Overview of water monitoring on Harrop (Mill) and Narrows creeks,1999-2014

Prepared for:

Harrop-Procter Watershed Protection Society and Harrop-Procter Community Co-op

HARROP-PROCTER WATERSHED PROTECTION SOCIETY

HPCC
Harrop Procter Community Co-Op

Prepared by:

Darcie Quamme, MSc., RPBio.
Integrated Ecological Research,
924 Innes St., Nelson, BC., V1L 5T2
Email: quamme@ecological.bc.ca

In partnership with:

Columbia Basin Watershed Network
www.cbwn.ca

PASSMORE LABORATORY LTD.

February 22, 2015

IER Integrated Ecological Research

Table of Contents

Cover photos taken by: Erik Leslie

1. Executive summary

This report provides an overview of water quality data collected in a long-term monitoring project (1999-present) that has been carried out on Harrop/Mill and Narrows creeks under the Harrop-Procter Watershed Protection Society (HPWPS) and the Harrop-Procter Community Co-operative (HPCC). These stations were selected for pre-harvest water quality monitoring prior to forest developments within the Harrop Creek watershed commencing in 1999 on Narrows Creek and 2002 on Harrop Creek. The creeks were monitored as forest harvest operations progressed from 2007-2014 in the Harrop Creek watershed under the HPCC forest license. The strategic water quality monitoring program was developed to assess impacts from forest harvest operations. But the program also provides information to the community on long-term trends in drinking water quality, the ecosystem health of Harrop and Narrows creeks, and serves to identify emerging concerns in these indicators.

Drinking water quality in Harrop and Narrows creeks for the period of record was rated as “Good” by BC Interior Health’s turbidity index for 92-96% of the samples, “Fair” for 2-7% of the samples and “Poor” for 0-1% of the samples collected. Typical of streams in Kootenay region, “Poor” ratings and peak turbidity occurred with higher spring discharges due to snow-melt and rain event. Moreover, the TSS and turbidity levels observed in the post-harvest monitoring period on Harrop Creek were lower than the range of values observed in pre-harvest monitoring, particularly in 2006 when peak levels reached 149 mg/L and 13 NTU at a discharge of 11.8 m^3/s. Sediment yields were slightly higher on Harrop Creek compared to Narrows Creek for similar periods. In the 2006 flood event, peak daily yields were 1.7 m-tonnes/day/km^2 on Narrows Creek compared to 3.6 m-tonnes/day/km^2 for Harrop Creek. However, low sampling intensity prevented estimation of annual loads.

Maximum summer temperatures were below the BC water quality aesthetic guideline for drinking water of 15°C with the exception of some values in 2014. In 2014, stream temperatures on Narrows Creek rose above 15°C in the late afternoon from mid-July to mid-August. Mean temperatures during the migration/spawning windows in mid-August to mid-October on Harrop Creek ranged from 7.5-8.7°C in 2006, 08, 09. These values were at or below the optimal ranges for spawning and migration for bull trout and for migration for sockeye. On Narrows Creek, mean temperatures ranged from 8.3-9.3°C in 2006, 2008-10 and 2013-14 during the spawning/migration window. Temperatures in Harrop and Narrows creeks were typically below or within optimal ranges for rainbow trout for rearing and spawning.

Macroinvertebrate sampling suggested that Harrop Creek was similar to reference streams surveyed under Environment Canada’s CABIN program.

The percent of samples exceeding the guideline for raw drinking water with no disinfection (0 CFU) during late summer was 61% fecal coliforms and 64% for E. coli monitored on Harrop Creek and 40% for fecal coliforms and 41% for E. coli for Narrows Creek in all years monitored. Fecal coliforms were above BC guidelines for systems with disinfection (90^{th} percentile >10 CFU) in 2013 and 2014 on Harrop Creek and in 2009 and 2014 on Narrows Creek. E. coli counts were above BC guidelines for systems with disinfection (10 CFU) in 2013 and 2014 on Harrop Creek and 2014 on Narrows Creek. The higher fecal coliform and E. coli counts observed in 2014 may be due the high temperatures observed in 2014, the highest on record since monitoring started in 2006.

In the future, the program should continue to document the recovery of the Harrop watershed and monitor forest operations that will occur in Narrows Creek watershed. Procter Creek could be used as a control watershed during this period because of its status of a community watershed. Sampling of creeks should also be carried out at similar times in the late afternoon in order to control for factors that cause hourly changes in sediment levels. Also, unusual observations of suspended sediment or turbidity should be used to initiate further inspection of watersheds for sediment sources by a geomorphologist.

As well, low flow monitoring could be emphasized particularly with respect to water governance issues within the community as related to water quantity, fish habitat and climate change.

Continued citizen engagement in emerging water issues related to climate change and other issues within the Harrop-Procter community will help to identify concerns, bridge governance gaps and support positive ecological outcomes.

2. Introduction

The objective of this document is to provide an overview of water quality data collected in a long-term monitoring project (1999-present) that has been carried out on Harrop/Mill and Narrows creeks under the Harrop-Procter Watershed Protection Society (HPWPS) and the Harrop-Procter Community Co-operative (HPCC). The purpose of the HPCC is to harvest timber in the community forest and oversee the Community Forest Agreement with the province of British Columbia. The HPWPS is a not-for-profit associated with HPCC that is devoted to ecosystem research, public education and sustainable community forestry.

In 1999, the HPWPS and the HPCC initiated a water monitoring program to address issues around forest development within the watersheds under their Community Forest License in the Kootenay Lake Forest District. More recently, the protection of water was identified as a high priority in a community survey that was mailed out to all households in Harrop-Procter in 2012 by the HPCC (HPCC 2012b). Also in 2012, Harrop-Procter Community Co-operative Management Plan (HPCC 2012a) highlighted three objectives with regards to water also consistent with previous goals (HPWPS 1999) including:

- Maintain water quality, quantity and timing of flows.
- Minimize the impacts of roads and timber harvesting on hydrological regimes.
- Minimize soil disturbance that could result in stream sedimentation.

Furthermore, two of the goals of the Harrop-Procter Watershed Protection Society include:

- The promotion of the preservation and protection of all watersheds in the community and the assurance of a consistent quantity and quality of water.
- Dedicated to ecosystem research, public education and sustainable rural communities.

Recent monitoring of water quality and quantity under the HPWPS and HPCC water monitoring program has focussed on the two larger watersheds including Mill (Harrop) Creek and Narrows Creek. However, four creeks within the License area have been monitored since 1999 including Jacobs Creek (2000-02), Carson (1999-2007), Mill (Harrop) Creek (2002 -present) and Narrows Creeks (1999-present). This long-term data set has been evaluated in the following reports: Carver (2005), Quamme (2009), Quamme (2010), Yeow (2011), and Yeow (2013). Narrows Creek was established as a control stream because timber harvest had not occurred within the watershed. However, with recent forest developments in the Narrows Creek watershed a new control stream may be considered.

An overview report summarizing the program's data on Harrop and Narrows creeks has been requested by the HPWPS and HPCC. The objectives of this report include:

- Review of data from the water monitoring program of Harrop/Mill and Narrows creeks including summaries of water quality and water quantity since 1999.
- Evaluation of trends in drinking water quality in Harrop and Narrows creeks including: specific conductance, turbidity, total suspended sediment, temperature, and coliform counts.
- Comparison of results with regional trends in regards to water quality parameters and quantity.

- Review of the macroinvertebrate data collected from Harrop Creek relative to reference sites in the Canadian Aquatic Biomonitoring Network (CABIN) database.
- Identification of any knowledge or data gaps.
- Provide recommendations on a possible alternative control watershed for future water quality monitoring.

3. Methods

3.1. Water monitoring program

Monitoring of water quality and quantity under the HPWPS and HPCC has focussed on the two larger watersheds including Mill (Harrop) Creek and Narrows Creek (Figures 1 and 2). Narrows Creek was established as a control stream early on in 1999 prior to development under the Harrop-Procter Community Co-op licence to capture baseline trends in water quality and monitoring has continued through to 2014 during the post-harvest monitoring of Harrop Creek. However, baseline monitoring in Harrop Creek began in 2002 and post-harvest monitoring was initiated in 2007 with development and road building in the watershed and has continued to 2014.

Forest operations potentially affect the domestic water for 47 households that collectively draw up to 35,000 m^3/day from Harrop Creek and 34 households that divert up to 77.3 m^3/day from Narrows Creek (BC MOE 2015). Accordingly, the following water quality parameters were selected to address forestry-related concerns over impacts to aquatic resources and drinking water quality (Table 1).

The main indicators that were monitored are:

- **Total Suspended sediment (TSS)** is any particulate matter transported by flow. TSS can affect drinking water & fish and their habitat.

- **Turbidity** is measured by the optical scattering of light & absorbance by particles in water. BC water quality guidelines have been developed for turbidity, can affect photosynthesis, visual-feeding organisms & drinking water quality.

- **Discharge** is measured primarily to interpret water quality data and to examine relative peak flows and timing of flows.

- **Specific Conductance** is a measure of dissolved ions and varies with geology, landscape disturbance and ground water input.

- **Temperature** can be altered with timber harvest and climate change. Increases in peak summer temperatures can affect the migration and spawning of fish species.

- **Microbiological indictors** are measured because they potentially affect human health. Total coliforms, fecal coliforms and E. coli are tested for in summer baseline flows during periods of high water temperatures.

- **Macroinvertebrates** are indicators of stream health. Multivariate tools developed under Environment Canada's, Canadian Aquatic Biomonitoring Program (CABIN) are used to assess impacts to streams relative to reference streams using the Reference Control Approach (RCA models).

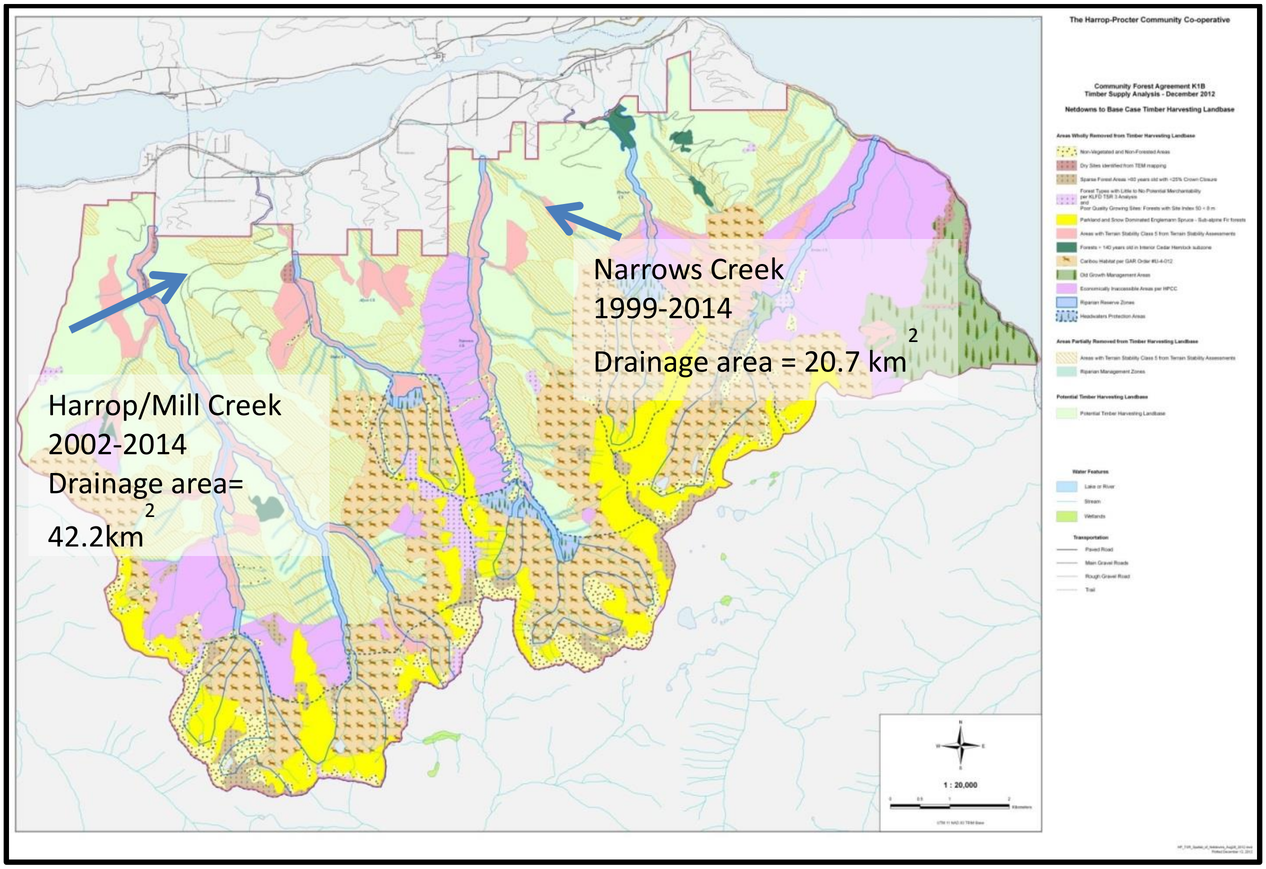


Figure 1: Water monitoring sites on Harrop (Mill) and Narrows creeks

Table 1. Water sampling program 1999-2014 on Harrop and Narrows creeks.

	Pre-harvest								Post-harvest							
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Harrop treatment				WD	WD	WD	WD	WD	WD	WCDM	WCD	WCD	WCD	WCDM	WCED	WCED
Narrows control	WD	WD	WD	WD	WD	WD	WD	WD	WD	WCD	WCD	WCD	WCD	WCD	WCED	WCED

W= TSS, Specific conductance, Turbidity, temperature, C=Total & Fecal coliform counts, E= E. coli counts, D=Discharge, M=Macroinvertebrates.

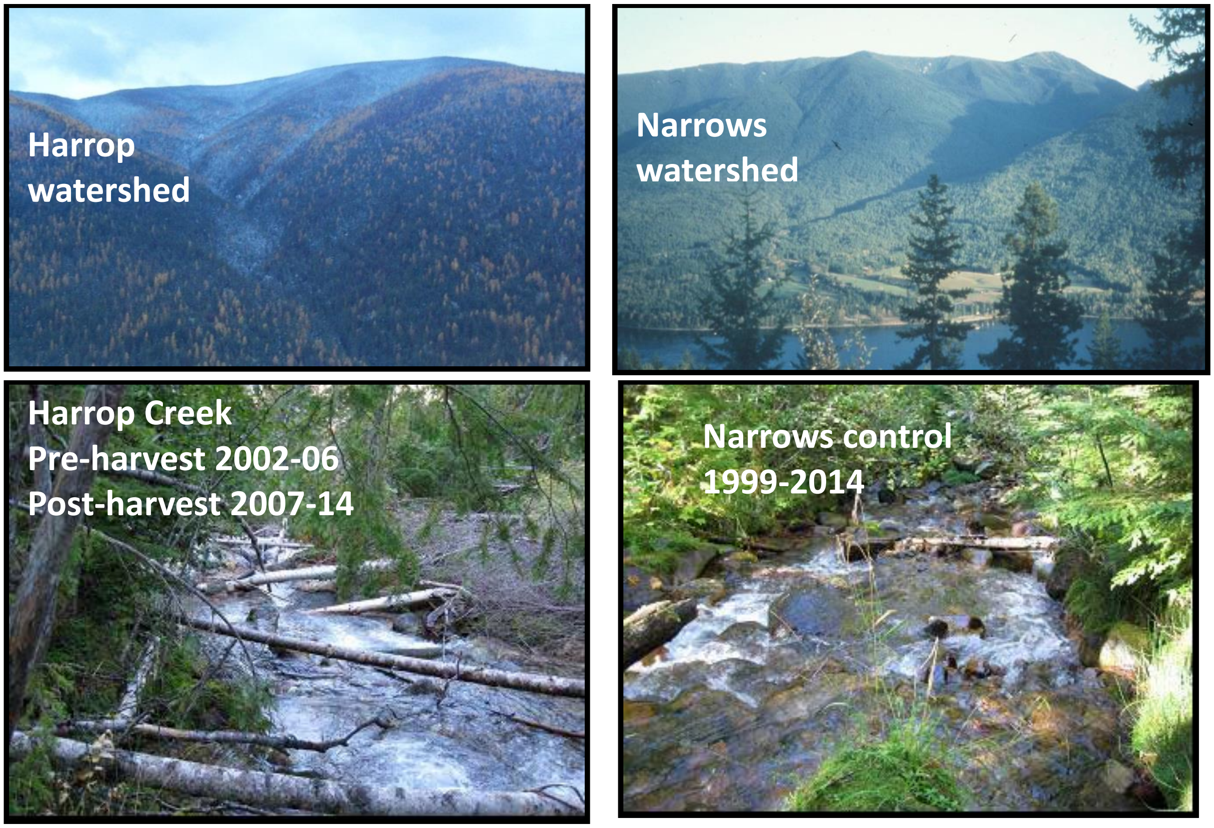


Figure 2. Harrop (Mill) and Narrows creeks. Harrop Creek was monitored from 2006-14 and Narrows Creek was monitored from 1999-2014 (Photos from Erik Leslie).

3.2. HPCC operations within Harrop and Narrows watersheds from 1999-2014

Operations within the Harrop Creek watershed began with road building in 2007 and have continued until 2014. Prior to commencement of operations in 2007 within the Harrop Creek watershed, the weighted percent equivalent area clearcut (%ECA, weighted) was estimated at eight percent. This estimate, which is thought to be slightly overestimated (pers. com. Erik Leslie), is largely due to a fire (Kutetl burn area) within the watershed (Carver 2005). From 2009 to 2014, operations within the watershed increased the %ECA (weighted) by four percent by 2014 for a total ECA of twelve percent including the burn area (Figure 3).

