COMPREHENSIVE SURFACE WATER MONITORING OF GOLDSTREAM CREEK FOR THE POTENTIAL DEVELOPMENT OF TMDLS

FINAL REPORT

ADEC ACWA-12-09

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Prepared by:

Debasmita Misra
University of Alaska Fairbanks

Assisted by:

Justin Thomas, Michael Magnan, Margaret J. Yngve, Peilin Xu and Catlin A. Stevens,
University of Alaska Fairbanks

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1. EXECUTIVE SUMMARY

UAF was awarded with an ACWA grant in July, 2010 and 2011 to initiate and continue monitoring at three sites of the Goldstream Creek watershed that were identified in the Quality Assurance Project Plan (QAPP) and Sampling and Analysis Plan (SAP), developed by ADEC in December 2009. Goldstream Creek near Fairbanks, AK was listed by ADEC on the Section 303(d) list as impaired for turbidity in 1992 and was evaluated for impairment of water quality by ADEC and the Water Quality Report was completed in 1994. The sources of turbidity were determined to be both point sources, including active placer mines, and nonpoint sources, which includes abandoned placer mines, stream bank erosion, and re-suspension of deposited sediment, as well as runoff from both abandoned and active mine sites. Monitoring stream data that demonstrate compliance with the water quality standards is required to remove Goldstream Creek from the list of waterbodies impaired for turbidity. Subsequent to the development of the QAPP and SAP of 2009, a major objective was to collect steady and near-continuous measurements of turbidity from both baseflow and stormflow conditions and measurements of stream discharge at those times at several selected locations from spring to fall of 2010, 2011 and May-June of 2012 in order to characterize conditions and potentially locate sources of impairment. Additionally, collection of monthly (or more frequently if needed) data of overall water quality, viz., dissolved oxygen (DO), pH, conductivity, temperature, etc. of Goldstream Creek from spring to fall of 2010, 2011 and May-June of 2012 in order to determine the degree of impairment was included in the sampling plan.

Using the recommendations provided in the 2009 SAP, two sites (GS-1 and GS-2) were instrumented and one site (GS-3) was used as a control site from which periodic grab samples were collected. Continuous data sampling (hourly and daily) started on August 2, 2010 for GS-1 and July 26, 2010 for GS-2. Continuous data sampling was discontinued after October 7, 2010 since the stream was freezing and there was a risk to the sensors. Continuous and periodic data sampling was resumed after the spring breakup. Automatic sensors were deployed on May 24, 2011 in GS-1 and GS-2 and were active until September 26, 2011. The automatic monitoring was resumed again in May 26, 2012 for GS-1 and May 20, 2012 for GS-2 and was active until June 30, 2012. Periodic samples using the YSI multimeter, Hach Turbidity meter and grab samples for TSS were procured from GS-3.

The turbidity data collected using Hach turbidity meter from GS-3 in 2011 field season was used to establish the Background Natural Turbidity (BNT) of the stream. The BNT was established using the mean of the averages of two replicate data sets at 15.24 NTU. The BNT value of 15.24 NTU being less than 50 NTU, Alaska Water Quality Standards (AK WQS) was used to establish that the stream turbidity should not exceed 40.24 NTU for aquatic life, 25.24 NTU for recreation and 20.24 NTU for water supply. AK WQS specifies standards for other water quality indicators such as water temperature, pH and DO. With respect to compliance to the three AK WQS standards for turbidity, it was observed that GS-1 complied with the standards in May 2011 but failed to comply in June 2011. GS-2 failed to comply with all the three standards in

2010 and May of 2011. However, it complied with the three standards in June of 2011. Similarly, applying the AK WQS to the hourly and daily water temperature at both the sites, it was found that the temperatures were within the prescribed standards for aquatic life, recreation and water supply. It was found that the stream met the DO standards at GS-1 94% of the time for aquatic life and water supply and 56% of the time for anadromous fish and 87.5% of the time for non-anadromous fish populations in 2011. The stream met the pH standards at GS-1 94% of the times in 2011. At GS-2, the stream met the pH standards for all three Alaska WQS standards 92% of the time in 2011. However, the DO standards were only met 86% of the time for aquatic life and water supply and 42% of the time for anadromous fish and 53% of the time for non-anadromous fish populations in 2011. So, it may be observed that the stream did not meet the recreation WQS standards for approximately 50% of the time. It was found that GS-1 turbidity responds more drastically to storm events than the GS-2 turbidity. It may be fair to establish a separate BNT standard for that site, since GS-2 receives diluted turbidity values due to the confluence of a turbid Gilmore Creek and a relatively clean Pedro Creek. It is recommended that at least 3 to 4 more years of continuous monitoring is necessary prior to development of any TMDL. Also, it is critical to fingerprint sediments to understand the sources and proportions so that TMDLs developed are fair to the land user.

2. BACKGROUND

In 1992, the Goldstream Creek near Fairbanks, AK was listed by ADEC on the Section 303(d) list as impaired for turbidity. Water quality sampling by ADFG and ADNR in 1987 - 1992 had demonstrated that segments of Goldstream Creek had been water quality-impaired for turbidity and fine sediments. Goldstream Creek was evaluated for impairment of water quality by ADEC and the Water Quality Report was completed in 1994. The sources of turbidity were determined to be both point sources, including active placer mines, and nonpoint sources, including abandoned placer mines, stream bank erosion, and re-suspension of deposited sediment, as well as runoff from both abandoned and active mine sites. The report provides information indicating that practices and control measures including the issuance of NPDES permits, settling ponds, and recycling of process wastewater on Goldstream Creek have significantly reduced the settleable solids and turbidity values for the creek from the mid-1970s through the early 1990s (ADNR, 1994). However, no information was found regarding successful implementation of the controls specified in the 1994 Water Quality Assessment report and no monitoring data subsequent to the 1993 study has been located. Monitoring data that demonstrate compliance with the water quality standards (WQS) is required to remove Goldstream Creek from the list of waterbodies impaired for turbidity (CDM, 2008). If the monitoring does not demonstrate that Goldstream Creek is meeting WQS, then Alaska will need to develop a TMDL or provide a demonstration of "other pollution controls (also known as a 4b demonstration)". Based on the need for such data monitoring, UAF was awarded with an ACWA grant in July, 2010 to initiate monitoring at three sites identified in the Quality Assurance Project Plan (QAPP) and Sampling and Analysis Plan (SAP) that was developed by ADEC in December 2009 (ADEC, 2009a).

Subsequent to the development of the QAPP and SAP of 2009, a major objective to collect steady and near-continuous measurements of turbidity data from both baseflow and stormflow conditions and the stream discharge data at those times at several selected locations from spring to fall of 2010, 2011 and May-June of 2012 in order to characterize conditions and potentially locate sources of impairment was established. Additionally, collection of monthly (or more frequently if needed) data of overall water quality, viz., dissolved oxygen (DO), pH, conductivity, temperature, etc. at several selected locations of Goldstream Creek from spring to fall of 2010, 2011 and May-June of 2012 in order to characterize the degree of impairment was included in the sampling plan.

Figure 1 is a GIS rendering of the Goldstream Creek with the three sampling sites identified. The GIS layers and data have been provided to ADEC in soft data format. The Goldstream Creek Watershed is located approximately 40 miles northwest of Fairbanks and encompasses an area of approximately 420 square miles (Figure 2; directly reproduced from the 2009 QAPP). Major portions of the Goldstream Creek Watershed lie within the Tanana-Kuskokwim Lowland, which is broad alluvial lowland with generally low relief topography.

