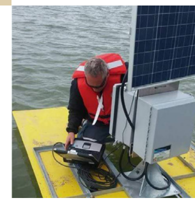
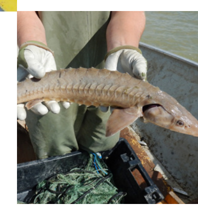
CAMP

Coordinated Aquatic Monitoring Program





Sedimentation and Erosion Studies

Sediment Transport using Continous Turbidity on the Burntwood River and Nelson River System, 2016

June 2018

COORDINATED AQUATIC MONITORING PROGRAM

SEDIMENTATION AND EROSION STUDIES

SEDIMENT TRANSPORT USING CONTINUOUS TURBIDITY ON THE BURNTWOOD RIVER AND NELSON RIVER SYSTEM, 2016

June 2018

This report should be cited as follows:

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EXECUTIVE SUMMARY

This report examines sediment transport processes within the Burntwood River and lower Nelson River systems. The analysis and results were used to aid the Coordinated Aquatic Monitoring Program in developing a system wide sediment monitoring program. The report uses data collected in 2008 under previous monitoring programs related to Wuskwatim, Keeyask and Conawapa physical environment sedimentation and erosion studies. Sediment loads were derived using continuous turbidity at sites located across the system.

Data analysis resulted in the following observations:

- turbidity shows no major correlations to discharge, while sustained increases in wind speed increased turbidity.
- Some lakes appear to act as sediment traps and sediment sources, while others act predominantly as sediment traps.
- Continuous data allows for a better determination of sediment sources and sinks as well as the full range of turbidity/sediment variability and events, that is not available from discrete sampling.
- When using turbidity to estimate sediment concentrations the relationship needs to be evaluated on a site-by-site basis.

STUDY TEAM

This report was prepared by Manitoba Hydro's Water Resource Engineering Department for the Coordinated Aquatic Monitoring Program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 Introduction

This report examines suspended sediment transport processes within the Burntwood River and lower Nelson River systems and is being prepared as a part of the Coordinated Aquatic Monitoring Program (CAMP). The purpose of the report is to analyze previously collected data (from 2008) to gain a better understanding of the sedimentation processes on the river systems with the intent of informing the CAMP about the type of data collected and the expected results; this information will be useful in discussion about the future monitoring requirements of the CAMP.

The report uses data collected in 2008 under previous data collection programs related to Wuskwatim, Keeyask and Conawapa physical environment sedimentation and erosion studies. The report brings the data collected under the different projects together to provide a broad view over the study area from Kinosaskaw Lake (upstream of Wuskwatim Lake) to the Nelson River downstream of the Limestone Generating Station (Map 1), a distance of over 350 km. The report divides the entire study area into several distinct areas: Kinosaskaw Lake to Wuskwatim Lake; Wuskwatim Lake to Split Lake; Split Lake, Spit Lake to approximately 35 km downstream of the Limestone Generating Station (GS) near the Angling River.

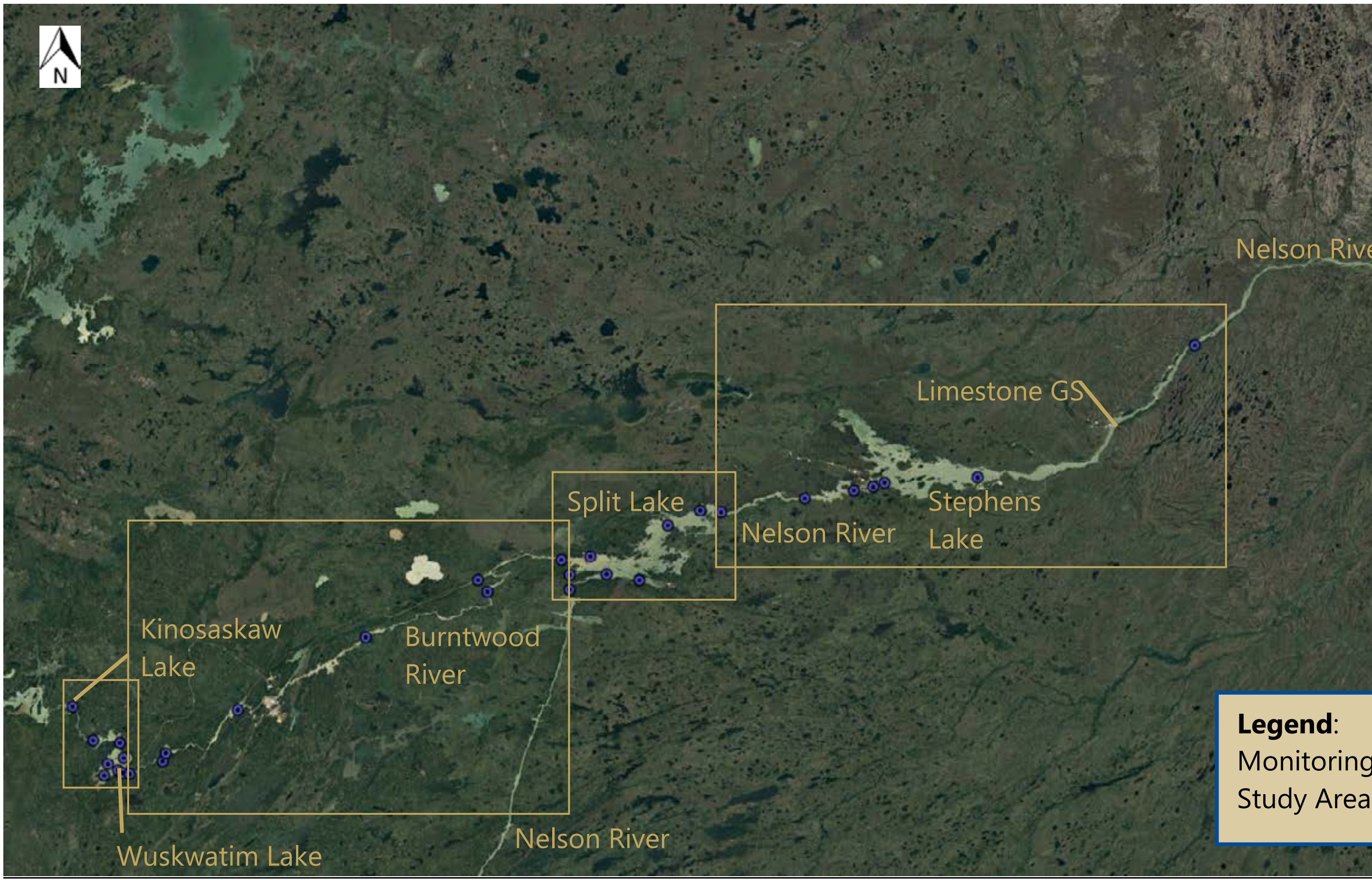

Figure 1: Study Areas and Monitoring Sites

2.0 Data Sources

Data used in this report comes from a variety of sources. The sedimentation data used in this report was collected by KGS Acres (now Hatch) and is from the 2008 openwater season (approximately June to October) prior to the Wuskwatim GS going into operation in 2012. The data includes:

- Sites from Kinosaskaw Lake, upstream of Wuskwatim Lake, to the lower Nelson River downstream of the Limestone Generating Station.
- Turbidity loggers installed at 2 m below the surface of the water.
- 15-minute average data based on data collected at 30-second intervals with outliers removed from the data set before averaging.

- Discrete total suspended sediment and turbidity data collected at the logger locations approximately once per month.

Other data used in the report includes:

- Climate data (wind, precipitation) taken from the Environment Canada station located in Thompson, Manitoba.
- Water level and discharge data collected by Manitoba Hydro.

3.0 Methodology

The report utilizes continuous turbidity data to provide a detailed temporal analysis of sediment transport (i.e. sediment concentrations and sediment loads). The benefits of using continuous data includes the ability to see how sediment moves through the system by observing changes in turbidity over time at sites located along the river systems and the ability to observe relatively short events such as sediment peaks due to storms.

Other studies have indicated that the Burntwood River and Nelson River are generally well mixed; therefore, this report assumes that the water bodies are well mixed at the monitoring location (i.e. indicating that the monitoring data is representative of the area).

One of the issues using turbidity is that the relationship between turbidity and TSS can vary from place to place and over time as previous turbidity – TSS relationship studies on the Burntwood River and Nelson River reported. Turbidity data is a measure of water clarity and it is well documented the turbidity changes with changes in sediment properties. To account for this, the turbidity-TSS relationships were examined for each site and individually equations prepared for each site or groups of nearby sites that showed similar relationships.

The suspended sediment load was calculated using the following equation:

$$Q_s = (TSS_{calc} * Q) / 1000^{3}$$

Where:

Q_s = Suspended Sediment Load (T/day)

TSS_{calc} = Calculated TSS using derived Turbidity-TSS relationship equation (mg/L)

Q = River Discharge (m^3/s)

To calculate the sediment load, missing time steps in the turbidity record were in-filled by estimating the turbidity values by looking at data before and after the missing time step and looking at trends from adjacent sites. Comparisons of measured TSS to calculated TSS are shown in Appendix A.

4.0 Anaylsis and Observations

4.1 Kinosaskaw Lake to Wuskwatim Lake

The reach from Kinosaskaw Lake to Wuskwatim Lake (Figure 2) is located on the Churchill River Diversion. The Churchill River Diversion (CRD) diverts the majority of the Churchill River flow into the Rat River-Burntwood River-Nelson River system and influences the flow and water levels along the entire Burntwood River reach. Manitoba Hydro controls the outflow from SIL into the Burntwood system at the Notigi Control Structure.

Water levels increased in the Notigi forebay from June to mid-August, 2008, while river discharge dropped resulting in corresponding dropping water levels in downstream Footprint and Wuskwatim lakes (Figure 3). From mid-August to October, discharge increased resulting in a lowering of Notigi forebay levels and increased water levels on the downstream lakes.

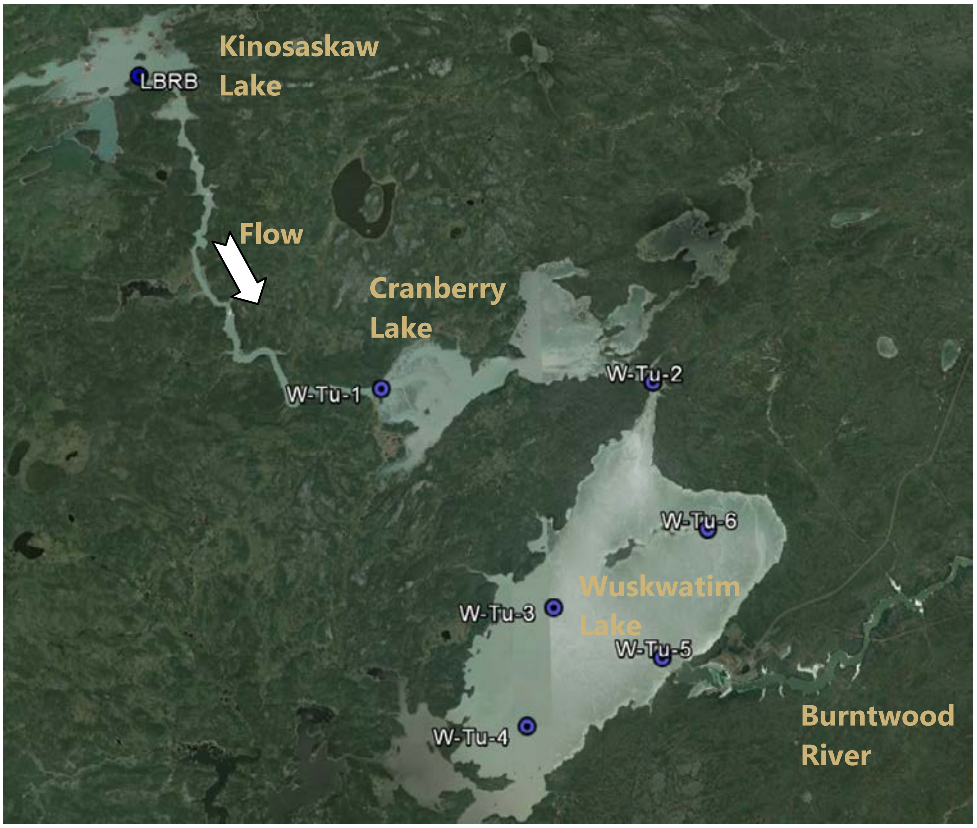

Figure 2 Kinosaskaw Lake to Wuskwatim Lake Monitoring Locations

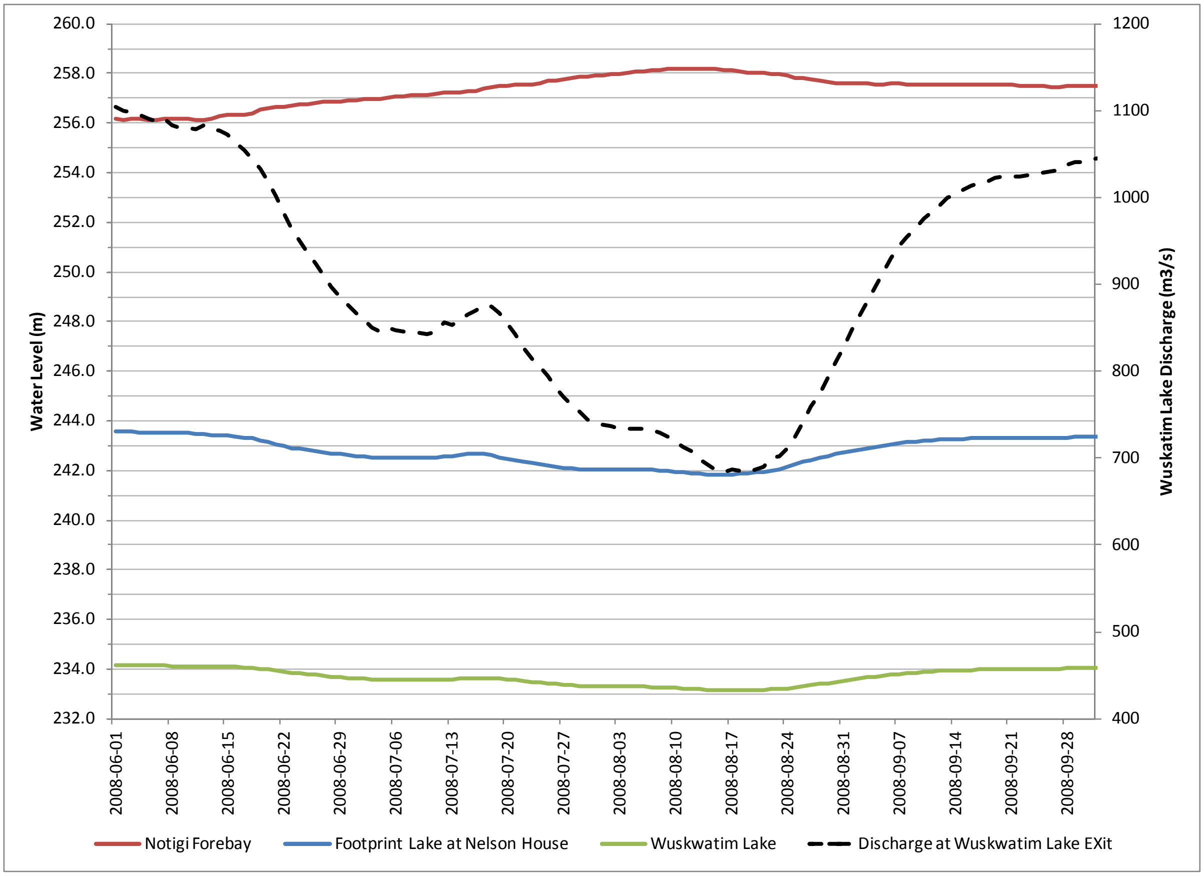

Figure 3 Water Levels and Discharge on CRD System

Figure 2 shows the location of the seven continuous turbidity loggers installed within this area. The sites are located near the inlets and outlets of the lakes with three additional sites on Wuskwatim Lake to monitor turbidity in different regions of the lake. The majority of the sites have data from early June until late September.

The continuous turbidity data (Figure 4) collected at the sites shows a general increase from early June until late August after which levels decreased slightly. There are several times when turbidity increased relatively quickly across the study reach.

The range and mean of the results (Table 1) indicate that the continuous data has a larger range and the average turbidity data is slightly higher. Most notable is the difference in maximum values, with maximum continuous values reported from 20% to 82% higher at the three sites compared with the discrete values. This is likely partially attributed to field sampling and the challenge of sampling during stormy weather when, as discussed later, turbidity levels can increase.

