Elk River Project Water Use Plan

Elko Dam Headpond Drawdown Environmental Monitoring 2001-2006

Reference: ELK MON-2

Elk River Water Use Plan Monitoring Program: Assessment of Suspended sediment and Fish Stranding during Headpond drawdown at Elko Dam

Study Period: Summary of 2001-2006 data
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1 EXECUTIVE SUMMARY

This study assessed the effect of the headpond reduction rate (ramp rate) on suspended sediment levels and fish stranding on the Elk River at the Elko Dam.

The headpond of the Elko Dam is drawn down twice annually for flashboard removal (late April early May), and flashboard installation (mid-July). In addition, a large drawdown of the headpond occurs occasionally for maintenance and refurbishing. Headpond reductions typically result in short-term elevated levels of suspended sediment in the Elk River within the headpond and downstream from the dam. Suspended sediment levels following drawdown are thought to result from mobilization of fine sediments that have settled within the headpond and along the headpond sidewalls. In addition, drawdown can result in stranding of fishes in the headpond area and connected side channels.

Some of the operating procedures for flashboard removal and installation are dictated by the design of the facility and protocols for safety that are not subject to change. However, our study examines the operations that can be varied to adjust the headpond reduction rate to minimize the effects of ramping on suspended sediments and fish stranding.

A critical question to managers is: what is the relationship between headpond reduction rate and subsequent effects on suspended sediment levels and fish stranding? We investigated the effects of headpond reduction rate on peak suspended sediment levels that were adjusted for the natural background levels of suspended in the Elk River (termed induced TSS). We also reviewed the possible effects of headpond reduction rates on fish stranding. This report provides a compilation and interpretation of the 2001-2006 data.

Low sample sizes of drawdown events, missing or sparse meter-based TSS measurements, and missing drawdown data prevented definitive conclusions for some aspects of this study. Despite these issues, some relationships between headpond reduction rate and induced TSS levels were evident. There was a positive relationship between peak induced TSS (90^{th} percentile) and mean headpond reduction rate at the headpond site. Peak induced TSS and the duration of the sediment pulse were both significantly related to headpond reduction rate downstream of the dam.

Recommendations from this study include establishing operational rules to reduce possible impacts of sediment exposure and stranding on fish under the operating constraints of the facility. Two such rules would be to target, (1) a mean headpond reduction rate of less than 10 cm/hr, and (2) consistent hourly headpond reduction rates. Further evaluations should focus on the efficacy of the recommended operational rules with regards to induced suspended sediment and fish stranding.

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3 ACKNOWLEDGEMENTS

Interior Reforestation collected all the field data for this project and they carried out the yearly reporting (Bisset et al., 2004, Edeburn and Wright 2003a and b, Wright 2001 and 2002, Wright et al. 2005).

Darcie Quamme of Integrated Ecological Research conducted data analyses and summary reporting of the 2001-2006 suspended sediment data. John Boulanger of Integrated Ecological Research conducted data analyses. Robert Westcott, formerly with BC Hydro now with Golder Associates, authored sections on fish stranding.

Robert Westcott and Dean den Biesen carried out the project initiation and contract monitoring and editing of the report for BC Hydro. Guy Martel of BC Hydro also reviewed the report and provided input.

4 INTRODUCTION

The BC Hydro Elko Project is a run-of-the-river facility located on the Elk River approximately 70 km east of Cranbrook and produces 73.0 GWh of electricity each year for 7300 homes (Figures 1 and 2, Appendix I). The headwaters of the Elk River originate at the Elk Lakes, 104 km north of Sparwood in the southern Rocky Mountains. The Elk River flows from Elk Lakes 185 km south to the Lake Koocanusa Reservoir and the Kootenay River.

The Elko dam (16 m high, 66 m long) creates a 10 ha headpond upstream of the spillway. Water from the Elk River is diverted via penstocks and surge tanks to a 12 MW capacity generating powerhouse located 1.2 km downstream of the dam at the bottom of Philips Canyon.

Drawdown of the headpond from the normal winter operating levels to a lower level above the spillway sill depends on river discharge and occurs prior to freshet in late April or early May. As flows recede by early July, flashboards are installed at the dam spillway to increase the hydraulic head by 2.8 m to store water for generation purposes. Flashboard installation and trashracks are checked prior to winter operations (Wright et al 2005).

These operations can result in increased suspended sediment levels in the Elk River downstream of the dam and within the headpond (BC Hydro 2005, 2006). Increases in suspended sediment during drawdown are thought to be due to resuspension of silt in the headpond and bank sloughing. As a result, headpond reduction rates of 15 cm/h were established in 1994 to minimize water velocities and erosion processes within the headpond and decreased flow and stage changes downstream of the dam.

Headpond drawdown can also result in fish stranding upstream of the headpond area of the Elko facility as the water recedes. Fish stranding occurs in shallow depressions in the main-stem river and in side channel habitat upstream of the dam at River Road Bridge (Bisset et al., 2004, Edeburn and Wright 2003a and b, Wright 2001 and 2002, Wright et al. 2005). Fish stranding studies conducted on the Columbia River have assessed a variety of factors influencing fish stranding including; time of day, habitat type (pool versus interstitial, cover versus no cover) and ramping rate (Golder 2005 and 2006). However, the main variable under the control of the BC Hydro Elko Project operations and the primary concern of the present assessment is the effect of headpond reduction rate on fish stranding.

The Elko Water Use Plan Consultative Committee (BC Hydro 2006) recommended that the Elko Water Use Plan examine the link between operational procedures at Elko Dam during headpond drawdown and its effects on suspended sediments and fish stranding. This included implementing a monitoring study to determine whether a slower target headpond water level reduction (ramp) rate of 10 cm/hr would reduce suspended sediments and fish stranding compared to the target 15 cm/hr rate that has been in place since 1994. However, accurate ramping at Elko Dam is difficult given the physical limitations of the facility and operational control of discharge releases. Thus from 2001-2006, headpond reduction rates were aimed at 10 cm/hr or 15 cm/hr using small frequent decreases in headpond volume. The results of this study will affect key water use decisions and operating procedures for the drawdown of the Elko Dam headpond.

OBJECTIVES

The objectives of the Headpond Drawdown Environmental Monitoring Project were to:

- Review 2001-2006 suspended sediment and fish stranding data as they relate to the headpond reduction rate of Elko Dam headpond.
- Review the Water Use Plan Terms of Reference and address the management questions.
- Error check and screen suspended sediment data against headpond operations.
- Summarize 2006 fish stranding data.

MANAGEMENT QUESTIONS

The management questions for the Water Use Plan Terms of Reference were:

1. Will a slower headpond reduction rate significantly reduce TSS and turbidity levels within the headpond?
2. Will a slower headpond reduction rate significantly reduce TSS and turbidity levels downstream of the dam?
3. Will a slower headpond reduction rate significantly reduce the incidence of fish stranding within the headpond?

MANAGEMENT HYPOTHESES

- H1: A slower headpond reduction rate is effective in reducing biologically significant elevated suspended sediment levels in the headpond from that observed under the existing 15 cm/hr headpond operation.
- H2: A slower headpond reduction rate is effective in reducing biologically significant elevated suspended sediment levels downstream of the dam from that observed from that observed under the existing 15 cm/hr headpond operation.
- H3: A slower headpond reduction rate is effective in reducing fish stranding in the headpond from that observed under the existing 15 cm/hr headpond operation.