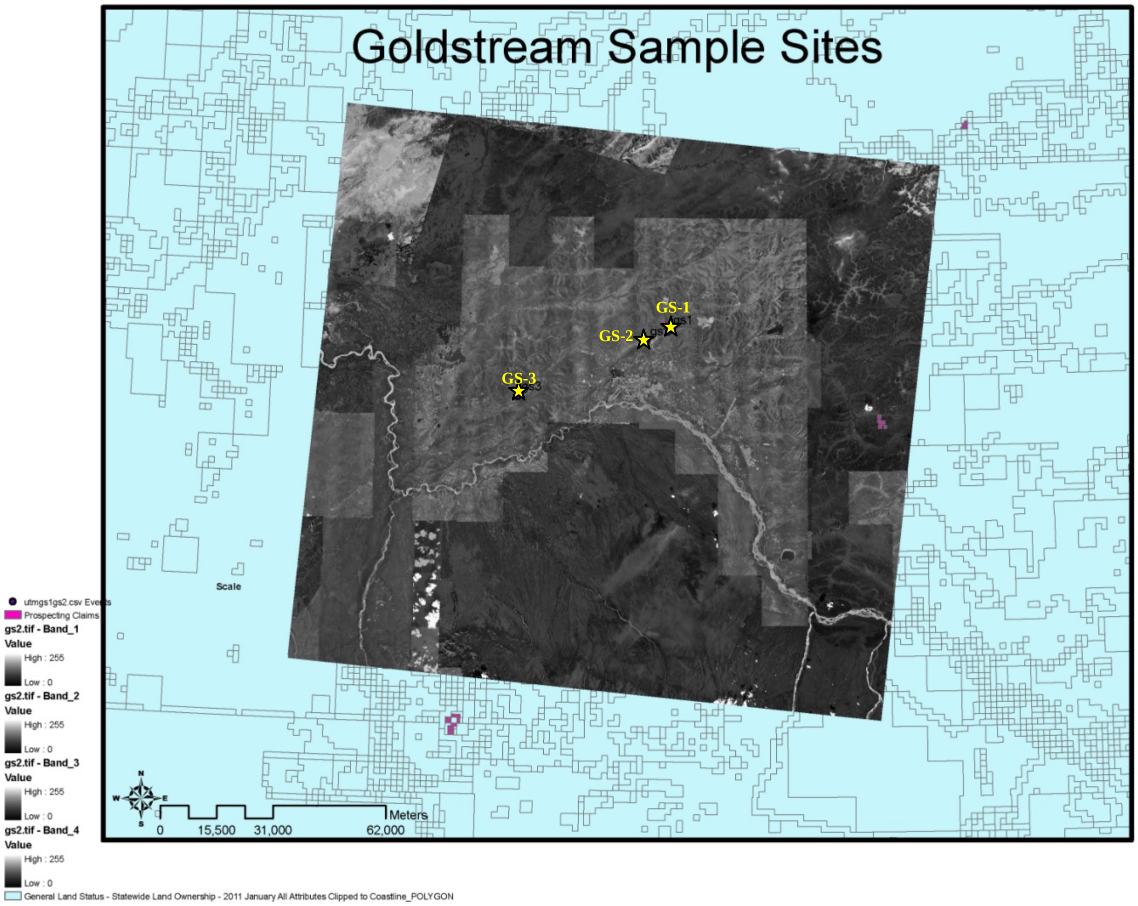

Figure 1. *GIS based map of Goldstream Creek with the three sampling stations.*

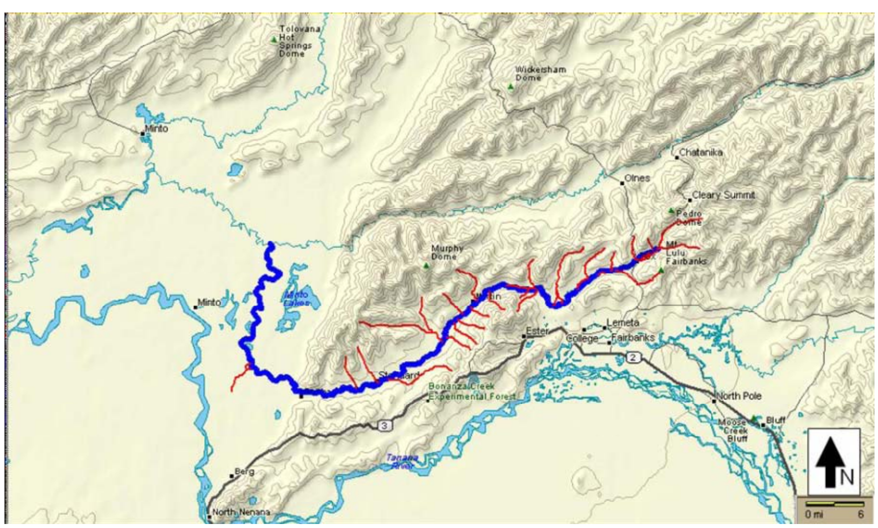

Figure 2. *Goldstream Creek (blue) and tributaries (red) is located just north of Fairbanks, AK (ADEC, 2009a).*

Goldstream and its tributaries flow through a highly mineralized tertian and the uplands have been a major and continuous mining area for nearly 100 years. The Goldstream Creek area is included in the Fairbanks Mining District and was one of the early major mining areas in the interior of Alaska. Goldstream Creek generally flows in a southwesterly direction (Figure 2). Goldstream Creek is formed by the confluence of Pedro and Gilmore creeks at an elevation of 270 m, than flows westward until it joins the Chatanika River at Minto Flats at an elevation of about 125 m. Base flows are estimated to be between 0.5 and 0.6 cubic meters per second (U.S. Geological Survey Water Year Data 1978 – 79 from USGS, 1994).

Goldstream Creek flows mainly through undifferentiated silt and to a minor extent through organic silt (Pewe, 1955). The upper portion of Goldstream Creek is characterized by a sand, gravel, and cobble bottom, shallow water, low banks, and overhanging vegetation, primarily dense willows. The lower portion of the creek below Ballaine Road consists of a mud and silt bottom, deep water, high banks, and an abundance of overhanging vegetation and tall trees. The upper region of Goldstream Creek is impacted excessively by placer mining. The upper region will be focused on to determine natural background conditions of turbidity from those directly due to placer mining. The turbidity present in the lower region is due to resuspension of previously deposited materials and non-point sources and can be characterized by examining resuspension in the mainstem in the upper watershed. Numerous streams are tributary to Goldstream, including Fox, Big Eldorado, O'Connor, and Moose Creeks from the north and Engineer and Sheep creeks from the south.

Based on the QAPP and SAP of 2009, the project should include an overall assessment of turbidity within Goldstream Creek with respect to influences from natural factors including erosion, resuspension, and the influences from anthropogenic sources, including placer mining. Samples should be collected primarily using continuous data loggers during critical periods including wet weather events (typically August – September). Sampling should also take place during the period of peak mining activity (June, July, and August). Targeted sampling, with respect to a spatial and temporal evaluation, may be needed to determine if exceedances of the water quality criteria are persistent or systemic and exceedances which may be a permit violation, but not systemic. Water quality in Goldstream Creek is affected by both point and nonpoint source discharges throughout the watershed. Point sources include active placer mining discharges. Potential nonpoint sources in the watershed include stormwater runoff from abandoned mines and active mine sites, as well as streambank erosion.

The 2009 SAP recommends that the need to fully characterize the aqueous sediment load of Goldstream Creek requires samples to be taken at multiple locations at various times over various flow regimes. The Goldstream Creek watershed is impacted heavily by placer mining, which is the major type of anthropogenic point source for turbidity to the stream. Sampling at GS-1 and GS-2 should be conducted downstream of mining operations to determine their potential impact to Goldstream Creek above allowable levels. These samples should be used to determine the effect of placer mining on stream turbidity in Goldstream Creek. The majority of anthropogenic non-point sources of sediment that effect Goldstream Creek are also related to mining, including abandoned mines, reclaimed mines, overburden piles and other disturbed areas. Overland flow from natural runoff will occur during spring break up and during periods of precipitation. Flow during these times will increase both the amount of sediment entering the stream, but the increased flow will also elevate the amount of sediment re-suspended in the water column. Of all the sources of sediment in Goldstream Creek, the natural non-point sources are the most difficult to characterize due in part to the fact that the whole basin is affected by anthropogenic non-point source sediment loads. Natural non-point source sediment loads will be characterized by establishing the reference location (GS-3) within Goldstream Creek (Figure 1).

3. METHODS

Using the recommendations provided in the 2009 SAP, the sites that were instrumented are shown in Table 1.

Table 1. *Identification of measurement devices used at each sample location.*

				Measurement Devices Employed				
Location ID	Tributary/Road Crossing	Location		Data Logger	ISCO Sampler	YSI Meter	Hatch Meter	Price Type AA (Pygmy Meter)
		Latitude	Longitude					
GS-1	Gilmore Creek	64°58.511'	-147°32.529'	X	X	X	X	X
GS-2	Goldstream Road	64°56.844'	-147°40.529	X	X	X	X	X
GS-3	Standard Creek Road	64°58.511'	-147°32.529'		X	X	X	X

The data was collected for several parameters as shown in Table 2.

Table 2. *Parameters, units, and intervals of measurement for each device.*

Measurement Device	Parameter	Units	Sensor	Precision	Sample Interval
Data Logger	Turbidity	NTU	Campbell OBS-3+SB 2.5-T1	0-1000 NTU with +/- 2%	Hourly and Daily Average
	Conductivity	µS/cm	CR 1000 Measurement and Datalogger	0-1000 µS/cm +/- 2%	
	Water Depth	cm	Campbell CS450-L45 Pressure Transducer	N/A	
	Water and Air Temperature	°C	Campbell HMPC45C-L 10	-40°C - 60°C	
	Relative Humidity	%	Campbell HMPC45C-L 10	0 – 100%	
YSI Multimeter	DO	mg/L	Steady State Polarographic	0 - 50	Bi-Monthly
	pH	std. units	Glass combination electrode	0 - 14	
	Conductivity	µS/cm	4-electrode cell with autoranging	0 - 200	
	Temperature	°C	YSI temperature precision thermistor	-5°C - 45°C	
Hach 2100 P Turbidity Meter	Turbidity	NTU	-	0-1000 NTU with +/- 2%	
Price Type AA Flowmeter/ Pygmy Meter	Flow	ft^3/sec	-	N/A	Monthly

Although the SAP recommended a sample interval of ~15 minutes using the dataloggers, it was decided during the first project meeting in July 2010 that hourly and daily background screening of turbidity and other water quality parameters should be sufficient as this will not be used for permitting.

Continuous data sampling started on August 2, 2010 for GS-1 and July 26, 2010 for GS-2. Periodic turbidity data was procured using the Hach Turbidity meter. Also, periodic data has been collected on stream discharge at each location.

Continuous data sampling was discontinued after October 7, 2010 since the stream was freezing and there was a risk to the sensors. All sensors were removed from GS-1 and GS-2 and stored for the winter. No data could be collected with the YSI multimeter for the 2010 field season as it was repaired and received after October 2, 2010. Continuous and periodic data sampling was resumed after the spring break up in 2011. Automatic sensors were deployed on May 24, 2011 in GS-1 and GS-2. Periodic samples using the YSI multimeter, Hach Turbidity meter and grab samples for TSS have been procured from GS-3. Continuous data sampling was discontinued after September 26, 2011 due to the stream beginning to freeze over. All sensors were removed from GS-1 and GS-2 and stored for the winter. Continuous and periodic data sampling was resumed after the spring break up in 2012 for GS-1 and GS-2. Automatic sensors were once again deployed on May 26, 2012 in GS-1 and May 20, 2012 for GS-2. Periodic samples using the YSI multimeter, Hach Turbidity meter and grab samples for TSS have been procured from GS-3. Continuous data sampling was discontinued after June 30, 2012 due to the end of contract period.

Standard Operating Procedures (SOPs) were provided by ADEC for General Field Testing and Measurement. SOPs were provided by ADEC for monitoring and calibrating turbidity, dissolved oxygen, specific conductance and hydrogen ion activity (pH). SOPs were provided by the Department of Fish and Game (DF&G) for monitoring and collecting water flow and velocity.

4. DATA PRESENTATION

In 2010, it was realized that the automatic turbidity data collected at GS-1 were erroneous. To understand what issue could be impacting the turbidity sensor, the following investigations were carried out –

- Potential issues with the datalogger code at GS-1.
- Potential wiring issue in the field, loose wire, or wire that was crimped on insulation thus not making a good electrical contact.
- Potential wiring problem that occurred after installation, such as coming loose, resulting in data being good for a period of time and then suddenly failing.
- Field issue with sensor, such as getting covered by sediment, working for a period of time and then not functioning correctly (sensor failure)
- Checking wiring diagrams

Despite several attempts to correct the issue, it was not resolved by the end of the season. The reason for the issue was not clear at all and is still beyond our perception. Hence, no presentation or validation of the data of GS-1 in 2010 is necessary. In this section, we will provide a discussion on establishment of background natural turbidity using data from GS-3, present the data of GS1 for 2011 and GS-2 for 2010 and 2011 field seasons. Next we will focus on parameters that have been recommended in the 2009 QAPP. These are the water temperature, DO and pH as water quality indicators.

The Alaska WQS is reproduced from the 2009 QAPP (ADEC, 2009a) in Table 3.