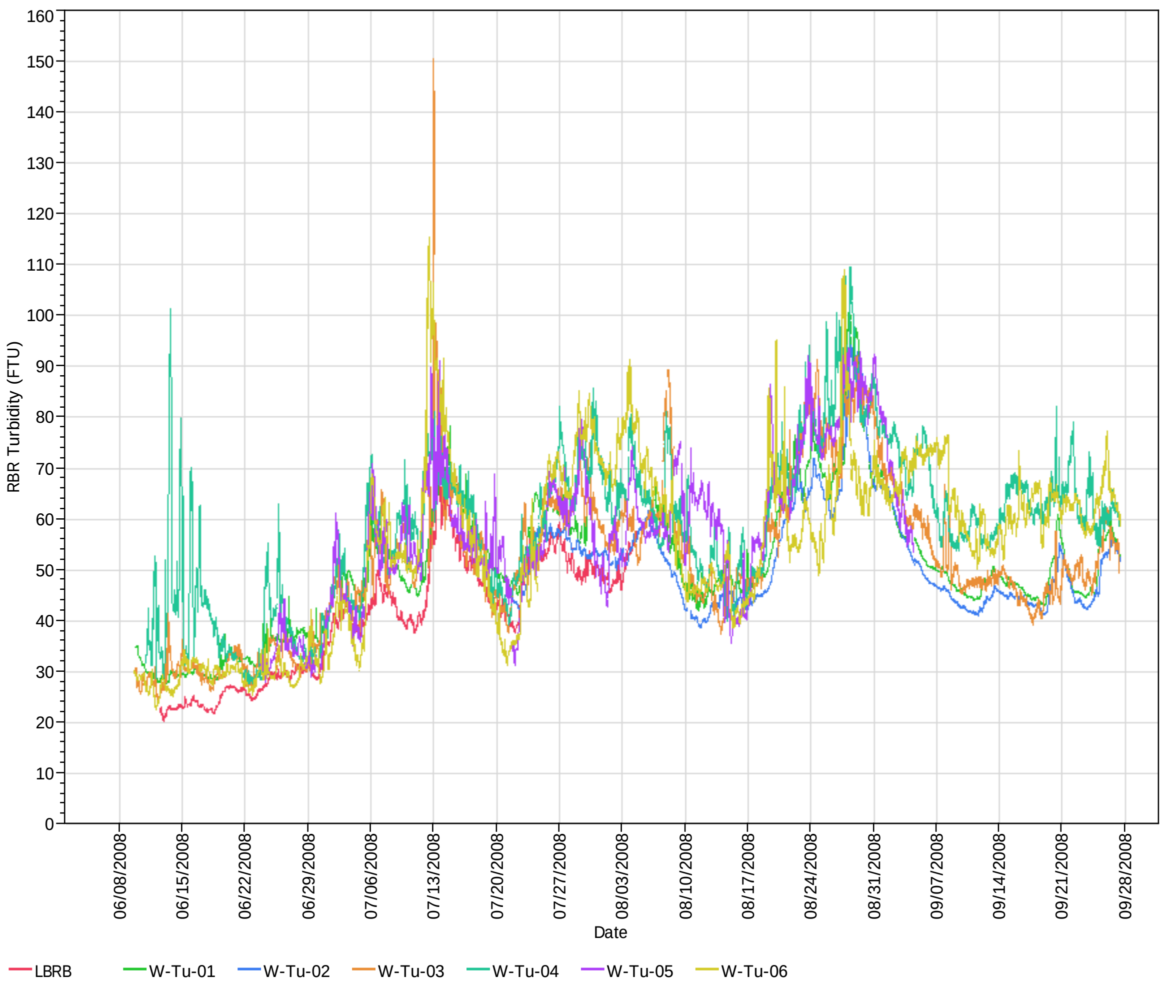

Figure 4 Continuous Turbidity from Kinosaskaw Lake to Wuskwatim Lake

Table 1 Summary Statistics of Turbidity and TSS Data from Kinosaskaw Lake to Wuskwatim Lake

Site ID	Total Suspended Sediment (mg/L)			Discrete RBR Turbidity (FTU)			Continuous RBR Turbidity (FTU)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
LBRB	7.0	11.4	18.3	23.5	40.4	55.6	20.3	40.4	70.2
W-Tu-01	11.3	16.5	25.4	36.0	48.3	56.0	27.5	50.3	102.1
W-Tu-02	9.0	14.2	19.6	33.3	50.7	76.2	38.7	52.6	94.2
W-Tu-06	2.7	8.2	16.1	30.0	49.4	73.0	22.6	54.5	115.4
W-Tu-03	6.8	12.3	22.1	30.7	53.3	76.6	23.8	51.9	150.5
W-Tu-04	5.7	12.1	22.6	31.0	50.9	66.1	27.3	58.7	109.6
W-Tu-05	5.4	12.7	23.2	31.6	50.8	77.9	28.0	58.1	93.7

Turbidity is highly correlated between the exit of Kinosaskaw Lake and entrance of Cranberry Lake and is observed increasing along the Burntwood River and decreasing through Cranberry Lake (Figure 5). The Cranberry Lake inflow (W-Tu-01) turbidity levels are consistently higher than outflow (W-Tu-02) turbidity levels by an average of 3.5 FTU as determined from a matched pairs' analysis; this equates to a calculated TSS of 1.5 mg/L. In comparison, the difference in measured TSS from water samples collected at the two sites is 2.3 mg/L, similar to inflow turbidity.

Comparing the sites at the inlets to Cranberry Lake (W-Tu-01) and Wuskwatim Lake (W-Tu-02) to the Wuskwatim Lake outlet (W-Tu-05) shows there are processes occurring in Wuskwatim Lake that affect the turbidity (Figure 6). While the general pattern of Wuskwatim Lake outflow turbidity follows that of the inflow to Cranberry and Wuskwatim Lakes, the outflow turbidity is more variable on short time scales and at times deviates from the inflow pattern. The turbidity can be lower or higher than the inflows, being on average 2.7 FTU higher than the Cranberry Lake inflow or 7.8 FTU higher than the Wuskwatim Lake inflow (matched pairs' analysis).

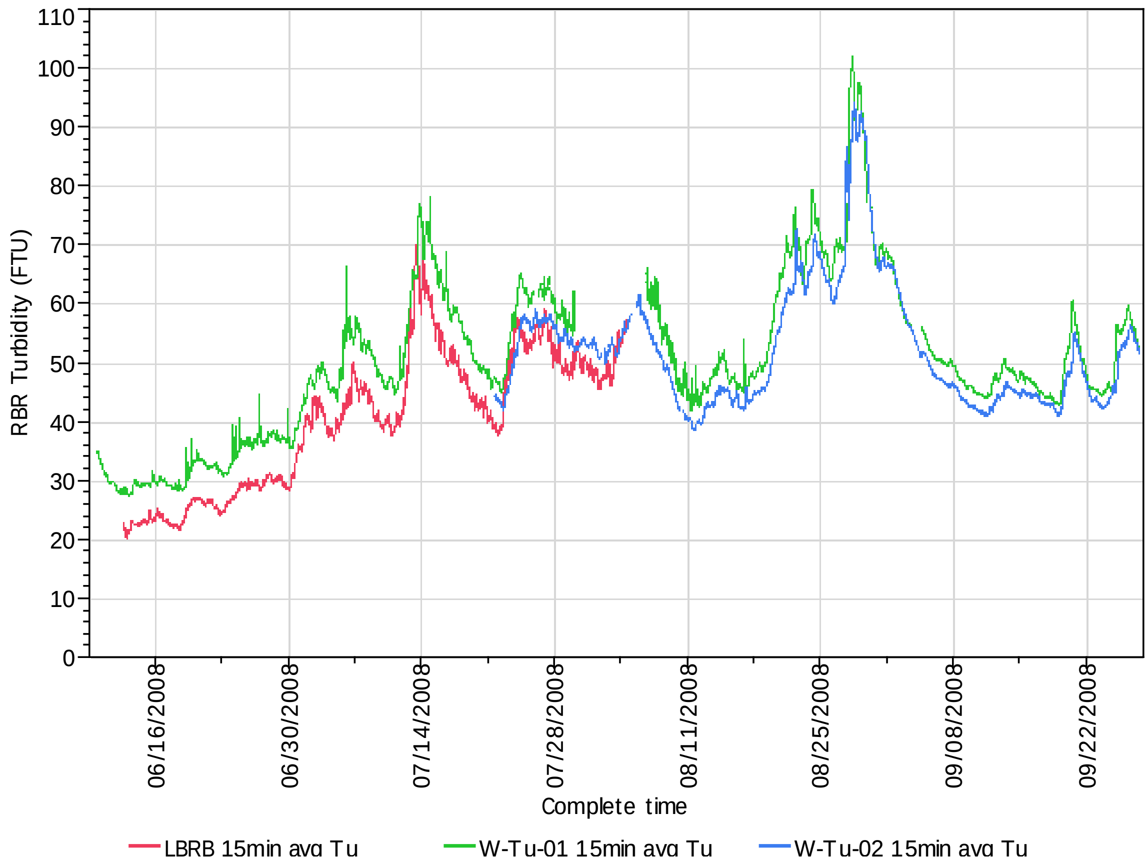

Figure 5 Turbidity at Kinosaskaw Lake Exit and Inlet to Cranberry and Wuskwatim Lakes

The measured TSS results show different results and are lower at W-Tu-05 than at W-Tu-01 and W-Tu-02. When comparing measured TSS concentrations (Table 1), the average outflow (W-Tu-05) TSS is 3.8 mg/L lower than the Cranberry inflow (W-Tu-01) and 1.5 mg/L lower than the Wuskwatim Inflow (W-Tu-02). Discrete data from 2005 and 2007 also showed a decrease in measured TSS between the inlet and outlet of Wuskwatim Lake (KGS Acres, 2009). The differences demonstrate challenges in estimating sediment transport and may be related to changes in sediment characteristics that can affect turbidity and instrument/sampling accuracy.

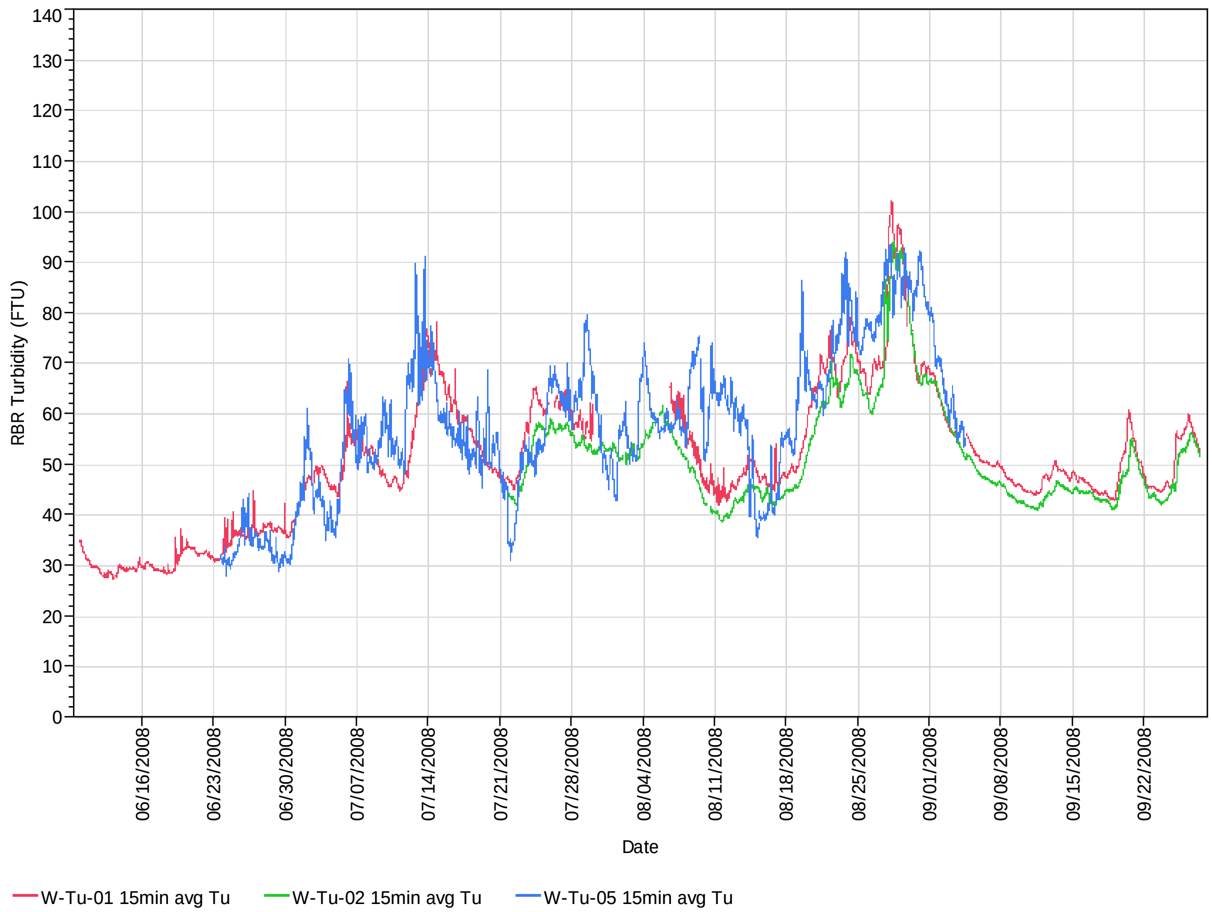

Figure 6 Turbidity from Inlet of Cranberry Lake to Exit of Wuskwatim Lake

Figure 7 compares turbidity, water discharge, precipitation and wind speed; a number of observations are noted:

- There is no correlation between instantaneous discharge and turbidity. While discharge was dropping from 1,000 to 700 m3/s the turbidity rose from 30 to 80 FTU over a period of 19 days with several cycles of increasing and decreasing turbidity.
- Windy days appear to increase turbidity and successive windy days further increases turbidity with each period of wind. This suggests that wind is a major driver regarding sediment mobilization.
- The sediment leaving Wuskwatim Lake is likely a combination of the sediment coming into the lake and sediment related to wind/wave driven processes within the lake.
- Rainfall appears to have little to no effect on turbidity levels.

- It is difficult to develop statistical relationships due to the complex nature of the turbidity response to wind.

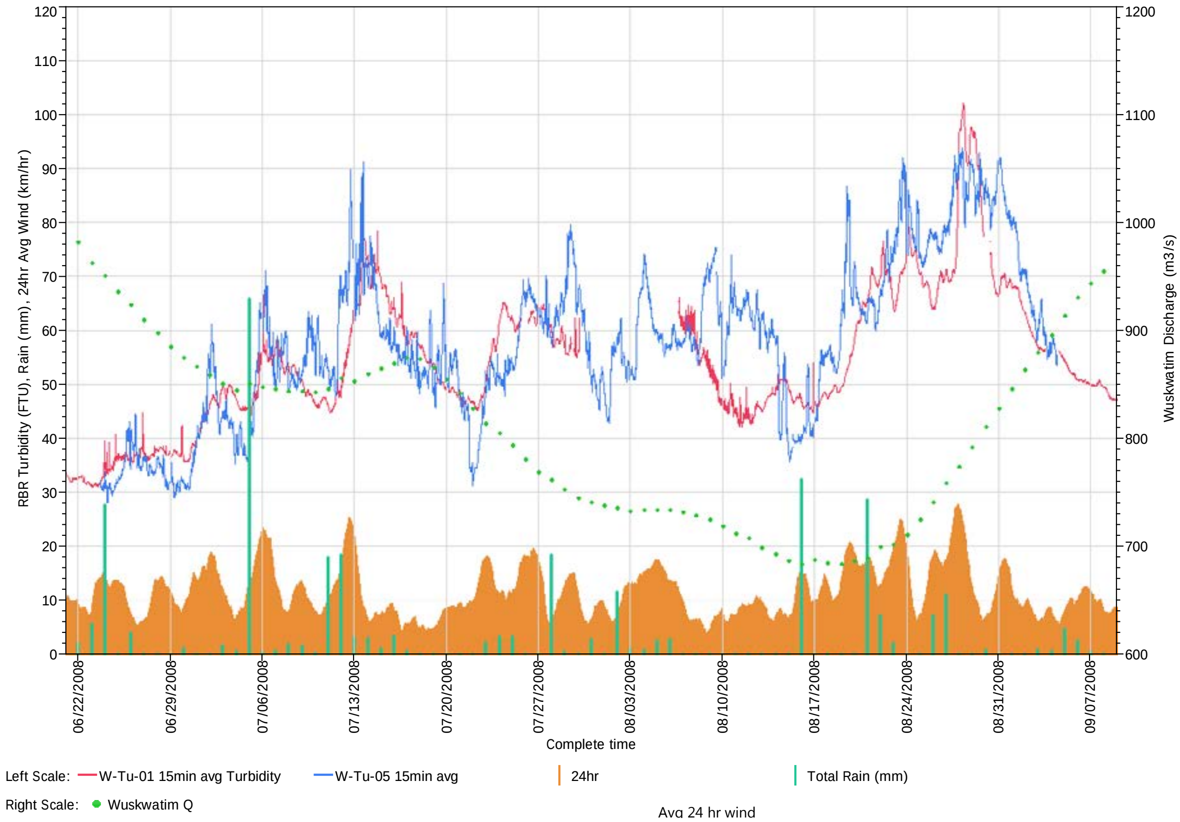

Figure 7 Turbidity at Inlet of Cranberry Lake and Exit of Wuskwatim Lake

Periods of hysteresis (i.e. the lag in response exhibited by a turbidity/sediment in reacting to changes in the wind) are observed in a counter-clockwise direction when comparing the 24-hr average wind speed and turbidity (Figure 8). Hysteresis is more strongly observed at W-Tu-02 than at W-Tu-05 where turbidity is sustained at a higher level after the wind speeds have dropped.

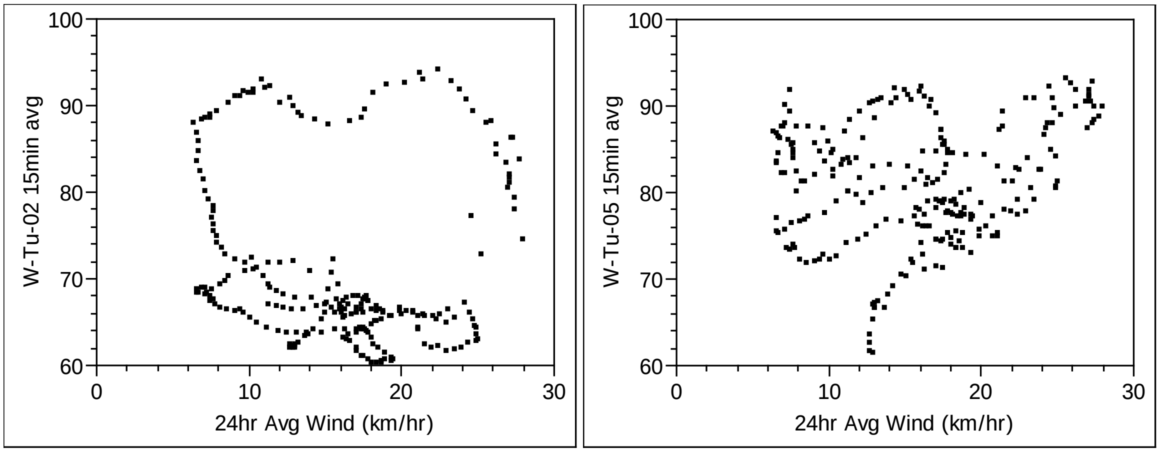

Figure 8 Wind - Turbidity Hysteresis for Time Period 08/21/2008 to 09/01/2008

Continuous turbidity from Wuskwatim Lake (Figure 9) shows that in general, turbidity across the lake follows the same trends in rise and falls, following the general pattern set by the inflows to the Lake. However, turbidity varies between sites including periods of time when turbidity in parts of the lake can be much different from other areas. In mid-June, the south part of the lake (W-Tu-04) has periods of turbidity 2 to 3 times higher than in the other areas (note that some loggers have no data at that time).