Also, within the Harrop Creek watershed there has been 70-80% lodgepole pine mortality (Figure 4). Twenty percent of watershed has greater than fifty percent lodgepole pine within a stand. Almost all the pine is above H60 line with potential to affect peak flows. However, hydrological recovery has started and other species within the mixed stands are presently regenerating. There are no further significant harvest plans for the Harrop watershed for the coming years (Figures 3 and 4).

Narrows Creek has served as a control for the water monitoring program since 1999 in order to help evaluate the effect of operations on water quality of streams under the HPCC licence (Figure 5). At present, the weighted equivalent clearcut area is <1% and includes some logging on private land and a small high retention partial cut that was carried out in 2007/08 by the Harrop-Procter Community Cooperative (HPCC). However, there are currently plans to develop the Narrows Creek watershed and initial road building for the upcoming harvest began in August 2014. As development progresses, two kilometers of old logging road at the top of Victor Road will be upgraded with an additional five-kilometer of new road to the south of the upgrade. Planned operations in Narrows Creek watershed comprise <6% of the watershed while 75% of the watershed will remain protected including riparian areas, headwaters, unstable slopes, and caribou habitat following the 2012 HPCC management plan (HPCC 2012a). An alternative control watershed was also evaluated for the water monitoring program.

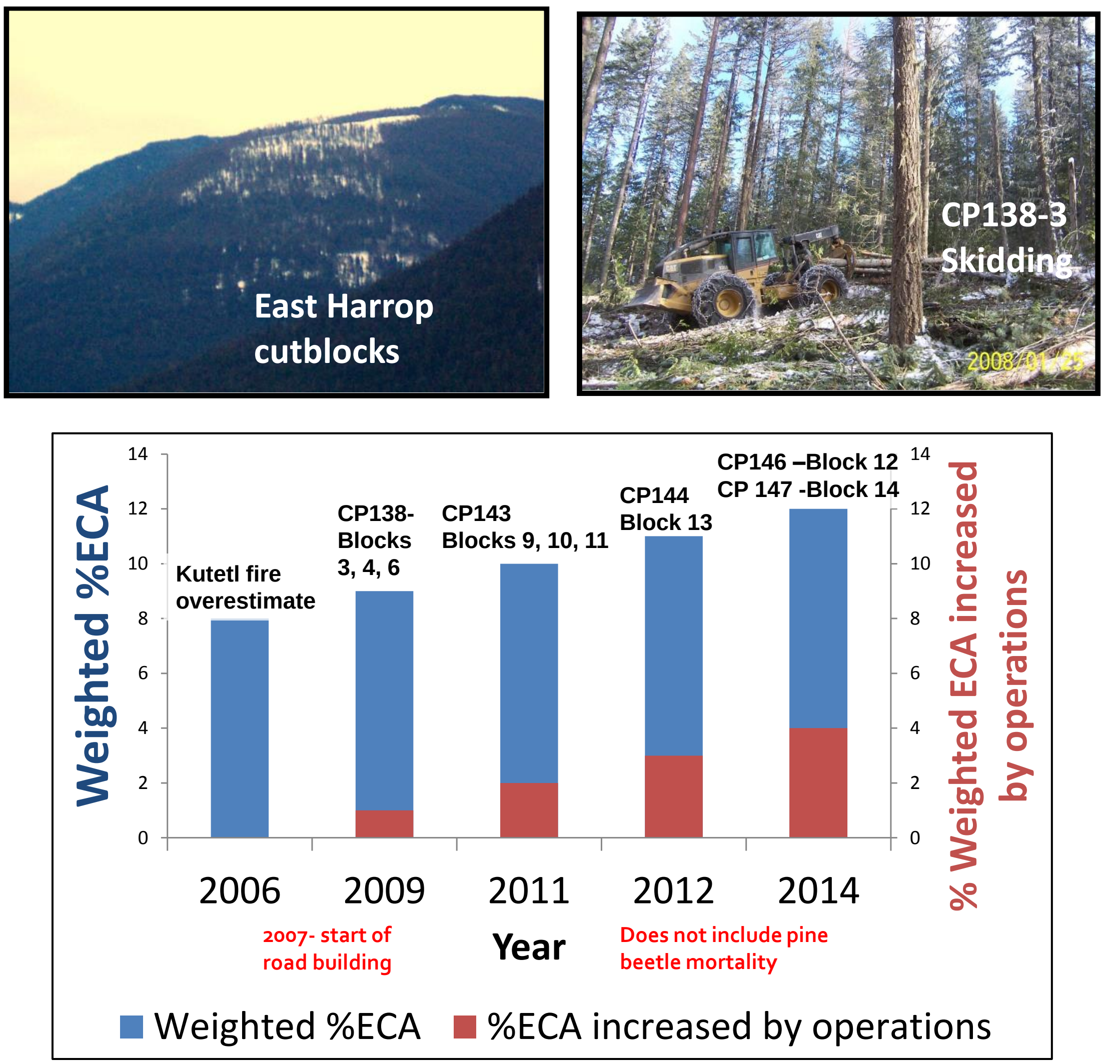
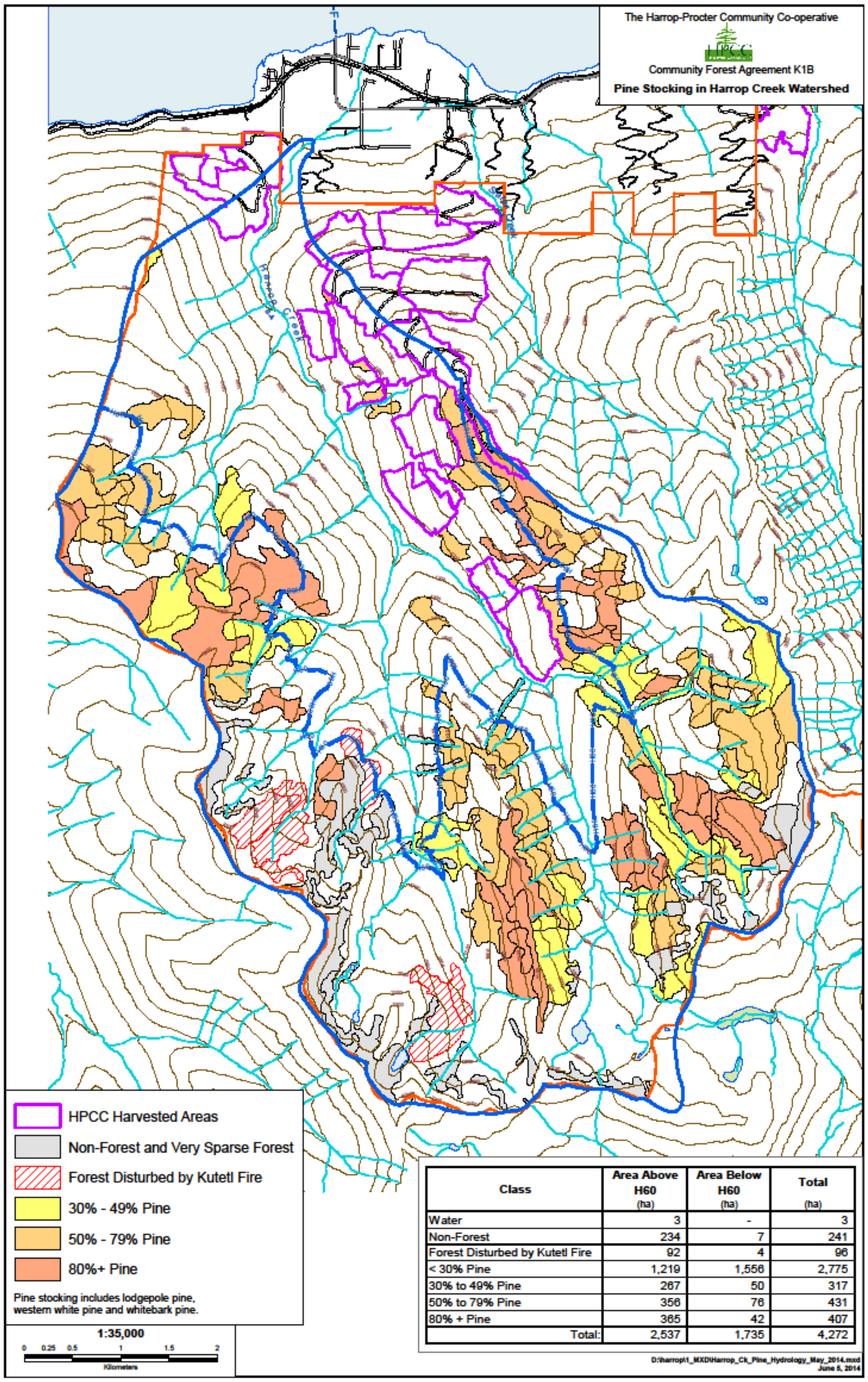


Figure 3. Weighted %ECA by year in Harrop (Mill) watershed. Operations began in 2007. Photos above from Erik Leslie.



Class	Area Above H60 (ha)	Area Below H60 (ha)	Total (ha)
Water	3	-	3
Non-Forest	234	7	241
Forest Disturbed by Kutetl Fire	92	4	96
< 30% Pine	1,219	1,556	2,775
30% to 49% Pine	267	50	317
50% to 79% Pine	356	76	431
80% + Pine	365	42	407
Total:	2,537	1,735	4,272

Figure 4. Harrop Creek watershed. Operations 2007-14 (indicated in purple), pine beetle kill (>80%) areas indicated in orange and Kutel fire (red).

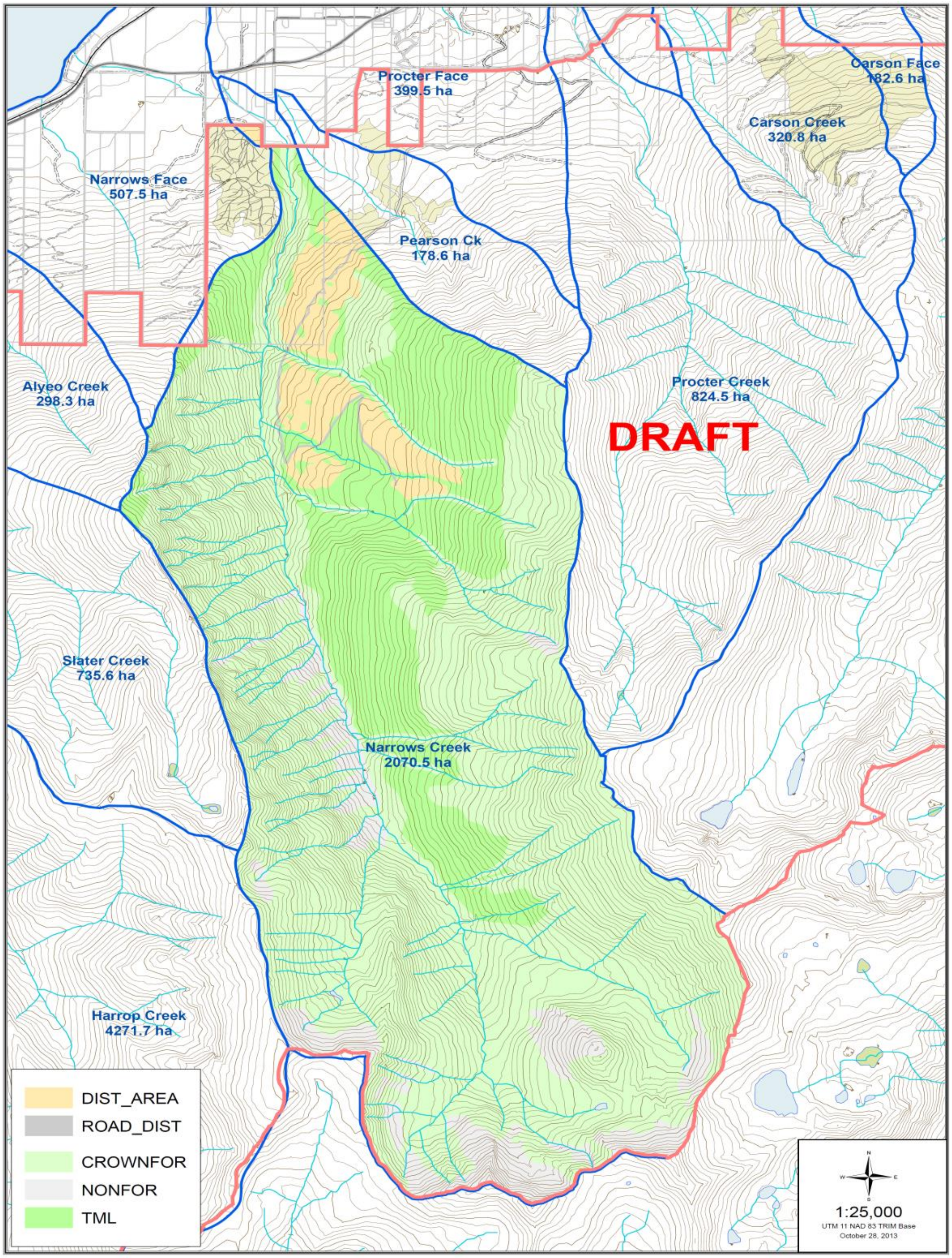


Figure 5. Narrows Creek watershed.

3.3. Water quality and quantity monitoring

A strategic grab sampling program (MacDonald et al 1991, Carver 2005, Yeow 2011 and Yeow 2013) was developed in 1999 when water monitoring was initiated on Narrows Creek. The program was developed in the 1990s from recommendations from J. Allan Issacson, Forest Hydrologist, Idaho State and Martin Carver, geomorphologist, Nelson, BC for Harrop-Procter creeks (Carver 2005, Quamme 2009, Quamme 2010, Yeow 2011 and Yeow 2013) and other streams in the region (Quamme and Green 2000, Summit 2001). The sampling design was reviewed in 2001 (Summit 2001) for a number of streams in the Kootenays and successfully audited under the Forest Investment Account program in 2008 (Quamme 2009a, 2009b). Recent direction given by Peter Jordan of the Ministry of Forest, Lands and Natural Resource Operations (MFLNRO) suggested that the methods are valid with some minor modifications to improve the interpretation of results (described below).

Grab samples are collected for water by community water samplers for turbidity, TSS, and specific conductance according to methods reviewed in Duncan and Duncan (2012) and Clark (2003). The sampling regime involves collecting samples before, during and after rain events with a greater number of samples collected during spring freshet and summer/fall storms or when water is turbid. Water samples are tested for turbidity and suspended sediments when turbidity exceeded 0.5 NTU.

Samples were collected using a standard 1 L bottle supplied by the analytical laboratory. Prior to being filled, all sample bottles were labelled with the date and time of sampling. For each sample, a bottle was tilted upright and moved through the water column until filled, taking care to avoid human/environmental contamination and air pockets (Cavanagh et al. 1997). Air and water temperature measurements and staff gauge readings were taken at the same time as water samples. In recent years, hourly water temperature was also monitored using Hobo Temp Pro data loggers. Weather reports and any other pertinent information were also recorded at that time. After being collected, water samples were placed in a refrigerator and shipped to Passmore Laboratory.

Total coliforms, fecal coliforms and E.coli bacteria are monitored in five samplers over thirty days during August and September at baseline flows following protocols for water sampling by Cavanagh et al. (1997). A sterile plastic bottle was filled with stream water. The sample was placed on ice immediately and brought to Passmore Laboratory within six hours of collection.

Water quantity was monitored mainly in order aid the interpretation of water quality data. Water level measurements were recorded for Harrop and Narrows creeks by manual readings of a staff gauge at the water monitoring stations. A Price Type AA Current Meter was used to measure stream velocity. Stream discharge measurements followed Resource Inventory Committee (RIC, 1998) standard procedures, and involved stretching a tape measure across the channel and metering the water velocity at intervals of 15-30 cm at least four times per year. Distances from the bank, water depth and water velocity were measured at each interval. The rod of the current meter was held in a vertical position with the meter completely submerged and pointing directly into the flow. Readings were taken at 0.6 of the total water depth at each interval. Each velocity measurement was taken over at least a 40 second period. Readings were recorded across the entire wetted width of the creek and the stage level was recorded. Width-velocity data, coupled with manual stage readings, were used to create stage-discharge rating tables (Quamme 2009, Quamme 2010, Yeow 2012, and Yeow 2013). Regression formulas (discharge= $a*stage^b$) that were consistent with the manual method were then used to calculate the stage-discharge tables with deviations to three decimal places for each creek.

3.4. Macroinvertebrate protocols

The protocols that were used for the macroinvertebrate monitoring program follow methods developed by Environment Canada under the Canadian Aquatic Biomonitoring Network (CABIN). Environment Canada's CABIN methods standardize field collection of macroinvertebrates, laboratory techniques and multivariate analyses in order to assess ecosystem health (Environment Canada 2014).

Macroinvertebrate sampling was carried out in 2008 and 2012 to evaluate Harrop Creek compared to other reference sites in the Kootenay/Okanagan Region. Macroinvertebrates were sampled from a variety of micro-habitats within the stream reach using a CABIN kick-net of length 45.7 cm, width 25.4 cm, and depth 25.4 cm with a 500 µm mesh net (Environment Canada 2007). All field sampling was carried out by field crew that were certified under CABIN's stream assessment protocol to ensure that data quality standards are met. Sample material was transferred to jars with 80% isopropyl alcohol used as a preservative. Sample material comprised no more than 50% of the jar. Identifications of macroinvertebrates to Family were carried out by *Ecoanalysts* (certified taxonomists under the Society for Freshwater Science) following Environment Canada (2012) for laboratory methods.