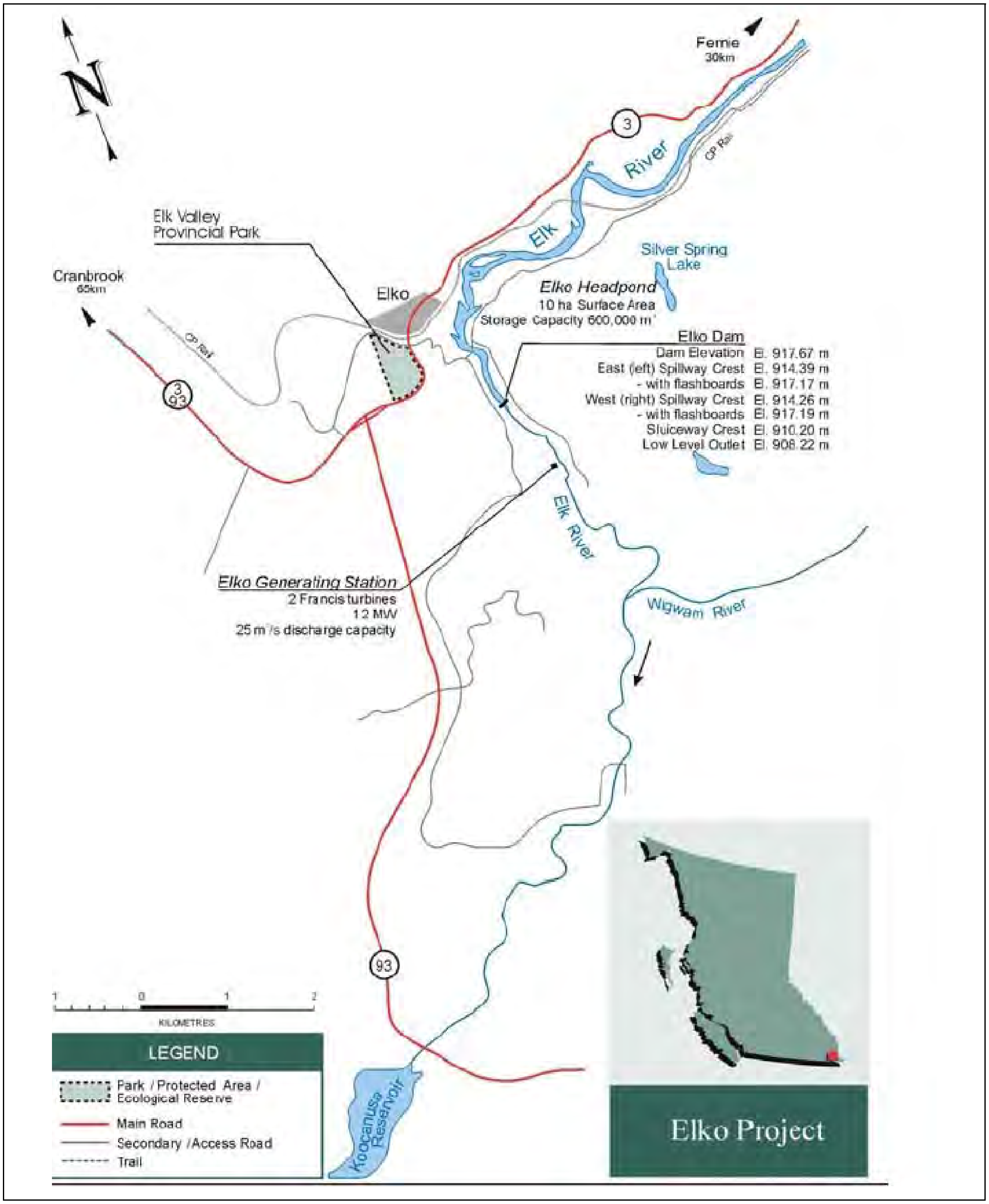

Figure 1. Location of Elko Hydroelectric Generating Facility. Map courtesy of B.C Hydro.

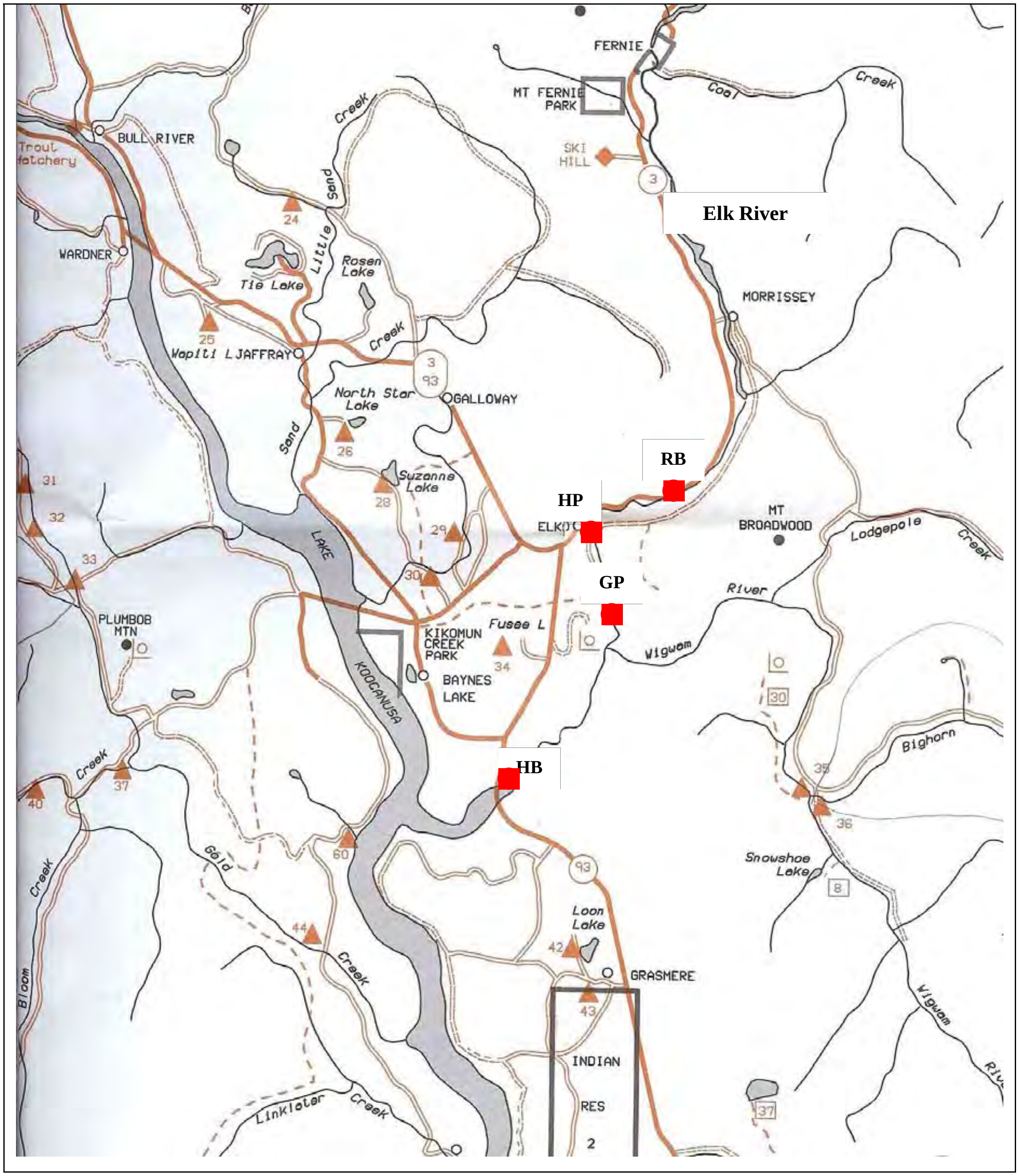

Figure 2. Location of monitoring sites (red circles): the railroad bridge site upstream control (RB); the headpond upstream of Elko dam (HP); the gas pipeline site (GP); the highway bridge (HB). Map courtesy of B.C Hydro.

5 METHODS

SITE LOCATIONS

From 2001 to 2006, six sites were monitored during different years and operations (Table 1). Monitoring began in 2001 with sites in the headpond of Elk Dam at the FSR Bridge (HP), the downstream tailrace pool (DS), and the power station pool (PS) (Wright 2001). In 2002, an upstream control site, the railway bridge (RB), was added (Wright 2002). In 2003, monitoring at the PS and DS sites, downstream of the Elko dam, was discontinued because it was thought that turbulence affected the turbidity readings (Wright 2003 a and b). Instead, monitoring was initiated a further 1.5 km downstream at the Gas pipeline site (GP). The Highway bridge site (HB) was monitored starting in 2003 (during installation only) to examine the extent of possible effects of ramping further downstream (16 km) of the dam.

Table 1. Monitoring sites that were included (shaded) or excluded[1] (unshaded) from analyses.

Site and location	Distance from Elko dam	Location	Treatment	Years Monitored	Data used in present analysis
RB – Railway Bridge site	4 km upstream	At the CPR bridge crossing of the Elk River	Upstream Control	2002-06	2003-06
HP – Headpond site	900 m upstream	Headpond of Elko Dam at FSR Bridge (Headpond is 10 ha in area with 0.006 km^2 storage capacity)	Subjected to effects of drawdown	2001-06	2003-06
GP- Gas pipe line site	3.35 km downstream	Foothills Natural Gas pipeline crossing of Elk River	Subjected to effects of drawdown	2002-06	2003-06
HB- Highway 93 bridge site	16 km downstream	Left bank of Elk River, Highway 93 Bridge crossing, 400 m upstream of the mouth of Lake Koocanusa – Downstream of Phillips Canyon	Subjected to effects of drawdown	2003-06	2003-06
DS- Down stream tailrace pool	75 m downstream	Downstream tailrace pool – on right downstream facing bank	Subjected to effects of drawdown	2001-02	Not included
PS- Power station site	950 m downstream	Adjacent to Power House Right downstream bank in pool – (Generating station includes 2 Francis turbines 12 MW 25 m^3/s discharge)	Subjected to effects of drawdown	2001-02	Not included

[1]Unshaded sites excluded because headpond reduction rates were unavailable for 2001-2002

HEADPOND REDUCTION OPERATIONS

B.C. Hydro's Southern Interior Control, based in Vernon, iniated remote drawdown of the Elko project's headpond. This was achieved by diverting increased flow via the generating units and the undersluice. Following this, the onsite field-staff opened two headgates to slowly increase flow via the sluiceway until the water levels reached below the spillway crest at 913.99 m elevation. At this point, the flashboards were either removed (late April and early May) or installed (July) and the headpond was refilled. During the headpond drawdown, an automated water level gauge located near the spillway monitored the headpond elevations each hour. In 2001, 2002, and 2005 target headpond reduction rates were set at 15 cm/hr while in 2003 and 2006 target rates were 10 cm/hr (Table 2). Target rates were difficult to achieve due to the facility design and as a result measured hourly headpond reduction rates (calculated from SIC records, Figure 3) were used in the analyses. Headpond elevations for 2001-02 were not available at the time of the reporting and only the data from 2003-06 were used in the analyses (Figure 3). Measured hourly headpond reduction rates (cm/hr) were calculated as: *(headpond elevation at hour$_i$ - headpond elevation at hour$_{i+1}$)/ hour*.

