Bio-fouling & Calibration Drift with Real-Time Water Quality Instruments in Leary's Brook

Project and report was completed as a
requirement of a work-term placement
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September 2009

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1.0 Introduction

The ability to monitor waterways throughout Newfoundland and Labrador is an essential tool for managing and identifying problematic situations with water quality. The Department of Environment and Conservation, Water Resources Management Division (WRMD) has an established system that monitors several waterways and provides real-time water quality data to the public.

The quality of the data recorded by the instrument is extremely important. The data has the potential to identify specific water quality events occurring in a waterway in relation to road salting or turbidity events. It is essential that the instrument's ability to record accurate and precise data is not affected and the integrity of the data is maintained.

During the warmer months of the year, the instrument has the potential to be influenced by naturally occurring biological growth present in the waterways. Bio-film can become affixed to the sensors on the instrument which may disrupt sensitivity.

2.0 Purpose

This report aims to identify the following:

- Bio-fouling occurring on the Leary's Brook real-time water quality instrument
- Does bio-fouling affect the data?
- When does it begin to affect the data?
- Proportion of calibration drift vs. bio-fouling drift.

This report may provide an insight into scheduled cleaning and calibration for the multi-parameter probes. The ability to determine the approximate time that sensors become affected may increase the efficiency of the instrumentation.

3.0 Instruments Used

The real-time water quality instruments that were utilized in this project were the Hydrolab Minisonde MS 5 and the Hydrolab Datasonde DS 5X, as well as an additional Hydrolab Datasonde DS 5X that was utilized as the quality assurance instrument.

The Hydrolab Datasonde DS 5X is the most commonly used instrument within the WRMD, Real-Time Water Quality Monitoring program. The instrument consists of several probes that measure water quality. The sonde is deployed into the waterway with a protective casing that allows water to flow over the sensors (see Figure 1.0). In this particular experiment, the data collected will be stored and logged internally within the instrument itself, hence this data will not be considered real-time but rather continuous in nature.

The Hydrolabs will be powered through an internal battery pack that requires eight C batteries which last approximately one month. Battery levels will be checked weekly along with water parameters to ensure the correct amount of power is available.

Figure 1.0 Hydrolab Datasonde DS 5 (HACH Hydrolab, 2009)

The Datasonde has the ability to measure and detect changes in the following water parameters:

- Turbidity (NTU)
- pH (Units)
- Dissolved Oxygen (%Sat, mg/L)
- Temperature (ºC)
- Specific Conductivity (µS/cm)
- Total Dissolved Solids (TDS)

All individual parameters, except TDS, have a physical probe on the Datasonde that determines the values (see Figure 1.1). An algorithm calculates TDS from Specific Conductivity and temperature.

Figure 1.1 Sensor probes on the Datasonde (HACH Hydrolab, 2009)

The Hydrolab Minisonde MS 5 is similar to that of the Datasonde. It also has several probes that can detect water parameter changes as water passes over the sensors (see Figure 1.2).

Figure 1.2 Hydrolab Minisonde MS 5 (HACH Hydrolab, 2009)

The Minisonde differs in that it is more compact and lightweight than the Datasonde, and it is not capable of containing as many probes as the Datasonde. Therefore, the Minisonde is without a turbidity sensor; however it will still provide an excellent comparison between other parameters of interest. The sonde is deployed into the waterway with a protective casing that allows water to flow over the sensors (see Figure 1.3). The Minisonde has the ability to detect the following water parameters:

- pH (Units)
- Dissolved Oxygen (%Sat, mg/L)
- Temperature (ºC)
- Specific Conductivity (µS/cm)
- Total Dissolved Solids (TDS)

Figure 1.3 Sensor Probes on the Minisonde (HACH Hydrolab, 2009)

The data collected by the Minisonde will be stored and logged internally within the instrument itself, this data will also be considered continuous in nature, but will not be transmitted in real-time. The power supply for the Minisonde will be an internal battery pack that requires eight AA batteries with an approximate lifespan of one month. Battery levels will be checked weekly along with the other Minisonde parameters to ensure there is sufficient power to avoid data loss.