Using CABIN online tools, reference streams were classified and selected based on habitat variables for screening against the Harrop Creek test site. The macroinvertebrate community at a test site was then compared to the subset of similar reference/control streams (based on habitat). The macroinvertebrate community was then ranked as to *Similar to Reference*, *Mildly Divergent, Divergent* or *Highly Divergent*. The more divergent the community was from the reference streams the more ecosystem stress was assumed to be acting on the site. The degree of impairment of a test site was assessed using a multi-dimensional ordination plot (MDS) plot of the community similarity based on Bray-Curtis dissimilarity measures. Confidence ellipses were drawn around a cloud of reference sites relative to the test site (Rosenberg et al. 1999, Bailey et al. 2004).

3.5. Data analysis methods

Data was primarily summarized using ggplot2 and other graphical packages in program R (Version 3.1.2, R Core Team, 2014). However, temperature plots and some comparisons of turbidity and TSS were summarized in SAS (SAS Institute 2000).

Boxplots were used to aid the summary of water quality parameters by year. Boxplots are a descriptive method of displaying water quality data. The box upper and lower edges of the box indicate the 25th and 75th quartiles of the data. The vertical lines or whiskers indicate the 90th and 10th percentiles of the data with outliers as points above and below the whiskers. The horizontal line within the box indicates the mean value. The sampling frequency and design of the program is opportunistic and the trends in the upper and lower spread of the data are the focus of the analyses rather than the mean value for each year.

Rating curves of TSS versus turbidity were developed for each creek in order to estimate sediment yield on a per-kilometer of basin basis. A log-log plot was developed (all years pooled, Appendix 5) for each creek from paired samples monitored for turbidity and TSS collected from 2010-2011 and limited sampling that occurred from 2011-2014. High values of TSS may have been underestimated by this regression relationship because of the abundance of data at the low turbidity values. However, TSS monitoring was captured by manual sampling and direct measurement of TSS at higher sediment levels and this data was used instead of the calculated values. Thus, turbidity was primarily used to interpolate moderate to low levels of TSS only in these years (2011-2014).

4. Results

4.1. Quality control/Quality Assurance

All physical and microbiological tests, CABIN sampling for macroinvertebrates and discharge rating calculations were performed by Passmore Laboratory Ltd. Water quality methods followed the Standard Methods for Examination of Water and Wastewater published by the American Public Health Association 21st edition (APAH 2005). Passmore Laboratory Ltd. participates in reviews through the University of British Columbia Clinical Microbiology Proficiency Testing (CMPT) Program and has recently received accreditation from the B.C. Provincial Enhanced Water Quality Assurance Program.

Duplicate water samples collected for total suspended solids, specific conductivity, and turbidity validated that field and laboratory sampling were both accurate and repeatable. The percent differences between replicates ranged from 0-22% for all parameters including TSS, turbidity and specific conductance (Table 2), below the recommended precision criterion of <25% difference for duplicates (Cavanagh et al. 1997). Duplicate samples for turbidity and TSS were at or close to detection, typically a higher percent difference is acceptable near detection, however, duplicate samples remained within the precision criterion of <25% for these parameters (Table 2).

Table 2. Duplicate sample results from Passmore Laboratory Ltd. collected 2010-13

	Date	TSS(mg/L)	Specific conductance (µS/sec)	Turbidity (NTU)	Precision Criteria
Harrop Creek	02/26/10	<0.5	112.0	0.20	
	02/26/10	<0.5	111.0	0.20	
	% Difference		0.9%	0.0%	25%
	07/13/11		67.4	0.20	
	07/13/11		67.0	0.20	
	% Difference		0.6%	0.0%	25%
	04/11/12		101.0	0.55	
	04/11/12		98.6	0.45	
	% Difference		2.4%	20.0%	25%
	07/17/13		90.8	0.25	
	07/17/13		90.8	0.20	
	% Difference		0.0%	22.2%	25%
Narrows Creek	26/02/10		168.0	0.20	
	26/02/10		170.0	0.20	
	% Difference		1.2%	0.0%	25%
	13/07/11		97.1	0.35	
	13/07/11		97.0	0.40	
	% Difference		0.1%	13.3%	25%

Trip blanks verified that there was no contamination of sample jars to and from the site (Table 3). TSS levels were below analytical detection limits, specific conductance levels were 1.2-1.7 µS/cm and turbidity was 0.1-0.2 NTU from these samples on Harrop and Narrows creeks. Measurements of distilled water are typically below detection for TSS (0.2 mg/L), 1-6 µS/cm for specific conductance, and 0.10-0.25 NTU for turbidity (Tony Yeow, pers. com.). The trip blanks were within these ranges and below environmental levels.

Table 3. Trip blank results of distilled water carried to and from the stations.

Creek	Date	TSS (mg/L)	Specific Conductance (µS/sec)	Turbidity (NTU)
Harrop	26/02/2010	Below detection (<0.5 mg/L)	1.2	0.15
	13/07/2011	NA	1.3	0.15
	23/04/2013	NA	1.3	0.20
	03/04/2014	NA	1.7	0.10
Narrows	26/02/2010	<0.5	1.2	0.15
	13/07/2011	NA	1.3	0.15

4.2. Water quantity and water quality monitoring

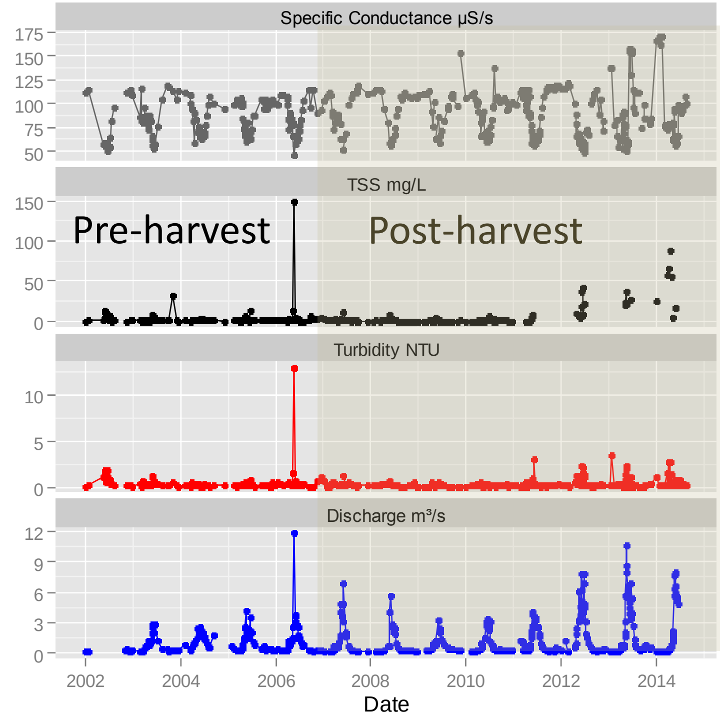
4.2.1. Discharge, sediment and specific conductance

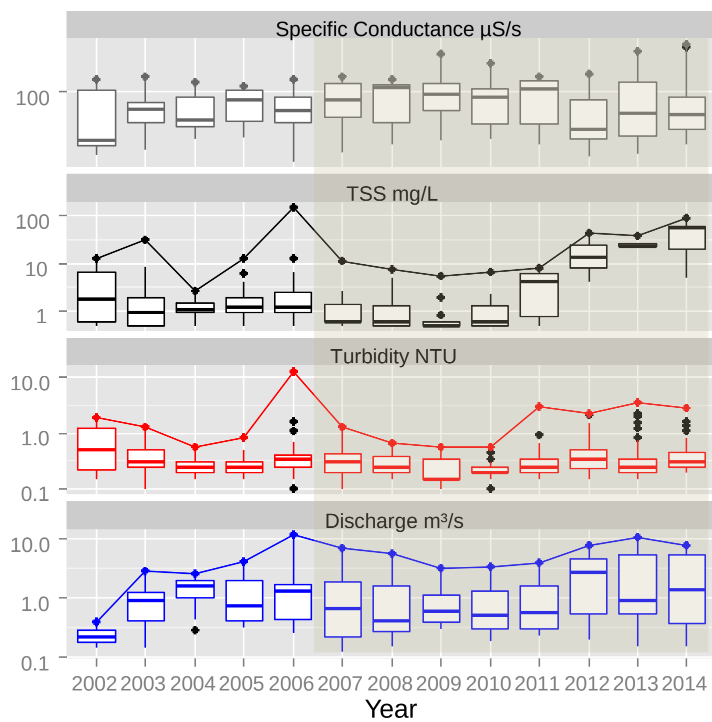
Peak discharges on Harrop Creek were highest in 2006 (May 18, 11.81 m^3/s), 2012 (June 2, 7.81 m^3/s), 2013 (May 13, 10.57 m^3/s) and 2014 (May 25, 7.89 m^3/s) with corresponding levels of elevated turbidity and TSS. The largest peaks in TSS (149 mg/L) and turbidity (13 NTU) occurred in 2006 (Figure 6). High discharges on these dates were associated with warming temperatures and rain in the days prior to flood conditions (Appendix 1).

Peak TSS and turbidity in Harrop/Mill Creek during post-harvest years were within the range of levels observed in peak flows in 2006 during pre-harvest years on Harrop Creek. Total suspended sediment (TSS) ranged from 0.5- 149 mg/L during the pre-harvest period (2002-2006) on Harrop Creek and varied from 0.5-88 mg/L during the post-harvest period of monitoring (2007-2014). Higher concentrations of suspended sediment have been observed in the past three years in Harrop Creek including; 42.9 mg/L (2012), 37.7 mg/L (2013) and 16.5 mg/L (2014) at peak discharges estimated at 7.89 m^3/s in all of these years. Turbidity ranged from 0.1- 13 NTU during the pre-harvest period (2002-2006) on Harrop Creek and varied between 0.1-5 NTU during the post-harvest period of monitoring (2007-2014). Specific conductance ranged from 45.7-119 µS/s during the pre-harvest period (2002-2006) on Harrop Creek and ranged from 48.4-171 µS/s during the post-harvest period of monitoring (2007-2014).

Peak discharges on Narrows Creek were highest in 2006 (May 20, 5.33 m^3/s), 2007 (June 1, 6.90 m^3/s), 2011 (June 21, 4.66 m^3/s) and 2012 (June 23, 4.01 m^3/s) with corresponding spikes in turbidity and TSS (Figure 7). Peak turbidity and TSS levels on Narrows Creek were highest in 2006 (7 NTU and 76 mg/L), 2007 (4 NTU and 58.5 mg/L) 2011 (0.95 NTU and 8mg/L) and 2012(8 NTU and 126 mg/L). High discharges in 2006, 2007 and 2012 were associated with warming temperatures and rain while warm temperatures alone were thought to be responsible for peak discharge in 2011 (Appendix 1).

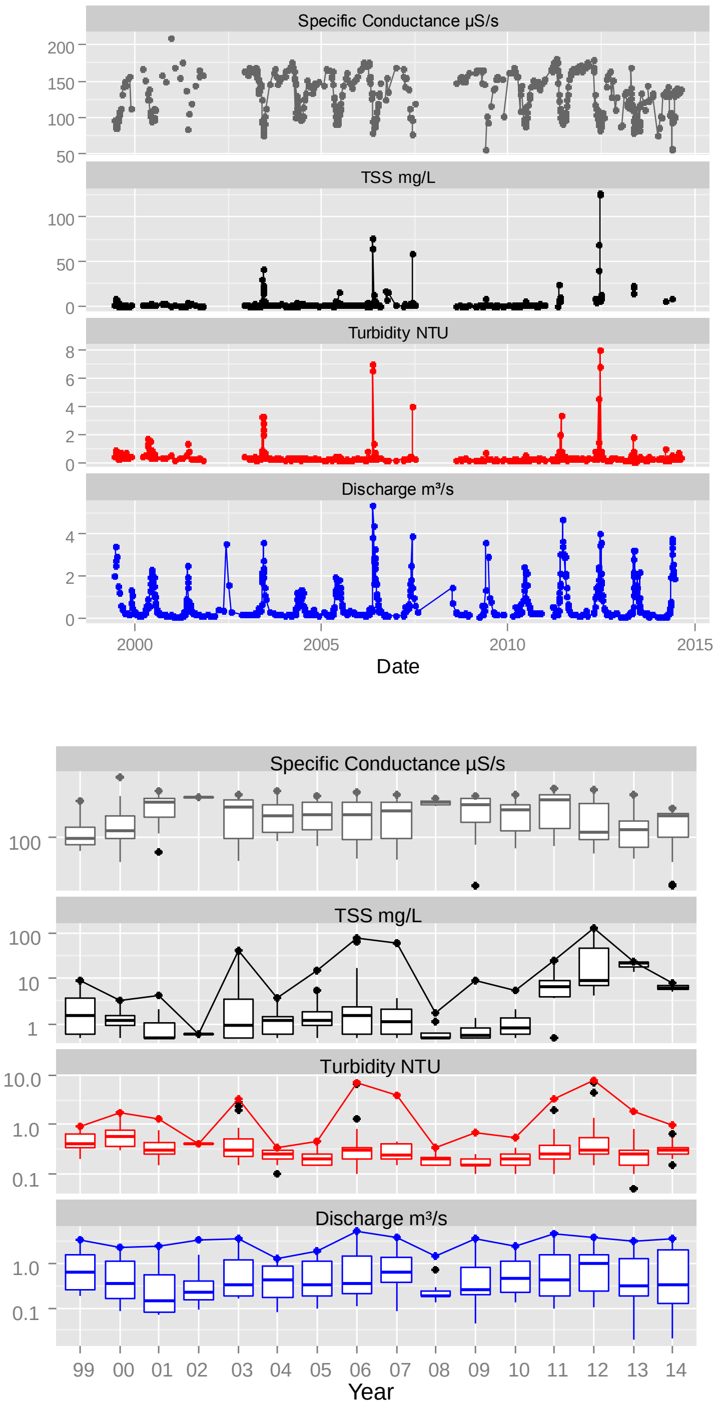
TSS levels were 0.5-76 mg/L during the pre-harvest period (1999-2006) on the Narrows Creek control and fluctuated from 0.5-126 mg/L during the post-harvest period of monitoring at Narrows Creek (2007-2014). Turbidity levels were 0.1-7 NTU during the pre-harvest period (1999-2006) on the Narrows Creek control and fluctuated from 0.05-8 NTU during the post-harvest period of monitoring at Narrows Creek (2007-2014). Specific conductance varied from 75.4-210 µS/s during the pre-harvest period (1999-2006) on the Narrows Creek control and ranged from 55.5-181 µS/s during the post-harvest period of monitoring at Harrop Creek (2007-2014).





From 2011-14, TSS was monitored only during turbid water events when TSS was greater than 8-10 mg/L.

Figure 6. Laboratory measured water quality parameters and discharge monitored on Harrop Creek from 2002-2014. Note log scale on lower graph with line indicating annual maximum value



From 2011-14, TSS was monitored only during turbid water events when TSS was greater than 8-10 mg/L.

Figure 7. Laboratory measured water quality parameters and discharge monitored on Narrows Creek control stream from 1999-2014. Note log scale on lower graph with line indicating annual maximum value.

Scatterplots of TSS versus discharge show that some unusual values in TSS (55.2-88 mg/L) on Harrop Creek occurred in the post-harvest period from March - April, 2014 at flows of 0.21-0.31 m^3/s but were not accompanied by large increases in turbidity (Figure 8). Rain at the Nelson NE climate station (570 m elevation) reported 15.2-32.6 mm of rain in the three days prior to these dates. Narrows Creek was not monitored for TSS at this same time but the stream showed little increase in turbidity for the same dates.

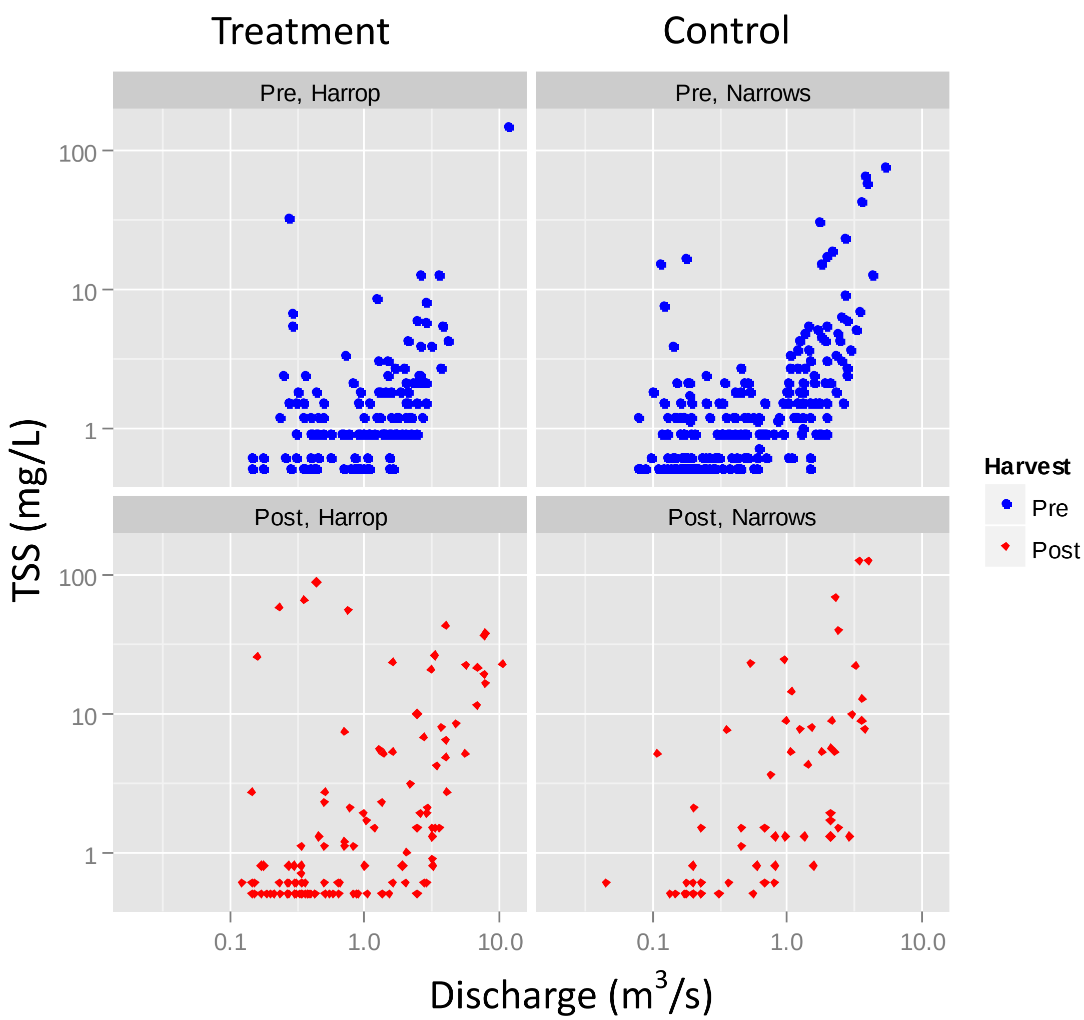


Figure 8. Log TSS (mg/L) versus Log discharge (m^3/second) for pre-harvest (2002-06) and post-harvest (2007-14) periods on Harrop Creek and control monitoring 1999-2014 on Narrows Creek. Harvest refers to harvest within the Harrop Creek watershed only.