The elevation of the headpond before downramping (at 0 hours in Figure 3), prior to removal of flashboards, in April/May was typically higher (915.0-917.0 m) than for installation in July (915.0-915.5 m) due to both freshet conditions and the effect of the flashboards. It should be noted that in 2005, the total drawdown could not be measured once water levels dropped below the exposed headpond water level gauge (below 912.5 m, 3.04 m total drawdown, Figure 3). The elevation target was 911 m (5.4 m total drawdown) for refurbishing and maintenance. The deep drawdown in 2005 (May 4, 8:30-11:00 am) was carried out so that a vacuum truck could be used to remove 12 m^3 of sediment deposits in the forebay between the trashracks and the intake gate.

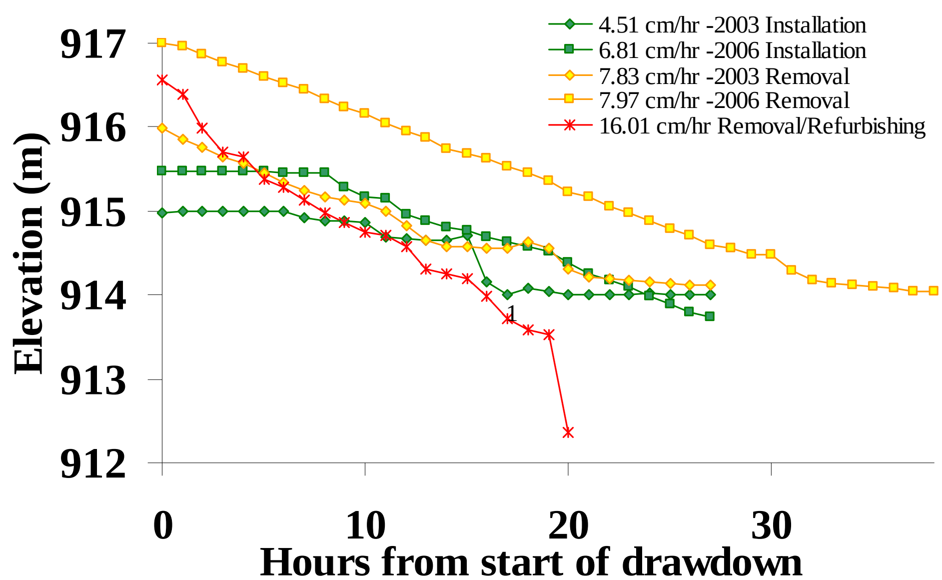

Figure 3. Headpond elevation (m) versus hours from start of (hr). Green, yellow and red lines indicate removal (April/May) and installation of flashboards (July) and refurbishing/removal (July 2005), respectively.

Table 2. Timing of headpond , total and reduction rates (cm/hr) by year/operation.

Year/ Operation	**Date/Time remote initiated**	**Date/Time completed**	**Target headpond reduction rate (cm/hr)**	**Total [1] (m)**	**Number of hourly ramps**	**Summary of hourly headpond reduction rates**					
						% >10cm/hr	**% >15cm/hr**	**Mean (cm/hr)**	**Median (cm/hr)**	**Minimum (cm/hr)**	**Maximum (cm/hr)**
2001 Installation[2]	June 25 05:15	Unknown	**15**	Unknown							
2002 Removal[2]	April 16 22:30	Unknown	**15**	Unknown							
2002 Installation[2]	July 18 00:00	July 18 10:00	**15**	Unknown							
2003 Removal	April 30 12:15	May 1 07:15	**10**	1.87	25	28	12	**7.97**	7.13	1.05	24.79
2003 Installation	July 8 15:00	July 9 18:00	**10**	0.97	40	19	19	**4.51**	1.61	0.002	56.07
2005 Removal & refurbishing	May 1 18:00	May 2 15:00	**15**	3.03[3] (4.72[4])	19[3] (38[4])	74[3]	47[3]	**16.03**[3]	13.48[3]	2.21[3]	41.43[3]
2006 Removal	May 1 00:00	May 2 14:00	**10**	3.56	38	26	3	**7.83**	7.85	1.07	18.03
2006 Installation	July 5 00:00	July 6 08:00	**10**	1.83	27	20	7	**6.81**	6.20	0.06	19.1

[1]Sum of hourly decreases in elevation over headpond period. [2]Headpond elevation data not available [3]From SIC but missing data as water levels dropped below sensor. [4] As reported or from data in Wright et al. 2005.

SUSPENDED SEDIMENT

Continuous turbidity metering

Turbidity levels before and after drawdown were monitored using Analite NEP 160 continuous turbidity meters at each site. The Analite NEP 160 has a resolution of ±0.02 at 0.1-20 NTU, ±0.1 at 1-200 NTU, ±1 at 10-2000 NTU. The meters were re-calibrated internally each year and upgraded at the factory. Methods are outlined Bisset al. (2004), Edeburn and Wright (2003a and b), Wright (2001 and 2002), Wright et al. (2005). Baseline turbidity levels were monitored at each site prior to drawdown from 5-10 minutes/day (at one minute intervals) for one-two days prior to headpond drawdown. Turbidity was also monitored throughout the headpond drawdown period during which meters were typically set to record a turbidity measurement once every 15 minutes. The dates and times of before and after drawdown monitoring are given in Appendix II.

Calibration of predicted TSS to continuous turbidity

Continuous turbidity values were used to obtain a simple linear regression between turbidity and TSS. Previous work by Lewis (1996) demonstrates that regressions of suspended sediment concentration versus turbidity are often linear with low variance.

Metered turbidity data were calibrated with paired laboratory analyses for TSS of discrete surface water grab samples collected near the sensors (2001-2006). Validation of the turbidity record with laboratory data was not carried out because the primary goal was to obtain the relationship between metered turbidity and laboratory TSS (as in Eads and Lewis 2002), not obtaining the absolute accuracy of the turbidity record.

Meter-based turbidity data were also screened for possible problems. If there were obvious problems with turbidity spikes during the power-up period, or for example, times where the probe was affected by bottom sediment or receding water levels the data were flagged and documented (see companion compact disc). Flagged data were then either removed from the statistical analyses or substituted with TSS values from grab samples analysed in the laboratory when possible. Minor to moderate problems with calibration drift were corrected when turbidity was converted to TSS using laboratory analyses of collected water samples.

The relationship between TSS and turbidity was likely influenced by individual site and operations at a given site. It is possible that each site and operation had a specific TSS/Turbidity calibration slope and associated intercept. Some of the other issues with the data included low numbers of paired measurements for laboratory TSS and metered turbidity at some sites; and sparse sampling during peak flows.

Simple linear regressions of laboratory TSS versus metered turbidity were inspected for each turbidity meter, site, year and operation. In some cases, the data were inadequate to describe each individual relationship. In order to improve overall estimates of the laboratory TSS and meter-based relationships, an analysis of covariance (ANCOVA) (Milliken and Johnson 2002) was conducted to calibrate lab TSS measurements with meter-based turbidity measurements. Analysis of covariance allows the modeling of group (site and operation) and continuous (turbidity) variables therefore allowing the statistical comparison of a series of regression slopes (Littell et al 1996). Using this approach, we tested for site-specific, operation-specific and site/operation-specific slopes. The general strategy was to find the simplest model that allowed estimates of the lab TSS-turbidity slope using the data from multiple sites (to offset low sample sizes) while still describing the majority of variation in the data.

Differences in the relationship (i.e., the slope and intercept) between TSS and turbidity were compared among sites and operations. If differences were not detected then overall relationships for TSS and turbidity was derived using the data from multiple sites. In the case of this analysis, the lab TSS and meter-based turbidity measurements were inherently linear and normally distributed as discussed in Lewis (1996). In addition, there was no evidence in the data, or theoretical reason why the variances of the lab-based TSS values were different across the range of meter-based TSS measurements. Therefore, the data were not transformed for the analyses. These assumptions were further scrutinized by inspection of residual plots.

