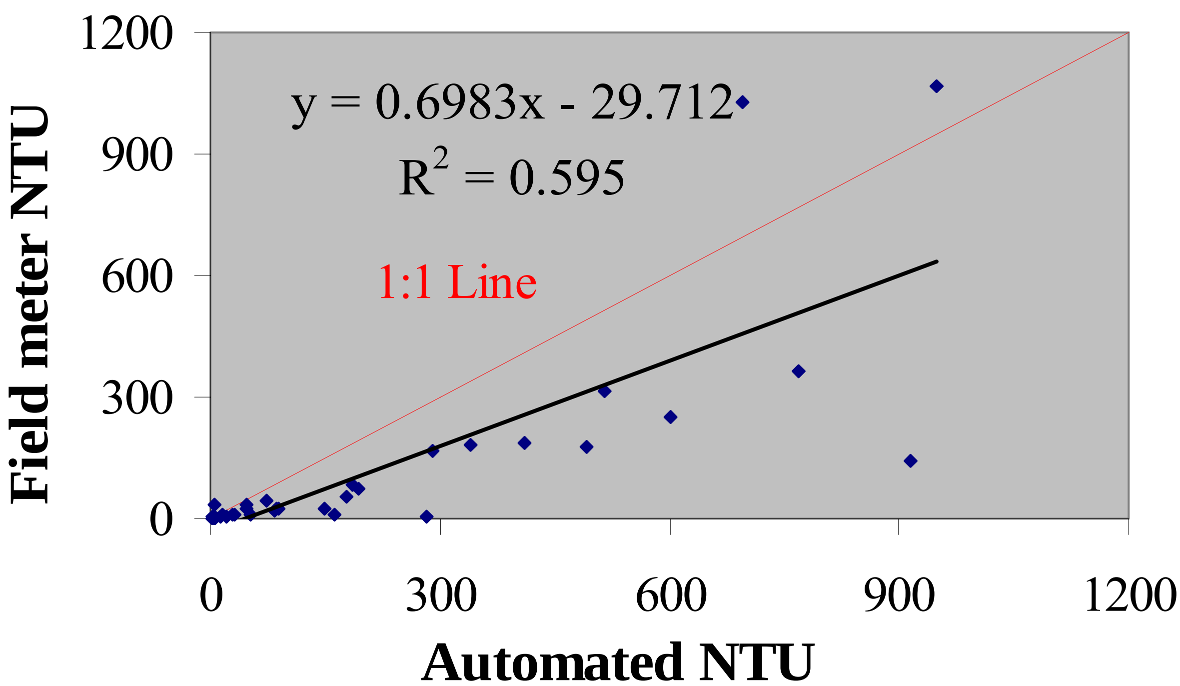

Figure 8. Turbidity measured using portable field meter versus continuous automated turbidity measurements ($p<0.001$). Automated data points are a mean of two values that bracket the field metered values unless automated turbidity values were metered within five minutes of field metered point then the closest automated value is used.

Appendix 5. Gravel studies data from Porto (2006).

Table 7. Percent fines and geometric mean diameter of spawning gravel before and after scarification 2005[1].

Scarification period	**Channel location**	**Sample location across channel**	**% Fines passing**		**Total % <6.4**	**Geometric Mean Diameter (d_g)**
			<2mm	**2-6.4 mm**		
Before scarification	**Upper**	**Left**	12.7	14.7	27.4	8.66
		Center	10.4	18.3	28.7	9.00
		Right	11.5	16.6	28.1	7.75
	Middle	**Left**	7.1	7.6	14.7	15.43
		Center	10.8	13.6	24.4	10.20
		Right	12.4	12	24.4	8.31
	Lower	**Left**	5.7	8.4	14.1	14.49
		Center	7.7	6.9	14.6	14.97
		Right	3.3	6.6	9.9	14.58
	Mean		**9.1**	**11.6**	**20.7**	**11.5**
After scarification	**Upper**	**Left**	4.3	10.6	14.9	13.23
		Center	4.2	11.5	15.7	13.86
		Right	5.1	17.3	22.4	11.18
	Middle	**Left**	6.0	9.7	15.7	13.86
		Center	21.8	22.1	43.9	4.86
		Right	8.6	14.7	23.3	11.62
	Lower	**Left**	7.9	12.9	20.8	11.62
		Center	0.9	4.5	5.4	20.00
		Right	6.8	9.7	16.5	13.86
	Mean		**7.3**	**12.6**	**19.8**	**12.7**

[1]Table taken from Porto (2006).