The BC Interior Health's turbidity index for drinking water rates water quality as "good" when turbidity is less than 1 NTU, "fair" when turbidity is between 1-5 NTU and "poor" when turbidity is greater than 5 NTU. The rationale for the index is that bacteria, viruses and parasites can attach to suspended sediment in water and interfere with disinfection of water.

Scatter plots of turbidity versus discharge shows that turbidity was below 1 NTU on most days monitored. In pre-harvest monitoring (2002-2006) on Harrop Creek, 10 out of 153 samples were between 1-5 NTU while only one sample exceeded 5 NTU (Figure 9). For the Narrows Creek control, 11 out of 225 samples ranged from 1-5 NTU and only two samples exceeded 5 NTU from 1999-2006. During the post-harvest monitoring period on Harrop Creek (2007-2014), 20 samples out of 293 samples exceeded guidelines of 1-5 NTU but no samples exceeded the 5 NTU guideline. During 2007-2014, on the Narrows Creek control there were six samples that ranged from 1-5 NTU and there were two samples that had turbidity readings > 5 NTU. Some data for turbidity do not show on scatterplots if discharge was not measured at the same time.

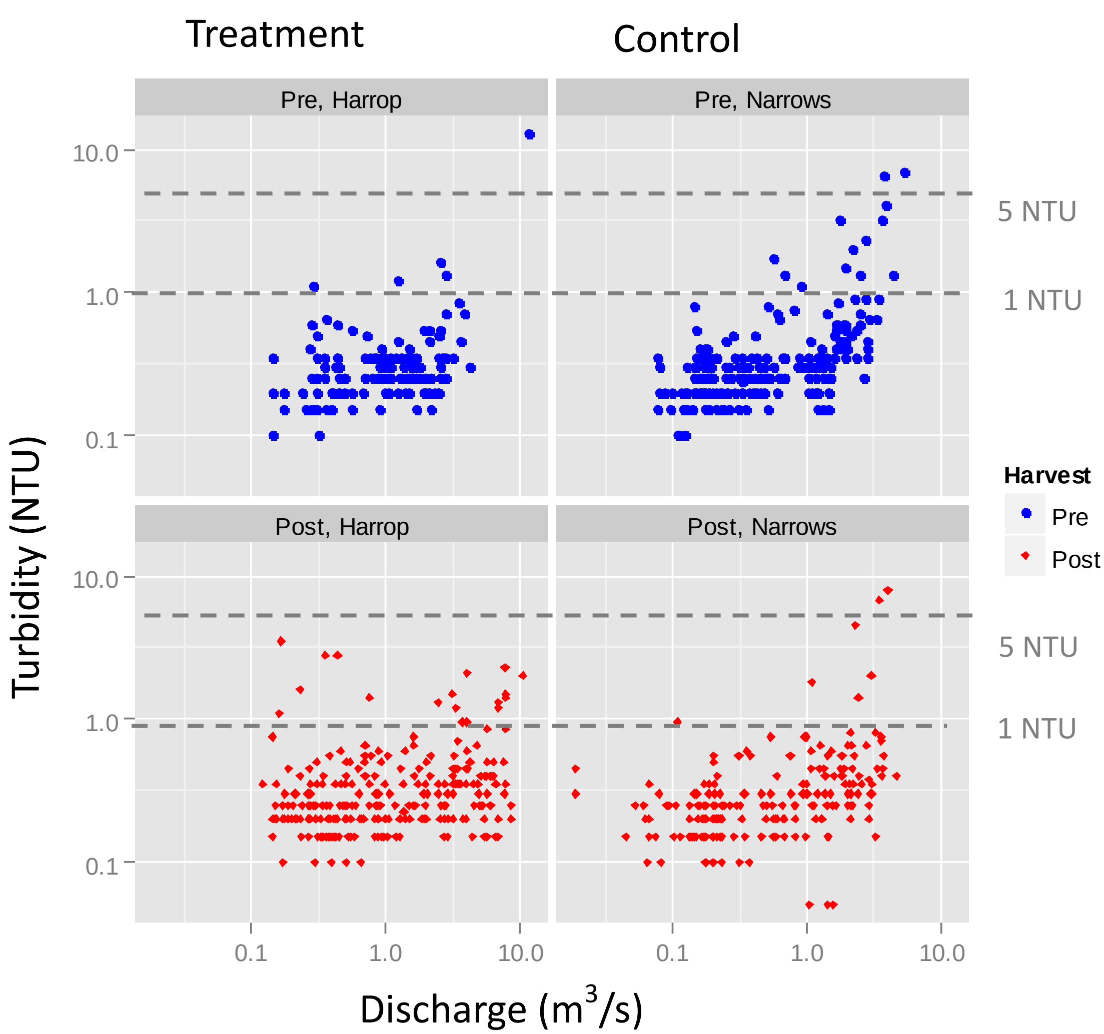


Figure 9. Log Turbidity (NTU) versus Log discharge (m^3/second) for pre-harvest (2002-06) and post-harvest (2007-14) periods on Harrop Creek and control monitoring on Narrows Creek including 1999-14.

The specific conductance of Narrows Creek was generally higher than Harrop Creek for a similar discharge likely due to differences in natural in geology. Harrop watershed is underlain by a more inert granitic material and gneiss (Carver 2005). In contrast, the geology of Narrows Creek is composed of metamorphosed fine-grained sedimentary and volcanic rocks such as shales and argillites (Carver 2005). Streams such as Harrop Creek that run through granitic bedrock tend to have lower specific conductance. While Narrows Creek with finer sediments may allow a greater proportion of the discharge to filter as groundwater for a period of time, accumulating dissolved solutes before it remerges (Jordan 2005). Additionally, the inverse relationship between flow and specific conductance as ground water becomes diluted with run-off is evident from Figure 10 for both Harrop and Narrows creeks.

However, high values of specific conductance on Harrop Creek have been observed in the last two years including: June 2013 as flows decline and at low winter flows in 2013 and 2014. In particular, the observation of high values in June 5-28, 2013 (> 3m^3/s discharge, post-harvest) were unusual. However, it is difficult to diagnose whether these are true values without further quality assurance for the same time period.

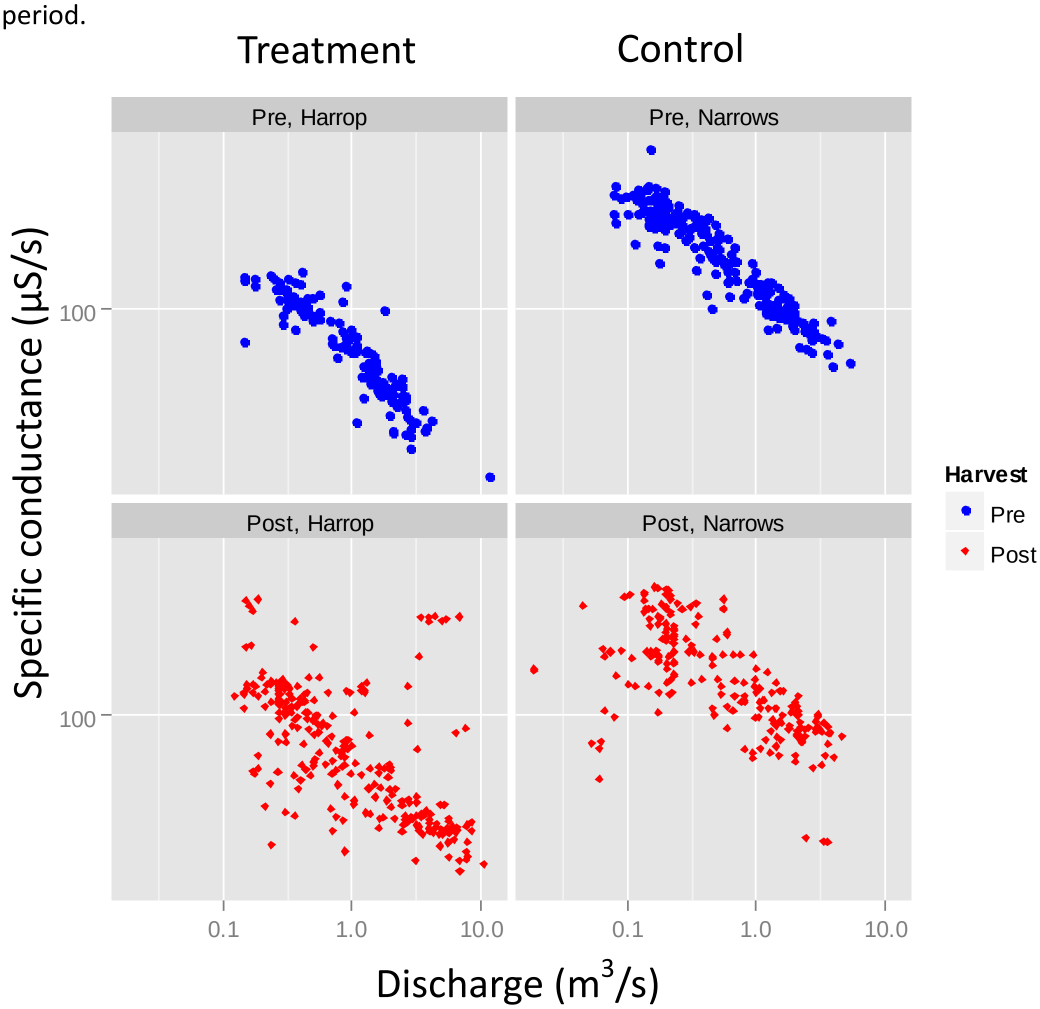


Figure 10. Log Specific Conductance (NTU) versus Log discharge (m^3/second) for pre-harvest (2002-06) and post-harvest (2007-14) periods on Harrop Creek and control monitoring on Narrows Creek including 1999-14.

4.2.1.1. Comparisons to other local streams

Comparisons of the discharge on Harrop and Narrows creeks standardized by square kilometer of watershed to other streams in the area including: Redfish, Five mile, Duhamel and Anderson creeks suggest that peaks in discharge on Harrop and Narrows creeks may be underestimated (Appendix 2). Discharges above 4 m^3/s were estimated for Harrop and Narrows creeks and not accurately gauged due to difficulties in metering and safety concerns at these levels of stream flow. Discharge is monitored primarily to provide a basis for interpretation of water quality data on these creeks.

Monitoring of turbidity carried out on Redfish Creek by the Ministry of Forest, Lands and Natural Resource Operations (MFLNRO, 2003-2010) was compared to the Harrop-Procter creeks (Jordan 2001, Jordan 2008, Jordan 2010 and Jordan 2012). Redfish Creek watershed (27.2 km^2) has been impacted by historical logging (12% of the drainage) with sediment sources resulting from a large road system. However, the watershed is thought to have stabilized in the last ten years with just two smaller cutblocks on the border of the basin (Jordan 2010). Peak annual turbidity levels on Redfish Creek ranged from 4.1-66.7 NTU from 2003-2010 were generally higher on Redfish Creek than for Harrop (0.25-13 NTU) and Narrows Creeks (0.3-7.0 NTU), Table 4. Similarly, a subset of paired comparisons of turbidity between Redfish Creek and both Harrop and Narrows creeks collected between 15:00-19:00 creeks from 2003-2007 were typically lower for the study streams than Redfish Creek (Appendix 3). While similar paired comparisons for turbidity and TSS between Harrop and Narrows Creek for all years (15:00-19:00, 2002-2014) were more similar (Appendix 4).

Table 4. Peak annual turbidity (NTU) by creek.

	Treatment period	**Harrop Creek Harvested**	**Narrows Creek Control**	**Redfish Creek Comparison**
2003	Pre-harvest	2.5	3.2	5.99
2004		0.25	0.3	8.3
2005		0.85	0.45	4.1
2006		13.0	7.0	66.7
2007	Post-harvest	1.3	4.0	8.6
2008		0.65		10.8
2009		5.5	0.7	9.0
2010		6.7	0.55	6.7

Data for Redfish Creek from Jordan 2008 and Jordan 2010.

4.2.1.2. Sediment yield

Sediment yields calculated on a per area basis based on one sample per day were slightly higher on Harrop Creek compared to Narrows Creek for similar periods (Figure 11). The highest yields were observed in 2006 for Harrop Creek (3.6 m-tonnes/day/km^2) for and 2006 and 2012 (1.7 and 2.1 m-tonnes/day/km^2, respectively for Narrows Creek. As expected sediment yields were highly correlated with discharge with higher yields during peak flows and lower sediment yields during the low flow months during the fall and winter. Sources of errors in comparing the yields between the two streams could result from a lack of paired sampling within 1-2 hours and extrapolating one instantaneous daily sample to a 24 hour period. The lack of sampling intensity prevented estimation of annual loads. Since discharges over 4 m^3/s were estimated and as a result calculated sediment loads reflect this accuracy. As a comparison, daily yields were plotted for Redfish Creek and for Harrop Creek using discharge from the Water Survey of Canada data (2015) for Five mile Creek for 2006 (Appendix 6).

Carver (2005) suggested that suspended sediment in Harrop Creek is of coarser size distribution than Narrows watershed because the Harrop watershed is underlain by coarse granitic material and gneiss while the geology of Narrows Creek is composed of metamorphosed fine-grained sedimentary and volcanic rocks. The regression relationship developed between turbidity and suspended sediment concentration (Appendix 5) demonstrates that the turbidity is higher on Narrows Creek than Harrop for a given sediment concentration because the fine particles scatter more light than coarse particles (Jorden and Fanjoy 1999, Jordan 2006).

The relationships between TSS and turbidity (Appendix 2) and plots of turbidity and TSS versus discharge (Figures 8 and 9) showed a large amount of scatter partly because of seasonal and rain-event related hysteresis. Suspended sediment is often higher on the rising limb of the seasonal hydrograph compared to the receding flows of the freshet (hysteresis) because sediment deposited on the stream banks from previous floods becomes re-suspended with rising water levels (pers. com., P. Jordan). Other sources of sediment that can contribute significant sediment under freshet conditions in the Kootenay Region include: landslides, snow avalanche debris and decayed leaves (Jordan and Fanjoy 1999, Jordan 2006). Increases in suspended sediment that result from forest development in the Kootenay region are primarily related to erosion from forest roads rather than logging operations (Jordan 2005).

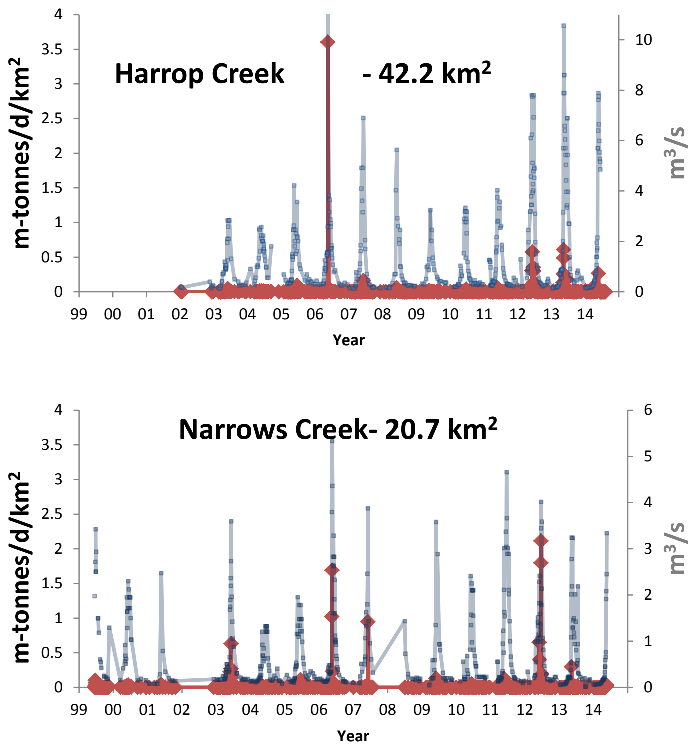


Figure 11: Daily sediment yield in metric tonnes per square kilometer for Harrop and Narrows Creek watersheds with corresponding discharge (m^3/s).