Calculation of induced TSS

Induced TSS was used to evaluate the effects of varying ramp rates on suspended sediment because background suspended sediment varied with each site, year and operation. This parameter was calculated as: *Induced TSS = TSS (after headpond reduction) - TSS (before headpond reduction).* Using induced TSS eliminated the additional variance in TSS caused by naturally varying levels of background TSS between years therefore improving the overall clarity and power of analyses. An induced TSS value of zero would imply that the TSS value was equal to the levels before drawdown occurred. Of most interest were induced TSS values that were greater than zero, which were assumed to reflect the effects of drawdown.

Selection of variables to summarize the effects of ramping

The mean headpond reduction rate was used to describe the rate of change in elevation at the sill of the headpond over the course of each drawdown period. It can also be conceptualized as the mean slope of the curves shown in Figure 3. Correlations between mean headpond reduction rate, total drawdown (Pearson correlation, $\rho=0.88$, $df=11$, $p=0.04$) and % of ramps >10 cm/hour (Pearson correlation, $\rho = 0.98$ $df = 11$, $p = 0.03$) suggest that all of these metrics are describing similar trends and levels of drawdown. The spring flashboard removal operations, which required higher total drawdowns, also had higher mean headpond reduction rates compared to summer flashboard installation operations (Table 2). Given these correlations, we selected the mean headpond reduction rate as a relative indicator of rate between years/operations.

The effects of headpond reduction rates on induced TSS

The distribution of induced TSS was described for each site using boxplots as related to mean headpond reduction rate. We used percentiles of the distribution of induced TSS values to summarize the effects of headpond reduction rate on peak induced TSS for each site/drawdown (see quantile regression methods US EPA 2009). Of most interest was the relationship between the peak induced TSS and mean headpond reduction rate. The 90th percentile was used as an estimate of peak induced TSS due to its robustness to outlier data points (Helsel 1987, Furer et al. 1996 and US EPA 2009).

The total time in which induced TSS exceeded 25 mg/L was estimated and related to mean headpond reduction rate. The provincial guidelines (MoE 2009) for induced TSS are non-exceedance of 25 mg/L in a 24-hour period during clear flows (when background is less than 25 mg/L). In addition, induced TSS should not exceed 10 mg/L during high flows (when background is greater than 25-100 mg/L) or 10% of measured background (when background is >100 mg/L) (MoE 2009). Background levels in the present study were generally below 25 mg/L. However, the goal of present analysis was simply to relate the duration of the sediment pulse (time that induced TSS exceeded 25 mg/L) to headpond reduction rate. This was not intended to be an assessment of compliance with provincial guidelines

An ANCOVA (Milliken and Johnson 2002) was used to test whether the 90^{th} percentile of induced TSS could be predicted by mean headpond reduction rates. The number of hours in which induced TSS were greater than 25 mg/L was also examined. The ANCOVA model tested whether there were different relationships between headpond reduction rate and induced TSS among sites. The ANCOVA model used 90^{th} percentile induced TSS or hours in which induced TSS > 25 mg/L as the response variable. Site, mean headpond reduction rate, and the interaction of site and mean headpond reduction rate were used as predictor variables. The general form of the ANCOVA model was: *Response variable = site + mean HP reduction rate + (mean HP reduction rate * site).* Non-significant terms were eliminated to derive the most parsimonious model for the data set.

Induced TSS values were log-transformed to meet the assumption of equal variances of the response variable across the range of predictor variables. The assumption of normality of the response (induced TSS value or hours of induced

TSS exceeding 25 mg/L) for corresponding mean headpond reduction rate values was reasonable given that the percentile values of induced TSS values were used as response variables rather than individual TSS measurements. Therefore, the distribution of percentile values was theoretically normal even if the distribution of individual TSS values used to estimate these values deviated from normality due to the central limit theorem (Zar 1984, US EPA 2009). Residual plots were used to further assess ANCOVA fit.

FISH STRANDING

BC Hydro has undertaken, with the assistance of contractors, fish stranding assessments around the Elko Headpond each year since 2002 when water levels were reduced to facilitate maintenance activities. Over the years, assessment crews have been successful in walking the perimeter of the Elko headpond during drawdown and identifying areas where fish stranding could occur. Water levels and fish habitats upstream of the dam, in areas prone to isolation/stranding of fish stranding, were monitored during both periods, with data collection undertaken near the completion of the drawdown event. Dewatered substrate was visually checked for the presence of stranded fishes and any isolated pools were sampled using a backpack electrofisher and dip-nets. All fish captured were identified to species and a sub-sample was measured to fork length (mm) with representative photos taken. All captured fish were subsequently returned to mainstem riverine habitats. The fish stranding data were reviewed to determine whether there was any difference in fish stranding risk between the flashboard removal and installation procedures.,. The risk assessment of fish stranding considered species presence, timing, extent, and headpond reduction rate and risk variables identified in related BC Hydro fish stranding assessment programs.

6 RESULTS AND DISCUSSION

SUSPENDED SEDIMENT

Calibration of predicted TSS to continuous turbidity

ANCOVA results suggested that Lab TSS and turbidity varied by site, by operation, and an interaction of site and operation. We therefore used a model that estimated site-specific slopes, operation specific slopes, and interaction of site-and operation slopes to account for these differences. See Appendix III for the exact parameters of this model. The overall model was significant (F=48.2, df=29, 284) and all model parameters were also significant (Table 3). The r-square for the model was 0.83 meaning that the model explained 83% of the variation in the data.

Table 3. Results of analysis of covariance to estimate the relationship between lab TSS and continuous turbidity[1].

Parameter	Degrees of freedom	F	p-value
Turbidity	1	23.25	<0.0001
Turbidity*site	4	10.57	<0.0001
Operation*site	13	5.16	<0.0001
Turbidity*Operation*site	9	14.2	<0.0001

[1]See Appendix III for exact equations used to model the differences between sites.

Induced TSS as a function of time

Induced TSS measurements were plotted for each site during each drawdown period by operation and year with headpond elevation (for some examples see Figure 4). The plots of induced TSS during 2005 refurbishing/removal operations show the time lags between upstream HP and GP sites and the 16 km downstream HB site. The mean value for induced TSS at the upstream control site (RB) was 5.02 mg/L (standard deviation = -4.54, range = -11.75 to 27.3 mg/L) when the year/operation combinations for this site were pooled suggesting that background induced TSS values were on average near zero in all analyses.

The effects of headpond reduction rates on induced TSS

There was a general positive relationship between the distribution of individual induced TSS points and mean headpond reduction rates (Figure 5). The ANCOVA model was used to estimate the relationship between the 90^{th} percentile of induced TSS and mean headpond reduction rate. The initial ANCOVA model tested was: *90th percentile=site + headpond reduction rate + headpond reduction rate*site*. Tests of individual model terms showed that the main site and headpond reduction rate terms were not significant but the site*reduction rate interaction term was significant. This suggested that a common intercept could be assumed for each of the site and headpond reduction rate curves. Therefore, the model was reduced to: *90th percentile = intercept + headpond reduction rate*site*. The significance of the overall ANCOVA model was tested with an F-test of the model mean square divided by the error mean square. This test was significant at $\alpha = 0.1$ (F=2.87, df=3,8, p=0.10).

The significance of ramp*site interaction terms meant that the relationship between peak induced TSS and headpond reduction rate had to be considered on a site-by-site basis. There was a positive relationship between mean headpond reduction rate and peak induced TSS (90th percentile) at the GP site (at a significance of p<0.05) and at the HP and HB sites (p<0.1) (Figure 6, Table 4). However, the sample size limited the overall power of the analysis and precision of slope estimates as indicated by the wide confidence intervals on model predictions.