Table 3. *Parameter and Levels of Concern*

Analyte	Media	Alaska WQS		
		Aquatic Life	Recreation	Water Supply
Turbidity	Water	< 25 NTU above natural condition	<+10 NTU when natural condition is ≤ 50 NTU; <20% increase if natural condition is >50 but not to exceed 15 NTU	<+5 NTU when natural condition is ≤ 50 NTU; <10% increase if natural condition is >50 but not to exceed 25 NTU
DO	Water	>4.0 mg/L	>7 mg/l for anadromous fish; >5 mg/l for non-anadromous fish; < 17 mg/L	>4 mg/l
pH	Water	6.5 - 8.5; not vary by > 0.5 from natural condition	6.5 - 8.5	6.0 - 8.5
Temperature	Water	<20°C Migration routes 15°C Spawning areas 13°C Rearing areas 15°C Egg & fry inc. 13°C	<30°C	<15°C
Conductivity	Water	NA	NA	NA
Flow/Discharge	Water	NA	NA	NA

NA = Not applicable.

In order to assess the turbidity data for meeting WQS of AK, we need to establish a background natural turbidity (BNT). The GS-3 site was recommended in the 2009 QAPP for such establishment. ADEC recommends using the Natural Condition Tool (http://dec.alaska.gov/water/wqsar/wqs/NaturalConditions.html) to establish BNT. However, the tool requires at least 20 data points over two years. Due to lack of the required number of data from GS-3 for establishing BNT we used alternate methods to establish BNT. Two methods were found in the literature: 1) The BNT was calculated as average of overall testing data (ADEC, 2002) and 2) the median value among over all data was used as natural turbidity (USEPA, 1999).

The turbidity data collected using Hach turbidity meter from GS-3 in 2011 field season was used to establish the BNT. There were two replicates of 16 data points over May 18 – September 26, 2011. The coefficient of correlation between the two replicate data sets is 0.987. The mean standard deviation of the two replicate data sets is 7.166 NTU. The BNT was established using the mean of the averages of the two replicate data sets, which is 15.24 NTU. The mean of the median values of the two replicate data sets is 16.1 NTU suggesting that there are hardly any variations. The CV is approximately 47%, which suggests that the data has very a small spread.

The BNT value of **15.24 NTU** is less than 50 NTU. According to the AK WQS (Table 3), the stream turbidity may not exceed **40.24 NTU** for aquatic life, **25.24 NTU** for recreation and **20.24 NTU** for water supply. However, with more data collected, the BNT needs to be reestablished using ADEC recommended Natural Condition Tool.

The statistics of hourly and daily turbidity, hourly and daily water temperature, pH and DO are presented in Tables 4a &b, 5 and 6a & b.

Table 4a. *Statistics of different parameters of water quality at GS1 in 2011.*

GS-1 in May - September of 2011					
Parameter	Frequency	Mean	Median	CV%	Number of samples
Water T (°C)	Daily	8.49	8.72	1.91	123
	Hourly	8.46	8.57	2.15	3031
Turbidity (NTU)	Daily	182.7	91.1	208.9	123
	Hourly	174.8	80.6	209.9	2937
pH	Variable	7.03	7.42	1.03	19
DO (mg/L)	Variable	21.83	9.41	32.37	20

Table 5b. *Statistics of different parameters of water quality at GS1 in 2012.*

GS-1 in May - June of 2012					
Parameter	Frequency	Mean	Median	CV%	Number of samples
Water T (°C)	Daily	9.21	9.07	0.18	34
	Hourly	9.26	9.12	0.21	840
Turbidity (NTU)	Daily	87.39	77.23	0.68	33
	Hourly	90.56	57.21	1.12	840
pH	Variable	7.12	7.06	0.34	5
DO (mg/L)	Variable	11.06	10.90	1.42	5

From Table 4, it is evident that the both hourly and daily turbidity are positively skewed. The coefficient of variation (CV = Standard deviation ÷ Mean) in both daily and hourly turbidities are high in 2011 but not so in 2012 owing to only two months of monitoring, reflecting that over the period of monitoring in 2011, the data variability has been large. This large variability could be due to a combination of several factors such as periods of stream bank erosion or other non-point source pollution and also periods of enhanced anthropogenic activities. We will discuss this aspect in monthly based data analysis later. Comparing the mean daily and hourly turbidity values to the AK WQS standards, it is evident that the stream turbidity exceeds all three standards on daily and hourly basis. Site visits have also confirmed that the Gilmore Creek is in general more turbid than the Pedro Creek that converges with the former to flow into the Goldstream Creek.

Both the mean daily and the hourly water temperature (Table 4a & b) have a considerably low variability and are hardly skewed. Comparing the mean daily and hourly water temperature values to the AK WQS standards, it is evident that the stream temperature complies with all the three standards on daily and hourly basis. The pH has low variability and skewness while the DO has moderate variability and a small skewness. Both the mean pH and DO comply with all the three AK WQS standards.

Table 6. *Statistics of different parameters of water quality at GS2 in 2010.*

GS-2 in July – October of 2010					
Parameter	Frequency	Mean	Median	CV (%)	Number of Samples
Turbidity (NTU)	Daily	165.31	62.76	126.61	69
	Hourly	164.11	52.51	131.62	1755
Water T (°C)	Daily	5.01	6.70	103.19	89
	Hourly	4.93	6.51	108.52	2133

In Table 5, we present the statistics for the 2010 season for GS-2 that includes daily and hourly turbidity and water temperature. No pH or DO data was collected in this season due to the YSI sensor problem. It is evident that the daily and hourly mean data compare well for both the parameters. The turbidity is positively skewed while the water temperature is negatively skewed to a small extent. There is a considerable variability in the data during this season for both turbidity and water temperature. This variability in turbidity is expected since the data collection covers periods of summer with high anthropogenic activities and early fall when the turbidity may only be caused due to natural factors. The high variability in the water temperature is also caused due to the drop in temperature from summer through early fall. Comparing the mean daily and hourly turbidity values to the AK WQS standards, it is evident that the stream turbidity exceeds all three standards on daily and hourly basis. However, comparing the mean daily and hourly water temperature values to the AK WQS standards, it is evident that the stream temperature complies with all the three standards on daily and hourly basis.

Table 7a. *Statistics of different parameters of water quality at GS2 in 2011.*

GS-2 in May-September of 2011					
Parameter	Frequency	Mean	Median	CV%	Number of samples
Water T (°C)	Daily	7.54	7.55	1.41	124
	Hourly	7.54	7.69	1.68	2977
Turbidity (NTU)	Daily	88.86	29.28	153.20	110
	Hourly	112.63	25.90	208.10	2878
pH	Variable	7.43	7.57	0.45	40
DO (mg/L)	Variable	9.72	7.82	5.48	40

Table 8b. *Statistics of different parameters of water quality at GS2 in 2012.*

GS-2 in May-June of 2012					
Parameter	Frequency	Mean	Median	CV%	Number of samples
Water T (°C)	Daily	7.30	7.18	0.20	46
	Hourly	7.24	7.32	0.27	982
Turbidity (NTU)	Daily	37.77	34.36	0.56	46
	Hourly	38.56	27.42	1.10	982
pH	Variable	7.00	7.31	0.07	5
DO (mg/L)	Variable	12.15	12.52	1.13	5

From Table 6, it is evident that the both hourly and daily turbidity are positively skewed in 2011 but not so in 2012 owing to only a bit above one month of effective monitoring. The CV in both daily and hourly turbidities are considerably high in 2011 but not so in 2012 owing to only a bit above one month of effective monitoring, reflecting that over the period of monitoring, the data variability has been large in 2011 as also observed in data from Table 4. Comparing the mean daily and hourly turbidity values to the AK WQS standards, it is evident that the stream turbidity is breached for all three standards in 2011 but meets the aquatic life standards only in 2012. Taking into consideration the skewness of the hourly data and the fact that the BNT has been based on the average of a few data points, the failure to comply with the water supply standards needs to be reevaluated in the future. Comparing the 2011 & 2012 mean turbidity data of GS-1 (Table 4) and GS-2 (Table 6) it is evident that Gilmore creek has considerably higher turbidity than the Goldstream Creek downstream of the confluence of Pedro and Gilmore Creeks. The reason for such difference could be attributed to the dilution caused at the confluence with a cleaner Pedro creek meeting with a turbid Gilmore creek. It may also be possible that there are more frequent anthropogenic activities upstream of GS-1, and GS-2 is less impacted by such activities since it is downstream of GS-1. Another possibility of this observed difference could be due to a combination of stream bed slope, terrain relief and altitude differences between GS-1 and GS-2, which could impact non-point source factors that cause turbidity. For example, upstream of GS-1 is prone to severe bank erosion as illustrated in Figure 3. Besides, the local geology and precipitation reaching the stream as discharge could affect the turbidity in GS-1 more than in GS-2.

Figure 3. *Examples of bank erosion upstream of GS-1 site.*

Both the mean daily and the hourly water temperature (Table 6a & b) have a considerably low variability and are hardly skewed. Comparing the mean daily and hourly water temperature values to the AK WQS standards, it is evident that the stream temperature complies with all the three standards on daily and hourly basis. The pH has low variability and skewness while the DO has moderate variability and a small skewness. Both the mean pH and DO comply with all the three AK WQS standards.

The monthly statistics of turbidity, water temperature, pH and DO are presented in Tables 7, 8 and 9.

Table 9. *Monthly turbidity (NTU) based on daily data.*

Site	Month/Year	Mean	Median	CV%	Number of samples
GS 1	May,2011	12.41	10.15	6.15	7
GS 1	June,2011	56.10	53.76	39.77	30
GS 1	July,2011	303.73	138.7	298.81	28
GS 1	August,2011	282.02	269.6	189.64	31
GS 1	September,2011	128.14	99.1	108.84	27
GS 1	May, 2012	54.09	46.64	0.71	5
GS 1	June, 2012	93.14	78.72	0.64	30
GS 2	July,2010	66.60	31.89	80.80	4
GS 2	August,2010	139.48	55.82	183.41	20
GS 2	September,2010	266.81	191.20	202.72	27
GS 2	October,2010	63.70	1.23	207.99	18
GS 2	May,2011	13.29	12.27	2.84	7
GS 2	June,2011	20.54	12.77	17.23	29
GS 2	July,2011	65.54	23.28	155.79	30
GS 2	August,2011	181.65	90.95	205.33	26
GS 2	September,2011	127.70	80.23	145.52	18
GS 2	May, 2012	60.46	69.46	0.36	11
GS 2	June, 2012	32.47	31.84	0.63	30

It is evident from Table 7 that the mean turbidity increased considerably from May to June in both 2011 and 2012 in GS-1, however, there was only a slight increase at GS-2 in 2011 but decreased significantly in 2012 during those two months. Possible reasons for this could be that GS-2 is downstream of the confluence of Gilmore Creek (GS-1 site) and Pedro Creek. We have observed that the Gilmore Creek is significantly more turbid than the Pedro

Creek on any day. Hence, the turbidity levels reaching GS-2 site are probably diluted due to the confluence of the two creeks upstream. Also, the primary sources of anthropogenic activities could be above the GS-1 site which would result in GS-1 showing significantly increased turbidity before GS-2. With that being said, GS-2 experienced a steady increase in the mean turbidity from May through September of 2010 and there was sudden decrease in October. This was expected since anthropogenic activities increase during the summer season and would slow down as the air temperatures start falling in October. This same trend was seen from May through August, 2011 and decreased in September. This is supported by the CV values. As anthropogenic activities increased and decreased, there was a corresponding rise or fall of the CV. With respect to compliance to the three AK WQS standards for turbidity, it is observed that GS-1 complies with the standards in May 2011 but fails to comply from June to September, 2011. GS-2 is in compliance in May of 2011, but fails to comply all of 2010 and June through September, 2011. All except June 2012 failed to meet the AK-WS standards.