4.2.2. Temperature

Continuous temperature monitors were secured in place from 2008-2014 on Harrop and Narrows Creek. In some years continuous temperature sensors were washed out so data is missing for those years and in 2007 a lack of funding prevented placement of the continuous meters.

Maximum summer temperatures did not exceed the BC water quality aesthetic guideline for drinking water of 15°C in most years and sites monitored (Figures 12-13, Table 5) with the exception of 2014. Temperature monitoring on Narrows Creek showed that 2014 was an exceptionally warm summer with stream temperatures rising above 15°C in the late afternoon from July 17-August 13 with a mean temperature of 13.4 °C during this time. The temperature recorder was washed out on Harrop Creek for 2014.

Temperature thresholds for bull trout are given in Figures 12-13 because of the important role temperature plays in migration and spawning success of this species. Upper threshold temperatures of 9°C (5-9°C +/-1 °C, BC water quality guideline, BC Min. of WLAP 2004) for spawning and 12°C for migration are optimal for bull trout (McPhail and Baxter 1996, BC Min. of WLAP 2004). Temperature thresholds for bull trout are also given for Narrows Creek for comparison to Harrop Creek because of missing data on Harrop Creek and use of the mouth of Narrows Creek during high water. The temperatures on Harrop and Narrows creeks may exceed these temperatures in late July and August especially during the late afternoon hours. However, average temperatures are typically below thresholds during the main spawning and migration window of mid-August to min-October.

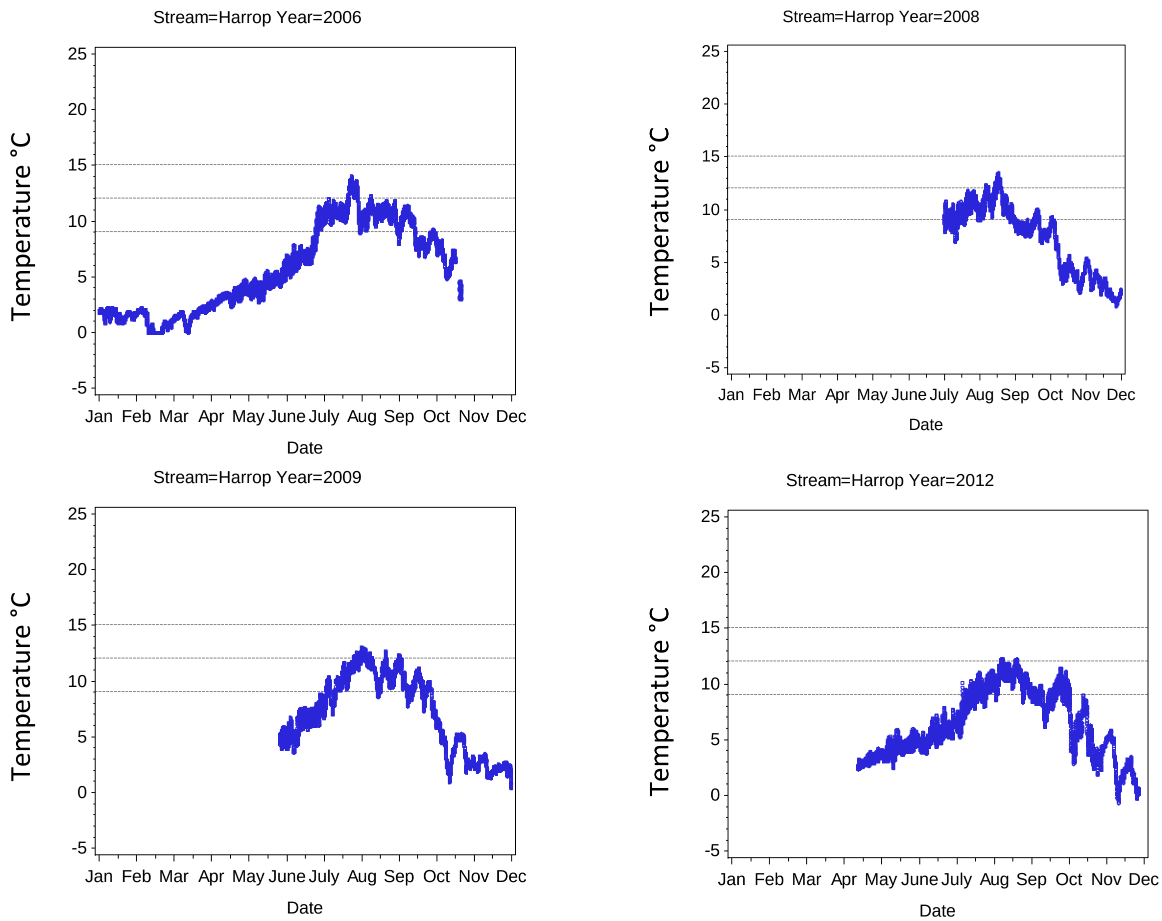


Figure 12. Water temperature °C by year for Harrop Creek. Temperature thresholds are indicated for BC guidelines of 15°C for water quality, and thresholds for bull trout migration 12°C and spawning 9°C.

Mean temperatures (Table 6) were calculated from August 15-October 15 for comparison to optimal ranges for migration and spawning for kokanee and bull trout in Harrop Creek. Masse (2002) verified the presence of kokanee, resident and adfluvial life population types of bull trout and rainbow trout Harrop Creek and resident rainbow trout in Narrows Creeks. Narrows Creek is commonly dewatered at the mouth during migration/spawning and not accessible to spawners. However, FISS (Provincial Fisheries Information Summary System) documents the presence of adfluvial bull trout and kokanee which may make use of the mouth at higher water levels. Additionally, Masse (2002) recorded the presence of rainbow trout in Narrows Creek in August 2001 when the lowest reach near the creek fan was dry.

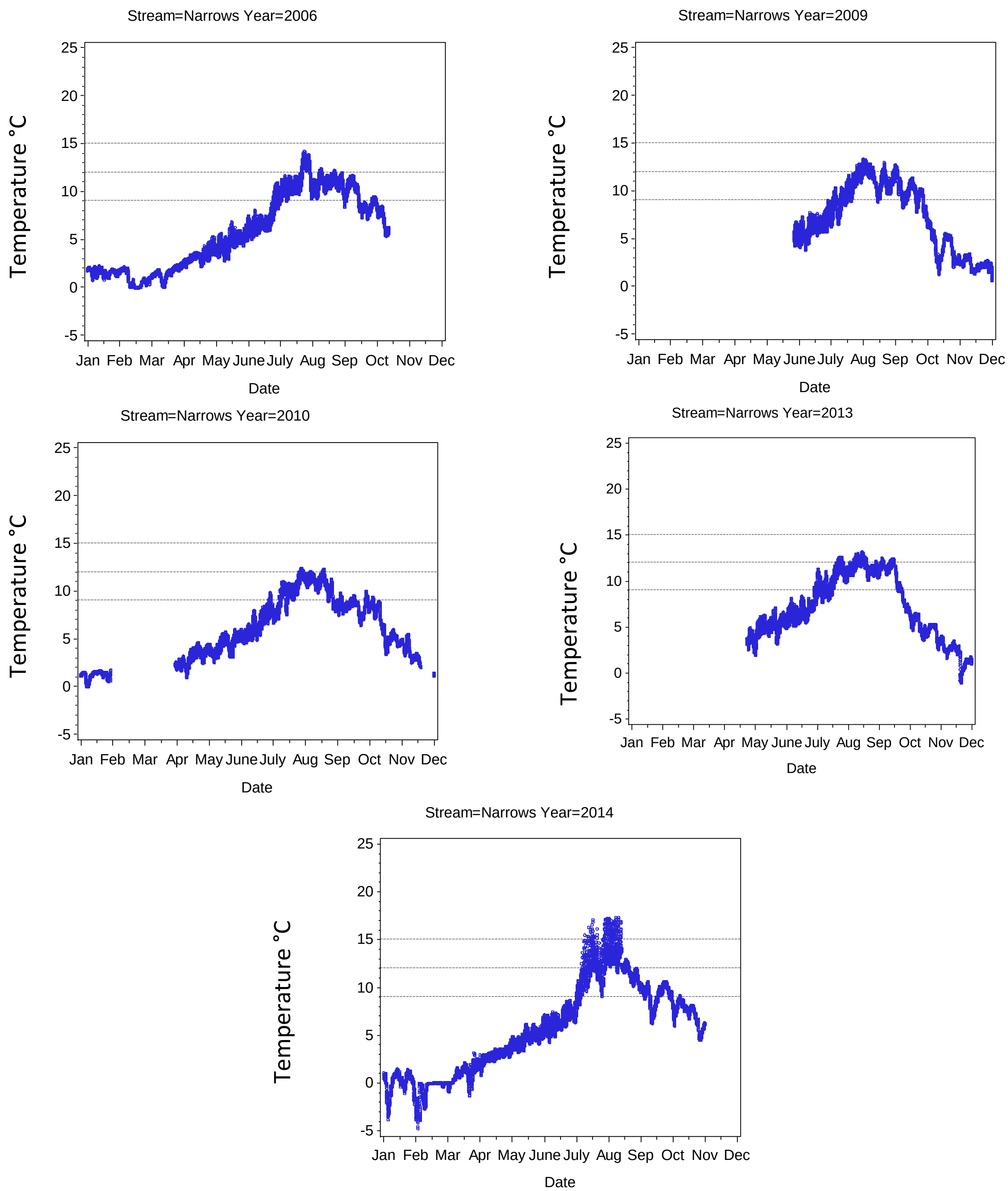


Figure 13. Water temperature (°C) by year for Narrows Creek. Temperature thresholds are indicated for BC water quality guidelines of 15°C for water quality, and thresholds for bull trout migration 12°C and spawning 9°C .

Mean temperatures on Harrop Creek ranged from 7.5-8.7°C in 2006, 2008, 2009, and 2012 during the migration/spawning windows. These values were within or under the optimal ranges for spawning and migration for bull trout and for migration for sockeye but were lower than optimal ranges for sockeye spawning (Table 7). On Narrows Creek, mean temperatures ranged from 8.3-9.3°C in monitoring years (2006, 2008-10 and 2013-14). However, water temperatures did not consistently get below the 9°C spawning threshold until mid-September to the beginning of October (Figures 12-13). Additionally, temperatures in Harrop and Narrows creeks were typically below or within optimal ranges for rainbow trout for rearing and spawning (Table 7).

Table 5. Annual minimum and maximum temperatures on Harrop and Narrows creeks by year.

Stream	Year	Min	Max	Std	n
Harrop	2006	-0.1	14.0	3.9	6993
	2008	-4.8	13.5	3.4	3761
	2009	-1.5	13.0	4.0	5242
	2012	-0.7	12.3	3.0	5503
Narrows	2006	-0.1	14.2	3.9	6840
	2008	-4.7	13.2	3.4	3760
	2009	-0.4	13.3	4.0	5240
	2010	0.0	12.4	3.4	7041
	2013	-5.3	13.2	4.1	6023
	2014	-6.4	17.3	4.7	7271

Table 6. Temperature summaries during fall migration and spawning periods from August 15-October 15 on Harrop and Narrows creeks each year.

Stream	Year	Mean	Min	Max	Std	n	Median
Harrop	2006	8.7	3.0	11.9	1.9	1545	8.7
	2008	7.5	2.1	13.5	2.7	1848	8.0
	2009	7.5	1.0	12.7	3.2	1848	8.7
	2012	7.8	1.9	12.2	2.5	1848	8.5
Narrows	2006	9.3	5.3	12.2	1.7	1392	9.3
	2008	7.3	2.0	13.2	2.7	1848	7.9
	2009	7.8	1.3	12.9	3.2	1849	9.0
	2010	7.9	3.4	12.3	2.0	1848	8.4
	2013	8.3	2.6	13.1	3.1	1838	8.9
	2014	8.9	4.5	12.9	1.9	1838	8.9

Table 7. BC water quality guidelines for optimum temperature ranges (+/- 1°C) for fish species with distributions in Harrop and Narrows creeks.

Species	Rearing	Migration	Spawning
Sockeye	10.0-15.0	7.2-15.6	10.6-12.8
Rainbow	16.0-18.0	—	10.0-15.5
Bull Trout	6.0-14.0	—	5.0-9.0

4.2.3. Microbiological parameters

Sampling for bacterial parameters involved the collection of five samples over a period of 30 days during baseline summer flows. These samples were evaluated with respect to two guidelines for drinking water quality including: (1) raw drinking water undergoing no treatment and (2) raw water undergoing disinfection. The BC provincial guidelines for drinking water (undergoing no disinfection) recommend zero fecal coliforms and E. coli in any 100 mL sample for households that draw raw water from their local creeks. Provincial guidelines for drinking water for households that draw raw water from local creeks and use disinfection recommend that the 90th percentile from 10 samples per month should be less than 10 CFU per 100 mL sample of water. Both guidelines were used to evaluate water quality for microbiological parameters as bench marks for the community.

In all years combined, the guideline for drinking water with no disinfection (0 CFU) was exceeded in 61% of samples (n=23) for fecal coliforms and 64% of the time (n=14) for E. coli on Harrop Creek. Whereas on Narrows Creek, 40% of samples (n=25) exceeded the guideline of 0 CFU when measured for fecal coliforms and 41% of samples (n=12) were higher than this guideline for E. coli.

Fecal coliform levels on Harrop Creek exceeded BC water quality guidelines for raw water with no disinfection (0 CFU) at least once out of the five samples collected each year in 2008, 2009, 2013, and 2014. As well, water quality guidelines for E. coli in raw drinking water were exceeded at least once in 2011, 2013 and 2014. Guidelines for fecal coliforms were exceeded at least once on Narrows Creek in 2009, 2010, 2013, 2014 but not in 2008 and 2011. E. coli levels on Narrows Creek exceeded this guideline at least once in 2013 and 2014 but not 2011.

On Harrop Creek, the 90^{th} percentile of fecal and E. coli coliforms counts exceeded BC water quality guidelines for raw water with no disinfection (10 CFU) in 2013 and 2014 (Figure 14). On Narrows Creek, the 90^{th} percentile of fecal counts exceeded 10 CFU/100 mL in 2009 and 2014 (Figure 15), additionally; the 90^{th} percentile of E. coli exceeded this value in 2014. However, the above calculations are based on five samples per month not the recommended 10/month.

At present no provincial guidelines exist for total coliforms, however, total coliforms have been monitored in the creeks since 2008. The 90th percentile of total coliforms ranged from 35.4-268.8 CFU from 2008-2014 on Harrop Creek and 13.0-165.0 CFU on Narrows Creek with the maximum values observed on both creeks in 2014. High values in 2014 of all microbiological parameters may be due to warmer than average stream temperatures observed in this year (Section 4.4). The sources of microbial contamination are thought to include: wildlife, recreational activities or forest operations because monitoring stations are generally upstream of residential development.

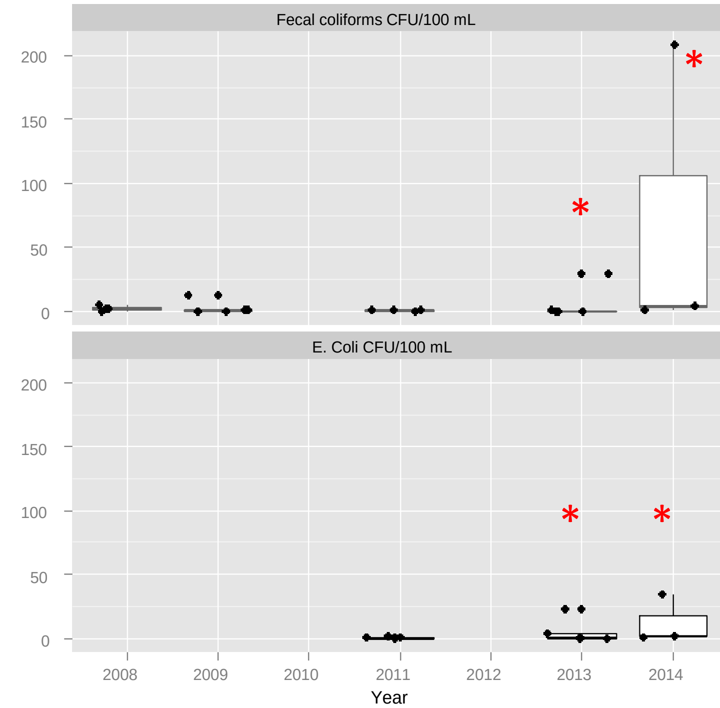


Figure 14. Box plots of fecal coliforms and E. coli by year for Harrop Creek. Red stars indicate exceedance of the BC guideline for raw drinking water (with disinfection) of a 90th percentile of 10 CFU.