The quality assurance (QA) instrument is a freshly cleaned and calibrated Datasonde. The QA instrument is brought into the field site and is used to compare the readings between the QA and the field deployed instrument before and after cleaning the deployed sonde.

4.0 Testing Site

The deployment of the Minisonde and Datasonde will take place at Leary's Brook, which runs parallel with Prince Phillip Drive, a busy urban street (see Figure 1.4). Leary's Brook is one of WRMD's Real-Time Water Quality Monitoring Stations. It is easily accessible, exhibits variable flow rates and has shown bio-fouling on previous instruments. Leary's Brook is influenced by several developments such as: runoff from roads, construction, urban events and storm sewage outfall (Environment and Conservation: Government of Newfoundland and Labrador, 2009). Figures 1.5 and 1.6 show Leary's Brook the day the instruments were deployed. Figure 1.7 shows the positioning of both sondes in Leary's Brook.

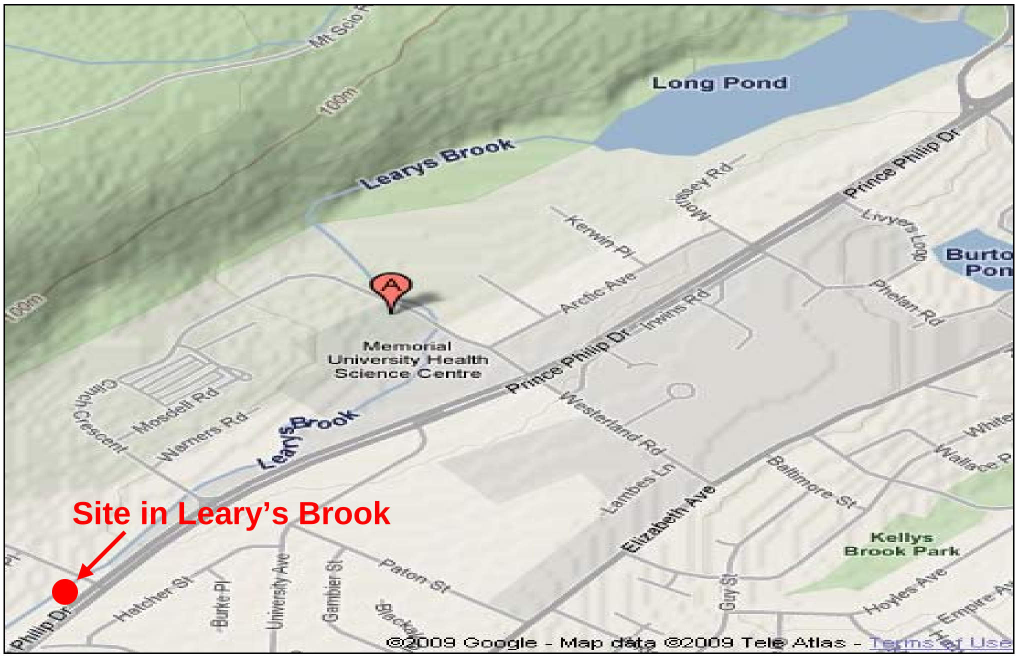

Figure 1.4 Map of Leary's Brook (Map Quest, 2009)