Turbidity at W-Tu-06 (located between the entrance and exit) is regularly higher than at the entrance (W-Tu-02) which is an indication that there is additional sediment being suspended after water enters Wuskwatim Lake. Although deposition may occur at the entrance to Wuskwatim Lake, it is likely that most material would stay in suspension as any larger material carried in the river would likely deposit upstream in Cranberry Lake.

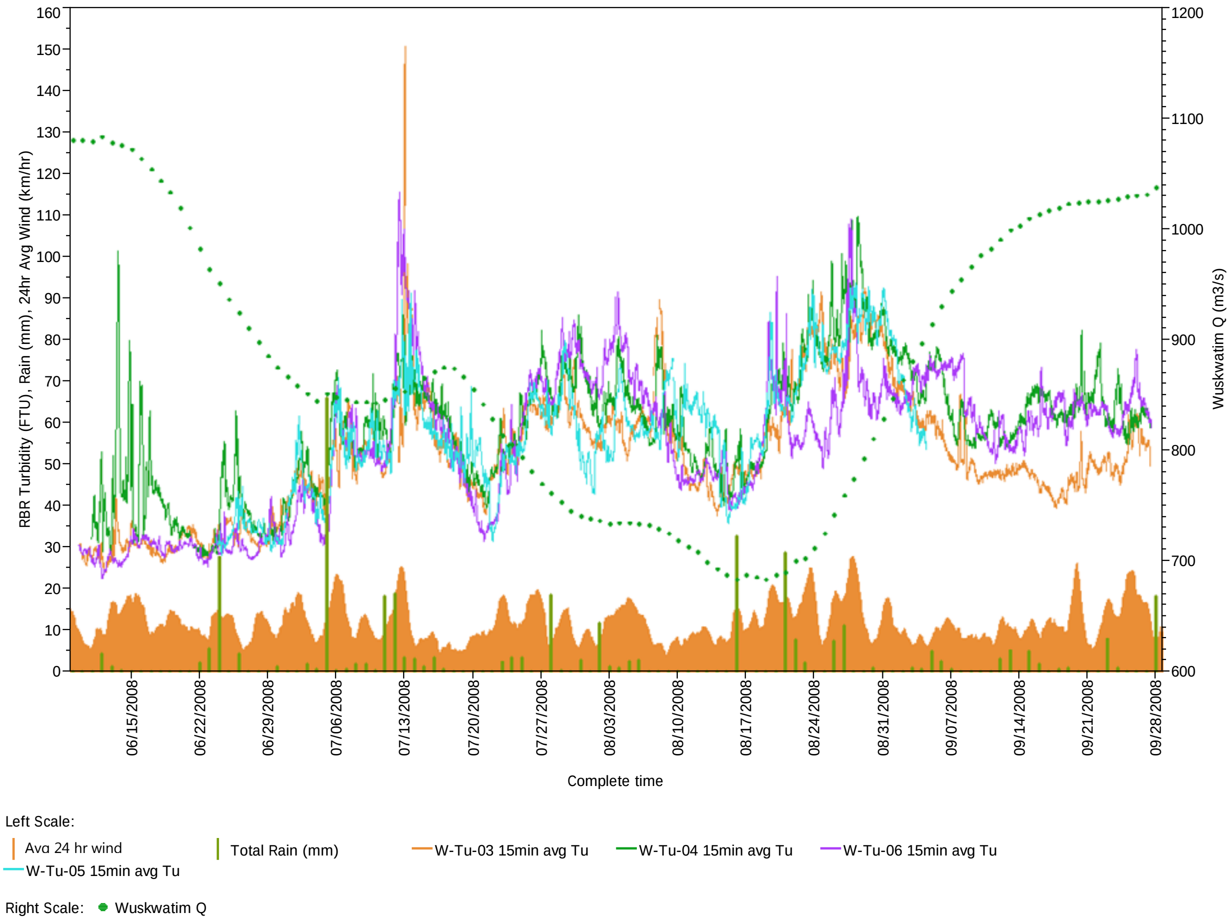

Figure 9 Turbidity in Wuskwatim Lake

The general level of turbidity throughout the season is observed in the average weekly data (Figure 10). The average weekly turbidity ranged from approximately 30 to 80 FTU with the highest average at most sites observed in the week starting August 24th (week 35).

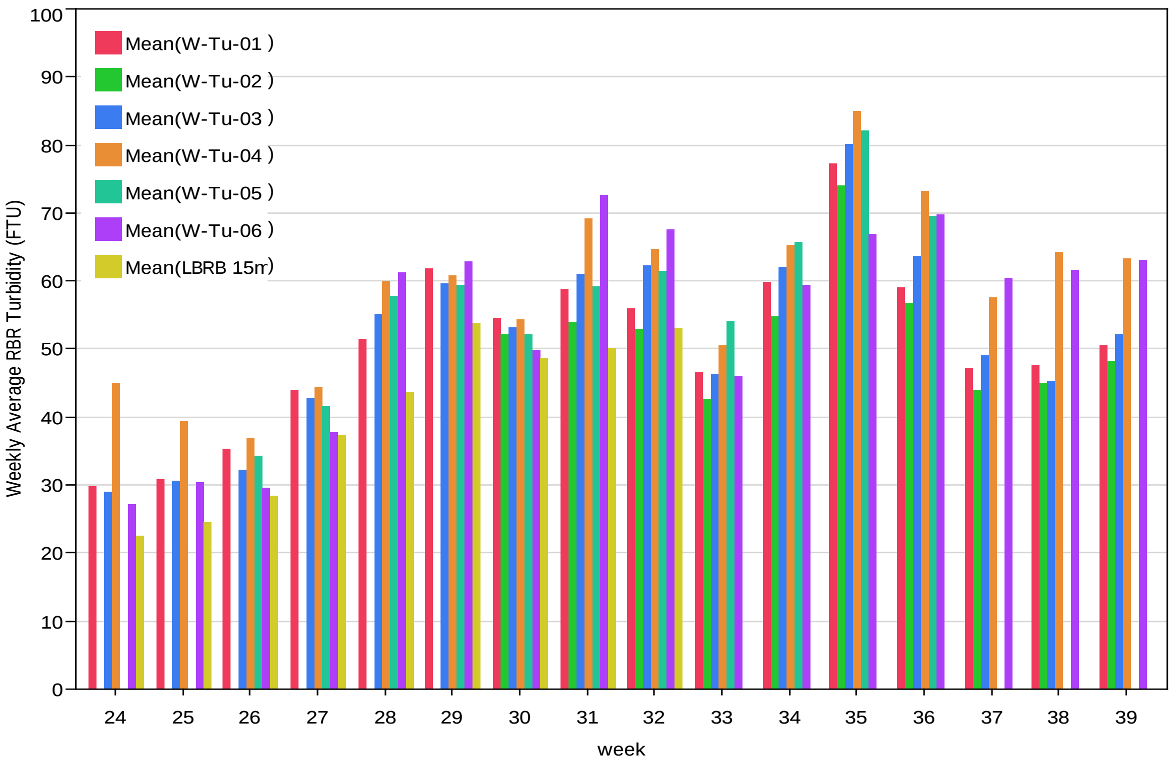

Figure 10 Weekly Average Turbidity from Kinosaskaw Lake to Wuskwatim Lake

Suspended sediment load was calculated at the inlets to Cranberry Lake (W-Tu-01), Wuskwatim Lake (W-Tu-02) and the exit of Wuskwatim Lake (W-Tu-05). The analysis shows there is not a very large difference in the daily sediment loads (within 5%) at the three locations (Table 2, Figure 11). Mid-July and late August showed the highest sediment load, corresponding to periods of high turbidity, and the maximum daily load is over two times higher than the lowest period.

Table 2: Cranberry/Wuskwatim Lake Suspended Sediment Load

Site ID	Daily Mean (T/day)	Daily Min (T/day)	Daily Max (T/day)	Sum (T in 71 days)
W-Tu-01	650	480	1050	46,440
W-Tu-02	620	450	1000	44,000
W-Tu-05	660	410	1050	47,200

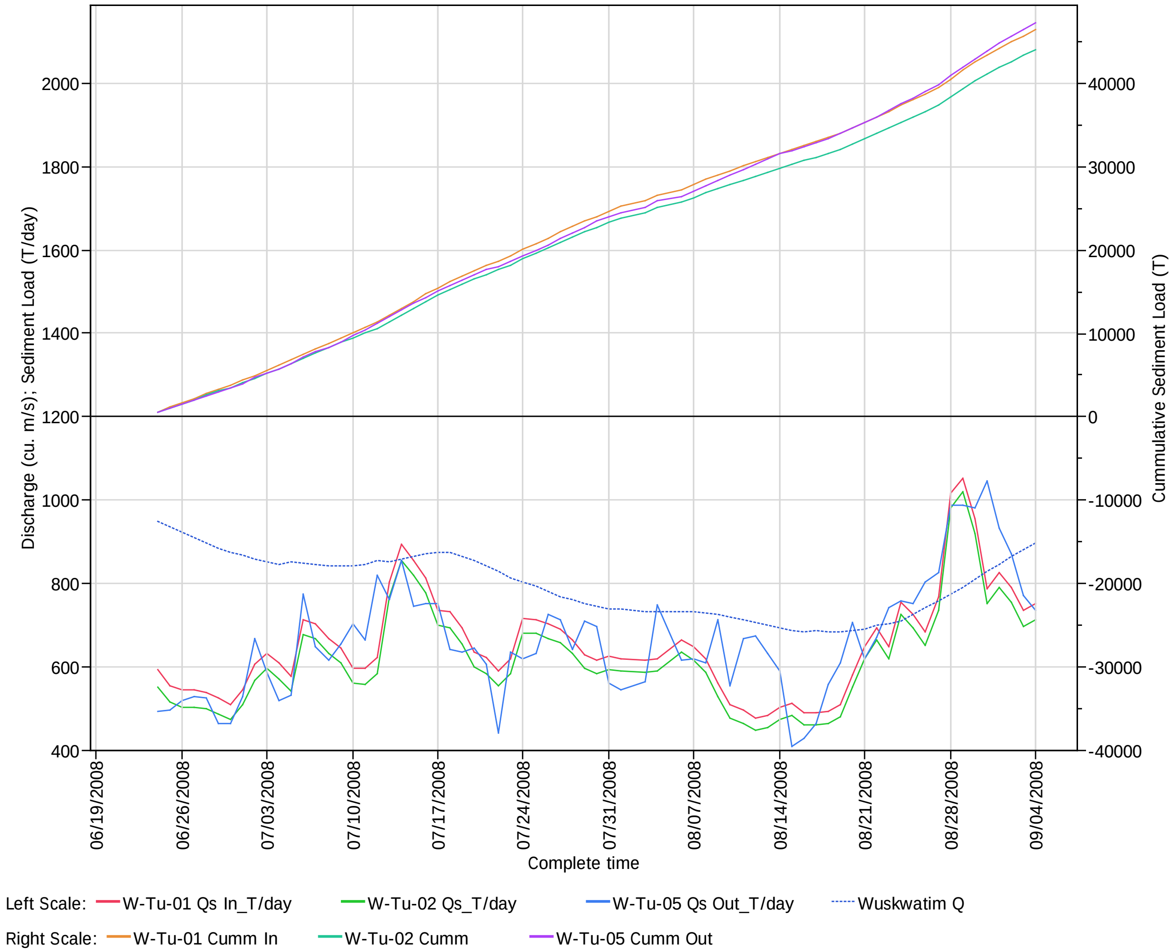

Figure 11 Weekly Average Turbidity from Kinosaskaw Lake to Wuskwatim Lake

Differences in sediment load were calculated between: the inlet and outlet of Cranberry Lake (W-Tu-02 minus W-Tu-01); the inlet and outlet of Wuskwatim Lake (W-Tu-05 minus W-tu-02); and between the inlet of Cranberry Lake and outlet of Wuskwatim Lake (W-tu-05 - W-Tu-01). The data (Figure 12) shows that there was a net deposition in Cranberry Lake (blue line) and a net export from Wuskwatim Lake (green line) which showed some periods with little difference between input and output. There is almost the same amount of sediment entering Cranberry Lake as leaving Wuskwatim Lake over the period (red line), but about 2,440 T or 5% deposited in Cranberry Lake and about 3,200 T or 7% were gained from Wuskwatim Lake over 71 days.

Between the two lakes, there was net deposition occurring until early August and then a net export over the last part of the period. By the end of the period, slightly more sediment had left the area than was received. It is not clear why the rate of sediment leaving Wuskwatim Lake changed to be greater than the rate of sediment coming into Cranberry Lake in early August.

This data suggests that the lakes can act as sediment sinks, where sediment from the incoming flow deposits and sediment sources, where the lakes contribute to the sediment load in the flow leaving the lake.

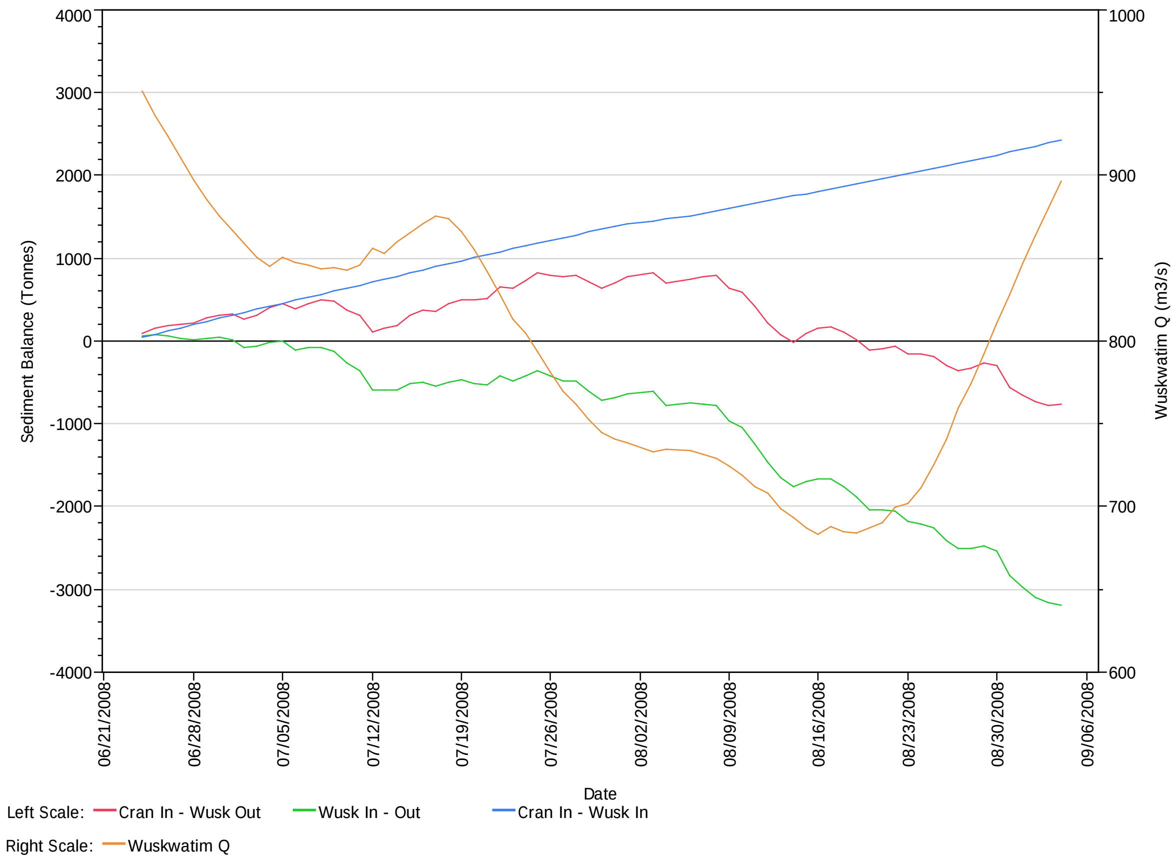

Figure 12 Sediment Balance on Cranberry and Wuskwatim Lakes

4.2 Burntwood River (Wuskwatim Lake to Split Lake)

This reach covers the Burntwood River from Wuskwatim Lake to the Split Lake (Figure 13). The river flows through Opegano, Birch Tree, and Apussigamasi Lake before reaching Split Lake. The Odei River is a major tributary that flows into the Burntwood River approximately 21 km upstream of Split Lake. Discharge along this reach is very similar to the discharge leaving Wuskwatim Lake and for this report are assumed to be equal.

In 2008, six continuous turbidity loggers were installed from the exit of Wuskwatim Lake to the mouth of the Burntwood River at Split Lake; this includes one logger on the Odei River upstream of the confluence with the Burntwood River.

Comparing discrete and continuous data reveals similar trends between the sites; however, the average continuous turbidity data is higher by as much as 14% (Table 3). Continuous turbidity from all the Burntwood River sites follow similar patterns and show moderate to very good correlations (Table 4) even without compensating for travel time. Turbidity and TSS generally increases from upstream to downstream along the Burntwood River and varies considerably throughout the period. Similar to the Wuskwatim Lake area, turbidity does not correlate with discharge and is observed to peak after multiple wind events in mid-June and late August (Figure 14).

Figure 13 Burntwood River Monitoring Locations

Table 3: Summary Statistics of Turbidity and TSS Data

Site ID	Total Suspended Sediment (mg/L)			Discrete RBR Turbidity (FTU)			Continuous RBR Turbidity (FTU)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
W-Tu-05	5.4	12.7	23.2	31.6	50.8	77.9	28.0	58.1	93.7
W-Tu-11	8.4	16.0	22.4	47.8	62.3	86.2	39.9	63.7	116.7
W-Tu-12	5.0	18.2	26.2	35.6	62.4	85.6	45.1	68.9	122.1
W-Tu-13	12.6	23.4	30.9	57.2	67.1	88.6	54.1	77.1	137.2
OD1	5.2	10.2	18.1	21.9	35.7	50.9	16.8	48.6	127.3
W-Tu-14	11.2	22.2	33.1	54.7	68.4	78.5	59.7	76.3	135.9

Table 4: Turbidity Correlation between Sites

Site ID	W-Tu-11	W-Tu-12	W-Tu-13	W-Tu-14
	Correlation (r^2)			
W-Tu-05	0.66	0.78	0.76	0.61
W-Tu-11		0.84	0.84	0.73
W-Tu-12			0.95	0.82
W-Tu-13				0.92

The turbidity levels throughout the season are also shown as average weekly data (Figure 15). The average weekly turbidity on the Burntwood River ranged from approximately 50 to 100 FTU with the highest average at most sites observed in the week starting August 24th (week 35), the same week that peak turbidity was observed in Wuskwatim Lake.