Table 10. *Monthly water temperature based on daily data.*

Site	Month/Year	Mean	Median	CV%	Number of samples
GS 1	August,2010	10.19	10.59	1.82	29
GS 1	September,2010	4.95	5.59	2.86	30
GS 1	October,2010	0.67	0.46	0.67	17
GS 1	May,2011	7.72	7.39	0.79	7
GS 1	June,2011	8.90	8.65	1.30	30
GS 1	July,2011	10.2	10.63	1.05	31
GS 1	August,2011	8.9	8.91	1.04	31
GS 1	September,2011	5.78	5.836	1.13	27
GS 1	May,2012	6.87	6.825	0.09	5
GS1	June,2012	9.6	9.55	0.15	30
GS 2	July,2010	9.76	9.51	0.69	5
GS 2	August,2010	9.40	9.66	1.27	31
GS 2	September,2010	4.90	5.62	2.67	30
GS 2	October,2010	-1.78	-1.04	3.83	23
GS 2	May,2011	5.29	4.93	0.78	7
GS 2	June,2011	6.97	6.53	1.14	30
GS 2	July,2011	8.8	9.1	0.87	31
GS 2	August,2011	8.37	8.37	0.68	31
GS2	September,2011	6.27	6.18	0.71	25
GS2	May,2012	5.44	5.31	0.09	11
GS 2	June,2012	7.98	7.95	0.16	30

Table 11. *Monthly pH and DO for 2011 field season.*

Site	Month/Year	Mean pH	CV pH (%)	Number of samples	Mean DO	CV DO (%)	Number of samples
GS-1	May,2011	7.49	5.95	5	8.79	23.71	5
GS-1	June,2011	7.37	7.79	10	7.35	41.28	10
GS-1	July,2011	6.94	0.72	2	10.9	0.42	2
GS-1	August,2011	6.58	0.58	2	11.64	0.62	2
GS-1	September, 2011	7.45	N/A	1	14.14	N/A	1
GS-1	May,2012	7.02	N/A	1	11.2	N/A	1
GS-1	June,2012	7.19	0.13	3	10.91	1.61	3
GS-2	May,2011	7.28	6.47	19	11.47	53.12	19
GS-2	June,2011	7.7	2.73	16	6.76	61.84	16
GS-2	July,2011	7.32	0.32	3	11.84	0.54	3
GS-2	August,2011	7.12	0.76	3	12.57	0.47	3
GS-2	September, 2011	7.21	N/A	1	13.31	N/A	1
GS-2	April,2012	6.8	N/A	1	11.47	N/A	1
GS-2	May,2012	6.19	N/A	1	12.65	N/A	1
GS-2	June,2012	7.45	0.17	3	11.58	2.22	3

The mean temperature changes are as expected over all months (Table 8). GS-2 is generally colder since it is downstream of the confluence with the colder Pedro Creek. All of the mean temperatures meet the WQS for AK. The mean pH in any given site in any month falls within 6.0 – 8.5, which is required to meet the AK WQS. The DO should be greater than 4.0 mg/L for Aquatic Life and Water Supply. These are easily met by the mean DO in any month. It may also be observed that the DO levels comply with the recreation AK WQS; except for GS-2 in the month of June 2011 for anadromous fish (7 data points out of the 15 do not meet this criterion). It could also be noted that the CV of the DO is considerably high in GS-2 as compared to GS-1 in a given month. The cause of this needs further investigation. Also, the DO levels fall at any given site in June compared to May. This is expected since the turbidity along with other parameters impact the DO level in the stream.

5. DATA VALIDATION

In the subsequent presentation of data, we will provide validation of turbidity data from automatic sampling against data collected using Hach turbidity meter for GS-2 in 2010, 2011 and 2012 and GS-1 only in 2011 and 2012. Hence, both the sensors were brought to a laboratory in UAF and a bench test was conducted in March 2011. The results (Table 10) showed that both the sensors had no errors as compared to independent turbidity measurements using the Hach turbidity meter. All the other sensors were calibrated in the laboratory for the 2011 and 2012 field season. Turbidity, pressure transducer, and conductivity sensors were tested in the lab and all three were found to be working properly under lab setting in 2011 but there were considerable variability in the Hach data in 2012, particularly for turbidities above 500 NTU (not presented). This needs further investigation.

Table 12. *Results of bench test of the automatic turbidity sensors of GS1 and GS2.*

Date	Time	GS1	GS1 % Diff	GS2	GS2 % Diff	Hach	Pass/Fail?
3/24/2011	16:01	1.731	-8.89%	1.981	4.26%	1.9	pass
3/24/2011	16:15	156	-5.45%	168	1.82%	165	pass
3/24/2011	16:22	270	4.65%	263	1.94%	258	pass
3/24/2011	16:24	463	0.43%	482	4.56%	461	pass
3/24/2011	16:26	902	1.58%	893	0.56%	888	pass
3/24/2011	16:32	1178	-2.48%	1155	-4.39%	1208	pass
Acceptance Criteria: 0.1-10 NTU +/- 10%; 11-40 NTU +/- 8%; 41-100 NTU +/- 6.5%; >100 NTU +/- 5%						**; Hach used as baseline**	

In order to assess the turbidity data collected against the Alaska WQS, the automatic data was validated using Hach turbidity measurements (except for GS-1 in 2010). Values that fell above the precision of the sensor were removed from the validation. The negative data and the data out of the precision of the measuring device (sensor) were removed. Table 11 provides a summary of the data removed from the total number of samples collected.

Table 13. *Project Completeness*

GS1	Turbidity						DO	pH
	Hourly Data			Daily Data				
Year	2010	2011	2012	2010	2011	2012	2012	2012
# of Total Samples	1825	3601	840	72	126	34	5	5
# of Data Used	0	2937	839	0	123	33	5	5
# of Data Removed	1825	664	1	72	3	1	0	0
Project Completeness(%)	0	81	99	0	98	97	100	100
GS2	Turbidity						DO	pH
	Hourly Data			Daily Data				
Year	2010	2011	2012	2010	2011	2012	2012	2012
# of Total Samples	2133	3574	982	88	123	40	5	5
# of Data Used	1565	2878	969	69	110	36	5	5
# of Data Removed	568	696	13	19	13	4	0	0
Project Completeness(%)	74	80	99	78	89	90	100	100

The validation plot for GS-2 in 2010 is provided in Figure 4. Even though, the R^2 value is 0.9055, yet the actual data differences between the datalogger and the Hach were not close to each other. It is unsure whether the quality of data was compromised due to the GS-2 automatic sensor or the Hach turbidity meter. We will discuss in the results and discussion section as to how the GS-2 data responded appropriately to precipitation events as was also observed in 2011 field season.

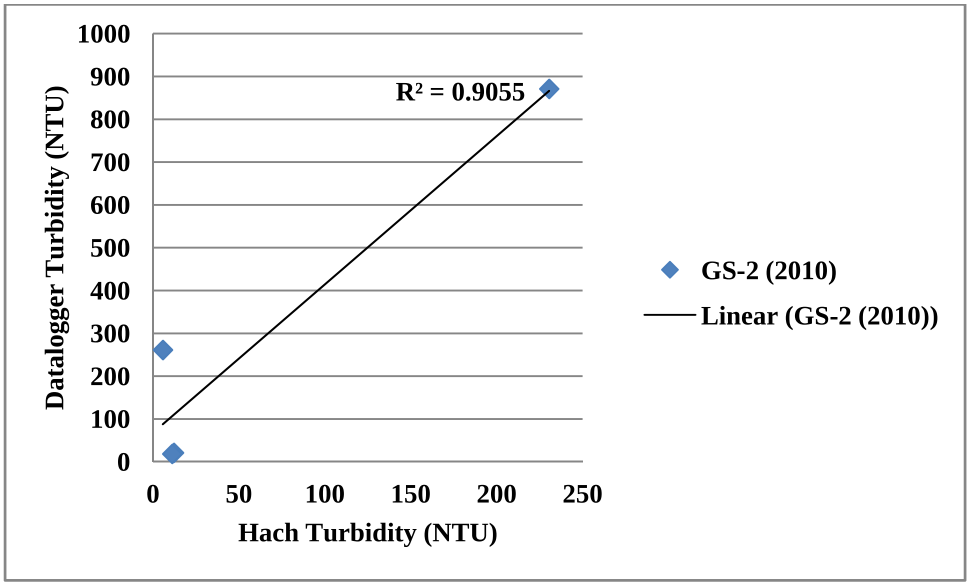

Figure 4. *Validation of turbidity data at GS-2 in 2010.*

Figures 5a & b and 6a & b show the validation plots for GS-1 and GS-2 in 2011 and 2012 field season for turbidity, respectively. The R^2 value for the regression fit was 0.7345 for GS-1 and 0.9805 for GS-2 in 2011 and 0.9906 for GS-1 and 0.6795 for GS-2 in 2012. A visual observation of the data revealed that most of the measurements fell within acceptable limits in both GS-1 and GS-2. Hence, the quality of data can be considered to be much better than the 2010 data from GS-2 (Figure 4).