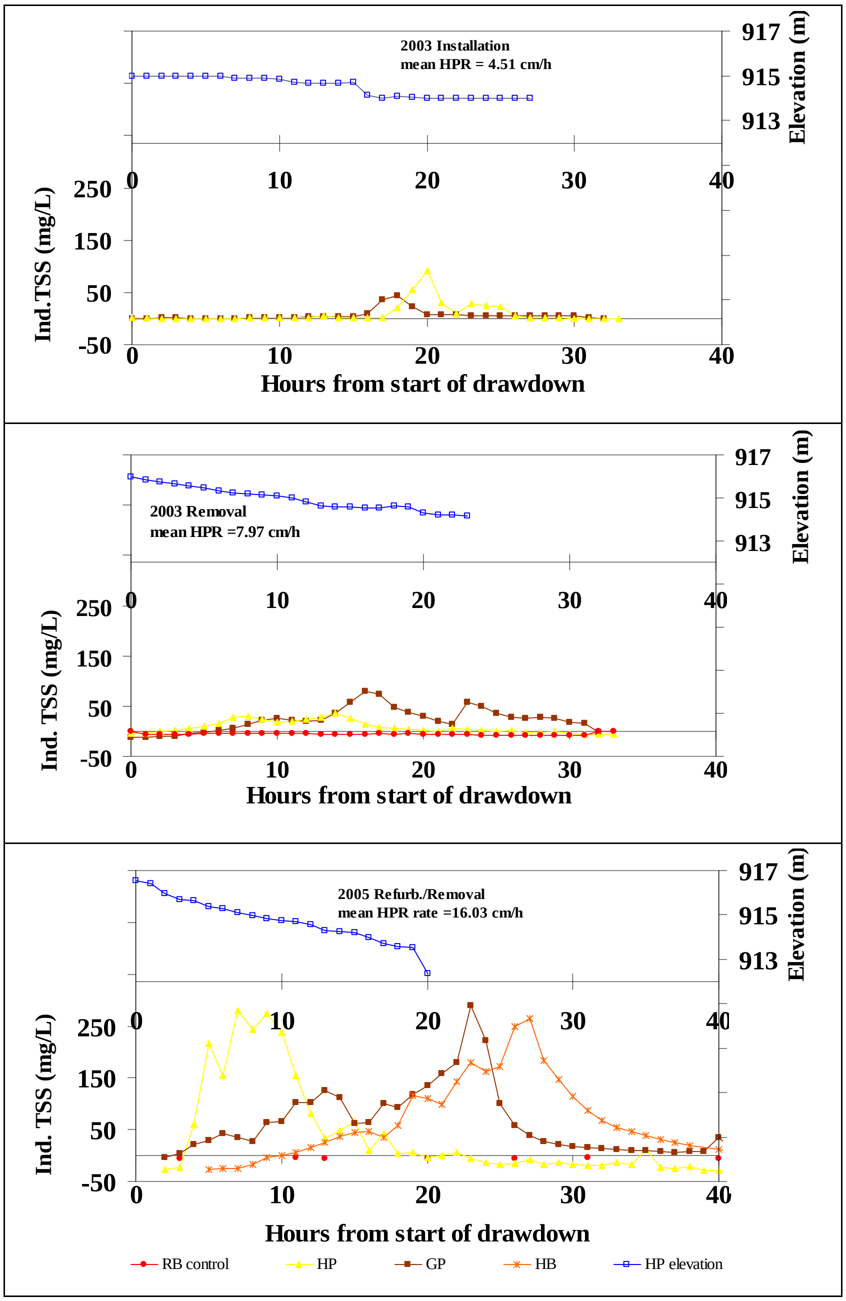

Figure 4. Induced TSS (mg/L) and headpond elevation (m) as a function of time from the start of for example operations. HPR = headpond reduction rate. See Figure 2 and Table 1 for locations and descriptions of sites.

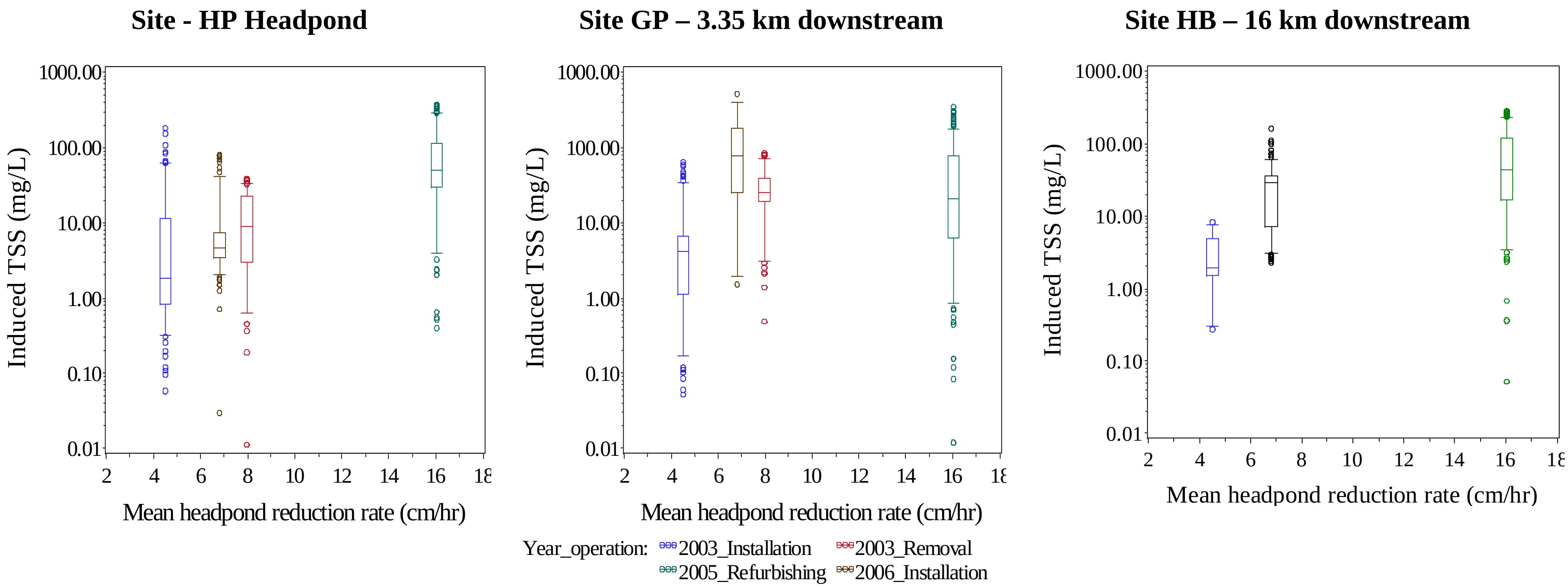

Figure 5. Boxplots of mean headpond reduction rate (cm/hr) versus induced TSS (mg/L, defined in Section 5). The box indicates the interquartile range with edges that are the 25th and 75th percentiles, the bar is the median value, and the whiskers specify 1.5-times the interquartile range. The circles denote possible outliers beyond the whiskers. Also note the log scale on the y-axis.

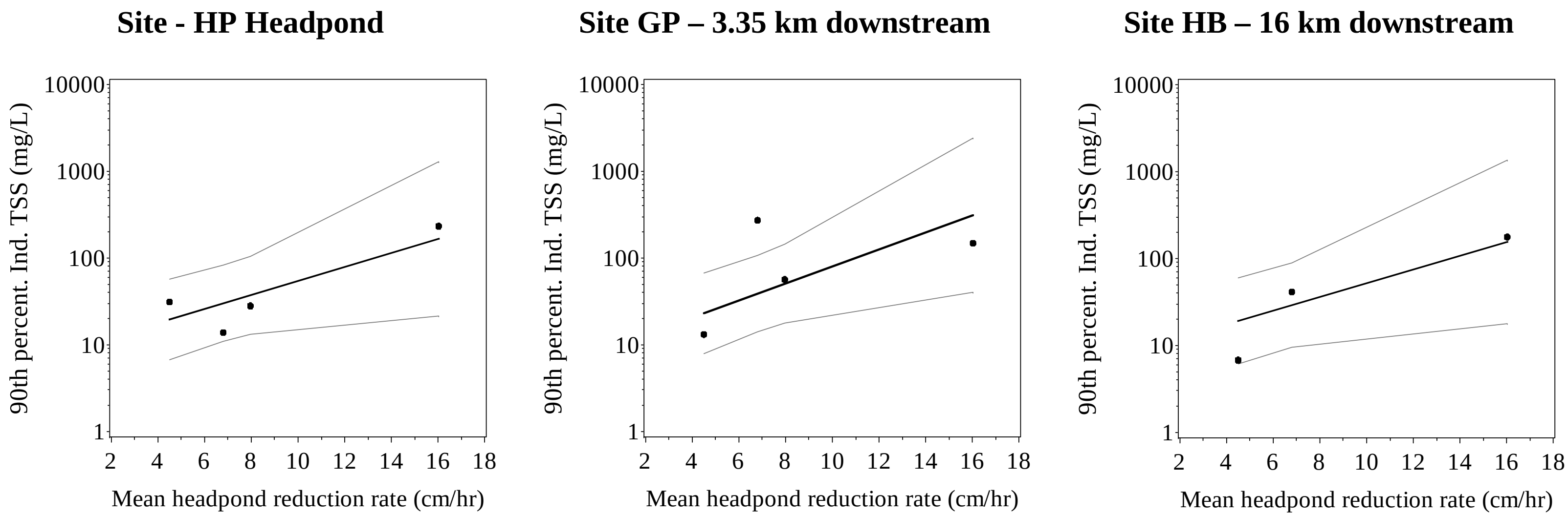

Figure 6. Mean headpond reduction rate versus peak levels (90th percentile) of induced turbidity (black circles) with 95% confidence intervals (grey lines) from ANCOVA analyses (Table 4). Note the log scale on the y-axis. All the relationships between 90th percentile and induced TSS were significant at α=0.10.

Table 4. Analysis of Covariance statistics of mean headpond reduction rate versus peak levels (90th percentile) of induced TSS .