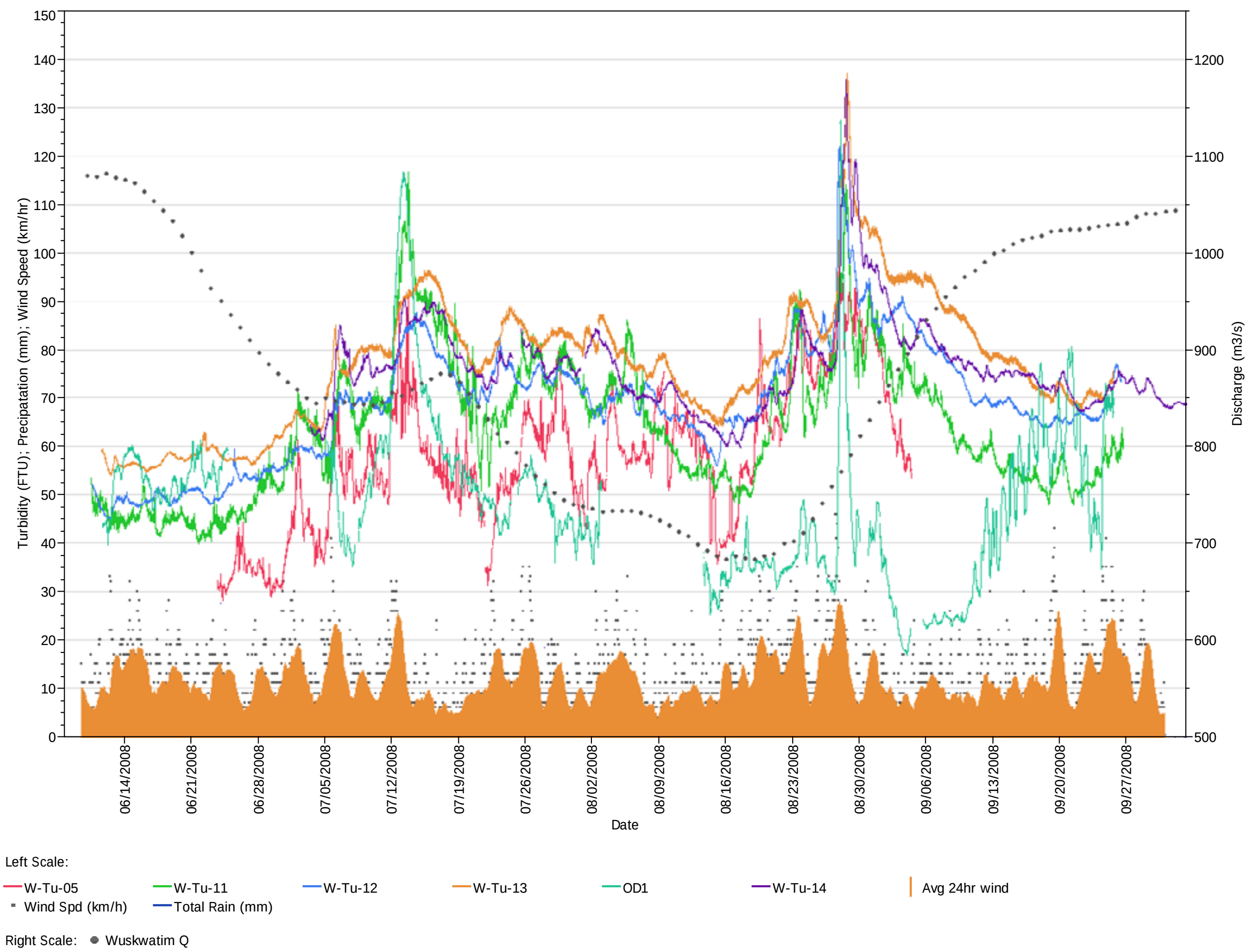

Figure 14 Burntwood River Turbidity from Outlet of Wuskwatim Lake to Split Lake

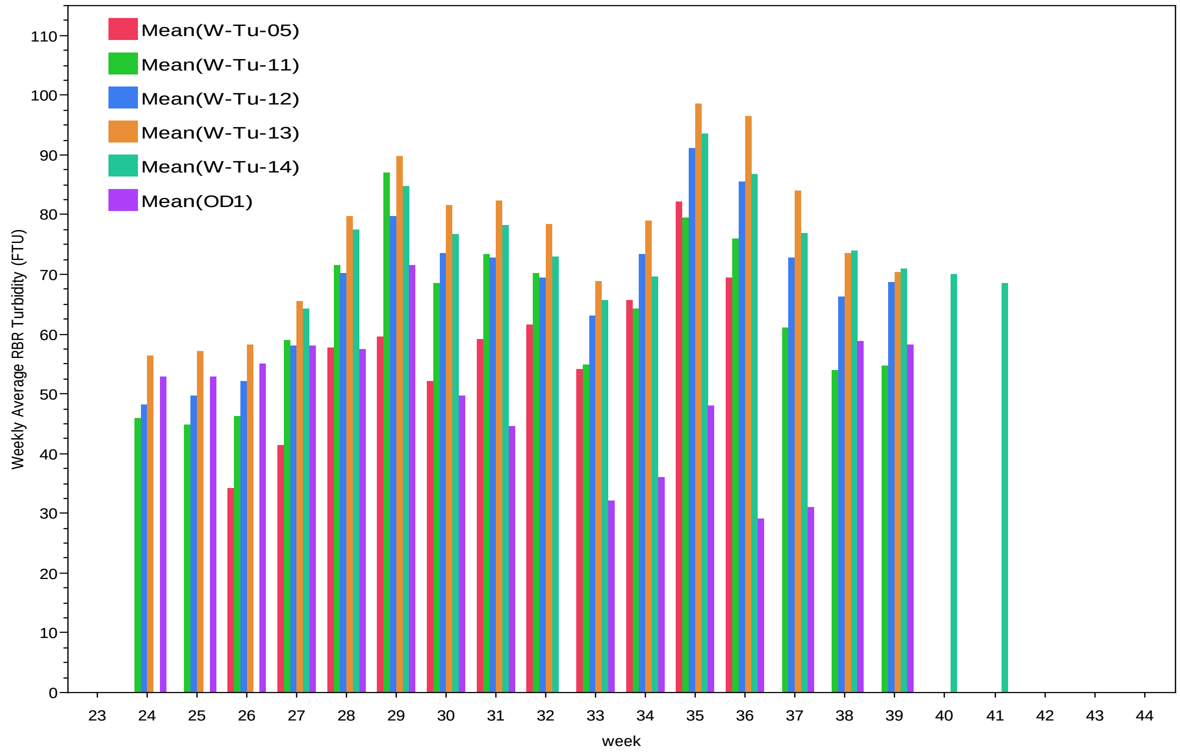

Figure 15 Weekly Average Turbidity from Outlet of Wuskwatim Lake to Split Lake

In late August a storm moved through the area with hourly wind speeds over 40 km/hr, the highest winds reported over the study period. The effects of the storm include an increase in turbidity and multiple waves of sediment passing through the sites (Figure 16). The multiple peaks observed at one site is most likely due to the timing of when local sediment sources (initial peak) and sources from further upstream (second peak) reach the site. One interesting observation is that site W-Tu-14 peaks earlier than the further upstream site W-Tu-13; this is likely due sediment from the Odei River (OD1) causing the earlier peak as the sediment from the Odei River reaches W-Tu-14 before the sediment wave from further upstream on the Burntwood River.

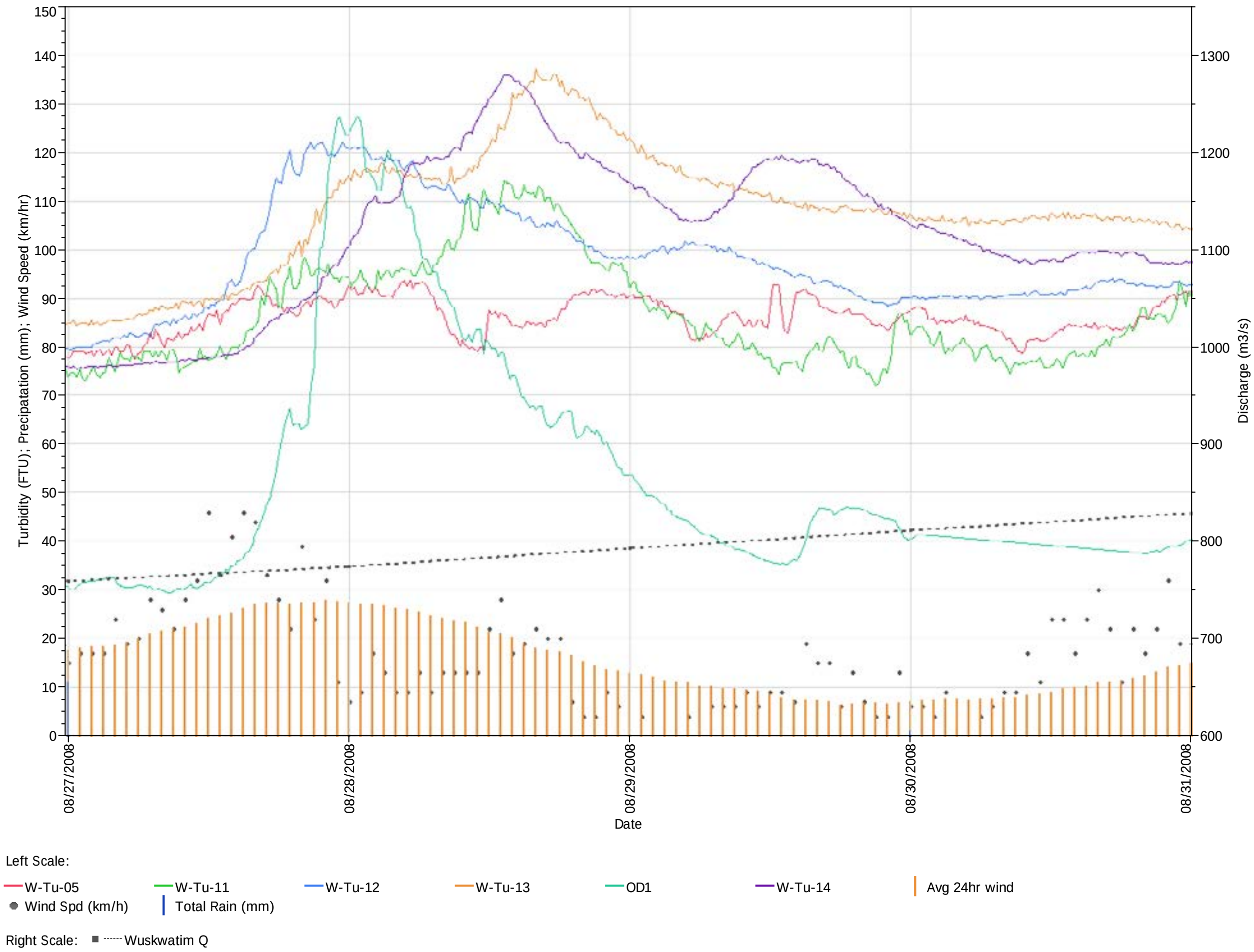

Figure 16 Storm Effects on Turbidity on Burntwood River

The sediment load (Q_s) in the Burntwood River (Table 4) increases in the downstream direction and more than doubles between the outlet of Wuskwatim Lake (W-Tu-05) and inlet of Split Lake (W-Tu-14). This is an indication that the Burntwood River was a source of sediment in 2008. The load appears to drop slightly between W-Tu-13 and W-Tu-14 suggesting some deposition is occurring in this area. This is likely due to the Split Lake beginning to influence water levels and velocities at the W-Tu-14 location.

Table 5: Burntwood River Suspended Sediment Load

Site ID	Daily Min (T/day)	Daily Mean (T/day)	Daily Max (T/day)	Sum (T in 63 days)
W-Tu-05	411	685	1046	43,182
W-Tu-11	516	796	1173	50,155
W-Tu-12	933	1331	2273	83,849
W-Tu-13	1040	1482	2390	93,358
W-Tu-14	1039	1461	2262	92,069

The largest increase in sediment load is between W-Tu-11 and W-Tu-12, suggesting this area is eroding more than the other reaches of the Burntwood River. The daily sediment loads fluctuate with peak periods observed (Figure 17) in mid-June and late August. The highest daily rates are more than twice as high as the lowest rates.

The rates of sediment transport between W-Tu-05 and W-Tu-14 are generally constant throughout the summer as represented by the straight line showing the difference in sediment load (Blue line in Figure 18). The results indicate the riverine section downstream of Wuskwatim Lake is a continuous source of additional sediment that is transported to Split Lake.

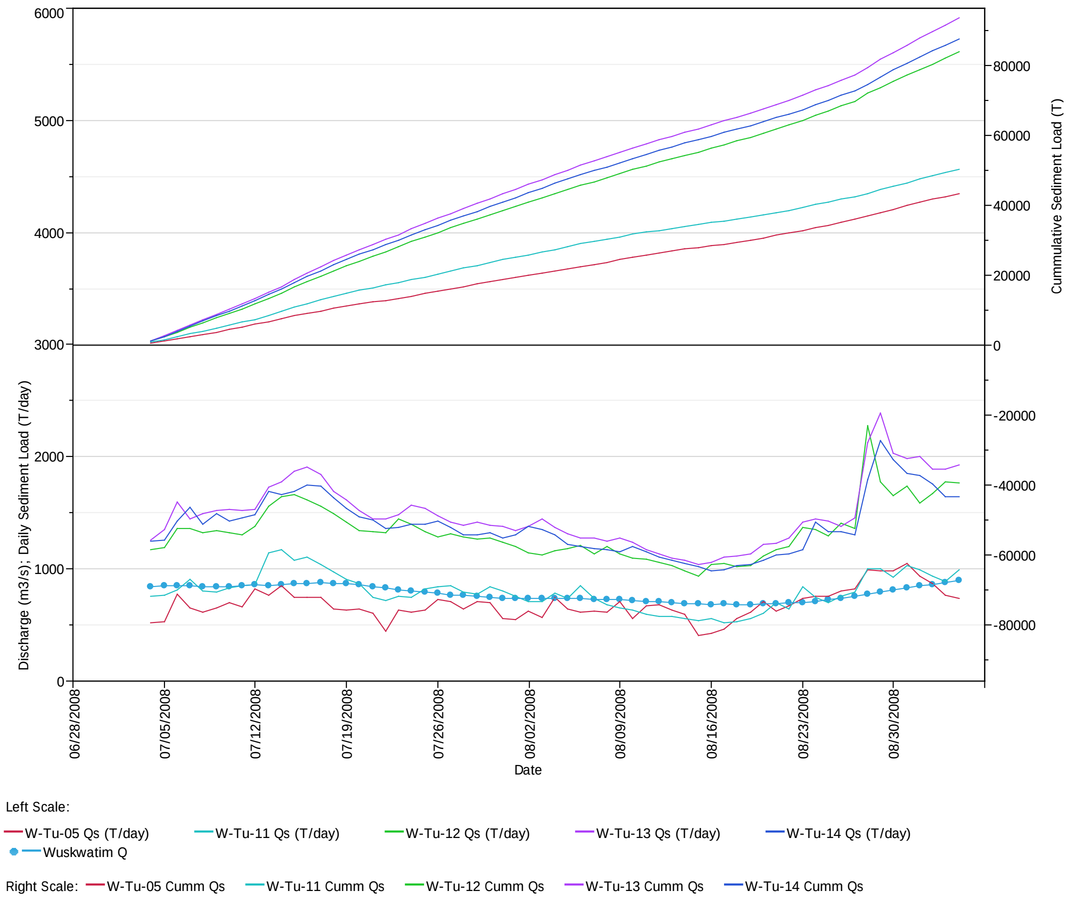

Figure 17 Suspended Sediment Load

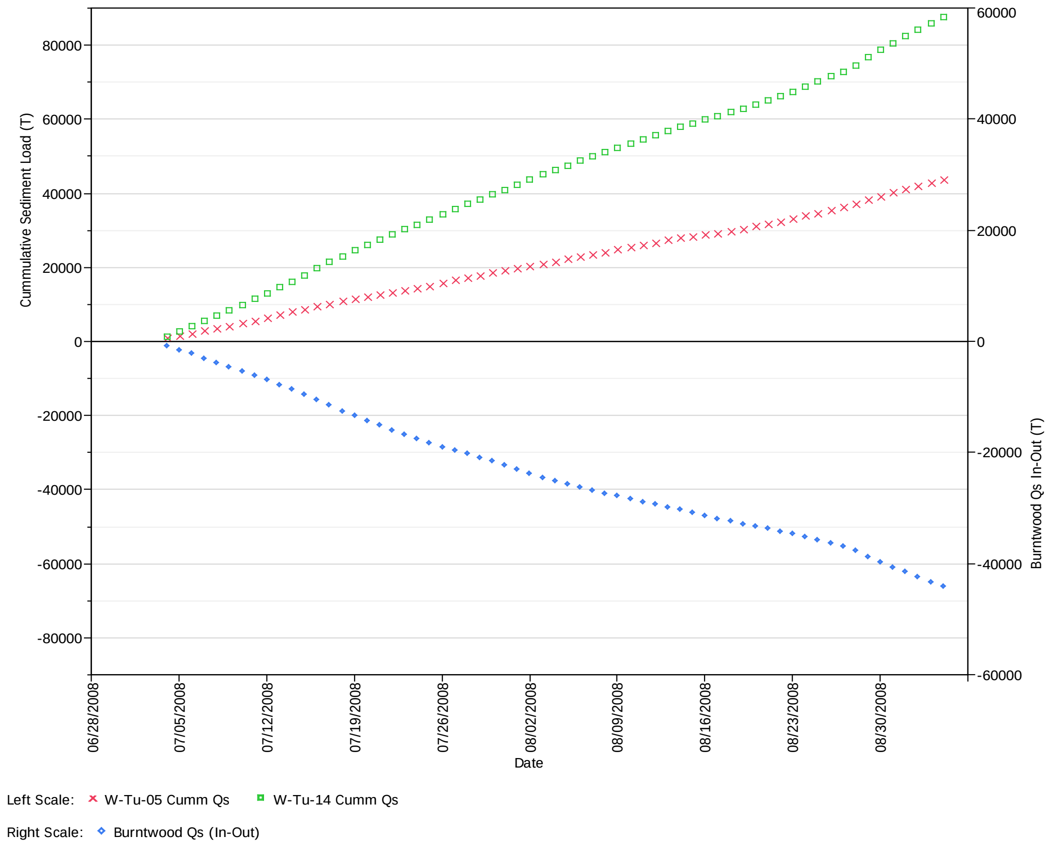

Figure 18 Sediment Balance on Burntwood River

4.3 Split Lake

This reach covers Split Lake that receives inflow from the Burntwood River and Nelson River; two separate watersheds influenced by Lake Winnipeg Regulation (upper Nelson River) and the Churchill River Diversion (Burntwood River). The Aiken River also discharges into Split Lake at York Factory First Nation in the southeast corner of the lake. In 2008, nine continuous turbidity loggers were installed across Split Lake (Figure 19). The combined discharge from the two inflows ranged from approximately 3800 to 5000 m3/s; increasing over the month of July and dropping again in September (Figure 20). The Burntwood River discharge was about 20% to 30% of the Nelson River discharge. Water levels on Split Lake increased from June through July before starting to drop in early September.