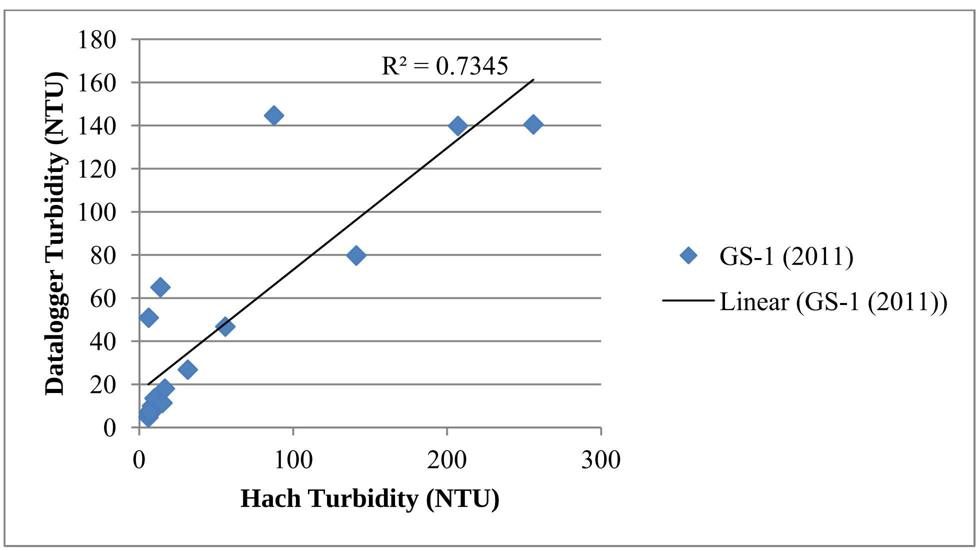

Figure 5a. *Comparison of Hach turbidity data with daily turbidity data recorded by the datalogger at GS-1 in 2011.*

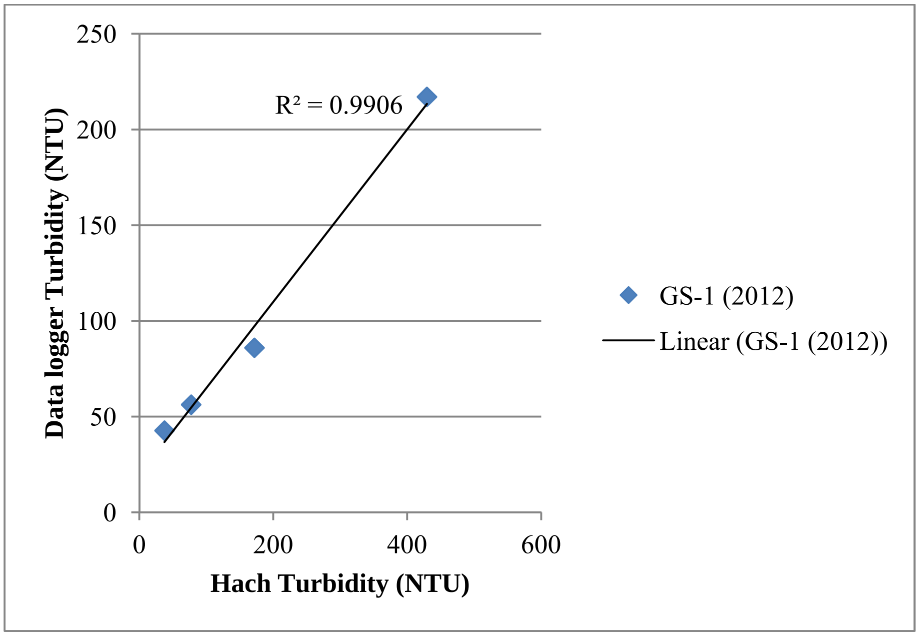

Figure 6b. *Comparison of Hach turbidity data with daily turbidity data recorded by the datalogger at GS-1 in 2012.*

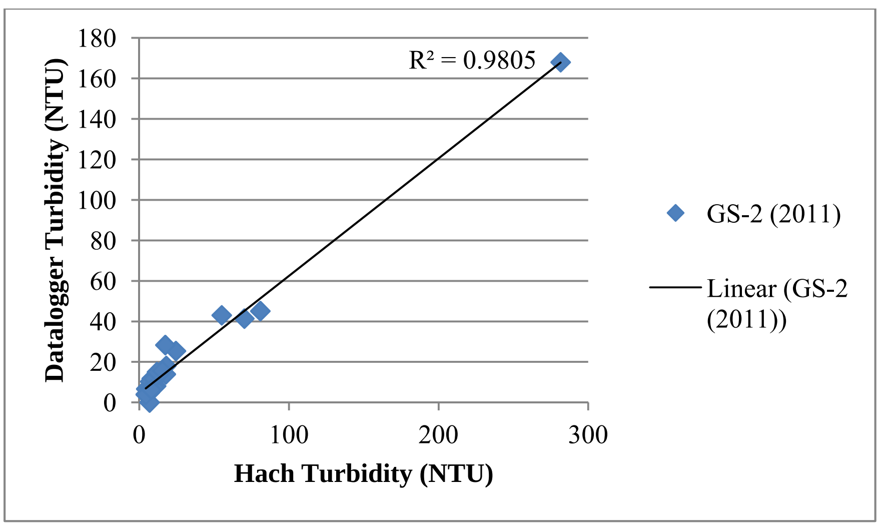

Figure 7a. *Validation of turbidity data at GS-2 in 2011.*

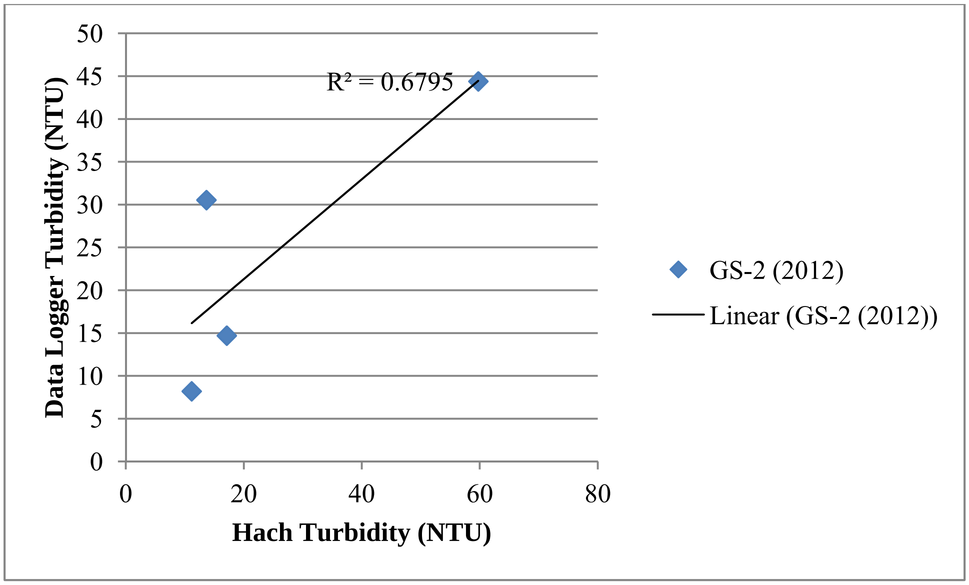

Figure 8b. *Validation of turbidity data at GS-2 in 2012.*

Figure 7a & b and 8a & b illustrate that the daily water temperature data recorded by the datalogger at GS-1 has a reasonable correlation (R^2 = 0.7417) while at GS-2 has a very low correlation (R^2 = 0.2739) with the water temperature data obtained using the YSI Multimeter in 2011. In 2012, there were only three data points for each site and the correlation in GS-1 was negative (R^2 = 0.8139) with the correlation for GS-2 being positive (R^2 = 0.8780).

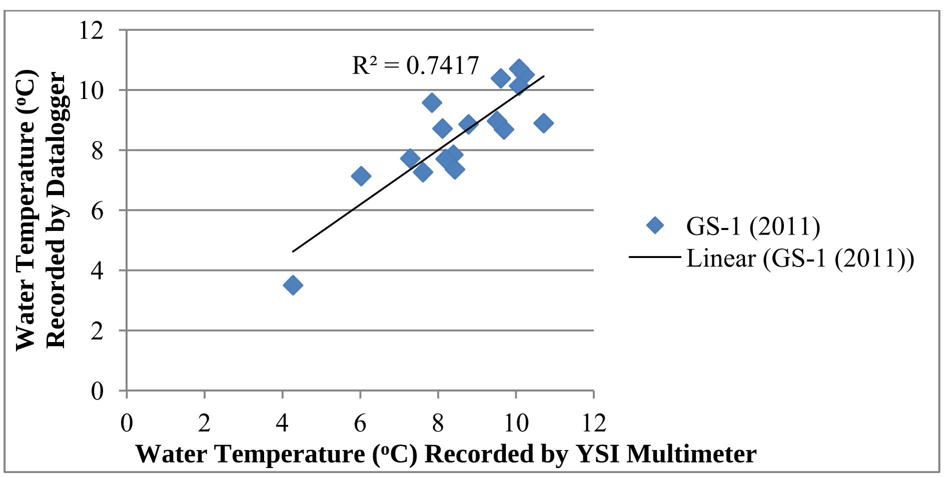

Figure 9a. *Comparison of YSI Multimeter water temperature data with daily water temperature data recorded by the datalogger at GS-1 in 2011.*

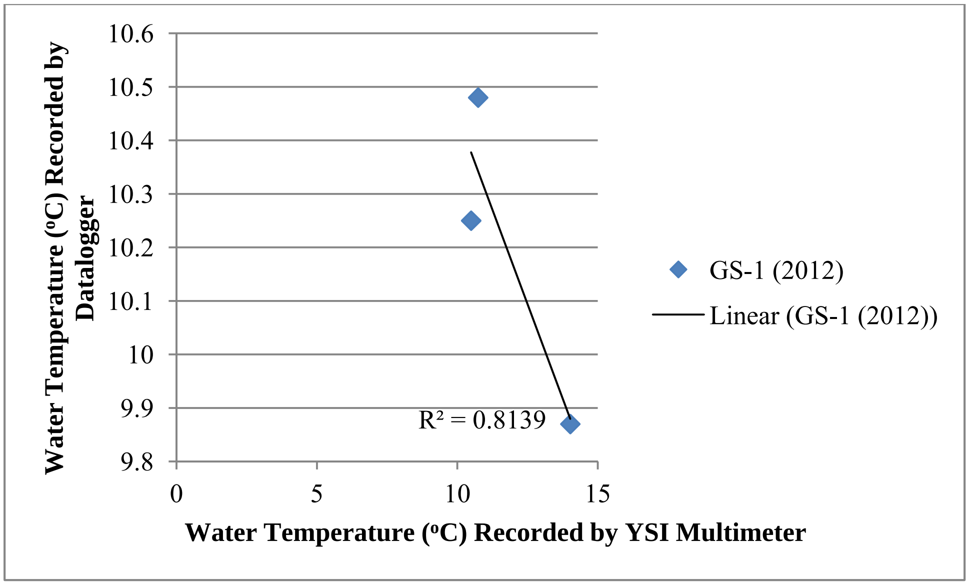

Figure 10b. *Comparison of YSI Multimeter water temperature data with daily water temperature data recorded by the datalogger at GS-1 in 2012.*