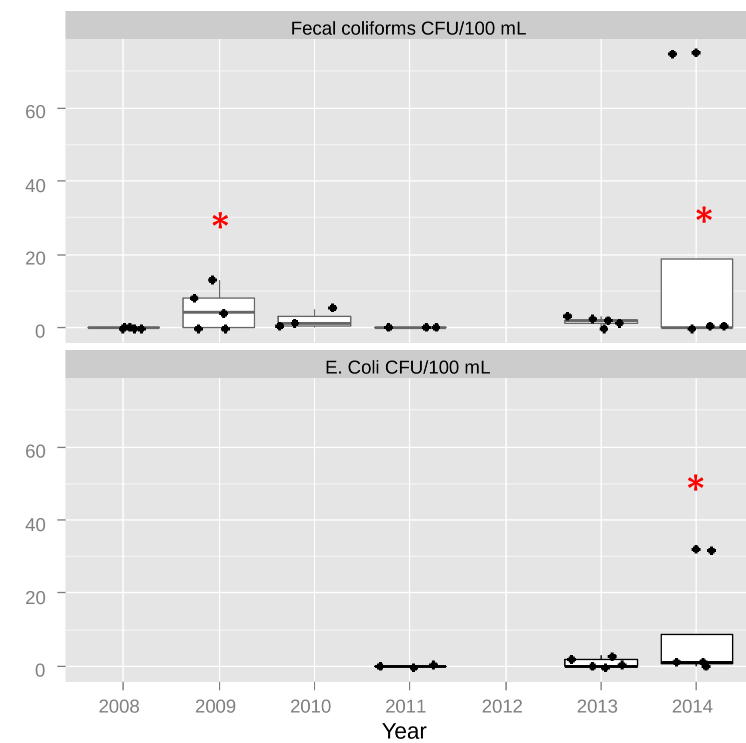


Figure 15. Box plots of fecal coliforms and E. coli by year for Narrows Creek. Red stars indicate exceedance of the BC guideline for raw drinking water (with disinfection) of 10 CFU.

4.3. Macroinvertebrates

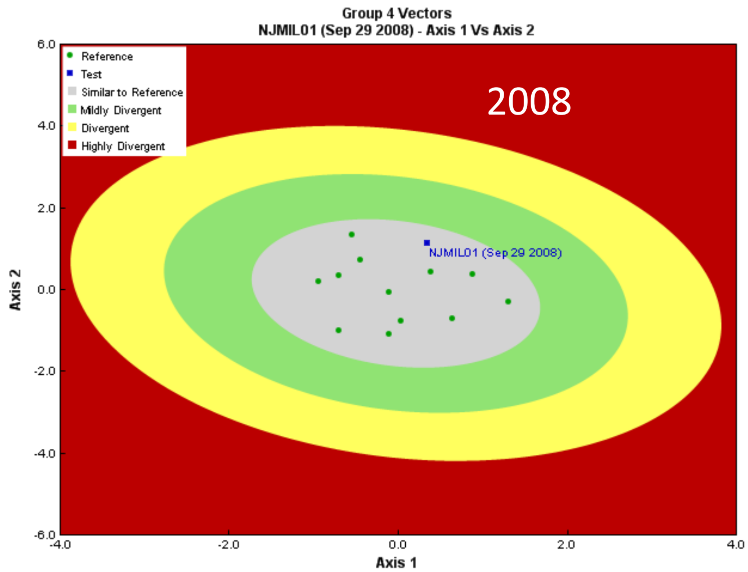
Macroinvertebrates collected from Harrop Creek in 2008 and 2012 indicated that benthic macroinvertebrate communities were similar to reference sites monitored under Environment Canada's CABIN program and did not change substantially between the two sampling periods relative to reference streams (Figure 16).

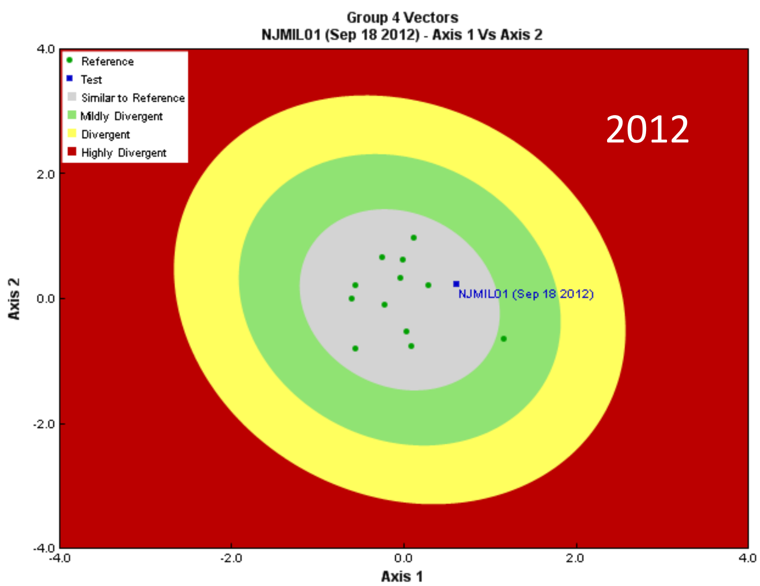
Harrop Creek was evaluated with respect to a group of twelve reference streams (Reference Group 4) within the CABIN Kootenay-Columbia Model for both 2008 and 2012 based on habitat characteristics. Most of the reference sites in this group were in the Columbia Mountain Highlands ecoregions with a few sites in the Western Continental Ranges and one site in the Southern Rocky Mountain Trench. Reference streams in were characterized by streams at elevations of 552-1294 m, slopes of 0.02-0.55 m/m with bankfull widths ranging from 5.1-33 m. Streams in these areas tend to be high velocity during spring runoff with cobble dominated substrates. Water chemistry was quite variable with specific conductance varying from 17-310 µS/s, alkalinity from 17-136 mg/L and pH from 6.2-8.3. Nutrient levels ranged from 0.02-0.22 mg/L for total nitrogen and below detection to 0.018 mg/L for total phosphorus.

Deposited sediment was assessed visually and by using Wolman pebble count methods (Environment Canada 2007). Deposited fine sediment was assessed at 0% for Harrop Creek and no fine sediments were recorded in the pebble count. These results were similar to the reference streams and are typical of streams with high flushing flows that result in little deposited sediment following freshet each year. However, detailed size analyses of deposited fine particles (less than 2 mm) that can be detrimental to stream invertebrates and fish habitat were not carried out. The effects of low levels of deposited sediment resulting from forest activities are difficult to detect without rigorous methods and comparisons of multiple sites (Anigradi 1999).

Benthic communities at the reference sites and at Harrop Creek were dominated by mayflies (Ephemeroptera) and stoneflies (Plecoptera). Sensitive taxa including mayflies, stoneflies and caddisflies (EPT taxa) comprised 88% (SE=7.3) of the abundance of the community and 93% and 88% of the community in Harrop Creek in 2008 and 2012, respectively. The dominant taxa within these groups were baetid and heptageneid mayflies and the small taeniopterygid and nemourid stoneflies. Baetid and heptageneid mayflies are scrapers and collectors-gatherers while the stonefly families are generally shredders, collector-gatherers and scrapers typically found in streams of this size. The percentage of midges (2% in 2008 and 6% in 2012) at Harrop Creek, indicators of possible impacts such as deposited sediment, were low and similar to reference sites (7% SE=1.8). The macroinvertebrate community also included some sensitive families including: the mayfly family, Ameletidae, and caddisflys from the Families Glossomatidae, Rhyacophilidae, Uenoidae and Brachycentridae (Appendix 7).

Overall the community at this station was diverse with 23 taxa identified to the taxonomic level of family in 2008 and 22 taxa in 2012 compared to a mean of 19±3 SE taxa for reference sites. Macroinvertebrates samples from Harrop Creek were only identified to family, thus, the description of the invertebrate community is limited to this taxonomic level. See Appendix 7 for comparisons of the percent abundance of macroinvertebrates from Harrop Creek to reference sites by taxa.





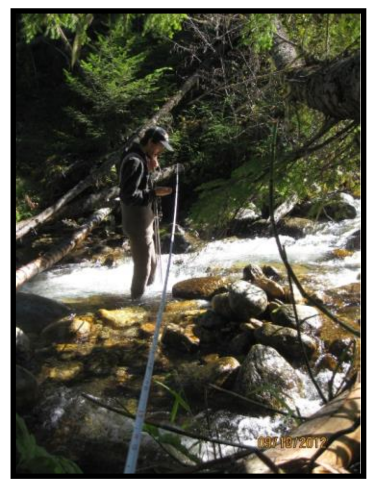


Figure 16. Confidence ellipses around reference sites (green points) located in the Kootenay Region relative to the test site on Harrop Creek in 2008 and 2012 (blue) indicate that Harrop Creek was in reference condition for these monitoring periods. Photos by J. & T. Yeow.

5. Conclusions

Drinking water quality in Harrop and Narrows creeks for the period of record was rated as "Good" by BC Interior Health's turbidity index for 92-96% of the samples, "Fair" for 2-7% of the samples and "Poor" for 0-1% of the samples collected (Table 8). In post-harvest monitoring of Harrop Creek, 93% of samples collected had turbidity values <1 NTU, 7% of the samples collected had values ranging from 1-5 NTU and

0% of the samples collected had values >5 NTU. This was similar to pre-harvest monitoring on Harrop Creek and pre and post-harvest monitoring periods on the Narrows Creek control in which 93-96% of samples collected had turbidity values <1 NTU, 3-7% of the samples ranged from 1-5 NTU and 0-1% of the samples had levels greater than 5 NTU. Low sediment yields (Figure 11) observed on Harrop and Narrows creeks are typical of streams used for domestic water supply within the Kootenay Region (Jordan and Fanjoy 1999). High values of TSS were typically coincided with high values of turbidity during freshet conditions (Appendix 2). Some higher values of TSS were observed in recent years (Section 2.2) on Harrop Creek. However, TSS levels in post-harvest years were lower than the 2006 flood (pre-harvest monitoring) at which time peak TSS reached 149 mg/L.

Macroinvertebrate sampling suggested that Harrop Creek was similar to reference streams surveyed under Environment Canada's CABIN program.

Across all years, the percent of samples exceeding the guideline for drinking water with no disinfection (0 CFU) monitored in the late summer was higher on Harrop Creek (61% fecal coliforms and 64% for E. coli, respectively) than for Narrows Creek, (40% for fecal coliforms and 41% for E. coli). Fecal coliforms were above BC guidelines for systems with disinfection (10 CFU) in 2013 and 2014 on Harrop Creek and in 2009 and 2014 on Narrows Creek. E. coli counts were above BC guidelines for systems with disinfection (10 CFU) in 2013 and 2014 on Harrop Creek and 2014 on Narrows Creek. The higher fecal coliform and E. coli counts observed in 2014 (Figures 14 and 15) may be due the warmer temperatures observed in 2014, the highest on record since monitoring started in 2006.

Table 8. Summary of drinking water quality and biological assessment benchmarks.

WQG/variable	Harrop Creek Pre-harvest 2002-2006	Harrop Creek Post-harvest 2007-2014	Narrows Creek Control 1999-2006	Narrows Creek Control 2007-2014
IHA Turbidity Index -% of samples	Good-92% Fair -7% Poor-1%	Good-93% Fair -7% Poor-0%	Good-96% Fair -6% Poor-1%	Good-96% Fair -3% Poor-1%
Biological (CABIN)	NA	Similar to reference streams, 2008 & 2012	NA	NA
Fecal coliforms 0 CFU[1]	NA	61% of samples >0 CFU (n=23)	NA	40% of samples >0 CFU (n=25)
Fecal coliforms 10 CFU[2]	NA	90th percentile below guideline in 2008,2009 90th percentile >10 CFU in 2013, 2014	NA	90th percentile below guideline in 2008, 2010, 2011, 2013, 90th percentile >10 CFU in 2009 & 2014
E. coli 0 CFU[1]	NA	64% of samples >0 CFU (n=14)	NA	41% of samples >0 CFU (n=12)
E. coli 10 CFU[2]	NA	90th percentile below guideline in 2011, 2013, 90th percentile >10 CFU in 2013, 2014	NA	90th percentile below guideline in 2011, 90th percentile >10 CFU in 2014
Maximum water temperature <15°C[1]	<15°C in in 2006	<15°C in 2008, 2009, 2012	<15°C in 2006	<15°C in 2009, 2010, 2013, >15°C in 2014

Text in red indicates that parameter was above guideline, [1] BC guideline for raw water (0 CFU in any 100 mL sample) , [2]BC guideline for water with disinfection (90th percentile > 10 CFU), WQG =BC water quality guidelines, IHA=Interior Health Authority.

6. Recommendations

In the future, unusual observations of suspended sediment or turbidity should be used to initiate further inspection of the watershed for sediment sources by a geomorphologist. The Ministry of Forest, Lands and Resources may be available to conduct a preliminary field assessment if sediment issues arise within the watershed (pers. com. Peter Jordan).

Furthermore, a criterion is suggested to trigger intensive sampling around events where there are outliers. For example, if high values of specific conductance (>125 µS/s) or turbidity (>5 NTU) at atypical times of the year are observed it should trigger more intensive event-based sampling and always include duplicate, trip blanks and a log of equipment blanks or calibration standards to validate observations, trends and outliers.

Paired hourly sampling at Harrop and Narrows creeks is advised for better comparisons of parameters in order to over-come issues that cause hourly changes in sediment levels including: varying discharge, daily and seasonal hysteresis effects. If possible samples should be collected in the later afternoon at the time of the highest daily discharge when discharge is dominated by snow-melt processes (similar to Jordan and Fanjoy 1999).

Other recommendations include:

- Continue water monitoring as a means to verify clean drinking water and trends
- Consider sampling microbiological indicators over 10 days to bring up to current water monitoring standards
- Revaluate macroinvertebrate ratings on Harrop Creek when Kootenay/Columbia model under CABIN becomes available in July 2015 and consider future sampling of Narrows Creek for macroinvertebrates including taxonomic resolution to the genus level.
- Continue to monitor Harrop Creek as the watershed continues to recover hydrologically over time.
- Continue to monitor Narrows Creek as operations continue within the watershed.
- Consider monitoring Procter Creek as a control because of its status of a community watershed possibly under the umbrella of the Columbia Basin Watershed Network.
- Inspect water level gauges as to the effectiveness for low flow monitoring on these creeks and install a second gauge if necessary.
- In future work, review water governance issues within the Harrop-Procter community in the context of climate change and impacts on water quantity, quality, and fish habitat.

7. Acknowledgements

Funding for this project was provided by the Harrop-Procter Watershed Protection Society and the Harrop-Procter Community Co-op. Thank you to Pamela Dykstra of P.R. Dykstra Resource Management for overseeing the project for the Harrop-Procter Watershed Protection Society and the Harrop-Procter Community Co-op and giving valuable feedback. Erik Leslie, Forest Manager for the Harrop-Procter Community Co-op provided indispensable information on operations, input and review of the project. Peter Jordan, Ministry of Forest, Lands and Resources, kindly provided direction on future monitoring and advice on the methods and analyses. Local residents, Amy Nealey and Leeza Trione of the Harrop-

Procter Watershed Protection Society collected water samples, monitored the water level gauge and aided with the macroinvertebrate collections.

All physical and microbiological tests were performed at Passmore Laboratory Ltd. owned and operated by Jennifer and Tony Yeow. Stream metering was carried out by Jennifer Yeow with the help of Aram Yeow while Tony Yeow developed the stage-discharge tables. The Columbia Basin Watershed Network provided funding for the monitoring of macroinvertebrates and associated stream measurements. Jennifer Yeow, recently recognized by the Kootenay Conservation Program for outstanding qualities of conservation leaders in the Kootenays, facilitated the collaboration with the Columbia Basin Watershed Network.

John Boulanger of Integrated Ecological Research produced the temperature graphs and paired comparisons of sediment levels between streams using SAS (SAS Institute, 2000).

Photo credits go to Jennifer and Tony Yeow and Erik Leslie. Maps provided by: Erik Leslie.

8. References

Anigradi, T.R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring application. J. N. American Benthic Soc. Vol. 18: No. 1.

APHA. 2005. Standard methods for the examination of water and wastewater. 18th ed. American Public Health Association, Washington, DC.

Bailey, R. C., R.H. Norris and T.B. Reynoldson. 2004. Bioassessment of freshwater ecosystems: Using the Reference Condition Approach. Kluwer Academic Publishers, Norwell, Massachusetts. 170p.

BC MOE (British Columbia, Ministry of Environment). 2015. Water license database. Government of BC. Web. Accessed. 21 January, 2015. http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input

Carver, M. 2005. Backgrounder for a water-monitoring program in the Harrop-Procter Community Forest. Prep. for Harrop-Procter Community Forest by Aqua Associates.

Cavanagh, N., R.N.Nordin, L.W.Pommen and L.G. Swain. 1997. Guidelines for designing and implementing a water quality monitoring program in British Columbia. Resources Inventory Committee, British Columbia Ministry of Environment, Lands and Parks.

Clark, M.J.R. (editor). 2003. British Columbia Field Sampling Manual. Water, Air and Climate Change Branch, Ministry of Water, Land and Air Protection, Victoria, BC, Canada.

Duncan, Jim and Laura Duncan. 2012. Operating Procedures: Columbia Basin Water Quality Monitoring Project. Prep. for the Columbia Basin Trust.

Environment Canada. April 2007. CABIN Field Manual for Streams. Reynoldson, T. B., C. Logan, T. Pascoe, S. Thompson, S. Sylvestre, C. Mackinlay, and H. McDermott.

Environment Canada. April 2012. CABIN Laboratory Methods: Processing, taxonomy and quality control of benthic macroinvertebrates. H. McDermott, T. Paul and S. Strachen.

Environment Canada. 2014. www.ec.gc.ca/rcba-cabin.