Table 8. Percent angularity of spawning gravel in MCSC in 2005[1].

Location	**% Angularity**				**% Angularity of Total**
	Angular	**Sub-Angular**	**Round**	**Sub-round**	
Upper	11	49	10	30	60
Middle	13	51	13	23	64
Lower	11	41	15	33	52
Mean					**59**

[1]Table taken from Porto (2006).

Appendix 6. Cumulative size distributions of spawning gravels.

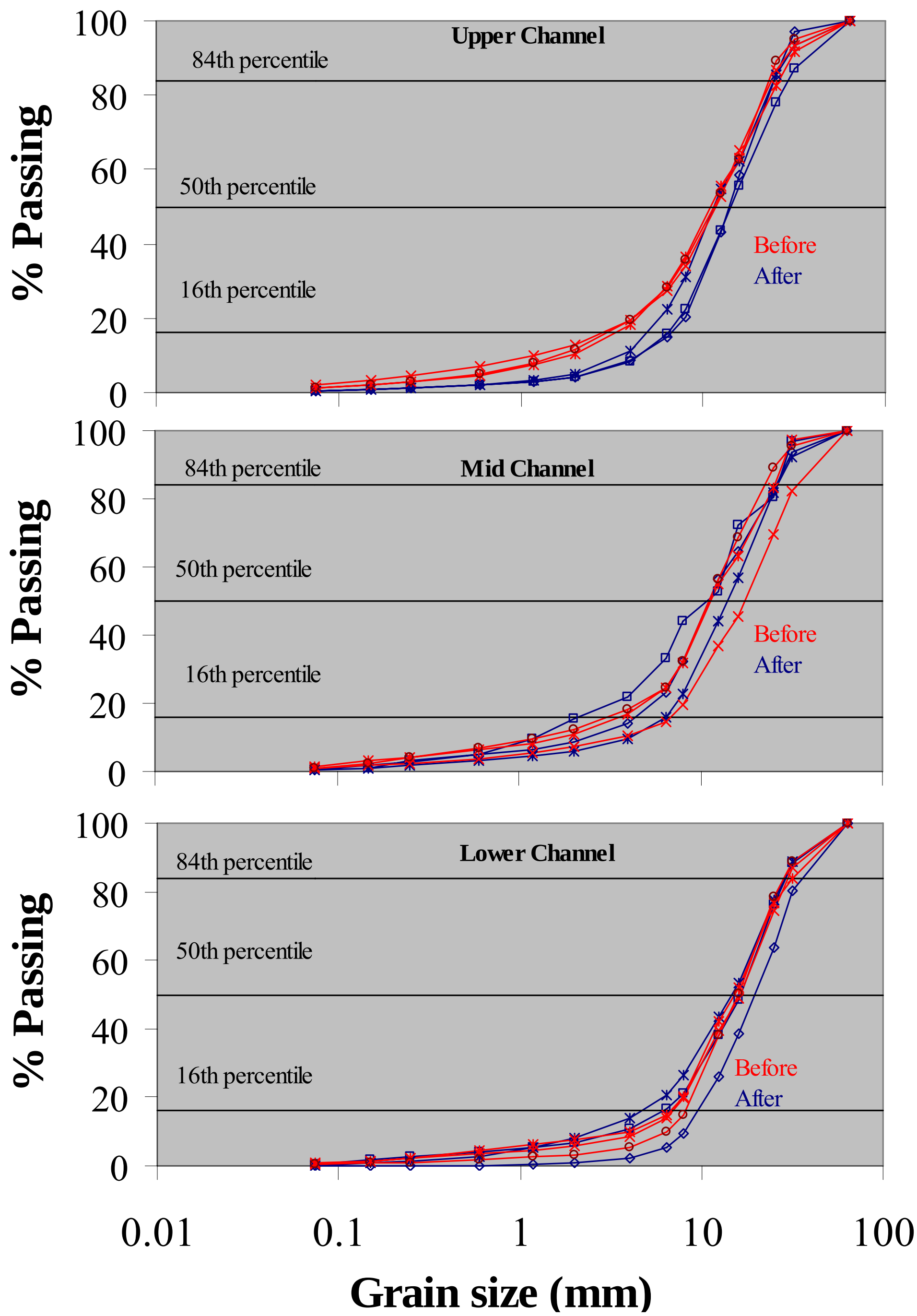

Figure 9. The cumulative particle size distributions for spawning gravels before and after scarification at upper, mid and lower locations within the channel (n=3 