Peak TSS (mg/L)	Parameter	Estimate	Standard Error	t-value	p-value
Log (90th percentile)	Intercept	0.924	0.288	3.21	0.01
	ramp*site HP	0.081	0.034	2.37	0.05
	ramp*site GP	0.098	0.034	2.86	0.02
	ramp*site HB	0.079	0.034	2.31	0.05

One assumption of analyses was that background TSS levels did not vary dramatically over the headpond reduction period. Induced TSS at the control site (RB) was near zero for most sites/operations indicating that background TSS did not vary considerably over the course of the monitoring (see RB site in Figure 4). The exception was the 2006 removal where TSS was high (229-249 mg/L at RB control) before drawdown and declined over the course of the monitoring period. As a result, the changing background TSS levels swamped the response of induced TSS at all sites. These sites and year/operation combinations were not included in the analysis.

The effects of headpond reduction rates on the duration of sediment pulse

The duration of the time in which induced TSS exceeded 25 mg/L was estimated and related to mean headpond reduction rate. This threshold was selected because provincial guidelines (MoE 2009) for induced TSS include a recommendation of not exceeding 25 mg/L in a 24-hour period during clear flows (when background is less than 25 mg/L). Background levels of site/year/operation combinations in the present analysis were generally below 25 mg/L. The individual slopes for two of the sites (GP and HB) of three sites were significantly different from zero (Table 5, Figure 7).

Table 5. Analysis of Covariance statistics for mean down ramp rate versus hours Induced TSS > 25 mg/L.

	Parameter	Estimate	Standard Error	t-value	p-value
Hours Inducted TSS >25 mg/L	Intercept	0.717	5.315	0.13	0.8964
	ramp*site HP	0.561	0.632	0.89	0.4041
	ramp*site GP	1.555	0.632	2.46	**0.0434**
	ramp*site HB	1.550	0.631	2.46	**0.0436**

Bolded values indicate significance at p=0.05

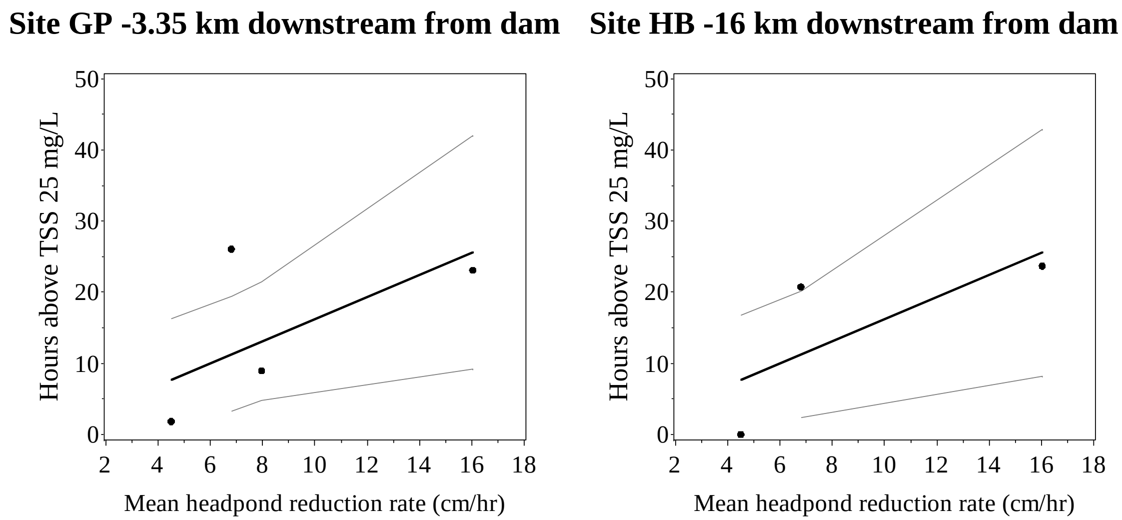

Figure 7. Mean ramp rate versus hours exceeding 25 mg/L of Induced turbidity (black circles) from ANCOVA analyses (Table 5). Grey lines are 95% confidence intervals. Note the log scale on the y-axis. All the relationships between 90th percentile and induced TSS were significant at α=0.10.

FISH STRANDING RISK

Fish stranding can occur in the headpond as a result of both natural inflow recession but also as a result of deliberate drawdown at the BC Hydro dam for operation and maintenance requirements. The Elk River upstream of the falls adjacent to the Elko generating station contains the following species that are at risk to stranding including: bull trout, mountain whitefish, rainbow trout, brook trout, westslope cutthroat trout (Yellowstone), largescale sucker, longnose dace (see Table 6 for scientific names). Sculpins are the only species found in the river that are not susceptible to stranding. The following section summarizes the findings of the 2006 fish stranding assessments and collates historic fish stranding information for a qualitative assessment of fish stranding risk.

2006 Flashboard Removal Monitoring

Fish salvage was completed on May 1st and 2nd, 2006, using a Dirigo 850 backpack electrofisher and dipnets. Fish salvage using multiple electroshocking passes was undertaken in isolated pools and side channels identified during the fish stranding assessment – primarily at the upstream end of the headpond. A total of 31 fishes were captured in dewatered habitat around the Elko headpond (Table 6). The majority of fishes salvaged were salmonids, including bull trout, which ranged from 265 to 282 mm in length, and mountain whitefish that ranged from 93 mm to 395 mm. The majority of habitats affected by the headpond drawdown were ephemeral sidechannels (which are seasonally inundated), and the upper headpond. The headpond reduction rate allowed the majority of fish to move into the main channel as water levels receded; however some fish did become stranded as isolated pools formed in sidechannels and at the upstream end of the headpond. The total affected habitat area associated with flashboard removal is estimated at 2.62 ha (Blocks 1-5, Appendix I) based on survey data and mapping completed by SEL Surveys and Design, and digitized by Interior Reforestation. All captured fishes were measured and released into the Elk River main channel. One dead mountain whitefish and three unidentified cyprinids were retained as voucher specimens. In areas where there was sufficient water depth and pool area to provide refuge habitat for a variety of species, particularly cyprinids, fish salvage was not completed. The pools were inundated and reconnected to the mainstem during refill once the headpond levels returned to normal operating levels.

2006 Flashboard Installation Monitoring

Fish salvage associated with the 2006 flashboard installation process was completed on July 6, 2006. Areas typically isolated during drawdown in the spring (side channels upstream of the FSR) were dry prior to drawdown, and were not affected by the headpond drawdown associated with flashboard installation. Fish species and numbers captured are summarized in Table 6. In 2006, limited pools were identified as a result of headpond drawdown and a total of 20 young-of-the-year mountain whitefish, ranging in size from 26 - 46 mm were captured. Typical stranding areas included headpond margins where isolated pools formed as water levels receded. The steep headpond slopes in the canyon immediately upstream of the dam limit the stranding potential at the lower end of the headpond. The total affected habitat area affected by the headpond drawdown was estimated to be 0.95 ha, about one third of the area observed during spring flashboard removal.

Summary of Existing Fish Stranding Information 2002-2007

The number of fish stranded during each drawdown event ranged from 4 to 2800 fishes (Table 6). Vulnerable life stages ranged from newly emerged fry through adults mainly in pool habitat. As describe above, the areas where stranding occurred was seasonally related to headpond elevation at the beginning of drawdown. The habitat where stranding typically occurred included: (1) isolated pools and side channels upstream of the FSR bridge at the upper end of the headpond April/May following flashboard removal and (2) isolated pools along lower gradient banks of the upper headpond in July after flashboard installation. The range in total numbers of stranded fishes was higher for removal/refurbishing operations (124 - 4765) than for installation operations (4 - 173) (Table 6) suggesting that installation operations may have less impact on fish stranding. Assessment crews did not find stranded fish on bare substrate, in interstitial spaces between cobbles or on the high gradients slopes of the lower headpond.

The headpond operation and subsequent restoration of normal operating levels with or without the flashboards also influenced fish stranding risk. During drawdown in the spring for flashboard removal, the headpond was lowered to remove the flashboards and then refilled to a level above the sill as determined by river discharge in excess of generating capacity. The large drawdown for flashboard removal resulted in larger areas of exposed habitat (2.62 ha 2006) compared to installation operations, which only required a small area (0.65 ha in 2006). Following flashboard removal, fish isolated in pools may or may not have been reconnected to the headpond during normal operations depending on refill elevation relative to the stranding site. Side channels and upper headpond pools may have been dewatered during flashboard installation operations if headpond elevations were unusually high in July.

Most young-of-the-year were observed only rarely during salvage of the main headpond area. This is thought to be because there is limited spawning habitat in the headpond and nearby side channels and they do not appear to be rearing within the main headpond. However, juvenile mountain whitefish, dace and cyprinids were found in side-channels off the upper part of the headpond in the spring and were vulnerable to stranding following removal of flashboards (in late April and early May). Lower numbers of adults were stranded following installation operations compared to removal of flashboards (July). But adult use of the headpond off-channel habitat was also lowest during these summer months because many of them may have moved further upstream to spawning and foraging areas which possibly accounted for lower numbers observed following installation of flashboard.