Figure 1.5 Upstream of site in Leary's Bk

Figure 1.6 Downstream of site in Leary's Bk

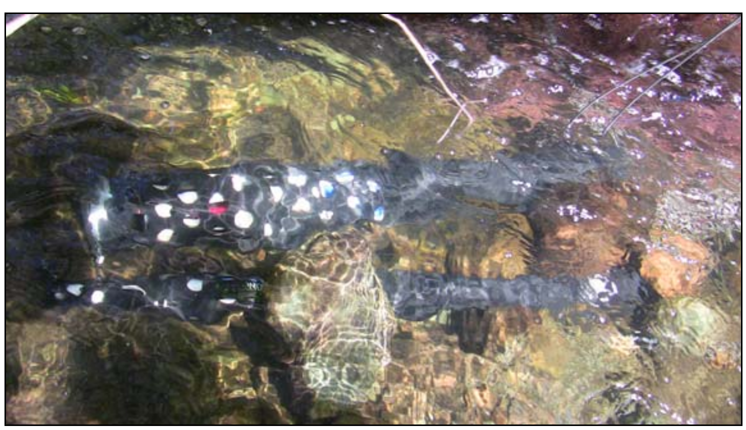

Figure 1.7 Datasonde and Minisonde positioned in Leary's Brook

The headwaters of Leary's Brook is Hummocky Marsh and Yellow Marsh which develop into small rivers that join in the vicinity of the Avalon Mall. (see Figure 1.8)The water flow is contained within a culvert underneath the parking lot of the Avalon Mall and then runs in open air parallel to a main city thoroughfare. The river flows through urbanized and industrial sections of St. John's before it drains into Long Pond. From Long Pond to Quidi Vidi, Leary's Brook is referred to as Rennies River. Rennies River flows through several residential neighborhoods and a linear park before pouring into the ocean at Quidi Vidi Gut.