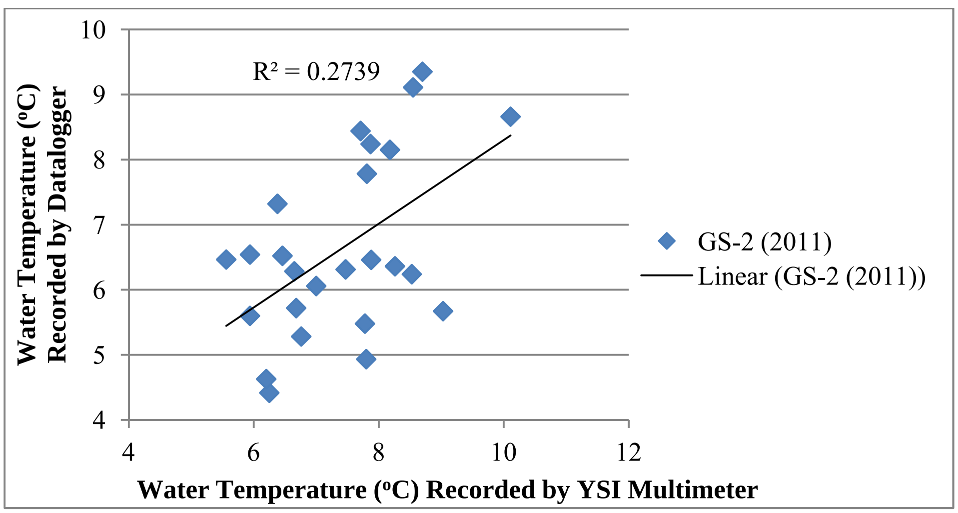

Figure 11a. *Comparison of YSI Multimeter water temperature data with daily water temperature data recorded by the datalogger at GS-2 in 2011.*

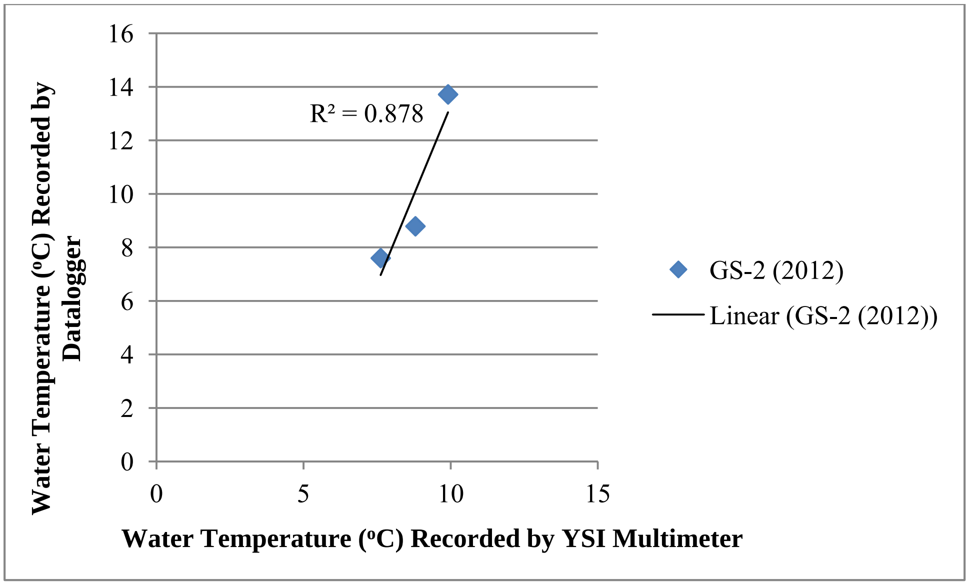

Figure 12b. *Comparison of YSI Multimeter water temperature data with daily water temperature data recorded by the datalogger at GS-2 in 2012.*

6. RESULTS AND DISCUSSION

Applying the AK WQS to the hourly and daily water temperature at both the sites, it was found that the temperatures were within the prescribed standards for aquatic life, recreation and water supply. Since, we were unable to collect DO and pH data in 2010, the AK WQS was applied to the data collected only in 2011. Table 12 summarizes the percent of time each of these parameters comply with the AK WQS. It may be observed that the DO WQS for GS-2 is more affected than that of GS-1. This was a surprise observation and definitely needs closer analysis and interpretation. The reason for such failure needs further interpretation. However, the pH standards had similar compliance for both GS-1 and GS-2 and needs more statistical interpretation.

Table 14. *DO, pH and Temperature Compliance with AK-WQS*

Station	Year	WQS		DO	pH	Temperature
GS-1	2011	Aquatic Life		95.23%	77.27%	100.00%
		Recreation	Anadromous Fish	66.67%	77.27%	100.00%
			Non-anadromous Fish	90.47%		
			Otherwise	85.71%		
		Water Supply		95.23%	86.36%	100.00%
GS-2	2011	Aquatic Life		88.23%	64.28%	100.00%
		Recreation	Anadromous Fish	52.94%	90.47%	100.00%
			Non-anadromous Fish	64.71%		
			Otherwise	100.00%		
		Water Supply		88.23%	97.62%	100.00%
GS-1	2012	Aquatic Life		100.00%	100.00%	100.00%
		Recreation	Anadromous Fish	100.00%	100.00%	100.00%
			Non-anadromous Fish	100.00%	100.00%	100.00%
			Otherwise	100.00%	100.00%	100.00%
		Water Supply		100.00%	100.00%	100.00%
GS-2	2012	Aquatic Life		100.00%	100.00%	100.00%
		Recreation	Anadromous Fish	100.00%	100.00%	100.00%
			Non-anadromous Fish	100.00%	100.00%	100.00%
			Otherwise	100.00%	100.00%	100.00%
		Water Supply		100.00%	100.00%	100.00%

The turbidity of the stream exceeds an estimated WQS for turbidity using BNT most of the time at both the sites. We have observed that the turbidity responds to precipitation events as illustrated in Figures 9 and 10a & b.

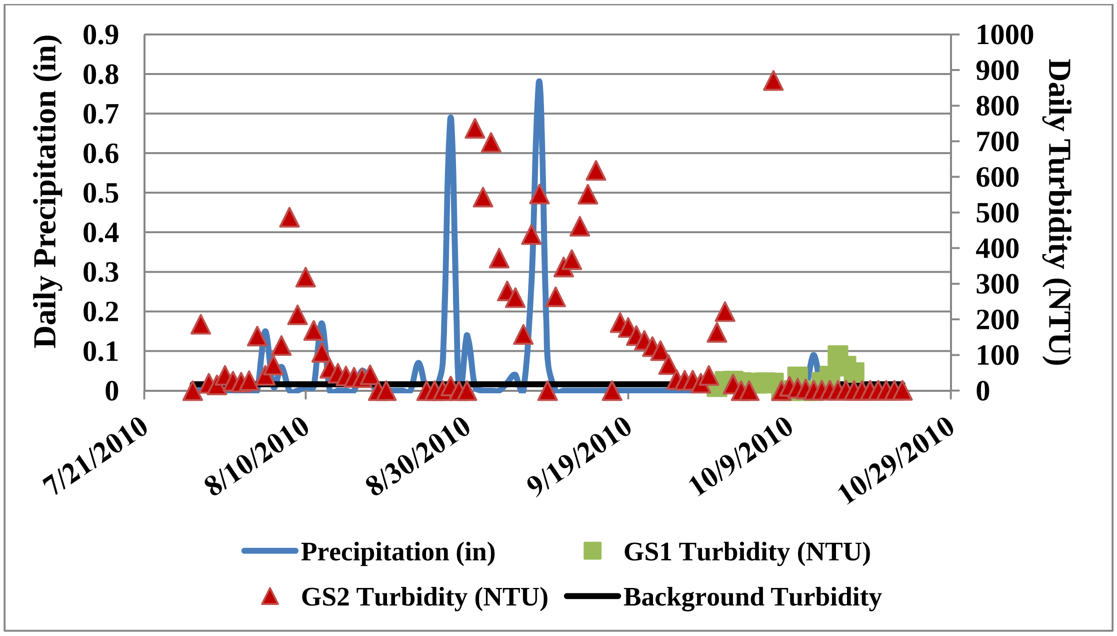

Figure 13. *Daily turbidity of the Goldstream Creek in 2010 field season and its response to precipitation events.*

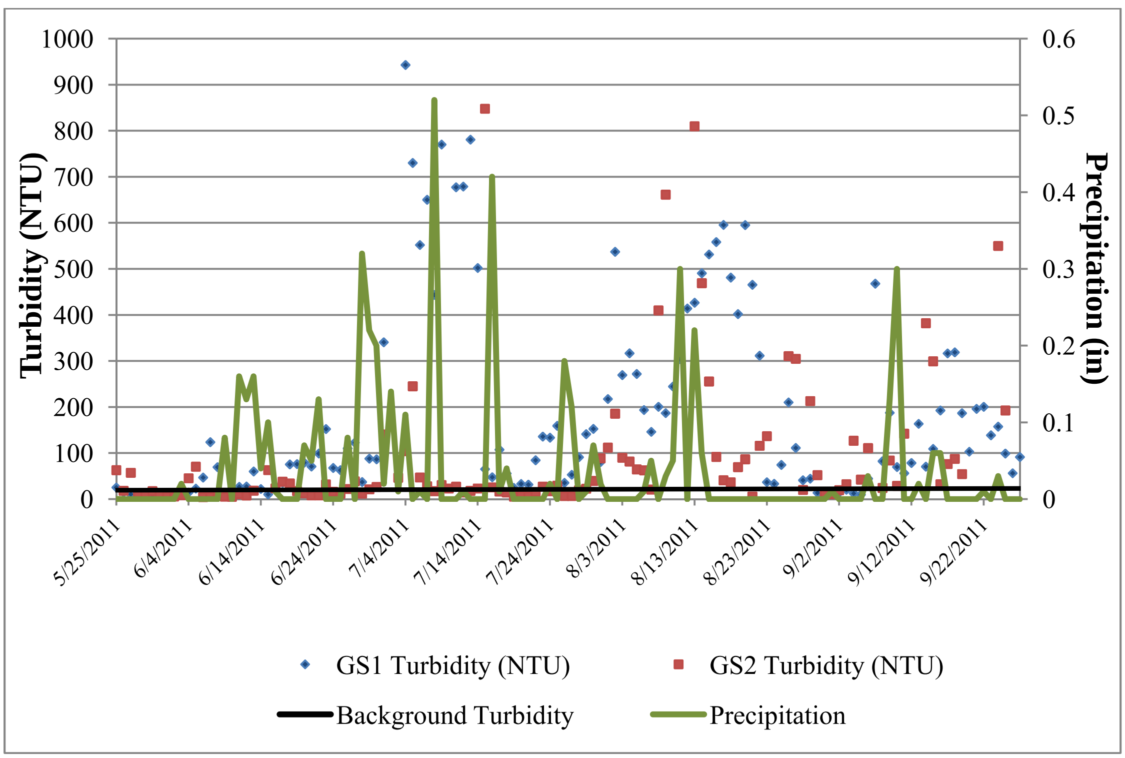

Figure 14a. *Daily turbidity of the Goldstream Creek in 2011 field season and its response to precipitation events*