Ministry of Water, Land and Air Protection. 2004. Accounts and Measures for Managing Identified Wildlife – Accounts V. 2004. . BULL TROUT, Salvelinus confluentus. J. Hammond. http://www.env.gov.bc.ca/wld/frpa/iwms/documents/Fish/f_bulltrout.pdf

Harrop-Procter Community Co-operative (HPCC). 2009. Community forest pilot agreement proposal: Application for a community forest licence. Pdf

Harrop-Procter Community Co-operative (HPCC). 2012a. Harrop-Procter Community Co-operative Management Plan #2. Pdf

Harrop-Procter Community Co-operative (HPCC). 2012b. Summary of June 2012 Community Survey Results. Pdf

Jordan, P. and E. Fanjoy. 1999. Sediment yields and sediment budgets of community water supply watersheds in southeastern British Columbia. B.C. Ministry of Forests, Nelson, B.C. Paper presented at Canadian Geophysical Union Annual Meeting, May 9-13, 1999, Banff, Alberta. Pdf

Jordan, P., 2001. Sediment budgets in the Nelson Forest Region. In: Toews, D.A.A., Chatwin, S. (Eds.), Watershed Assessment in the Southern Interior of British Columbia: Workshop Proceedings, March 9–10, 2000, Penticton, British Columbia. British Columbia, Ministry of Forests, Research Branch, Working Paper 57, Victoria,B.C., pp. 174–188.

Jordan, P., 2005. The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. Geomorphology 79:27-44.

Jordan, P., 2006. The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. Geormorphology 70: 27-44.

Jordan, P. 2008. Report of activities: Turbidity, suspended sediment and water quality monitoring, FIA Project #4745001. http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=13610.

Jordan, P. 2010. Sitkum, Redfish, and Laird Creeks Water Monitoring, FIA project 9031001, BC Ministry of Forests and Range, BCTS Kootenay Timber Sales Office, Final report, 15 March 2010

Jordan, P. 2012. Sediment yields and water quality effects of severe wildfires in southern British Columbia. Wildfire and water quality: Processes, impacts and challenges. Proceedings of a conference held in Banff, Canada, 11-14 June 2012 (IAHS Publ. 354, 2012).

MacDonald, L.H., A.W. Smart and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. U.S. EPA Rept. No. EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, Seattle, WA. 165 p.

Masse, S. 2002. Reconnaissance (1:20,000) Fish and Fish Habitat Inventory (Phases 4-6) of Harrop Creek to Irvine Creek Study Area. Prep. for Harrop-Procter Community Cooperative, Nelson BC, 18p plus two appendices and map.

McPhail, J. D. and J. S. Baxter. 1996. A review of bull trout (Salvelinus confluentus) life-history and habitat use in relation to compensation and improvement opportunities. Fisheries Management Report 104.

Quamme, D.L. 2009a. Water quality update for Harrop (Mill) and Narrows creeks 2005-2008. Prep by Integrated Ecological Research for Harrop-Procter Community Forest, Harrop-Procter, B.C.

Quamme, D.L. 2009b. Bird Creek Water Resource Inventory. Prep. for Kalesnikoff Lumber Co. Ltd., Thrums, B.C., Nelson, B.C.

Quamme, D.L. 2009c. Wolverton Creek Water Resource Inventory. Prep. for Kalesnikoff Lumber Co. Ltd., Thrums, B.C., Nelson, B.C.

Quamme, D.L. 2010. Water quality update for Harrop (Mill) and Narrows creeks. Prep. by Integrated Ecological Research for Harrop-Procter Community Forest, Harrop-Procter, B.C.

Quamme, D.L. and K. Green. 2000. Bird Creek Water Resource Inventory. Prep. for Kalesnikoff Lumber Co. Ltd., Thrums, B.C. and B.C. MWLAP, Nelson, B.C.

Resource Inventory Committee (RIC) 1998. Manual of Standard Operating, Procedures for Hydrometric Surveys in British Columbia. Resource Inventory Branch, Environment, Victoria.

Rosenberg, D., T.B. Reynoldson and V.H. Resh, 1999. Establishing reference condition for benthic macroinvertebrate monitoring in the Fraser River catchment, British Columbia, Canada. Environment Canada, Vancouver, British Columbia DOE-FRAP 1998-32. 149 p.

R Core Team. 2014. A language for environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

SAS Institute. 2000. The SAS System for Windows. The SAS Institute, Cary, NC.

Summit Environmental Consultants. 2001. Summary and review of water quality monitoring studies: Arrow Forest District, 1996-1999.

Water Survey of Canada. 2015. Archived hydrometric data. Environment Canada, Water Office. Web. Accessed. 21 February, 2015. http://wateroffice.ec.gc.ca/search/search_e.html?sType=h2oArc.

Yeow, J. 2011. Harrop and Narrows creeks monitoring summary report for 2010. Prep. by Passmore Laboratory Ltd. for the Harrop-Procter Watershed Protection Society.

Yeow, J. 2013. Mill and Narrows Creek monitoring report 2011-2012. Prep. by Passmore Laboratory Ltd. for the Harrop-Procter Watershed Protection Society.

9. Appendix 1: Timing of peaks in discharge, sediment and specific conductance.

Table 9. Dates of peak discharge and suspended sediment, turbidity and minimum specific conductance on Harrop Creek during freshet.

Year	Date	Discharge m^3/s	TSS mg/L	Turbidity NTU	Specific Conductance	Precipitation report at monitoring station
Harrop Creek						
2002	May 29	-	12.6	1.8	56.3	No discharge data available during freshet
	June 17	-	8.1	1.9	51.4	Rain
	June 18	-	6.6	1.2	49.6	Rain
2003	May 4	-	2.1	2.5	91.1	-On rising limb of hydrograph
	May 28	2.832	8.4	1.2	66.3	
	June 10	2.832	5.7	0.7	52.2	-Warm temperatures, possibly missed peak due to lack of sampling
	June 16	2.832	2.1	0.35	57	-Warm temperatures
2004	May 28	2.572	2.4	0.25	64.8	
	June 14	2.229	0.9	0.25	63.5	-Descending limb of hydrograph
2005	May 17	4.218	4.2	0.3	59.6	-Rain and melting snow
	June 17	3.567	12.6	0.85	62.5	-Rain
2006	May 18	11.807	149	13	45.7	
2007	June 6	6.896	11.4	1.3	50.8	
2008	May 19	0.320	7.4	0.65	58.3	-Warm temperatures
	June1	5.631	5.1	0.40	55.3	-Rain and warm temperatures
2009	May 17	1.286	5.5	0.45	63.5	-Rising limb of hydrograph
	May 31	3.242	0.8	0.55	85.2	-Warm temperatures
	June 16	2.455	0.5	0.35	58.2	
2010	June 14	3.335	1.5	0.35	59.5	-Rain previous day
	June 17	3.186	1.3	0.35	59.9	-Rain
	June 24		6.7	0.20	61.1	-Descending limb of hydrograph
2011	May 25	3.743	8	0.95		-Rain
	May 26	4.033	6.4	0.95	61.6	-Rain
2012	June 2	7.806	19.2	1.5	53	-Rain
	June 7	7.745	36.3	2.3	53	
	June 16	4.024	42.9	2.1	60.6	-Rain, June 9 banks overflowing
	June 22	6.923	21.2	1.2	48.4	-Rain, banks overflowing
2013	May 12	7.888	37.7	2.3	51.8	-Increasing limb of hydrograph, warm temperatures
	May 13	10.568	22.6	2.0	50	-Rain
2014	May 25	7.888	16.5	0.85	55	-Rain in previous 4 days

Any discharges greater than 4 m^3/s are estimates due to difficulties in metering at high flows.

Table 10. Dates of peak discharge and suspended sediment, turbidity and minimum specific conductance on Narrows Creek during freshet.

Year	Date	Discharge m^3/s	TSS mg/L	Turbidity NTU	Specific Conductance	Precipitation report at monitoring station
Narrows Creek						
1999	June 24	2.713	9.0	0.9	86.2	
	June 26	3.425	6.8	0.9	86.2	
	July 12		6.6	0.45	85.2	-No discharge data, warm temperatures
2000	June 7	2.300	3.3	0.9	93.7	-Warm temperatures
	June 8	1.579	<0.5	1.1	74	
2001	May 25	2.474	4.2	1.3	83.2	-Warm temperatures and melting snow
2002	June 16	3.529	-	-	-	-Water quality not monitored during freshet, warm temperatures
2003	June 9	3.595	42	3.2	80.7	-Warm temperatures
2004	June 8	1.319	1	0.3	97.1	-Peak discharge possibly missed because of lack of sampling, rain
	June 14	1.319	1.8	0.25	96.6	-Rain
	June 28	1.319	2.1	0.25	97.6	-Warm temperatures
2005	May 17	1.953	5.4	0.45	90.5	-Rain
	June 17	1.783	15	0.45	105	-Rain
2006	May 20	5.333	76	7	77.9	
2007	June 5	3.876	58.5	4	76.7	
2008						Freshet monitoring not available
2009	May 31	3.578	8.8	0.7	55.5	-Warm temperatures
2010	June 3	2.408	1.5	0.3	90.5	-Warming
	June 14	2.251	5.3	0.55	87.9	-Rain previous day
2011	May 26	3.015	9.8	2	100	-Warm temperatures
	June 21	4.658		0.4	90.6	-Warm temperatures
2012	June 2	2.287	68.3	4.5	88.4	-Rain
	June 7	2.417	39.5	1.4	93.6	-Rain
	June 22	3.440	125	6.8	82.7	-Rain
	June 23	4.013	126		82.1	-Rain, banks overflowing
2013	May 6	1.081	14.3	1.8	110	-Warming
	May 12	2.778		0.65	78.1	-Warming
	May 13	3.239	22	0.8	79.1	-Rain
	May 24	3.239		0.15	92.3	-Warm weather
2014	May 23	3.338		0.45	55.6	-Showers in previous 3 days
	May 25	3.758	7.7	0.55	92	

Any discharges greater than 4 m^3/s are estimates due to difficulties in metering at high flows

10. Appendix 2: Discharge/km² of study creeks compared to other Kootenay streams

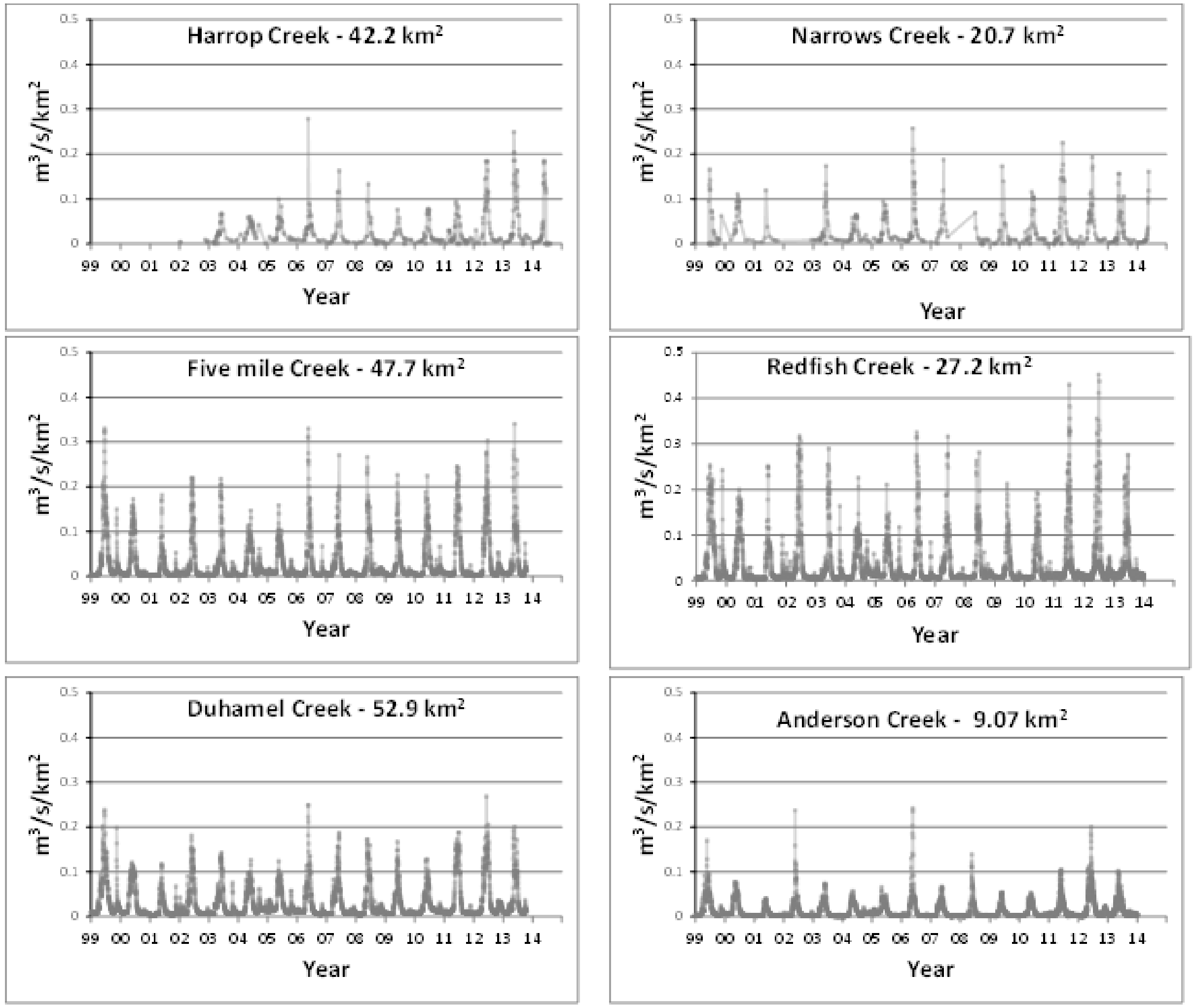


Figure 17. Discharge/km^2 for Harrop, Narrows, Five mile, Redfish, Duhamel and Anderson creeks 1999-14. Data from present study for Harrop and Narrows creeks and WSC (2015) for other streams.

11. Appendix 3: Paired comparisons of turbidity from Redfish Creek and study creeks, 2003-07.

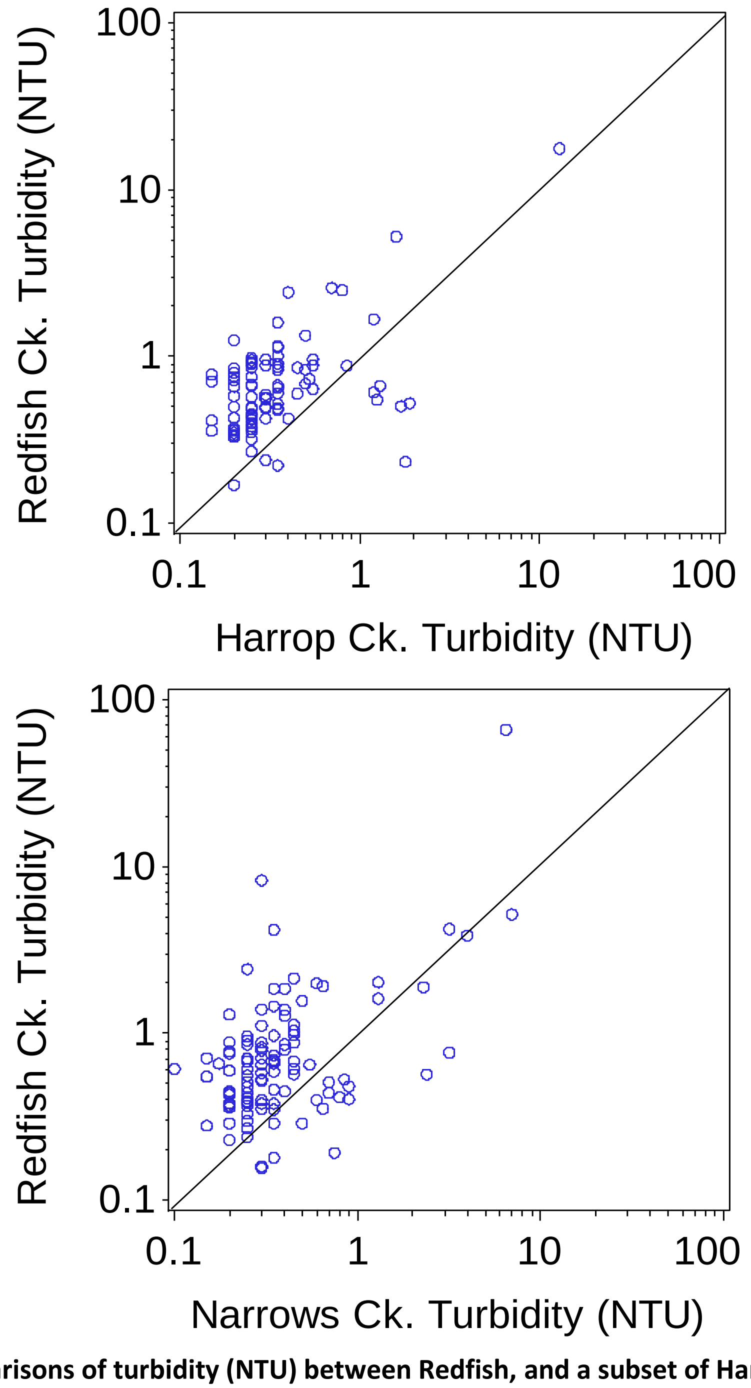
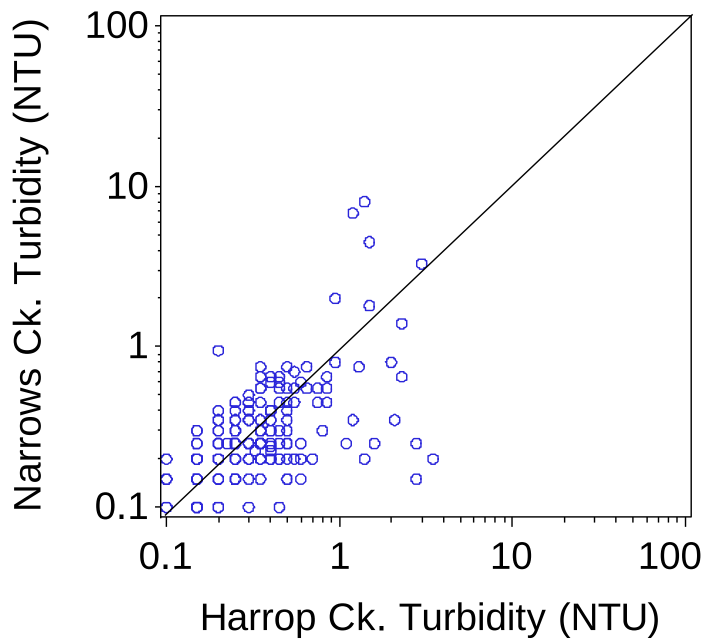


Figure 18. Paired comparisons of turbidity (NTU) between Redfish, and a subset of Harrop and Narrows Creeks collected from 15:00-19:00, 2003-2007. Data for Redfish Creek from Jordan 2008.