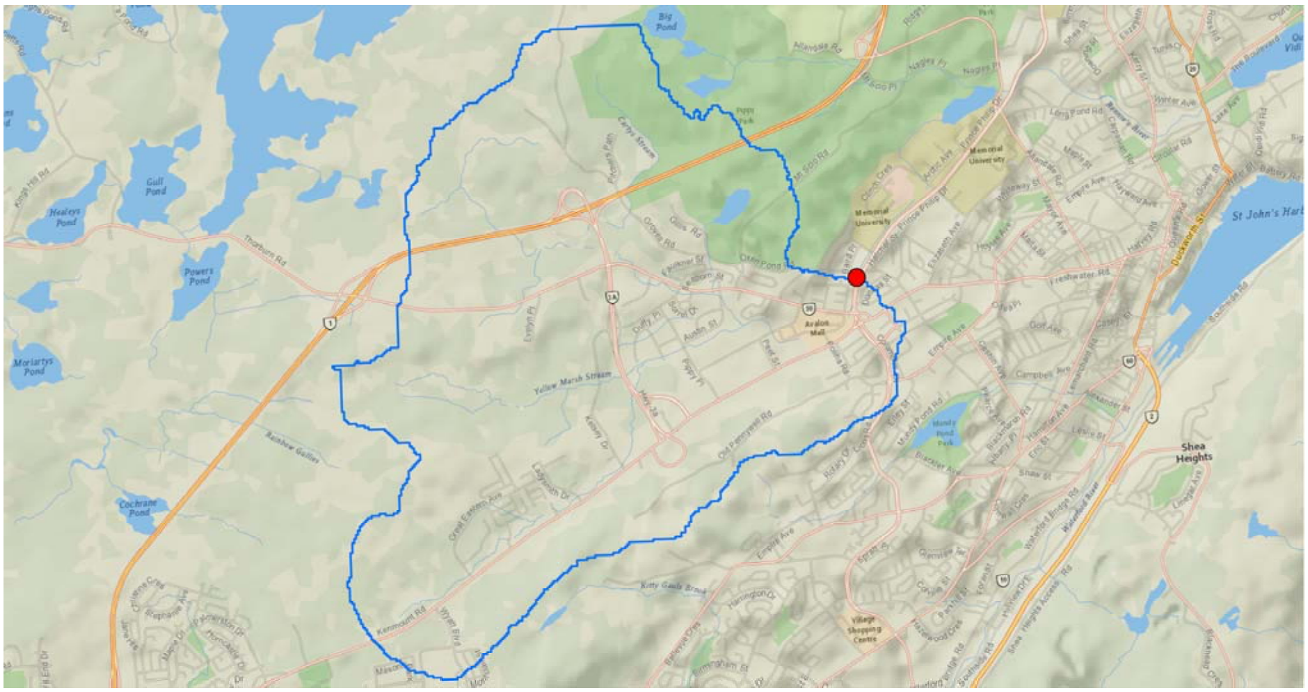

Figure 1.8 Map of complete watershed for Leary's Brook

5.0 Methodology

To ensure a first-rate representation of the type of data drift occurring in Leary's Brook the exercise was divided into two phases.

5.1 Phase I – Minisonde Deployment

On July 8th, 2009 a cleaned and calibrated Minisonde was deployed. The instrument was placed in a protective casing and deployed into Leary's Brook. According to the WRMD protocols, a monthly recalibration is required on all instruments to maintain accurate and precise readings. However in this case, the Minisonde was left in Leary's Brook for approximately 60 days without calibration.

The 60 day deployment period was used to provide insight on the point in time when bio-fouling became a problem. Weekly checks were completed to ensure the instrument was functioning correctly and to take photos of any evident bio-fouling growth. The weekly checks also involved comparing the Minisonde with a QA sonde to document any data drift or change in the data over this period. This provided an insight into whether the data was actually drifting from 'true' readings.

The Minisonde was set to take readings at 30 minute intervals to commence the afternoon of July 8th. On September 3rd, 2009 the data was downloaded from the internal logger within the instrument. However due to a battery malfunction, the instrument was not able to read data during the month of July, therefore the results display the water parameter data for the month of August only.

5.2 Phase II – Datasonde Deployment

Phase II of the project involved deploying the Datasonde. This instrument was cleaned and calibrated before being deployed alongside the Minisonde on July 8th, 2009. The Datasonde remained in Leary's Brook until August 3rd, 2009, when it was removed for cleaning and calibration.

The Datasonde was checked weekly and the readings from the Datasonde were compared against the QA instrument. Approximately every 28 days a reading was taken before a field clean and a reading was taken after a field clean. The field clean involved a brisk scrub with a toothbrush and river water. The aim was to remove any bio-fouling that may have affected the sensitivity of the probes. These readings were compared against the QA instrument's values. The field instrument was then removed from Leary's Brook for cleaning and calibration in the WRMD laboratory. At this time the internally logged data was downloaded.

The before and after readings during calibration were recorded, providing an indication of the amount of calibration drift occurring on the Datasonde. The instrument was then re-deployed into Leary's Brook to collect another 28 days worth of data. The intention of Phase II was to quantify the amount of drift occurring and the type of drifting occurring on the data.

The Datasonde was set to take readings at 30 minute intervals to commence the afternoon of July 8th until August 3rd, 2009. On August 3rd, 2009 the data was downloaded from the internal logger within the instrument. However, due to a battery malfunction, the Datasonde was not able to store data during the month of July. The data set was inconsistent and did not represent the water parameters within Leary's Brook. The decision was made to adapt the project to include data for the month of August. The data from the month of July was retrieved from WRMD's own instrument that is deployed consistently throughout the year in Leary's Brook. This instrument was located approximately 5 feet from the project instruments.

5.3 Classifying Drift Type

It is important to distinguish between the types of drift occurring, to assist in the management. The data was put through a statistical analysis to determine the intensity of bio-fouling drift and the level of calibration drift occurring. By determining the type of drift, instruments can be more effectively managed and the standard time intervals for cleaning and calibration can be adjusted to suit waterways and reduce the likelihood of inaccurate data. For this project, the data correction procedures that are outlined in the *'Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Operation, Record Computation, and Data'* by Wagner, Boulger, Oblinger & Smith, 2006 were followed.