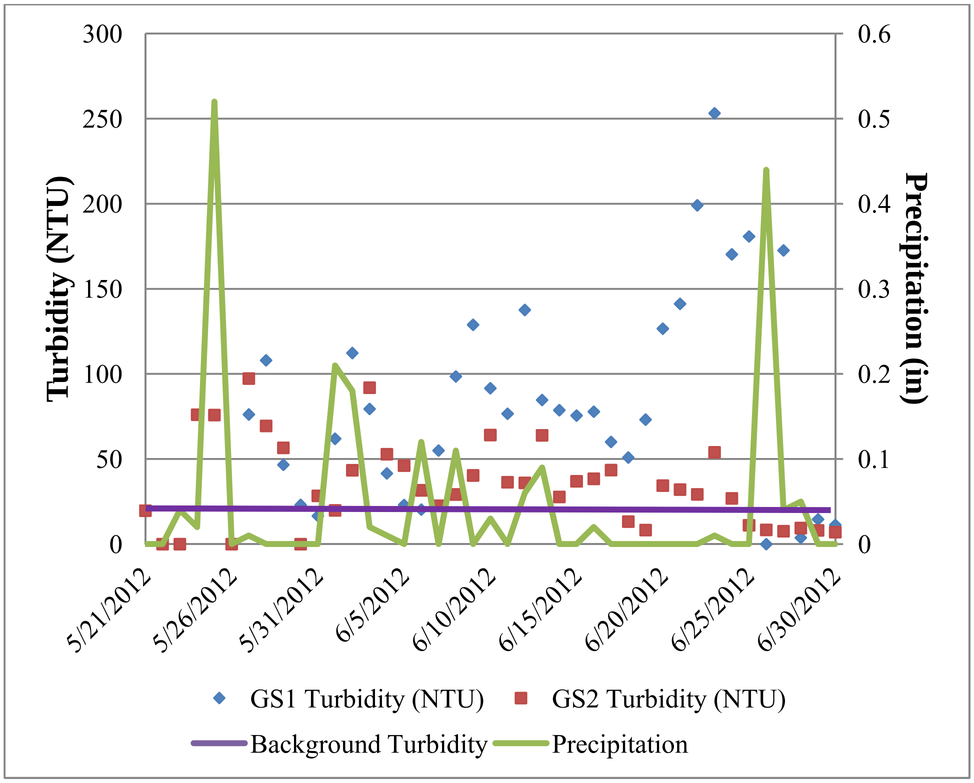

Figure 15b. *Daily turbidity of the Goldstream Creek in 2012 field season and its response to precipitation events*

Figures 9 and 10a show that GS-1 is more responsive to precipitation events earlier in the season than GS-2. As the year progresses, both sites respond to precipitation equally and exceed AK WQS during these times. It may be inferred that there is a lag time associated with sediment moving downstream earlier on in the season, which would account for the sensitivity to precipitation for GS-1 and not GS-2 in June and July. Also, as stated before, GS-2 is downstream of the confluence of Pedro Creek, which is significantly less turbid, which could affect the responsiveness to precipitation at GS-2. In Figure 10b, no particular trend was observed between turbidity and precipitation events. Hence, for the rest of the discussion, no results have been further analyzed for 2012 field season.

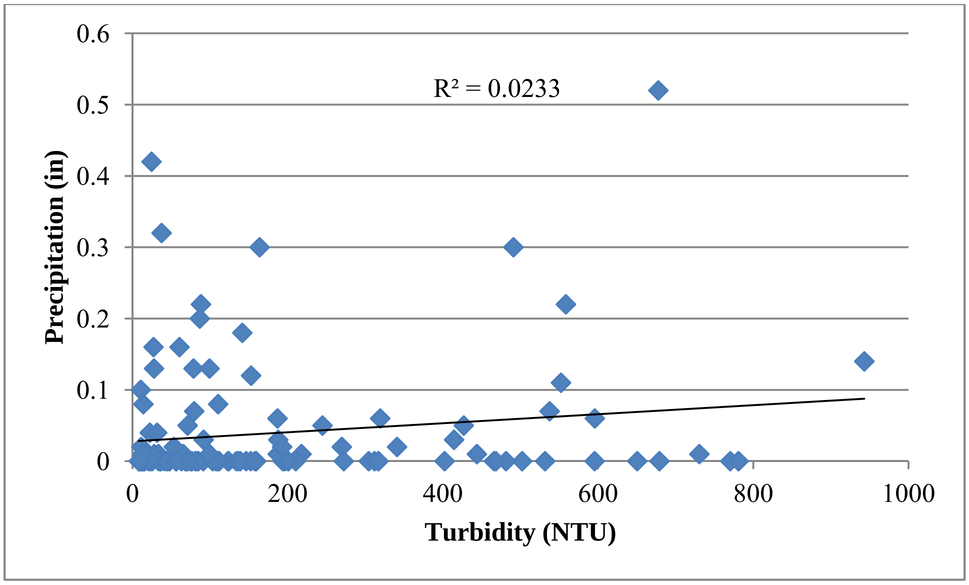

Figure 16: *Plot of Turbidity vs. Precipitation at GS-1in 2011 with an* R^2*=0.0233*

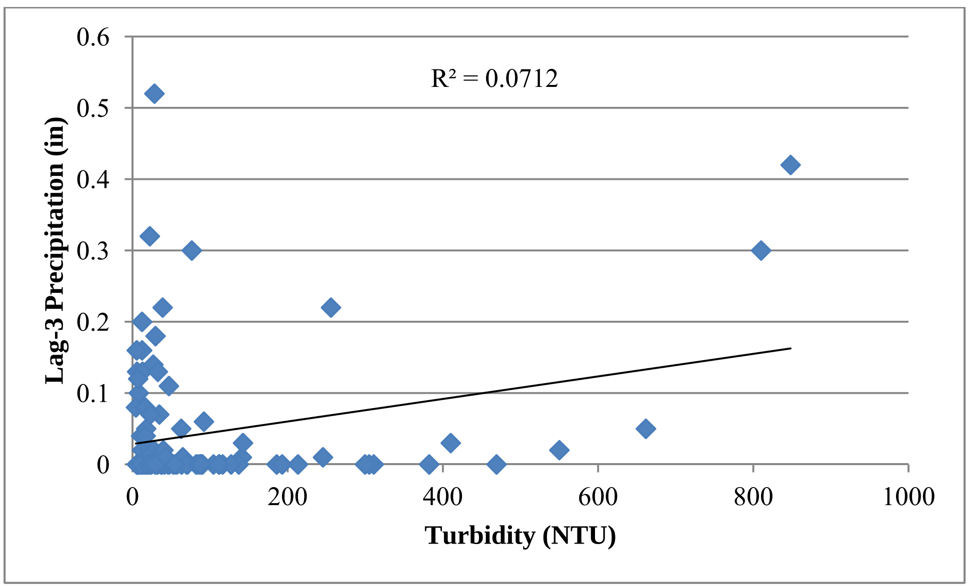

Figure 17: *Plot of Turbidity vs. Precipitation at GS-2 in 2011 with an* R^2*= 0.0712 with a lag of 3 days*

Figures 11 and 12 show a general correlation between precipitation and turbidity. For GS-1, the best correlation occurred the day of the precipitation event. The best correlation for GS-2 occurred 3 days after the precipitation event. While the data is not well correlated, it shows that GS-1 shows an immediate response to storm events, whereas, there is approximately a 3 day lag for the precipitation to appear as discharge in GS-2. Response to precipitation, local geology and anthropogenic activities in the vicinity are factors that provide such difference in correlations to precipitation events. Also, predominantly zero precipitation events, perhaps bias the correlation between turbidity and precipitation. It may be essential to study extreme events and associated turbidity using some statistical model of precipitation such as a Gumbell distribution and then correlate those to the associated turbidity in order to assess if the source of turbidity was indeed anthropogenic in nature. Hence, more investigation and analyses is needed to determine the precise correlation between precipitation and turbidity.