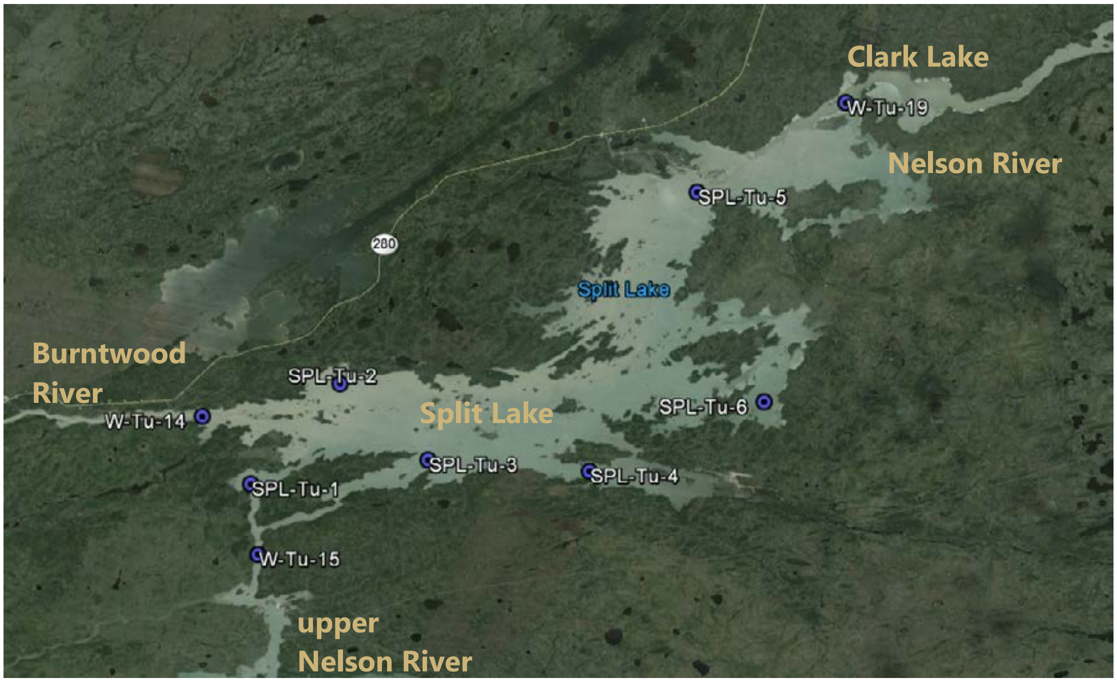

Figure 19 Split Lake Monitoring Locations

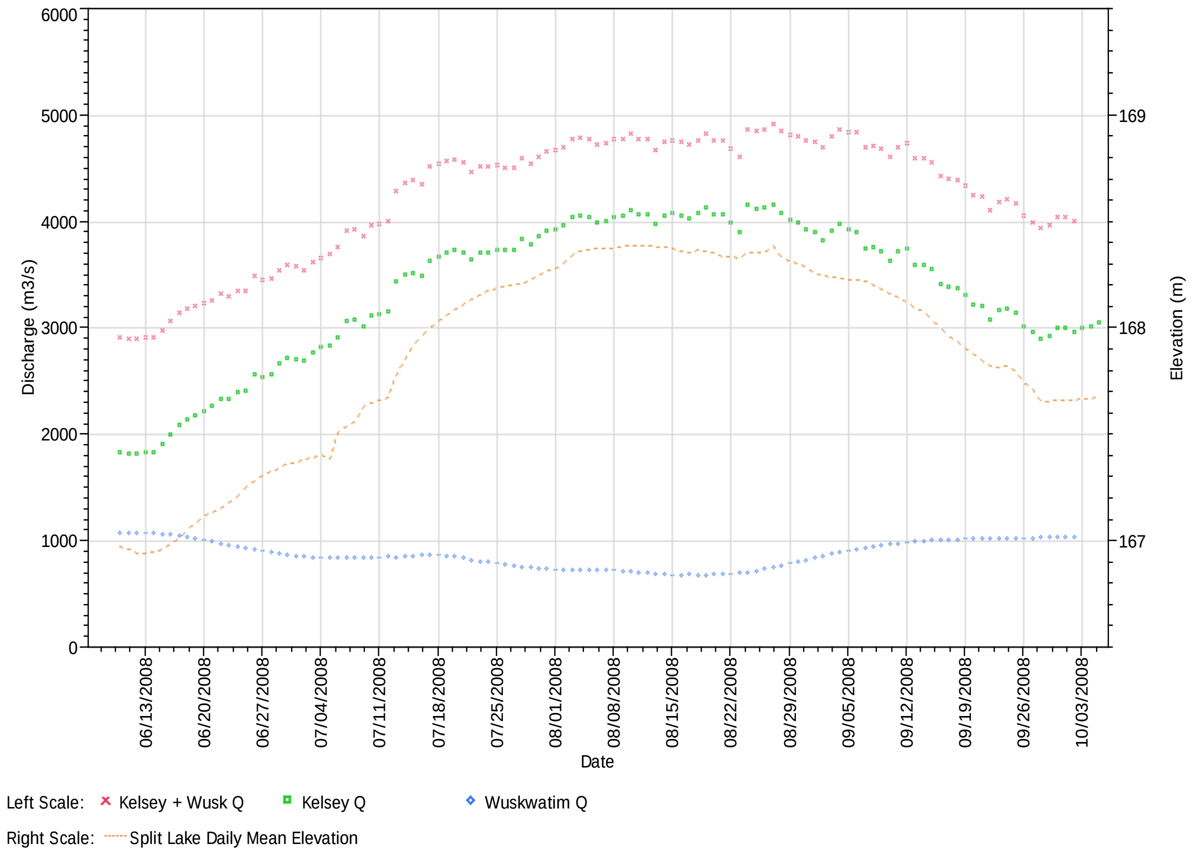

Figure 20 Split Lake Discharges and Water Level

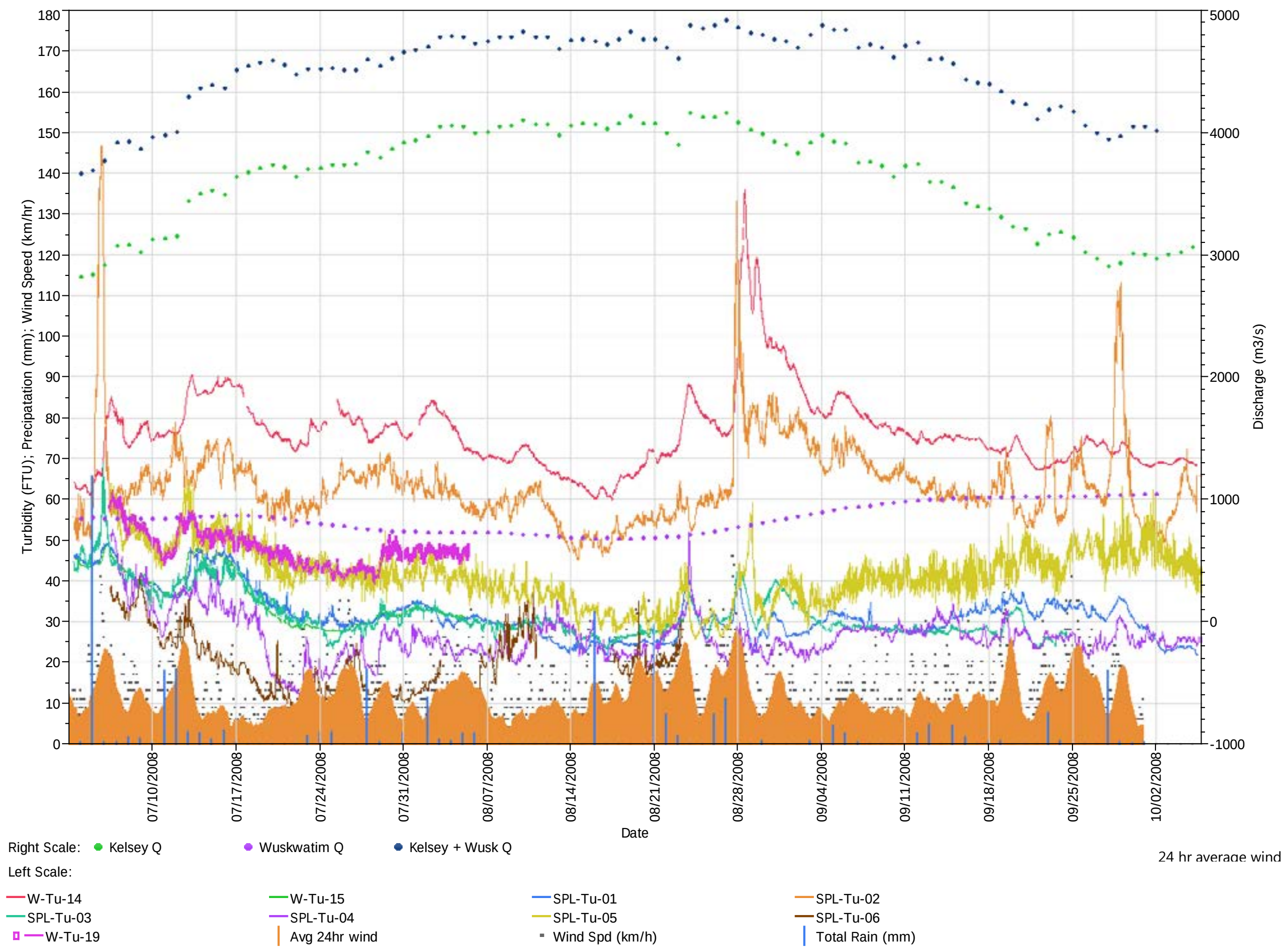

Figure 21 Split Lake Continuous Data

The turbidity at the monitoring locations shows some distinct trends (Figure 21). The Burntwood River inflow (W-Tu-14) and the northwest part of the Lake (SPL-Tu-02) have the highest turbidity and the southeast part of the Lake (SPL-Tu-04 and SPL-Tu-06) generally has the lowest turbidity. The turbidity from the upper Nelson River is considerably lower than the Burntwood River; the site downstream of the Kelsey Generating Station (W-Tu-15) is highly correlated to the levels in the two downstream channels (SPL-Tu-01 and SPL-Tu-03). Turbidity levels near the Split Lake community (SPL-Tu-05) and exit of the Lake (W-Tu-19) are also highly correlated and generally falls somewhere between the Nelson River and Burntwood River turbidity levels.

The SPL-Tu-02 site, located downstream of the Burntwood River inflow (W-Tu-14),has a turbidity pattern that closely follows W-Tu-14, but at times, sharply deviates from the inflow. This is an indication that the general turbidity in the area is established from the Burntwood River flow but there are periods of time when local processes increase turbidity at the site.

The turbidity from the upper Nelson River (W-Tu-15, SPL-Tu-01 and SPL-Tu-03) is highest in the earlier weeks of the monitoring period and shows no correlation with discharge (Figure 21). Similar to what is observed on the Burntwood River reach, there are time periods when wind events are observed to closely correlate to increases in turbidity.

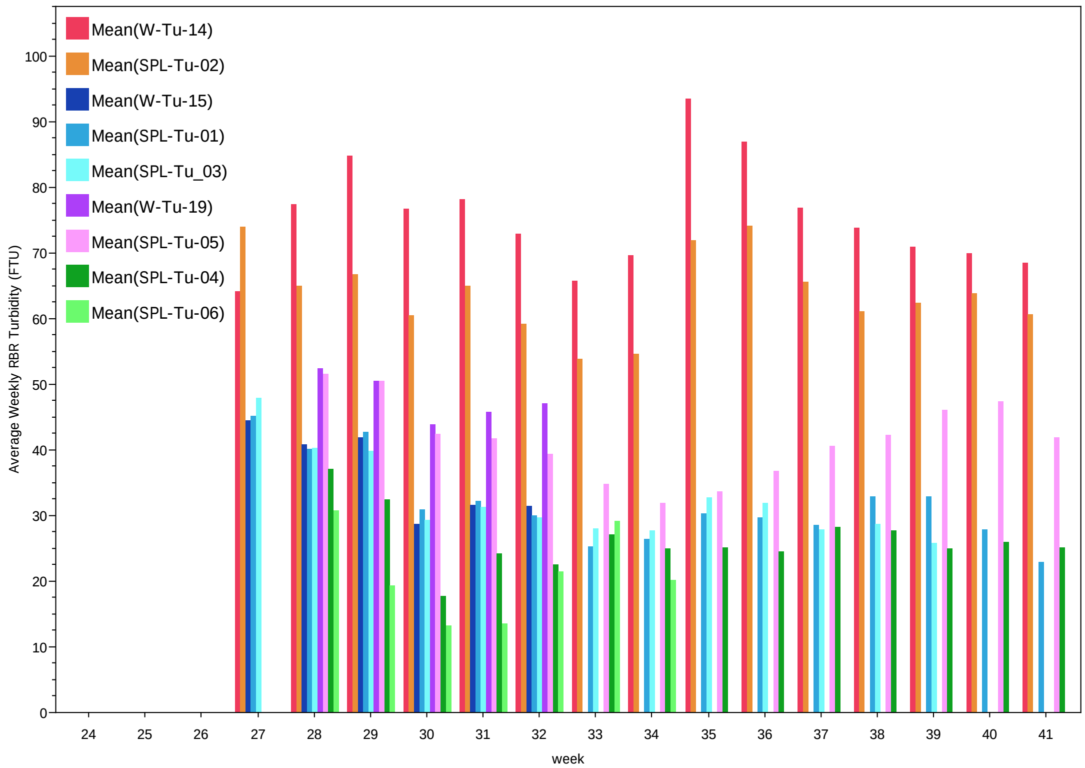

Figure 22 Split Lake Weekly Average Continuous Turbidity

Comparing discrete and continuous data reveals similar trends between the sites. The average continuous turbidity data is generally higher and has a larger range of data (Table 6).

Table 6: Summary Statistics of Turbidity and TSS Data

Site ID	Total Suspended Sediment (mg/L)			Discrete RBR Turbidity (FTU)			Continuous RBR Turbidity (FTU)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
W-Tu-14	11.2	22.2	33.1	54.7	68.4	78.5	59.7	76.3	135.9
SPL-Tu-02	8.4	15.6	26.1	51.6	64.7	75.2	44.9	63.7	146.6
W-Tu-15	11.5	15.1	23.9	22.0	28.4	43.2	27.6	36.1	49.1
SPL-Tu-01	10.6	16.0	23.1	22.9	30.0	43.2	21.7	31.8	49.2
SPL-Tu-03	10.3	13.6	23.0	22.2	28.9	44.1	23.2	31.8	69.0
SPL-Tu-04	7.1	11.6	22.4	19.0	28.3	50.1	11.8	26.3	52.4
SPL-Tu-05	6.8	15.2	24.6	32.0	41.1	52.6	25.6	41.4	64.8
SPL-Tu-06	4.0	8.0	11.7	12.4	21.4	36.1	7.7	19.8	40.9
W-Tu-19	16.5	20.1	28.4	37.4	46.5	54.6	39.7	47.9	62.2

Turbidity correlation (Table 7) between the sites indicate that sites on the Split Lake generally have moderate to good correlations with the upper Nelson River inflow (W-Tu-15) and poor correlations with the Burntwood River inflow (W-Tu-14).

Table 7: Turbidity Correlation between Sites

Site ID	W-Tu-15	SPL-Tu-1	SPL-Tu-2	SPL-Tu-3	SPL-Tu-4	SPL-Tu-5	SPL-Tu-6	W-Tu-19
	Correlation (r^2)							
W-Tu-14	0.13	0.21	0.52	0.32	0.14	0.13	0.03	0.38
W-Tu-15		0.97	0.28	0.91	0.86	0.81	0.72	0.85
SPL-Tu-01			0.32	0.8	0.54	0.61	0.32	0.8
SPL-Tu-02				0.46	0.12	0.19	0.11	0.18
SPL-Tu_03					0.56	0.59	0.45	0.85
SPL-Tu-04						0.42	0.69	0.86
SPL-Tu-05							0.32	0.79
SPL-Tu-06								0.75

The effects of wind on Split Lake are seen during the storm that occurred in late August (Figure 23). Increases in turbidity are observed to occur at almost the same time at W-Tu-14 and at SPL-

Tu-02, with the latter having a much faster and greater response; with the turbidity increasing by approximately 50 to 70 FTU at the two sites. The faster response at site in Split Lake (SPL-Tu-02) likely indicates that sediment is being generated near the site, possibly from re-suspension of sediment due to waves and/or shoreline erosion. The upper Nelson River also saw an increase but only by 10 FTU. At SPL-Tu-05, the turbidity started to increase before the Burntwood inflows but peaks over a day later, increasing by approximately 30 FTU, than SPL-Tu-02 as it takes time for the sediment from upstream to reach the site and the water from the Burntwood and Nelson mix.