Currently, the data from this project is useful to determine species and cohorts vulnerable to stranding and habitat where the risk is high. But wide ranges in the abundance by species captured during salvage prevented statistical analysis of fish stranding counts relative to headpond reduction rate (Table 6). Factors such as standardized search effort, habitat associated with stranding, surface slopes, spatial patterns, prior fish density, and wetted history need to be included in the study design to help explain this variance (Halleraker et al 2003, Bell et al. 2008, and Irvine et al. 2008).

Table 6. Fishes captured[1] during salvage by year/operation from 2002 – 2007 in the Elko River headpond during the flashboard removal and installation processes

	Removal					**Installation**			
Year Operation	**2002**	**2003**	**2004**	**2005** [2]	**2006**	**2005**	**2003**	**2006**	**2007**
Target ramp rate (cm/hr)	**15**	**10**	**Unknown**	**15**	**10**	**Unknown**	**10**	**10**	**10**
Mean HP reduction rate (cm/hr)	**Unknown**	**7.97**	**Unknown**	**16.03**	**7.83**	**Unknown**	**4.51**	**6.81**	**Unknown**
Bull trout – ***Salvelinus confluentus***	0	0	0	0	2	0	0	0	0
Westslope cutthroat trout - ***Onchorhyncus clarki lewisi***	1	0	0	0	0	0	0	0	0
Mountain whitefish - ***Prosopium williamasoni***	27	2	2	66	24	1	0	20	21
Longnose dace - ***Rhinichthys cataractae***	0	1965	705	28	0	0	4	0	70
Largescale sucker- ***Catostomus macrocheilus***	0	0	0	0	62	22	0	0	0
Longnose sucker- ***Catastomus catostomus***	80	2790	203	0	33	0	0	0	0
Unidentified larval fry	15	10	0	0	3	0	0	0	0
Unidentified cyprinids	35	0	0	0	0	0	0	0	82
Total	**158**	**4767**	**910**	**94**	**124**	**23**	**4**	**20**	**173**

[1]Search effort/area was not recorded and varied by operation and from year-to-year. [2]Refurbishing year

7 CONCLUSIONS AND RECOMMENDATIONS

MANAGEMENT HYPOTHESES

H_1: A slower headpond reduction rate is effective in reducing biologically significant elevated suspended sediment levels in the headpond from that observed under the existing 15 cm/hr headpond reduction operation.

Monitoring suspended sediments suggested that there was positive relationship between peak TSS and measured mean headpond reduction rate at the headpond site when all operations (removal, installation, refurbishing/removal) were pooled (section 6.1.1). However, there were not enough data to make an assessment of this relationship by operation. Low sample sizes (11 data points in total with 3-4 points per site) limited the complexity of the ANCOVA models and the power of the analyses.

Headpond reduction rates were difficult to control due to the channel morphology and operational control and mean headpond reduction rates were quite often different than target down ramping rates. For, example, in years/operations when target headpond reduction rates were 10 cm/hr, the mean head pond reduction rates varied from 4.51 to 7.97 cm/hr. From an operational point of view, the desired mean ramp rate could be achieved by planning the required drawdown over a calculated number of hours. This would give a mean headpond reduction rate for the period, such as was used in the present study. Recent monitoring of mean headpond reduction rates suggest that <10 cm/hr is feasible (Table 2). Thus, the **operational rule #1** would be that the mean hourly headpond reduction rate should not exceed 10 cm/hr.

However, this study does not address the effects of hourly variance in headpond reduction rates for the same mean ramp rate. The relationship between headpond reduction rate variance and suspended sediment cannot be easily teased from the time series data within a year. This is because the suspended sediment levels at any one time are dependent on the increased velocities and erosional processes that begin with the initiation of the headpond reduction. Site-specific bank failure mechanisms need to be considered as well. These factors likely add to the variance in the relationship between peak headpond reduction rate and peak TSS between year/operations.

Green (1999) suggests that the rate should be set at the same rate that water can drain out of the bank material. This is the rate at which water flows through bank material (dependent on soil permeability) to prevent bank slumping. Although an assessment of this kind has not been done at Elko, visual observations (Duval Env. Cons. 1993 and Redden Cons. 1994) suggest that minimizing hourly headpond reduction rates (within operating constraints) is important to preventing suspended sediment from sloughing from the sidewalls of the headpond. Thus, **operational rule # 2** could be established such that the variance in hourly headpond is minimized. This rule would result in a consistent hourly headpond reduction rate. In 2006, consistent hourly headpond reductions were achieved and resulted in a large decrease in hourly downramps (Table 2). Unfortunately, changing background turbidity levels during the 2006 removal monitoring swamped the suspended sediment response and these data could not be included in the analysis.

One method to simply describe the amount of variation in the headpond reduction rate would be to use the coefficient of variation of the mean headpond rate. A large coefficient of variation would imply an uneven and varied headpond reduction rate. This could be used as an additional predictor variable in the ANCOVA model. Low sample sizes precluded the use of this variable in the current analysis.

H_2: A slower headpond reduction rate is effective in reducing biologically significant elevated suspended sediment levels downstream of the dam from that observed under the existing 15 cm/hr headpond reduction operation.

In our analyses, positive relationships were found between mean headpond reduction rates and peak induced TSS levels (Table 4) at 3.3 km downstream of the dam (GP site) and 16 km downstream (HB site) (Figure 6). Our findings are corroborated by historical monitoring of suspended sediments at the tailrace site summarized in Figure 8 (Duval Env Cons. 1993, and Redden Bio. Cons. 1994).

A positive relationship between the duration of the sediment pulse (time in which induced TSS exceeded 25 mg/L) and mean headpond reduction rate was also observed downstream of the dam (at GP and HB sites, Figure 7). The duration of sediment exposure, in addition, to the concentration of suspended sediments, can lead to behavioural, and sublethal effects in fish (Newcombe and Jensen 1996).

The above findings together support the hypothesis that slower headpond reduction rates reduce both the concentration and duration of elevated levels of suspended sediments over a large range in headpond reduction rates downstream of the dam. Determination of whether 10 or 15 cm/hr is an optimum rate may be not possible given the limited number of data points, the variability in suspended sediment, and the limited ability of the facility to achieve targeted headpond reduction rates. Instead, general operational rules described above for planning purposes are the most practical method to minimize suspended sediment.

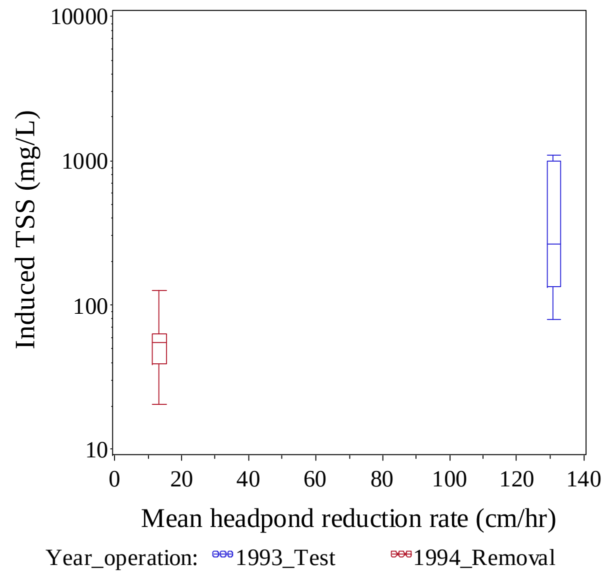

Figure 8. Boxplots of mean headpond reduction rate (cm/hr) versus induced TSS (laboratory values) at the tailrace downstream of the dam (site DS, Table 1 and Figure 2). The blue boxplot indicates data from Duval Env. Cons. (1993) and the red is from Redden Cons. (1994).

***H_3*: A slower headpond reduction rate is effective in reducing fish stranding in the headpond from that observed under the existing 15 cm/hr headpond operation.**

Determination of whether 10 or 15 cm/hr is an optimum headpond reduction rate (ramp rate) to prevent fish stranding at the Elko facility may not be possible given the high variability in fish stranding (Table 6, Halleraker et al 2003, Bell et al. 2008, Irvine et al. 2008). Increased stranding rates with higher ramping rates have been observed over a wide range in ramp rates including; <10 to >60 cm/hr for brown trout in artificial streams (Halleraker et al. 2003), 6 to 60 cm/hr for juvenile chinook and coho in sidechannels (Bradford 1997), and 7.4 to 35.3 cm/hr for various wild fish (<100 mm) in pools (Irvine et al 2008). A lower range in ramp rates of 3.9 to 13.3 cm/hr did not predict interstitial stranding in Irvine et al (2008) due in part to the high variability in stranding probability. Similarly, field surveys of potholes and interstitial spaces among cobbles at Trail Bridge Reservoir, Oregon, detected no relationship between ramp rates (>18 to 45 cm/hr) and salmonid fry stranding (Bell et al 2008). This study hypothesized that there may have been a decrease in stranding mortality if a wider range of ramp rates (including <18 cm/hr) had also been tested.