5.3.1 Identifying Bio-fouling Drift

Sensor fouling can occur from various sources. It is generally caused by a build up of biological matter on the sensitive probes that measure the water quality. As these instruments are placed in water, biological growth can multiply and over time reduce the probe's ability to detect true water characteristics. Bio-fouling in this experiment was determined by finding the difference between sensor measurements before field cleaning and after field cleaning. This project included two monitoring events for the Datasonde and one monitoring event for the Minisonde.

Water environments are rarely stable and Leary's Brook is influenced by many different landscapes such as urban and roadside runoff, therefore this brook can have high flows and can be very flashy. It is important to capture the change in water parameters if environmental conditions change during the field cleaning of the Datasonde and Minisonde (Wagner, Boulger, Oblinger, & Smith, 2006). This was accomplished by using the following equation:

$$E_f = (M_a - M_b) - (F_e - F_s)$$

Where:

E_f = sensor fouling error,

M_a = sonde reading after cleaning,

M_b = sonde reading before cleaning,

F_s = QA instrument reading at the start of servicing, and

F_e = QA instrument reading at the end of servicing.

(Wagner, Boulger, Oblinger, & Smith, 2006)

5.3.2 Identifying Calibration Drift

Calibration drift is a result of electronic or normal wear and pH reference solution dilution from the last time the sensor was calibrated. For this experiment, calibration drift was determined by the difference between cleaned sensor readings in standard solutions and the true, temperature – compensated value of the standard solution (Wagner, Boulger, Oblinger, & Smith, 2006). A formula was used to describe the changing conditions,

$$E_d = V_s - V_c$$

Where;

E_d = calibration drift error,

V_s = value of a calibration standard solution of known quality (i.e. DO the standard value is represented by the DO100% saturation value)

V_c = sensor reading in the calibration standard solution.

(Wagner, Boulger, Oblinger, & Smith, 2006)

5.4 Calculating Absolute Error

If the absolute value of the fouling error (E_f) plus the absolute value of the calibration drift error (E_d) exceed the data-correction criteria (see Table 1.0) a correction of the raw data is required. The data-correction criteria used for this project was taken from Wagner, Boulger, Oblinger, & Smith, 2006 For the purpose of this report **all** the data was corrected to show any differences over the month for the Datasonde deployment and the two months for the Minisonde deployment even if it did not exceed data-correction criteria values.

Table 1.0: Criteria for Water Quality Corrections

Measured Field Parameter	Data-Correction Criteria (apply correction when the sum of the absolute value for fouling and calibration drift error exceeds the value listed)
Temperature	±0.2ºC
Specific Conductance	±5 µS/cm or ±3% of the measured value, whichever is greater
Dissolved oxygen	±0.3 mg/L
pH	±0.2 pH units
Turbidity	± 0.5 turbidity units or ±5%of the measured value, whichever is greater

(Wagner, Boulger, Oblinger, & Smith, 2006)

6.0 Results

Tables 1.1, 1.2 and 1.3 provide a breakdown of the error calculations obtained throughout the project deployment period. Detailed calculations of error can be found in Appendix A.

Table 1.1 Errors of the Datasonde Data for the month of July

Parameter	Fouling Error	Calibration Drift Error	Absolute Error (Fouling + Calibration)
Temperature (ºC)	0.15	-0.36	0.21
pH (units)	-0.03	0.005	0.025
Sp. Conduct (µS/cm)	0.4	1	1.4
Turbidity (NTU)	0	-0.95	0.95
LDO (%Sat)	-0.2	-0.2	0.4

Table 1.2 Errors of the Datasonde Data for the month of August

Parameter	Fouling Error	Calibration Drift Error	Absolute Error (Fouling + Calibration)
Temperature (ºC)	-0.05	-0.06	0.11
pH (units)	0.31	0.05	0.36
Sp. Conduct (µS/cm)	-2.3	-0.6	2.9
Turbidity (NTU)	2.6	1.45	4.05
LDO (%Sat)	0.8	-0.2	0.6