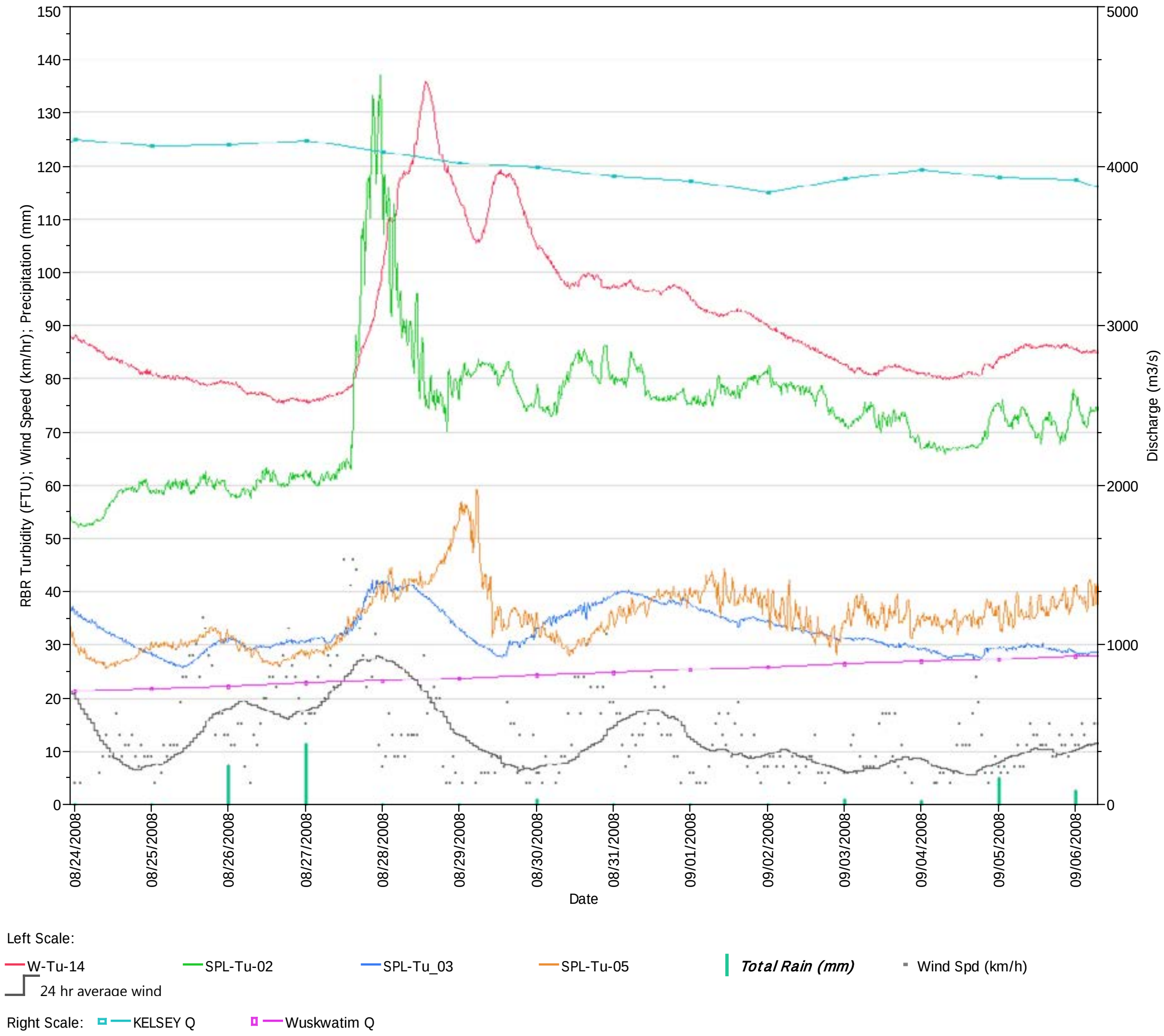

Figure 23 Storm Effects on Turbidity in Split Lake

The average daily sediment load (Table 8) entering Split Lake was 6628 T; the Burntwood River, although being more turbid than the Nelson River, contributed approximately 22% and the upper Nelson River approximately 78%. Two distinct peak periods were observed; in mid-July and late August (Figure 24). The two lowest daily loads are reported in mid-August and late September; it is interesting to note mid-August is near the time of the highest flows and water level on the lake. There is insufficient data from looking at one year's data to assess whether there is a correlation in long-term suspended sediment concentrations/turbidity and water level.

Table 8: Split Lake Suspended Sediment Load

Sites	Daily Mean (T/day)	Daily Min (T/day)	Daily Max (T/day)	Sum (T in 88 days)
W-Tu-14	1487	979	2145	130,842
SPL-Tu-01*	5141	3337	7139	452,425
W-Tu-14 + SPL-Tu-01*	6628	4991	8826	583,268
SPL-Tu-05	5351	3954	8872	470,930

*Data from SPL-Tu-01 is used to represent the upper Nelson River inflow

The net sediment budget for Split Lake, comparing the combined inflows (W-Tu-14 + SPL-Tu-01) to the outflow (SPL-Tu-05), is 112,000 more tonnes (T) of sediment enters the lake than leaves the lake over 88 days. At most times the lake is receiving more than contributing but there are several days when more sediment is leaving (Figure 25); the exception appears at the end of October when the sediment outflow increases whereas the Nelson River Inflow increases while the Burntwood remains largely unchanged. The sediment out flow closely matches the Nelson River inflow and the total outflow are very close to the total Nelson River contribution over the 88 days.

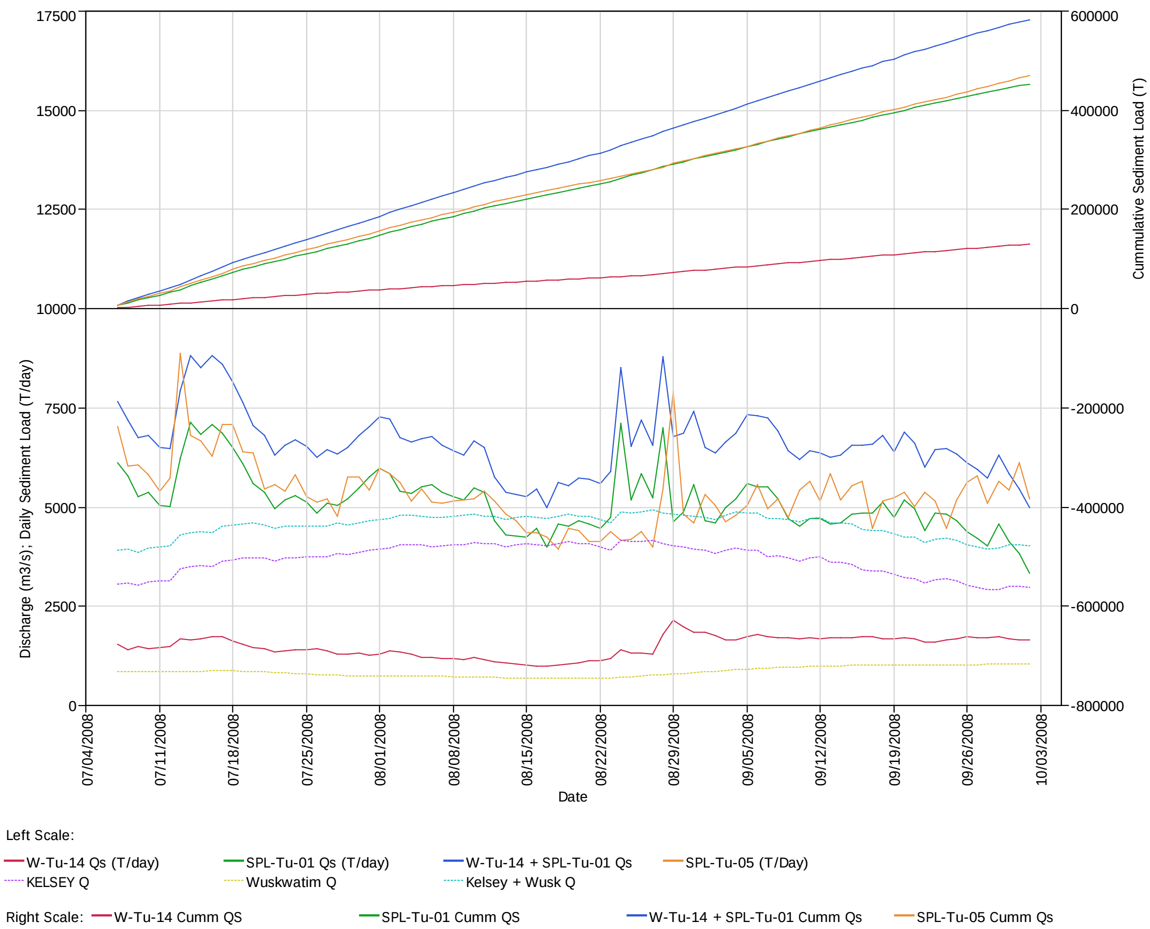

Figure 24 Suspended Sediment Load

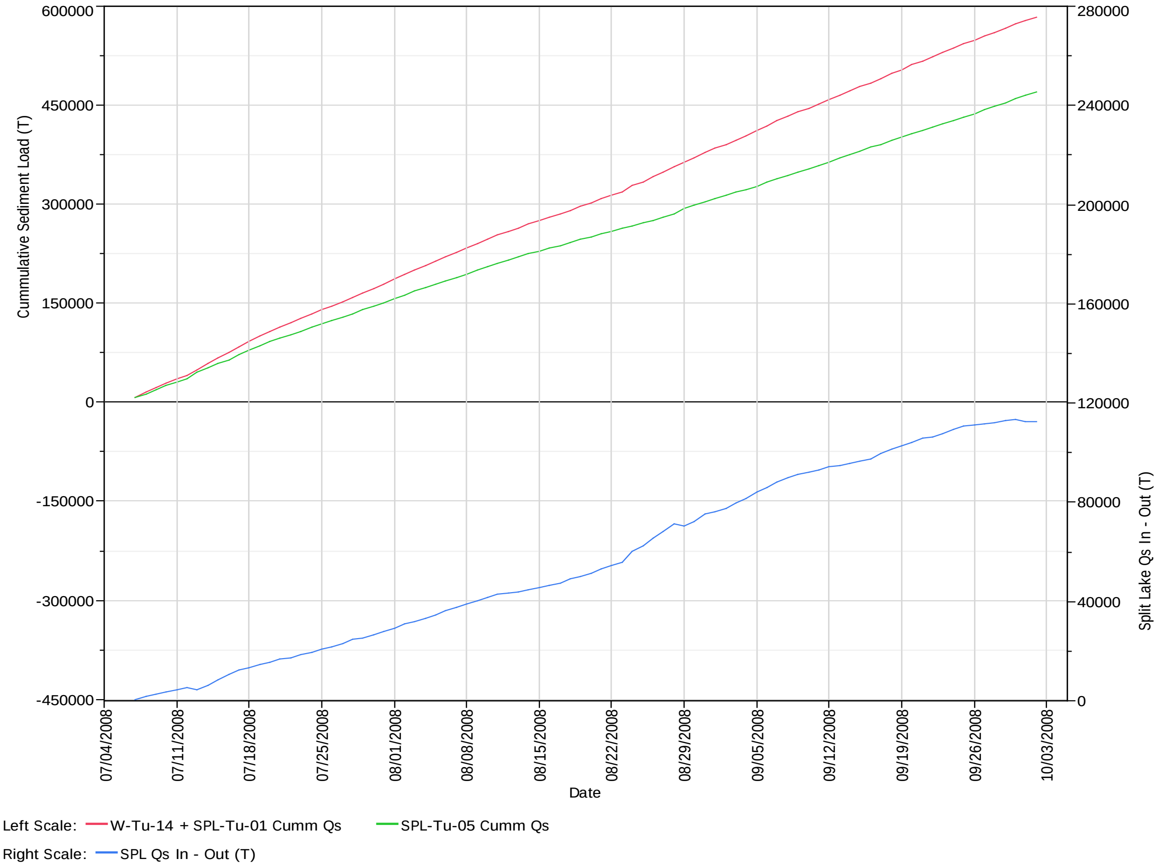

Figure 25 Sediment Balance on Split Lake

4.4 Lower Nelson River from Split Lake to Downstream of LImestone GS

The lower Nelson River reach extends from Split Lake to downstream of the Limestone GS near the Angling River. In 2008, eight continuous turbidity loggers were in place across this reach (Figure 26). The reach consists of Clark Lake, Gull Lake, Stephens Lake (Kettle GS reservoir) and the Long Spruce and Limestone GS reservoirs. The discharge throughout the reach does not change much and local flow contribution is minor in comparison to the flow of the lower Nelson River.

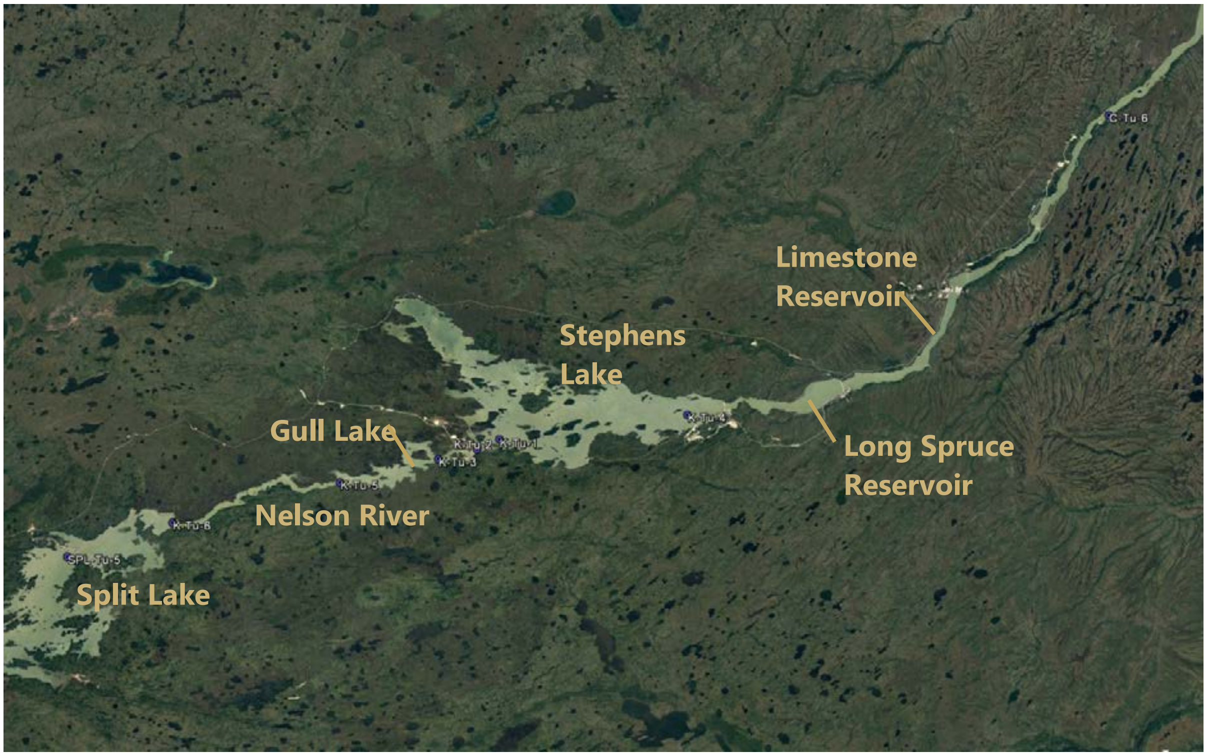

Figure 26 Lower Nelson River Study Reach

The turbidity from Split Lake to the entrance of Stephens Lake generally have similar levels and exhibit the same patterns (Figure 27). The turbidity is not correlated to discharge and is generally falling throughout the period while discharge is increasing.

Sediment plumes are observed moving through Split Lake to Stephens Lake with a time lag between the peak turbidity levels. The highest turbidity was observed in late August, however, the highest weekly average turbidity is in June with a general declining trend from late June till mid-August. In late August, a higher degree of variability is observed with turbidity nearly doubling from 40 to 80 FTU over the span of a day as discussed in more detail below.

The turbidity at the exit of Stephens Lake (SPL-Tu-04) was noticeably lower than the upstream sites until mid-August, at which time the turbidity is similar to the inflow turbidity. Two peak periods are observed, in early July and late August, with the lowest turbidity occurring in mid to late July.

The turbidity at the site in the lower Nelson River (C-Tu-06) located downstream of the Limestone GS remained steady between 30 and 40 FTU much of the time. The logger was no longer installed at the time turbidity spiked in late August at the other sites.

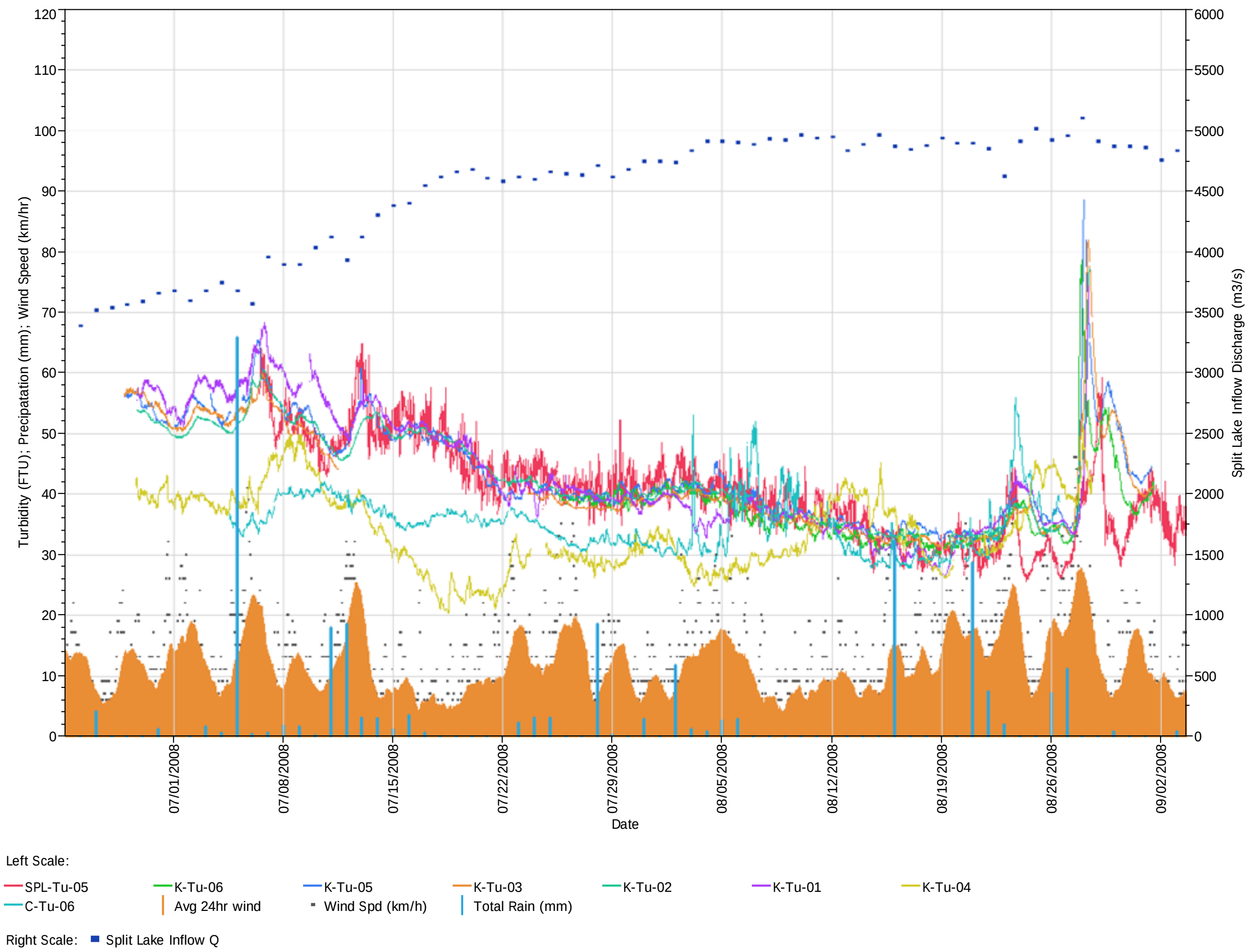

Figure 27 Lower Nelson River Continuous Data

The highest average weekly turbidity (Figure 28) upstream of Gull Lake was observed in the first part of the monitoring period (Weeks 26 to 29) while in Stephens Lake and the downstream Nelson River the peak occurs in week 35, although it is not much greater than the averages around weeks 27-28.