for each location and time period). The 84^{th} and 16^{th} percentiles are used to calculate the mean geometric diameter (see Section 3.3)

Appendix 7. Minimum sample number requirements to detect a difference in % fines with a paired t-test.

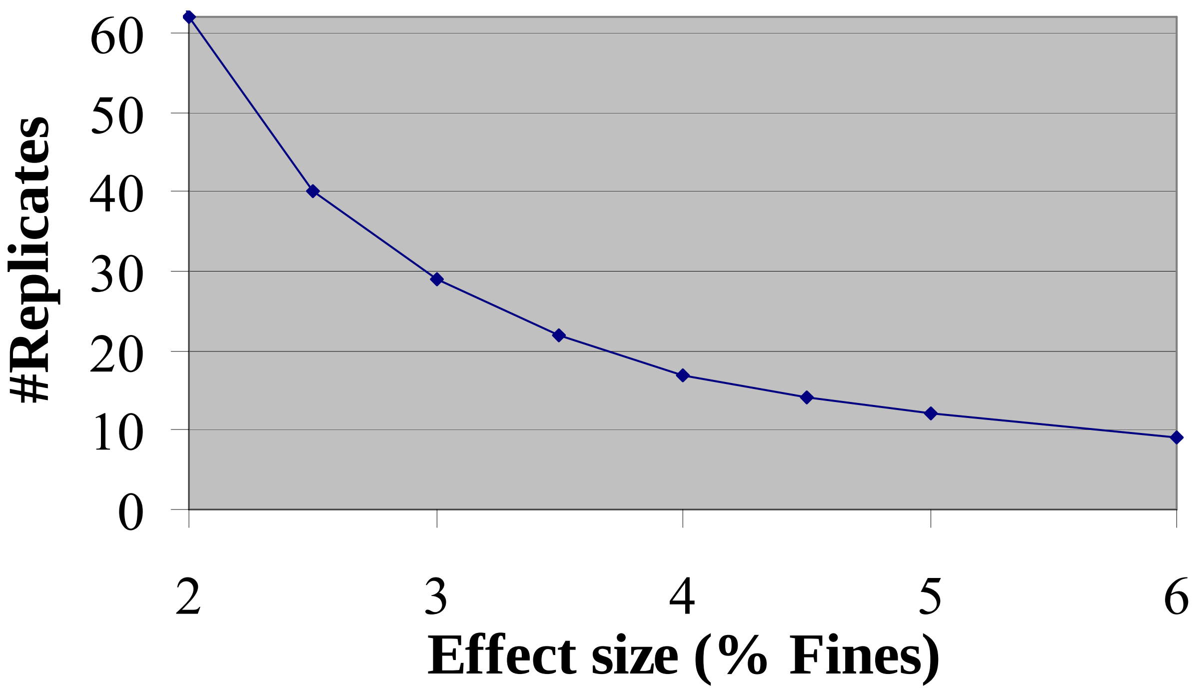

Figure 10. The number of replicates required to detect a difference in % fines (effect size) for a standard deviation =5.5. The standard deviation used here was an average of the observed standard deviations measured for size fractions of <2mm and 2-6 mm percent fines.