12. Appendix 4: Paired comparisons of turbidity from Harrop and Narrows creeks, 2002-14



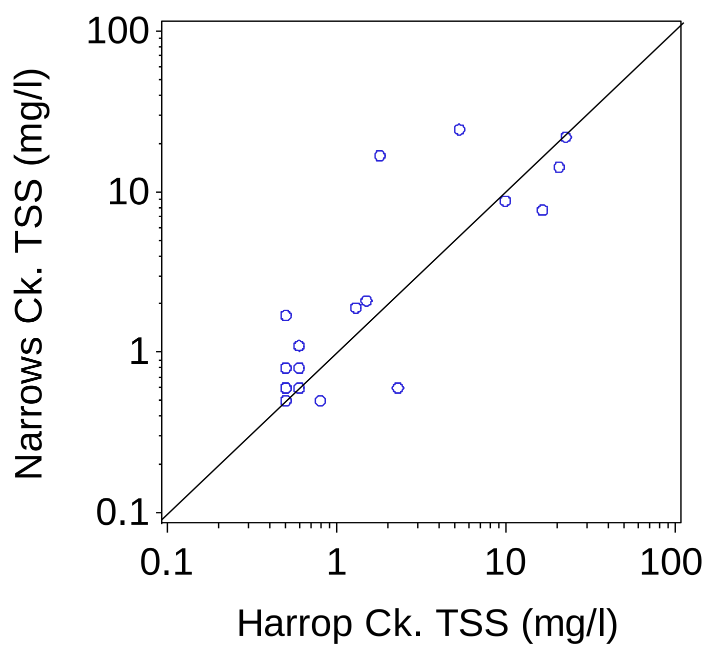


Figure 19. Paired comparisons of TSS (mg/L) between Harrop and Narrows Creeks collected in only in late afternoon constrained to 15:00-19:00, subset from 2002-14.

13. Appendix 5: Log-log plots of TSS concentration versus turbidity

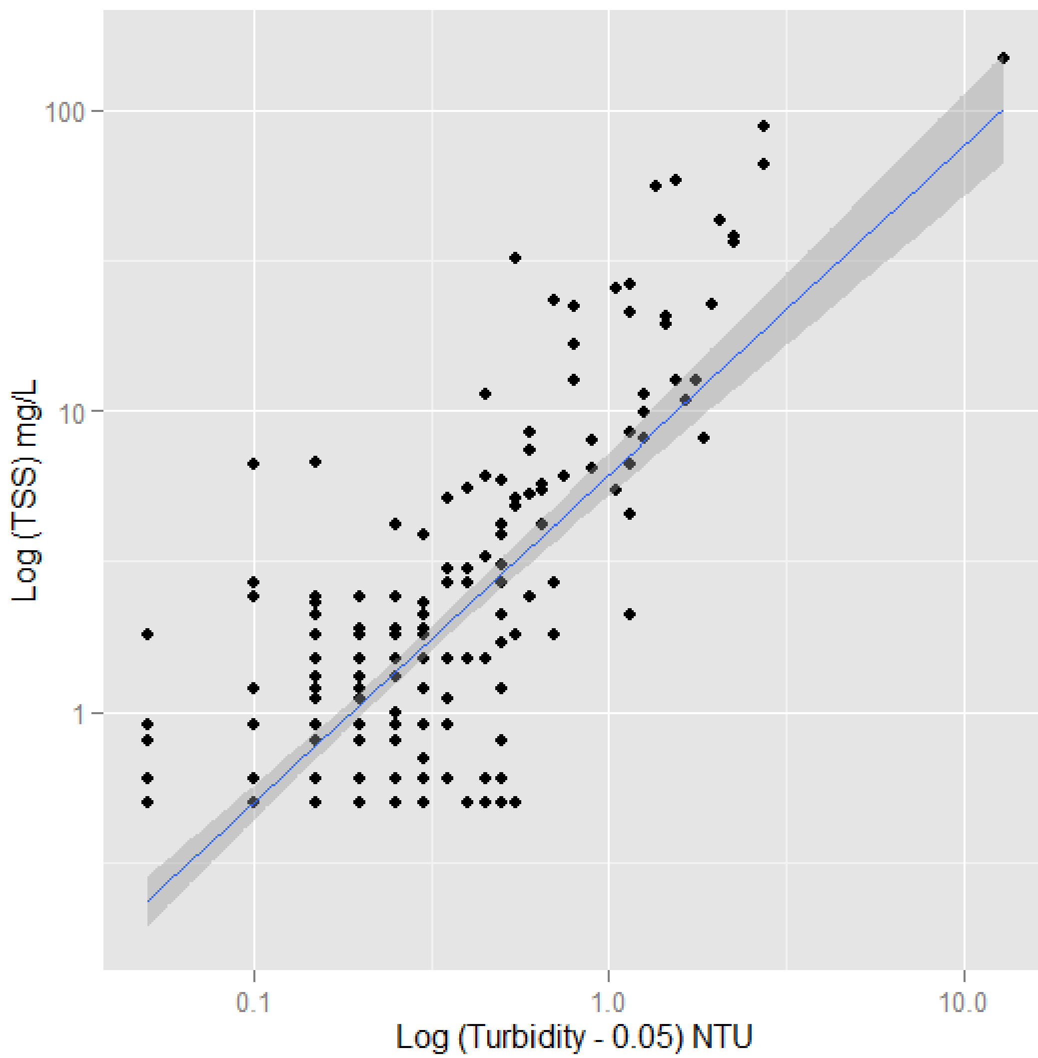


Figure 20. Log (TSS) versus Log(Turbidity – 0.2, NTU) for Harrop Creek Log (TSS)= 1.092*Log(Turbidity – 0.05)+0.790 Adjusted r^2=0.596, p<0.001.

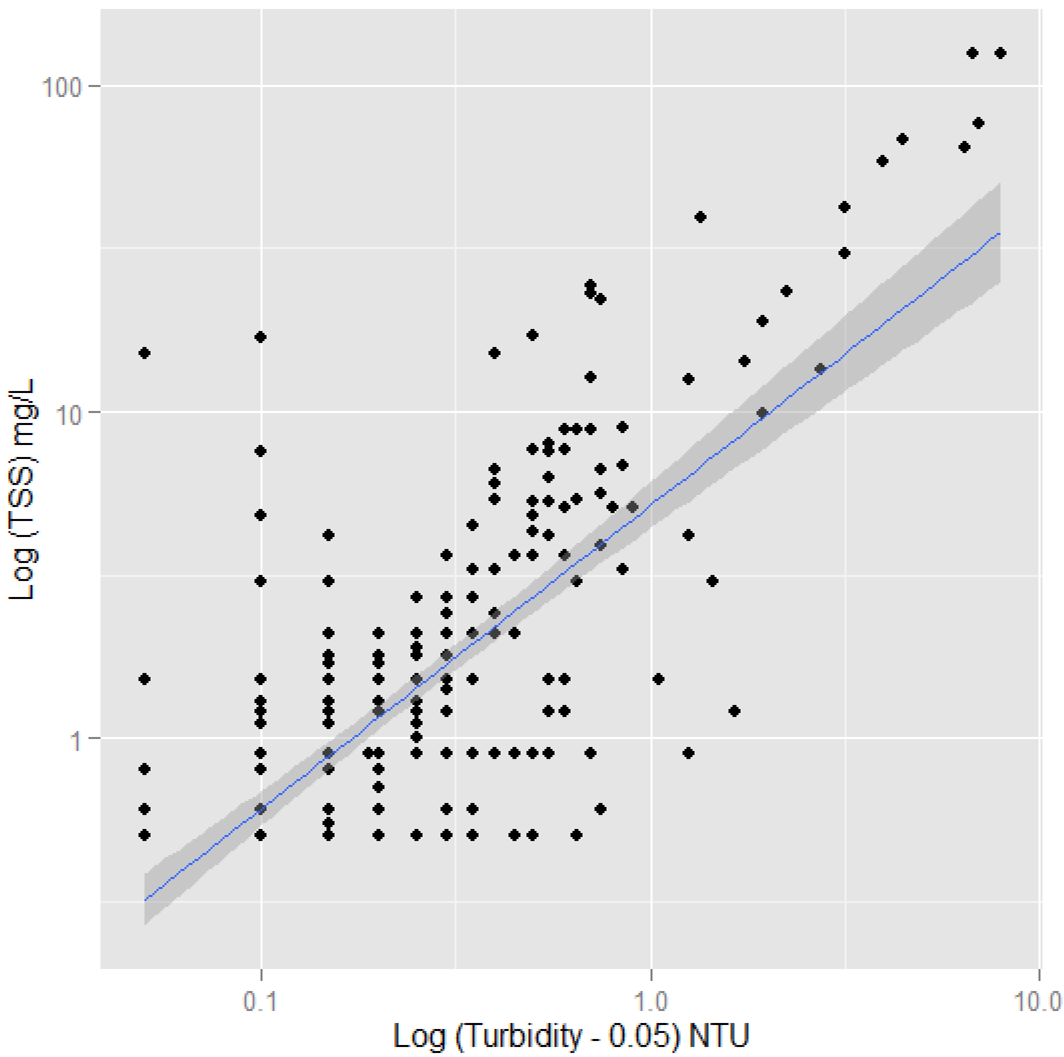
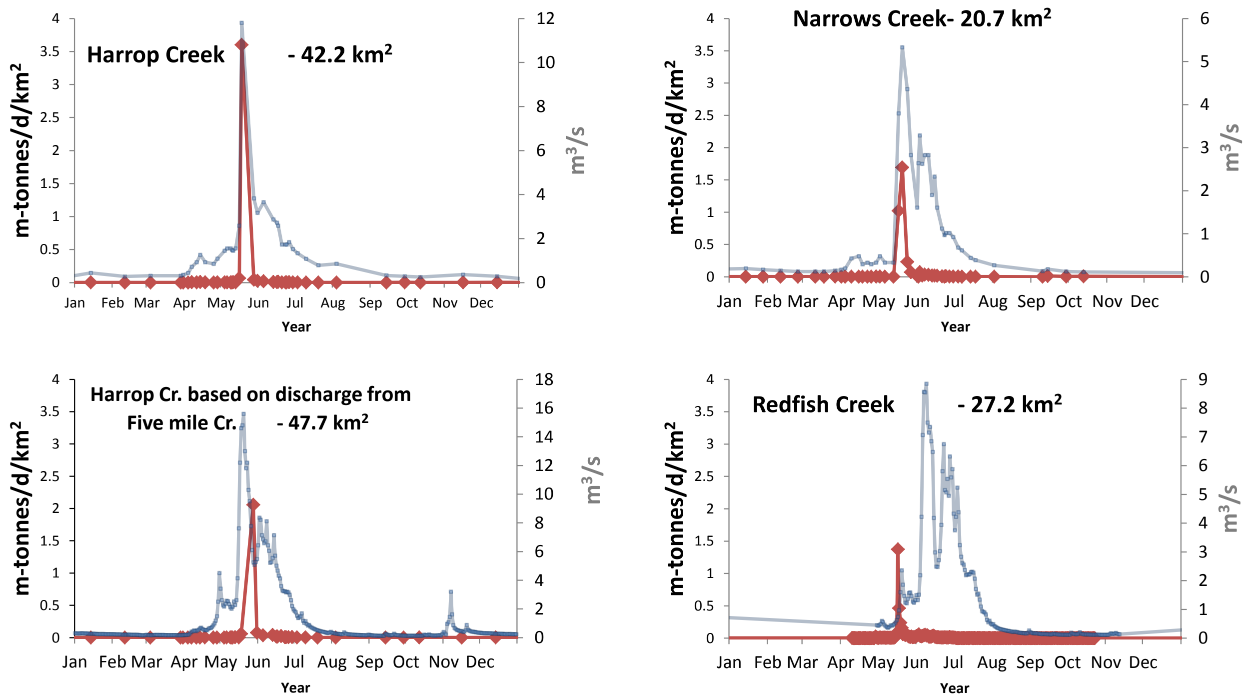


Figure 21. Log (TSS) versus Log(Turbidity – 0.2, NTU) for Narrows Creek Log (TSS)= 0.930 Log(Turbidity – 0.2)+0.714, Adjusted r^2=0.511, p<0.001.

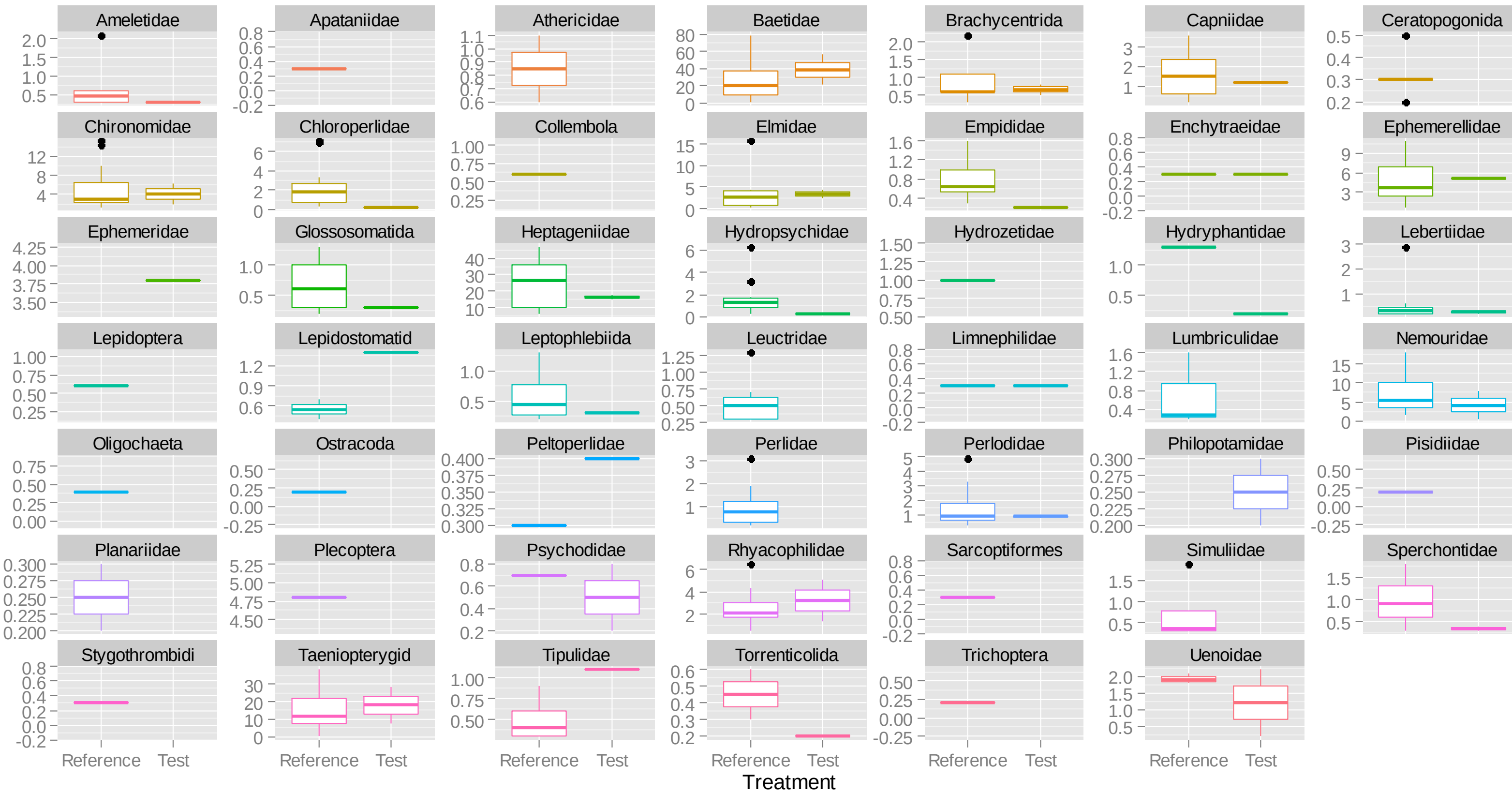
14. Appendix 6: Daily sediment yield of study creeks compared to other local creeks



Discharge data from Five mile and Redfish creeks from Water Survey of Canada (2015). Note: sediment yield for Harrop creek was also calculated using discharge for Five mile Creek for comparison because measurement of flows >4m^3/s on study creeks were estimations.

Figure 22. Daily sediment yield from Harrop, Narrows, and Redfish creeks, 2006.

15. Appendix 7: Macroinvertebrates from reference versus Harrop Creek site samples



Note: Plecoptera and Trichoptera groups are individuals identified to Order because of size or damage, n=12 for CABIN reference group 4 sites and n=2 for test sites.

Figure 23. Percent abundance by macroinvertebrate taxa at reference sites versus Harrop Creek (test) sites.