Turbidity and TSS generally increases from upstream to downstream along the Nelson River upstream of Gull Lake with Stephens Lake acting as a sediment trap with average concentrations dropping by approximately 50% between site K-Tu-01 and K-Tu-04 (Table 9).

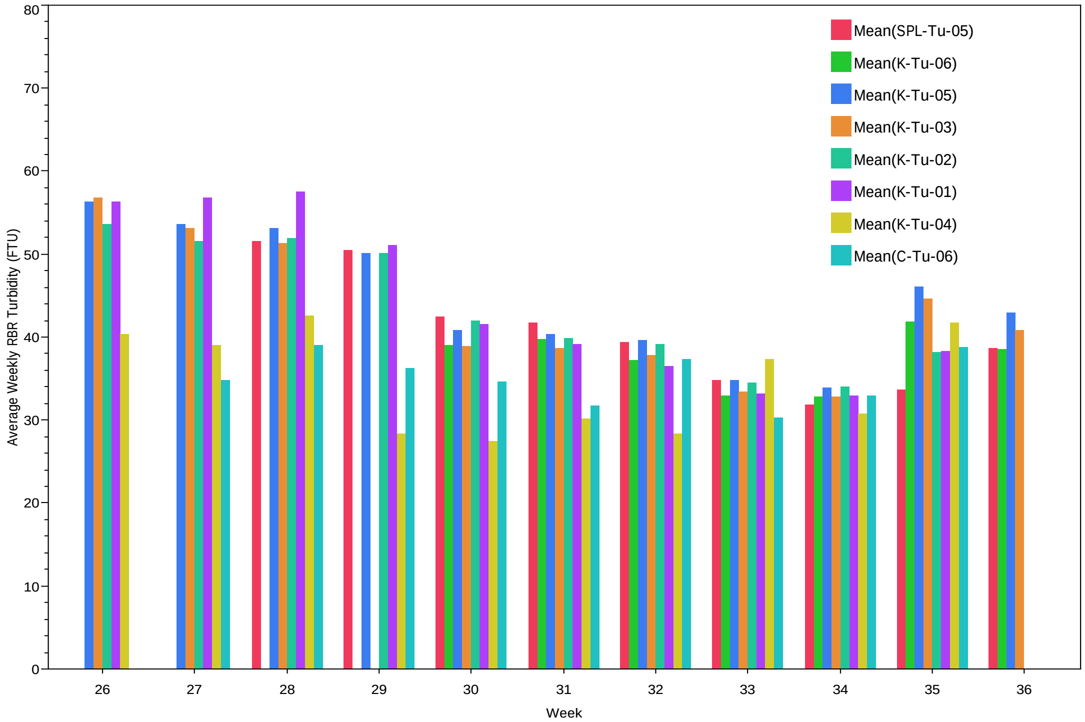

Figure 28 Lower Nelson River Weekly Average Continuous Turbidity

Table 9: Summary Statistics of Turbidity and TSS Data

Site ID	Total Suspended Sediment (mg/L)			Discrete RBR Turbidity (FTU)			Continuous RBR Turbidity (FTU)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
SPL-Tu-05	6.8	15.2	24.6	32.0	41.1	52.6	25.6	41.4	64.8
K-Tu-06	13.1	17.1	20.3	33.0	39.8	47.0	30.2	37.1	78.6
K-Tu-05	14.5	17.1	18.7	37.4	46.3	58.0	32.2	43.7	88.4
K-Tu-03	13.2	17.7	20.8	38.1	45.4	61.1	30.8	41.6	81.9
K-Tu-02	13.3	24.7	53.0	34.1	52.7	82.8	32.5	42.8	77.1
K-Tu-01	12.1	22.6	46.8	34.0	48.1	78.1	26.4	43.3	74.4
K-Tu-04	6.9	11.0	19.0	28.7	36.7	51.7	20.3	33.9	51.3
C-Tu-06	5.6	12.6	31.2	25.0	29.1	36.7	27.6	35.0	55.9

The turbidity at sites on the Nelson River sites generally show average to good correlations (Table 10) in particular with nearby sites; noting that the correlations do not account for time lag between the sites. The exception is site K-Tu-04 and C-Tu-06 that generally shows poor correlation to other sites. K-Tu-04 is located at the downstream end of a larger reservoir that has internal processes that likely affect the turbidity levels and C-Tu-06 is located downstream of three reservoirs that influence turbidity levels.

Table 10: Turbidity Correlation between Sites

Site ID	K-Tu-06	K-Tu-05	K-Tu-03	K-Tu-02	K-Tu-01	K-Tu-04	C-Tu-06
	Correlation (r^2)						
SPL-Tu-05	0.51	0.71	0.64	0.86	0.83	0.01	0.33
K-Tu-06		0.89	0.81	0.75	0.62	0.00	0.17
K-Tu-05			0.96	0.95	0.91	0.33	0.46
K-Tu-03				0.98	0.95	0.51	0.38
K-Tu-02					0.96	0.23	0.40
K-Tu-01						0.37	0.47
K-Tu-04							0.20

The effect on turbidity from the storm that moved through the area in late August is very apparent in the reach (Figure 29). Turbidity increased from approximately 30 to 40 FTU to around 75 to 85 FTU and can be seen to peak at different times as the plume moved downstream Spit Lake. The site near the exit of Stephens Lake (K-Tu-04) begins to increase at the same time as upstream sites, likely from local effects of the storm but the logger was removed before the large plume observed upstream reached the site.

The same storm had caused SPL-Tu-05 to peak about a day after the storm occurred as the upstream plumes reached the site (as reported in the previous section). This second wave of sediment from the upper Nelson River and Burntwood River is the cause of the second smaller peak observed at sites K-Tu-06, K-Tu-02 and K-Tu-03 on August 29 and 30.

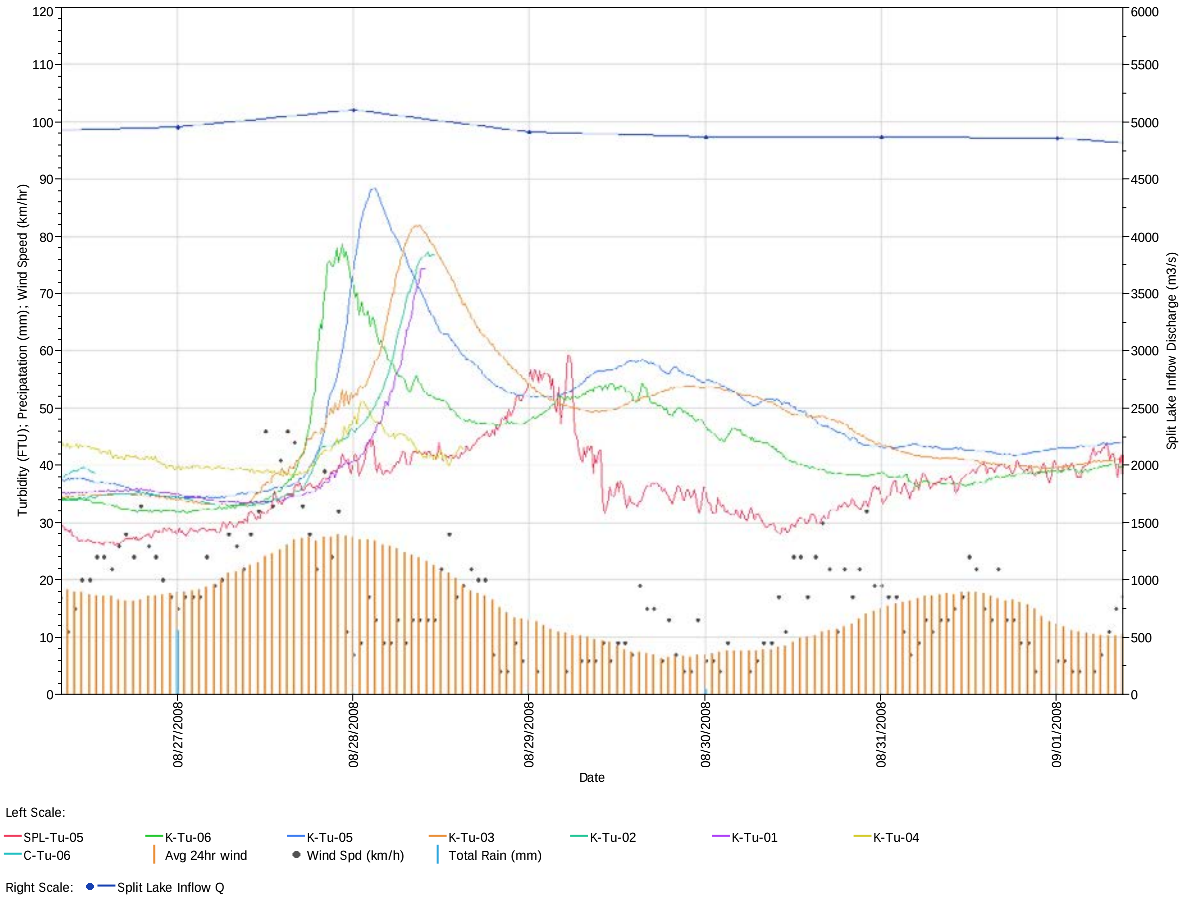

Figure 29 Storm Effects on Turbidity in lower Nelson River

The average daily sediment load (Table 111) varies considerably at the sites located on the river with less variation at the exit of Stephens Lake (K-Tu-04). The highest sediment loads are observed between Clark Lake and Gull Lake and average around 6,300 T/day. The exit of Stephens Lake has the lowest average sediment load at around 4,200 T/day, about a 30% drop from the entrance to the lake at site K-Tu-02. Loading to the lake was highest in mid-July and by mid-August there was little difference between the inflow and outflow. Downstream of Stephens Lake (C-Tu-06) the sediment load once again increases to an average of nearly 6,000 T/day.

The sediment load at the sites upstream of Stephens Lake showed a small decreasing trend over the summer (Figure 30) while the Stephens Lake and downstream site remained steady most of the summer. Stephens Lake was a sediment trap throughout the monitoring period with a net accumulation of approximately 107,000 T of sediment over 51 days (Figure 31).

Table 11: Lower Nelson River Suspended Sediment Load

Sites	Daily Mean (T/day)	Daily Min (T/day)	Daily Max (T/day)	Sum (T in 51 days)
SPL-Tu-05	5414	3954	8872	276,120
K-Tu-05	6287	5144	9167	320,648
K-Tu-02	6357	5233	8542	324,192
K-Tu-04	4254	3148	5825	216,952
C-Tu-06	5954	4749	10,855	303,675

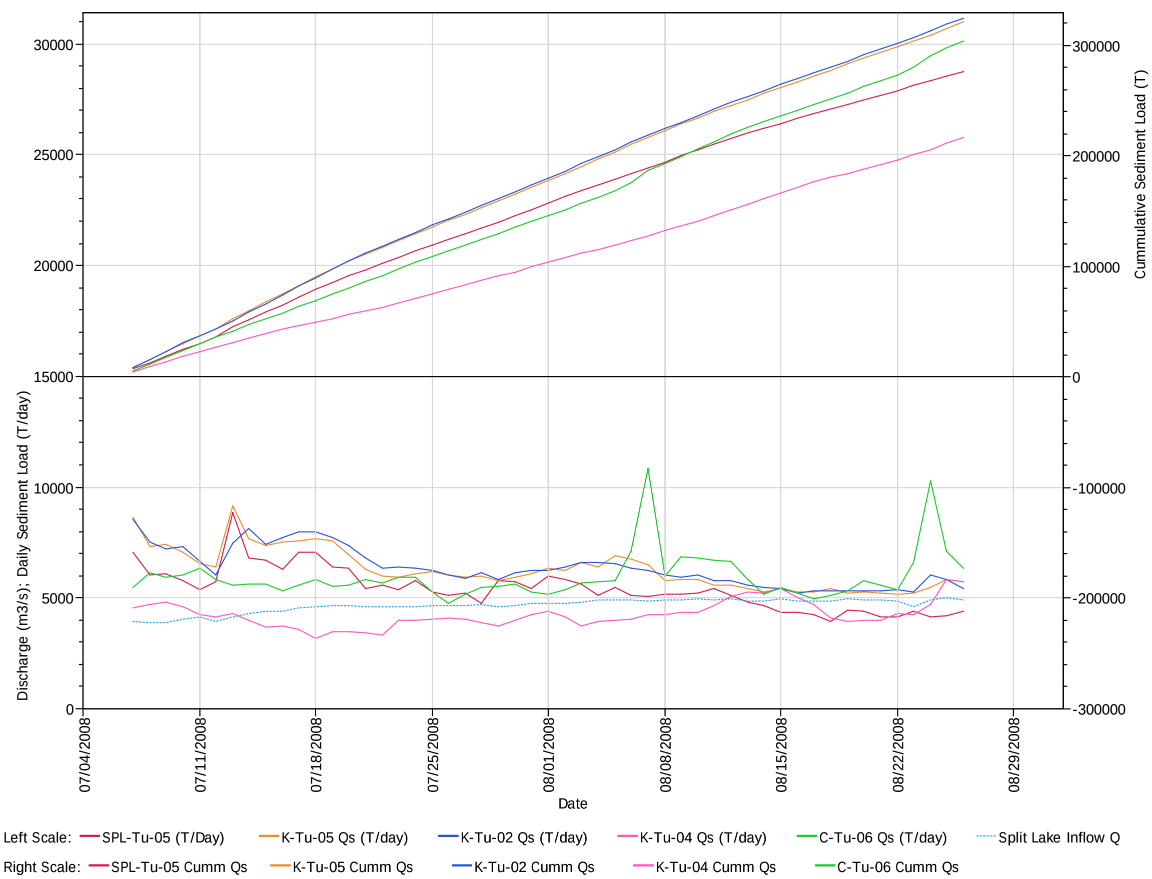

Figure 30 Suspended Sediment Load

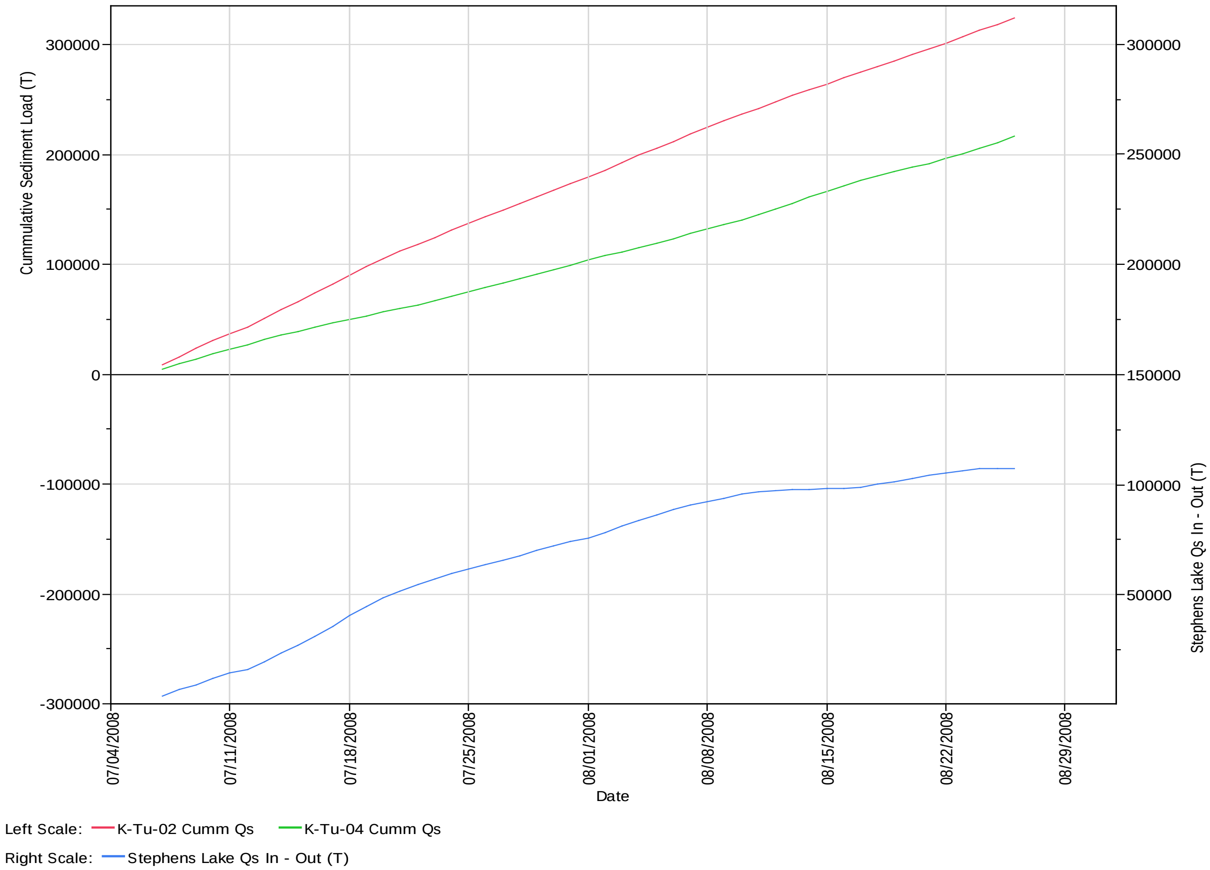

Figure 31 Sediment Balance on Stephens Lake

5.0 Conclusions

This report examines suspended sediment transport processes within the Burntwood River and lower Nelson River systems to provide understanding of the process on the river systems. Sediment loads were derived using continuous turbidity at sites across the system (Figure 32). Sediment load tended to increase along river reaches and be lower at the exit of lakes than the entrance.