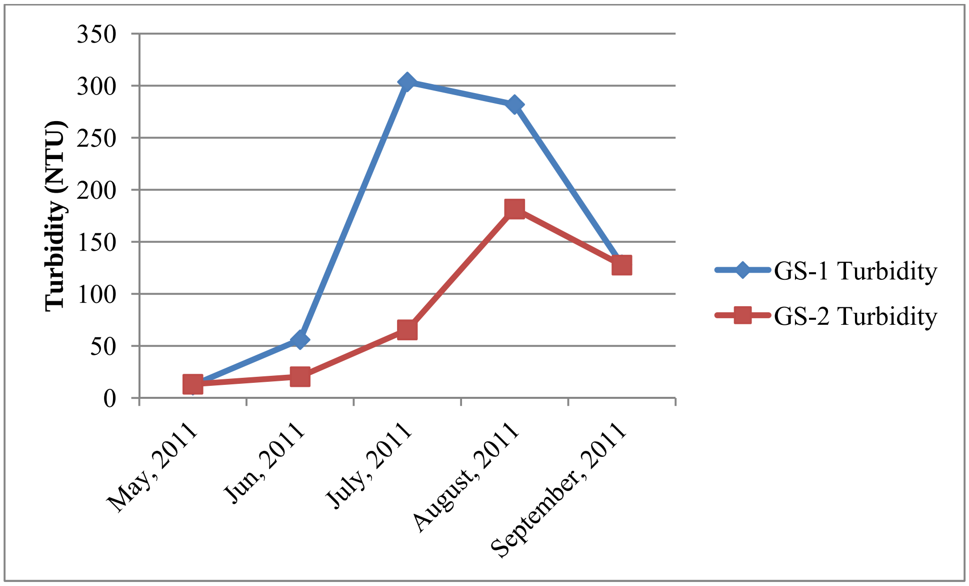

Figure 18: *Comparison of turbidity between GS-1 and GS-2 in 2011*

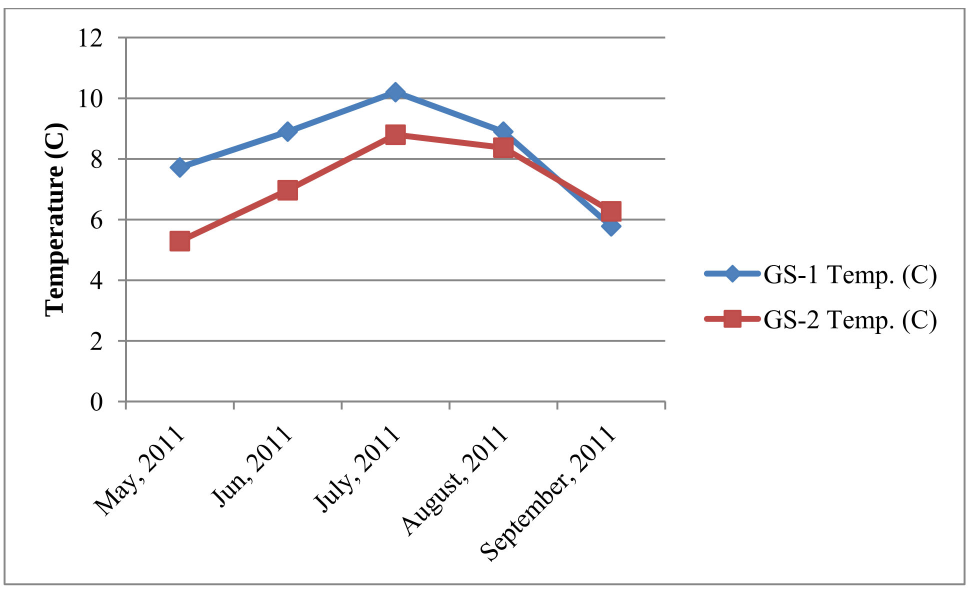

Figure 19: *Comparison of temperature for GS-1 and GS-2 in 2011*

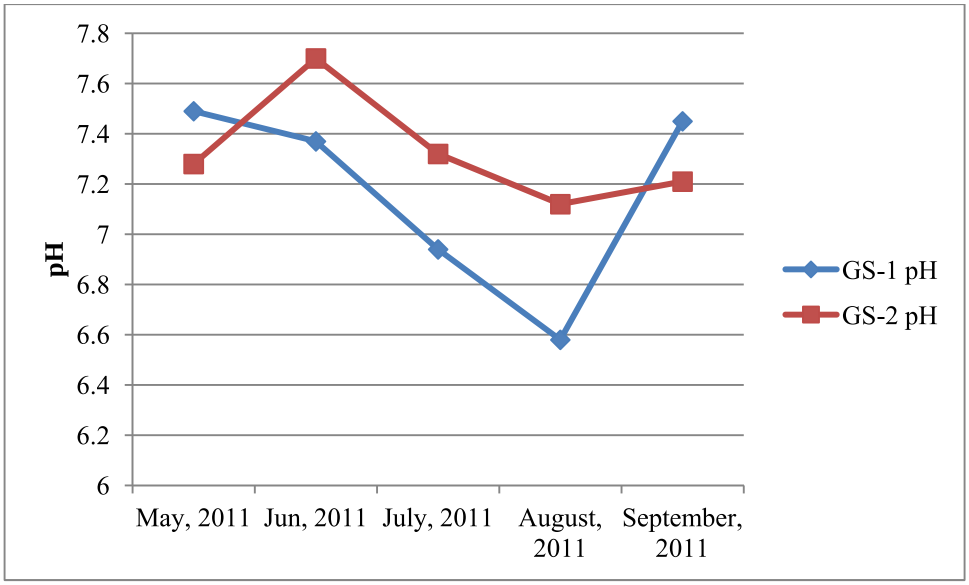

Figure 20: *Comparison of pH of GS-1 and GS-2 in 2011*

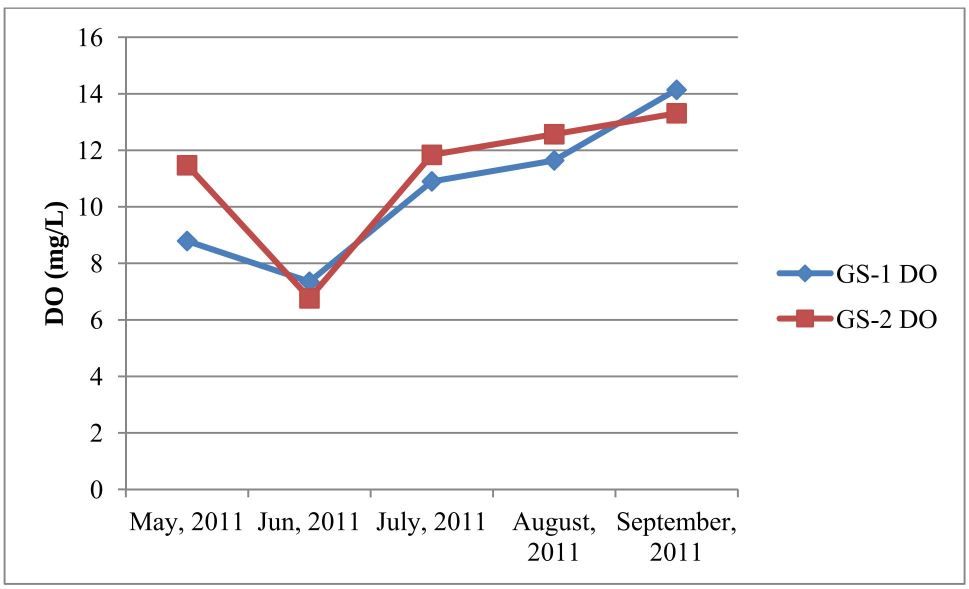

Figure 21: *Comparison of DO for GS-1 and GS-2 in 2011*

Figures 13 through 16 show a comparison of turbidity, temperature, pH and DO for GS-1 and GS-2 through the 2011 season. There are several critical points to note. It appears that the peak turbidity lags by about a month at GS-2 when compared to GS-1. This was also evident from Figure 10 in a qualitative way. The fact that the peak turbidity responds fast at GS-1 and is also higher than GS-2 could be attributed to (without taking storm events into account) the mostly unconsolidated terrain through which the surface water flows in the Gilmore stream catchment as opposed to the more compact and predominantly silty terrain for the catchment of Goldstream. Of course, placer mining activities mostly in the vicinity of GS-1 may not be ruled out completely. The fact that GS-1 attains peak turbidity in July may be attributed to either increased mining activities or a combination of streambank erosion, overland erosion and mining waste leaching. As mentioned earlier, the peak turbidity in GS-2 being delayed reflects the dilution from Pedro creek to some extent and also could be attributed to other natural and anthropogenic factors. Nevertheless, the turbidity in GS-1 is systemically higher than that of GS-2 (Figure 13). This observation supports the difference in trends of the temperature. Due to increased turbidity, GS-1 is consistently at a higher temperature than GS-2 (Figure 14). Even though the temperatures comply with the AK WQS, but they could be a matter of concern if pollution continues. The trends observed in the pH at both stations are similar (Figure 15). They tend to be mostly compliant with AK WQS although the pH violates the AK WQS towards August in GS-1. It may be noted that the months of July and August are high in turbidity. It may be critical to study the changes in the conductivity of the streams in order to analyze the impact of Total Dissolved Solids (TDS) on overall change in pH. The trends in DO (Figure 16) for both the sites are similar. It appears that the DO responds to a change in turbidity, early in the season, but recuperates as the season progresses.

An equally important parameter that is mostly responsible for turbidity is the Total Suspended Solids (TSS) in the stream. It may be critical to develop an understanding of how turbidity in the stream relates to TSS. It is difficult to obtain TSS data from field on a continuous or frequent basis. Recently, through a contract with SGS North America, Inc. in Fairbanks, AK a few TSS samples have been procured using SM20 2540D protocol from all three stations (ADEC, 2009a). Table 13 provides a comparison between the average TSS and the mean turbidity at each of the stations. It may be observed that there is a qualitative correlation between turbidity and TSS, i.e. high turbidity corresponds with high TSS and vice versa. Also, it may be observed that the turbidity and TSS both decrease from GS-1 through GS-3 in September but not in June, which needs to be investigated further.

Table 15. *Average TSS (mg/L) and corresponding Mean Turbidity (NTU) for all monitoring stations.*

DATE	STATION	AVERAGE TSS (mg/L)	MEAN TURBIDITY (NTU)
September 11, 2011	GS-1	235.00	519.50
	GS-2	13.00	24.45
	GS-3	2.58	6.21
September 26, 2011	GS-1	20.85	46.40
	GS-2	9.00	25.5
	GS-3	5.10	8.57
June 2, 2012	GS-1	61.50	77.50
	GS-2	96.75	59.75
	GS-3	48.55	20.45
June 16, 2012	GS-1	18.70	37.65
	GS-2	8.70	13.65
	GS-3	22.10	15.35

Turbidity might respond to discharge. While discharge data is being collected, there is not sufficient data to conclude the correlation. However, in general, a higher discharge has corresponded with a higher turbidity.

7. CONCLUSIONS

It may be concluded from the limited data collected so far that –

1. Goldstream Creek fails to meet turbidity WQS when compared to an estimated standard from one season approximately 50% of the time. More failure of the standard is observed after storm events.
2. GS1 turbidity responds more drastically to storm events than the GS2 turbidity.
3. Temperature standards are met adequately by the creek.
4. DO and pH standards are met reasonably for aquatic life and water supply but DO fails approximately 50% of the time for recreation purposes.
5. Turbidity and TSS correlation should be developed in order to assess the actual loading of sediments in the stream. TSS responds similarly to the turbidity during storm events.
6. GS-1 might have bank erosion contributing to the higher turbidity values at the Gilmore Creek. It may be fair to establish a separate BNT standard for that site, since GS-2 receives diluted turbidity values due to the confluence of a turbid Gilmore Creek and a relatively clean Pedro Creek.
7. It is recommended that at least 3 to 4 more years of continuous monitoring is necessary prior to development of any TMDL. Also, it is critical to fingerprint sediments to understand the sources and proportions so that TMDLs developed are fair to the land user.

8. REFERENCES

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