Given the probable low power to detect a difference in fish stranding over a narrow range in ramp rates (10 versus 15 cm/hr) at the Elko facility, it is recommended that a mean headpond reduction rate of less than 10 cm/hr and consistent hourly headpond reduction rates be adopted based on the operating practices to minimize sediment transport. However, these recommendations are also consistent with ramping rates suggested to decrease fish stranding (<10-15 cm/hr Halleraker et al. 2003, 2007) and recommendations by Bradford (1997) to reduced ramp rates when off-channel habitat is present.

A standard procedure should be developed for mitigating fish stranding impacts associated with headpond drawdown activities. Flashboard removal requires drawdown of the headpond from the normal winter operating levels (high) to levels above the spillway sill, dependent on river discharge. Fish stranded in isolated pools above post-flashboard removal water levels should be salvaged and returned to the mainstem. Flashboard installation requires a more limited drawdown and subsequent re-watering process. Lower numbers of stranded fish were observed following installation of flashboards compared to removal and refurbishing operations (Table 6). The specific risks to fish as a result of the short-term drawdown are unknown and therefore we recommend that pools at risk of dewatering should be monitored to determine if fish are capable of surviving until headpond levels are restored. If fish are capable of surviving the short-term dewatering, an argument could be made to cease future fish salvage during this procedure.

Future assessment of operational rules could also include measures of relative abundance of fish before drawdown to be contrasted with after fish counts using a BACI design (Underwood 1997). This would separate the effects of drawdown from natural variation in fish population size and distribution prior to drawdown. Alternatively, mark-recapture based measures of fish survival could be used to assess overall impacts of drawdown on fish survival (Burnham et al 1987).

OTHER RECOMMENDATIONS

Our analyses demonstrated general relationships between headpond reduction rates and induced TSS levels. Low sample sizes and data collection procedures limited the precision of estimates of induced TSS levels and fish stranding based on headpond reduction rates and the complexity of analyses that could be conducted.

1. Models that also consider the inter-relationships of operations, total drawdown headpond reduction rate and site-specific relationships would require a larger sample size of data points and may better quantify suspended sediment as function of headpond reduction rates. However, given the limited ability of the facility to achieve targeted headpond reduction rates and the variability in suspended sediment data, it may be difficult to determine whether 10 or 15 cm/hr is an optimum rate. Instead further monitoring could be used to determine the effectiveness of the operational rules (a mean headpond

reduction rate of less than 10 cm/hr and consistent hourly headpond reduction rates) particularly during removal or refurbishing operations.

2. Continuous turbidity sensors should be calibrated with laboratory measurements of TSS and turbidity over the range of observed turbidity values for each headpond reduction, particularly at peak suspended sediment levels. Quality control procedures for the continuous meter should follow White (1999) and Butcher and Gregory (2006).
3. Monitoring stage levels and discharge at each site during drawdown operations is essential to aid in interpretation of suspended sediment levels. This would allow an analysis of suspended sediments versus stage. A geomorphologist should be consulted for interpretation of such data.
4. Future risk assessment efforts should standardize fish collection methods and continue to monitor fish stranding including; fish salvage by area, fish species, length, age class, and search effort..
5. Fish stranding studies should examine factors such as habitat, surface slopes, spatial patterns, mapping of stranding locations, natural fish abundance, and wetted history.

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9 APPENDICES

APPENDIX I. SATELLITE IMAGES OF ELKO DAM AND HEADPOND

Figure 9. View of Elko Dam and headpond from plunge pool to north, upstream.

Figure 10. View of headpond from FSR bridge downstream.

APPENDIX IV. DATES AND TIME OF CONTINUOUS TURBIDITY DATA USED IN THE ANALYSES

Table 7. Dates (month/day) and time of continuous turbidity data used in the analyses (before and after headpond reduction).

Sites	2003 Removal	2003 Installation	2005 Refurbishing	2006 Removal	2006 Installation
Target ramp rate	**10 cm/hr**	**10 cm/hr**	**15 cm/hr**	**10 cm/hr**	**10 cm/hr**
Mean ramp rate	**7.97 cm/hr**	**4.51 cm/hr**	**16.03 cm/hr**	**7.83 cm/hr**	**6.81 cm/hr**
RB (Control)	Before: April 28 17:06 -April 30 8:50 After: April 30 11:10 -May 1 20:50	Before: July 7 16:18 -July 8 10:29 After: July 8 16:49 -July 9 23:30	Before: April 28 15:22-15:27 After: May 21:34 - May 3 14:58	Before: April 30 13:15 -13:27 After: May 1 15:26 – May 3 14:36	Before: July 4 13:55 -July 4 4:09 After: July 5 11:13 - July 8 9:45
HP	Before: April 28 16:29 -April 30 9:36 After: April 30 9:52 -May 1 20:30	Before: July 7 16:45 -July 8 11:01 After: July 8 15:59 - July 10 0:06	Before: April 28 15:42 -15:46 After: May 1 20:56 - May 4 11:33	Before: April 30 14:27-14:40 After: May 1 17:16- May 7 12:37	Before: July 4 14:30-14:42 After: July 5 16:38- July 7 18:55
GP	Before: April 28 15:22-April 30 10:09 After: April 30 10:10-May 1 20:00	Before: July 7 17:17 - 17:26 After: July 8 13:37 – July 10 0:30	Before: April 28 14:30-14:35 After: May 1 20:02 - May 4 11:56	Before: April 30 15:18 - 15:29 After: May 1 13:41- May 4 15:44	Before: July 4 15:22-15:33 After: July 5 13:35- July 7 8:31
HB		Before: July 7 8:01 - July 8 12:58 After: July 8 8:00- July 10 1:10	Before: none After: May 1 23:19 - May 4 12:40	Before: April 30 16:52 - 17:05 After: May 1 12:18 - May 3 16:40	Before: July 4 16:15-16:25 After: July 5 14:43 - July 7 10:30

APPENDIX III. ANCOVA STATISTICS FOR PREDICTED TSS VERSUS CONTINUOUS TURBIDITY MEASUREMENTS BY SITE, YEAR AND OPERATION

The equation used in the ANCOVA model was:

TSS_{pred}= Estimate $_{(all\ intercept)}$+(Estimate$_{(all\ turbidity)}$ * turbidity) + (Estimate$_{(site/turbidity)}$ * turbidity)-Estimate$_{(site/operation)}$.

For example, using the ANCOVA coefficients from Table A9, the equation for Site DS Installation would be: TSS_{pred} = 6.26+(0.83*turbidity)+(1.5*turbidity)-8.76

Table A8. Analysis of covariance statistics for predicted TSS versus continuous turbidity.

Site		Estimate	StdErr	t-value	p-value
All	**Intercept**	6.26	5.918	1.06	0.2911
All	**Turbidity**	0.83	0.079	10.52	<.0001
DS	**Turbidity**	1.50	0.326	4.6	<.0001
DS	**Operation (Installation)**	-8.76	26.921	-0.33	0.7451
DS	**Operation (Removal)**	-69.83	30.572	-2.28	0.0231
DS	**Turbidity*Operation (Installation)**	-1.18	1.477	-0.8	0.4266
GP	**Turbidity**	0.07	0.099	0.68	0.4989
GP	**Operation (Installation)**	13.21	9.383	1.41	0.1602
GP	**Operation (Refurbishing)**	70.69	15.034	4.7	<.0001
GP	**Operation (Removal)**	-2.98	10.536	-0.28	0.7775
GP	**Turbidity*Operation (Installation)**	-0.06	0.134	-0.44	0.6603
GP	**Turbidity*Operation (Refurbishing)**	-0.54	0.097	-5.51	<.0001
HB	**Turbidity**	-0.48	0.149	-3.22	0.0014
HB	**Operation (Installation)**	-10.90	13.272	-0.82	0.4121
HB	**Operation (Refurbishing)**	-13.58	15.012	-0.9	0.3666
HB	**Operation (Removal)**	127.05	29.228	4.35	<.0001
HB	**Turbidity*Operation (Installation)**	0.79	0.547	1.45	0.1482
HB	**Turbidity*Operation (Refurbishing)**	1.21	0.232	5.2	<.0001
HP	**Turbidity**	0.06	0.120	0.49	0.6270
HP	**Operation (Installation)**	-8.75	9.762	-0.9	0.3706
HP	**Operation (Refurbishing)**	-21.44	12.205	-1.76	0.0801
HP	**Operation (Removal)**	16.65	8.373	1.99	0.0477
HP	**Turbidity*Operation (Installation)**	0.35	0.408	0.86	0.3879
HP	**Turbidity*Operation (Refurbishing)**	2.27	0.276	8.23	<.0001
PS	**Turbidity**	-0.40	0.331	-1.21	0.2274
PS	**Operation (Installation)**	0.19	30.523	0.01	0.9949
RB	**Operation (Installation)**	-5.63	19.946	-0.28	0.7780
RB	**Operation (Refurbishing)**	2.88	28.075	0.1	0.9183
RB	**Turbidity*Operation (Installation)**	-0.24	1.172	-0.2	0.8404
RB	**Turbidity*Operation (Refurbishing)**	-0.33	2.561	-0.13	0.8965