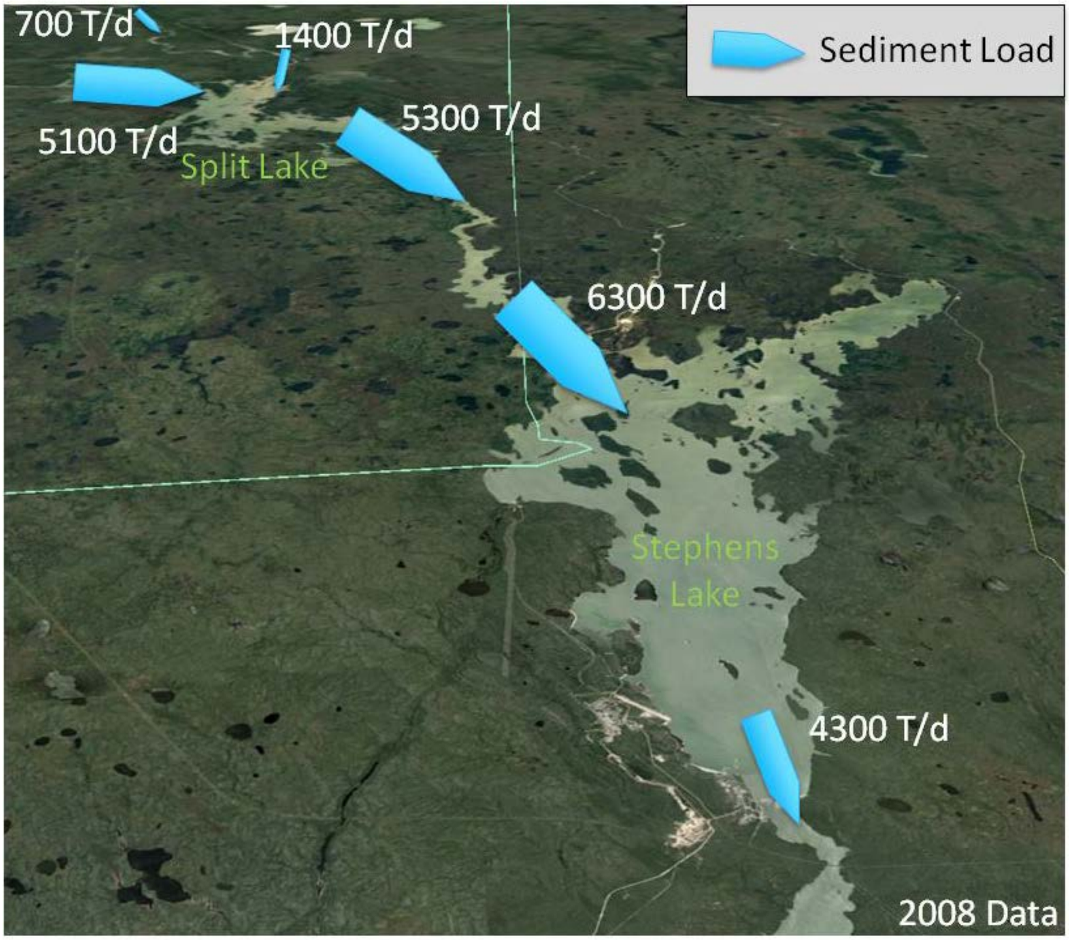

Figure 32: Daily Average Sediment Loads

The following observations and conclusions are based on data collected in a single open water season in 2008:

- Turbidity/suspended sediment are higher on Burntwood River than Nelson River
- Turbidity – TSS relationships vary from site to site and equations need to be evaluated on a site-by-site basis

- Calculated TSS matches reasonably well with measured TSS
- Turbidity/suspended sediment tend to increase along river reaches
- Strong correlation between nearby sites is usually observed
- Turbidity shows no major correlations to discharge
- Sustained increases in wind speed increases turbidity primarily due to lakes where larger waves stir up bottom sediment and/or adds sediment from shore erosion
- Turbidity at a site can be affected more than once by a single storm event as sediment plumes from local effects and effects further upstream may pass by at different times
- Timing of the highest average weekly turbidity varies throughout the study area
- Continuous data shows larger ranges and higher averages than discrete data
- Continuous data allows for a better determination of sediment sources and sinks as well as the full range of turbidity/sediment variability and events that is not available from discrete sampling
- Sediment Load of the upper Nelson River was about three times higher than Burntwood River
- Some lakes appear to act as sediment traps and sources of sediment while others are predominantly sediment traps
- The monitoring results do not allow for estimating the amount of sediment depositing in the lakes/reservoirs as there is no account of internal lake loading (i.e. from eroding shorelines).
- There is insufficient data from looking at one year’s data to assess whether there is a correlation in long-term suspended sediment concentrations/turbidity and water level

REFERENCES

Environment Canada, Historical Climate Data: http://climate.weather.gc.ca/historical_data/search_historic_data_e.html

KGS Acres 2009, Draft Report on Study of Total Suspended Solids on the Burntwood River System from Kinosaskaw Lake to Birch Tree Lake from 2005 to 2007, Manitoba Hydro File 00184-11140-0178_00.

APPENDIX A
COMPARISON OF MEASURED TSS TO CALCULATED TSS

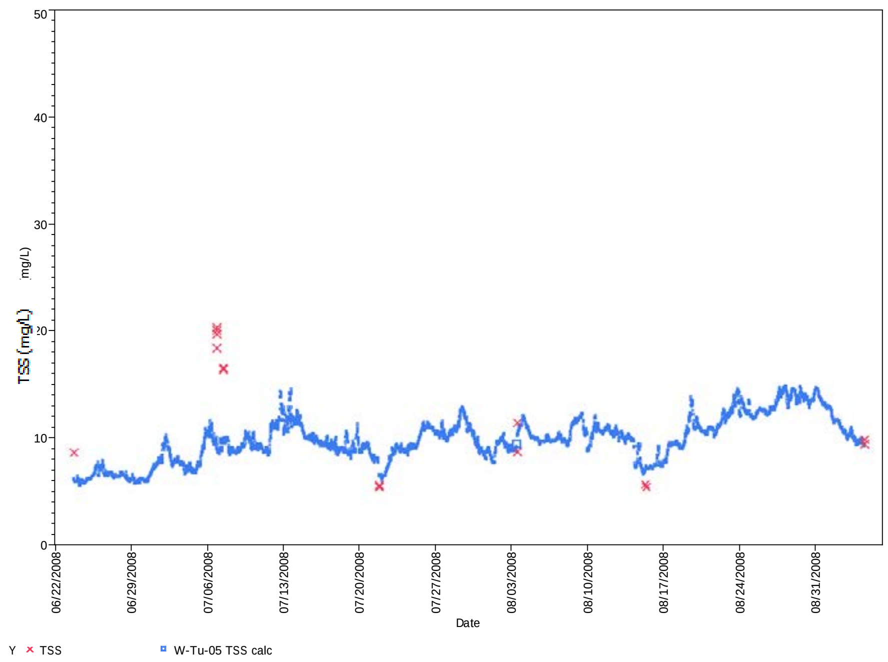

Figure A-1: W-Tu-05 Discrete and Continuous Turbidity – TSS Comparison

TSS = 0.142Tu + 1.598

RSquare = 0.598

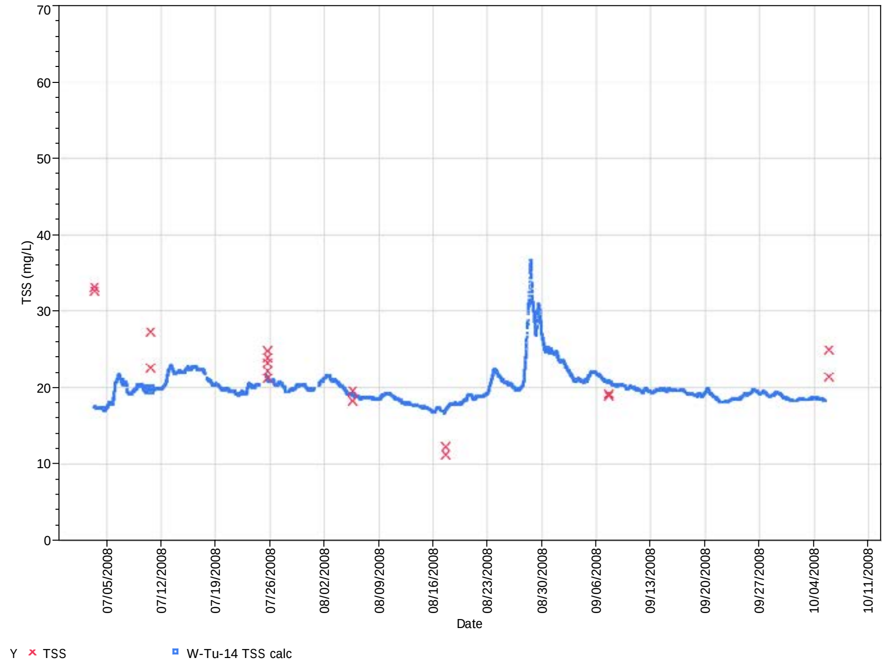

Figure A-2: W-Tu-14 Discrete and Continuous Turbidity – TSS Comparison

Log(TSS) = 2.083 + 0.012 * turbidity

RSquare = 0.187

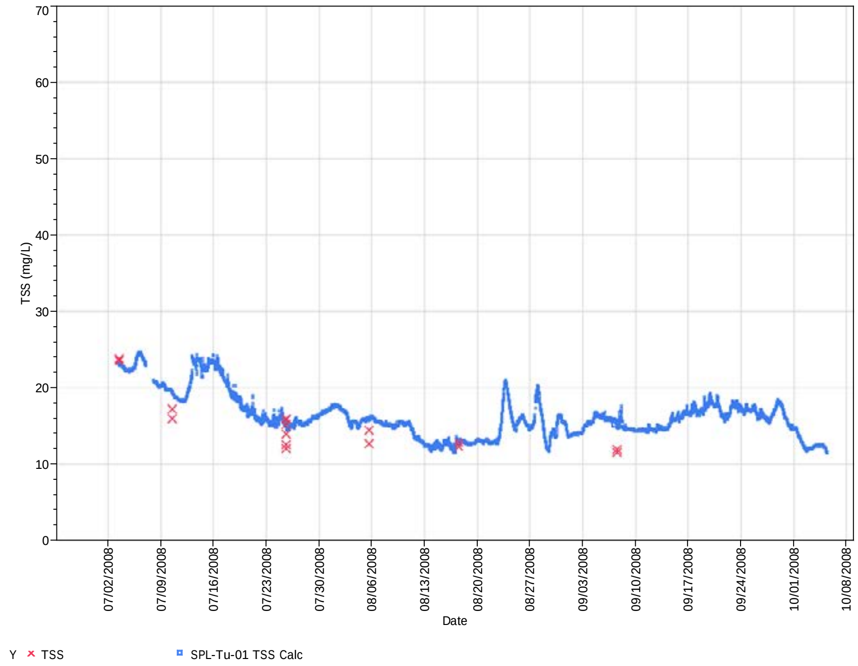

Figure A-3: SPL-Tu-01 Discrete and Continuous Turbidity – TSS Comparison

TSS = 0.912 + 0.483 * turbidity

RSquare = 0.630

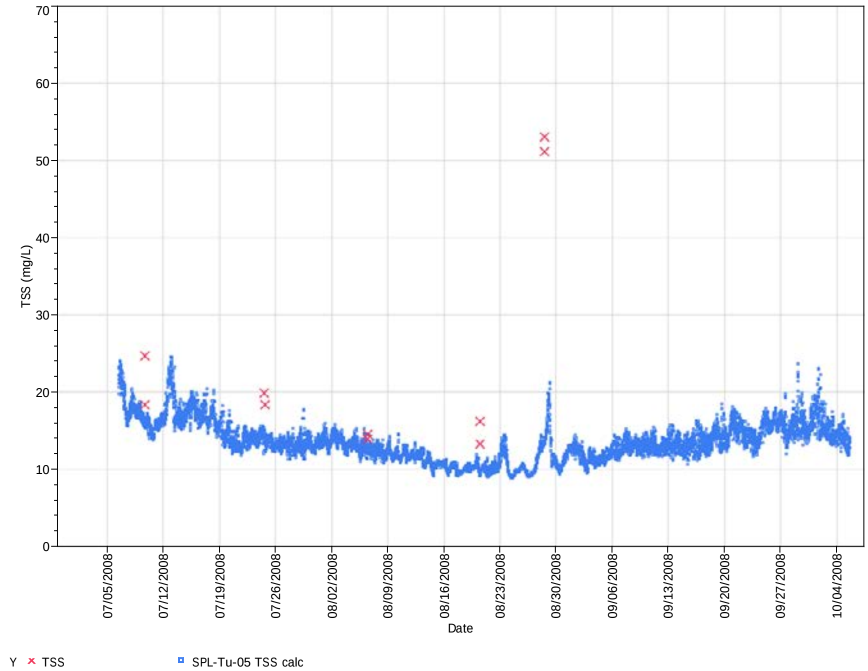

Figure A-4: SPL-Tu-05 Discrete and Continuous Turbidity – TSS Comparison

Log(TSS) = 1.509 + 0.026 * turbidity

RSquare = 0.350

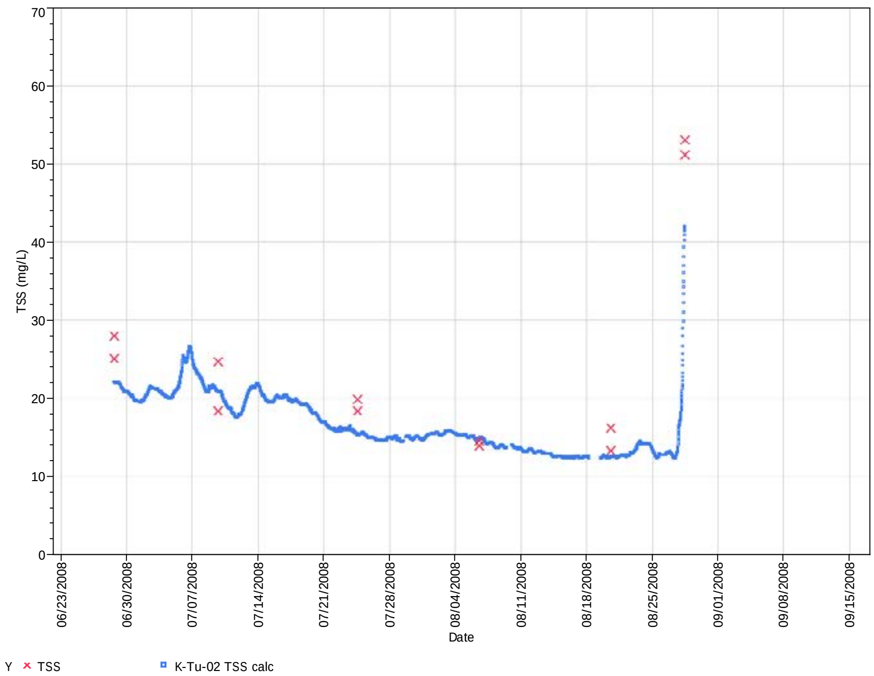

Figure A-5: K-Tu-02 Discrete and Continuous Turbidity – TSS Comparison

Log(TSS) = 1.613 + 0.028 * turbidity

RSquare = 0.902

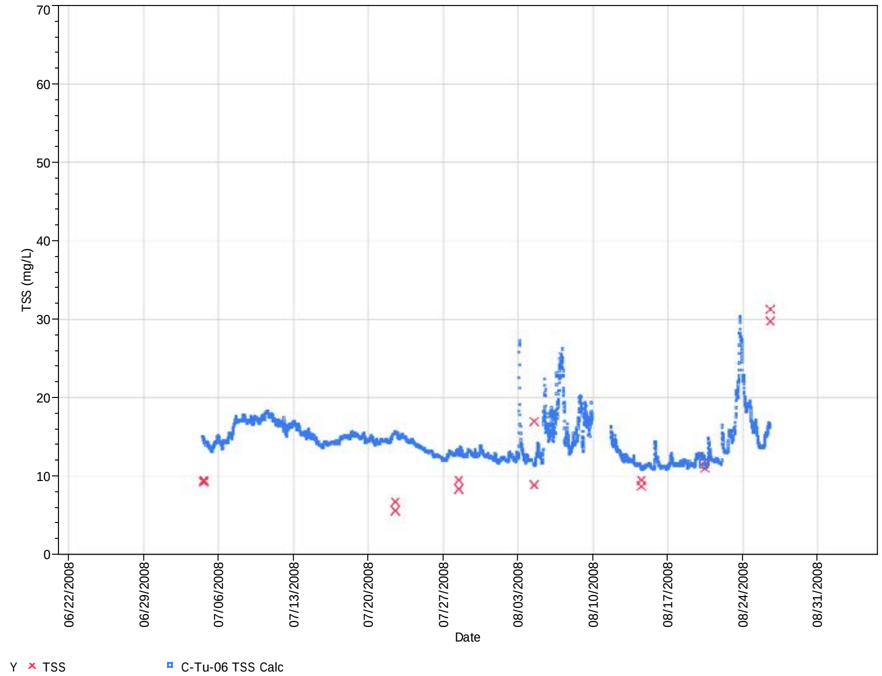

Figure A-6: C-Tu-06 Discrete and Continuous Turbidity – TSS Comparison

Log(TSS) = 1.380 + 0.036 * turbidity

RSquare = 0.333