Table 1.3 Errors of the Minisonde Data for July/August

Parameter	Fouling Error	Calibration Drift Error	Absolute Error (Fouling + Calibration)
Temperature (ºC)	-0.05	0.13	0.08
pH (units)	0.01	-0.01	0
Sp. Conduct (µS/cm)	0.1	9	9.1
LDO (%Sat)	3	-1.4	1.6

7.0 Discussion

Table 1.1 displays the fouling and calibration drift errors for the 31 days the Datasonde was deployed in Leary's Brook during the month of July. After the standard monthly calibration and cleaning of the Datasonde it was placed back in Leary's Brook for the month of August. The fouling and calibration drift errors calculated for August using the Datasonde are displayed in Table 1.2. Finally, the fouling and calibration drift errors for the Minisonde during the longer July/August deployment period are displayed in Table 1.3.

7.1 Datasonde

Water Temperature

The water temperature data recorded for July had a fouling error of 0.15 ºC (App A, Table A-1). It was evident in the statistical analysis that the temperature probe was also influenced by a small calibration drift error of -0.36 ºC (App A, Table A-2). According to the criteria for water quality data corrections, water temperature is just within the range that does not require correction. When corrected and graphed for report purposes, the data corrected for fouling, calibration drift error and the raw (uncorrected) data display that there are no noticeable differences between the data sets (App B Figure B-1). At the end of August, the fouling error was calculated at -0.05 ºC (App A, Table A-3), with a calibration drift error at -0.06 ºC (App A, Table A-4). The absolute error for temperature was 0.11 ºC, and according to the criteria for water quality data corrections the data does not require correction. This is also visible on the scatter plot (App B, Figure B-6), whereby all plotted data is synchronized.

pH

The pH data recorded for July had a fouling error of -0.03 pH units (App A, Table A-1) with a calibration drift error of 0.005 pH units (App A, Table A-2). The absolute error for pH in July was 0.025 pH units and within the data-correction criteria, thus it was unnecessary to correct the pH July data for errors. The datasets were graphed for comparison (App B, Figure B-2) and the graph indicated that when corrected for fouling error the data is slightly below the raw data and when corrected for calibration drift it was on par with the raw data readings. In August, the pH had a higher fouling error at 0.31 pH units (App A, Table A-3) and a calibration drift error of 0.05 pH units (App A, Table A-4). The absolute error was calculated at 0.36 pH units which is considerably higher than July at 0.025 pH units. The absolute error is outside the criteria for corrections at ±0.2 pH units therefore this dataset does require correction. The scatter plot (App B, Figure B-7) indicates a difference between the data corrected for fouling and calibration drift from the raw data. The larger fouling error in August would suggest a greater amount of fouling present on the probe, hindering its ability to take an accurate reading. It appears that fouling played a greater part than calibration drift in adjusting the readings for this probe during August.

Specific Conductivity

In July, specific conductivity had the highest calculated fouling error at 0.4µS/cm (App A, Table A-1) and calibration drift error at 1µS/cm (App A, Table A-2). The absolute error is 1.4µS/cm which was the highest absolute error for data in July. The absolute error was still below the criteria for correction, therefore the data did not require correction. When the data was corrected for reporting purposes and compared against the raw data in a scatter plot; there is little or no difference between the data (App B, Figure B-3) as would be expected. In August, the calculated fouling error for specific conductivity was -2.3µS/cm (App A, Table A-3) and the calibration error was -0.63µS/cm (App A, Table A-4). The absolute value of the errors was 2.9µS/cm, which was within the data-correction criteria. The fouling error was larger than the calibration error indicating that fouling played a greater part in adjusting the readings for the conductivity probe during August (App B, Figure B-8).

Dissolved Oxygen

In July, the raw data recorded for dissolved oxygen was influenced by a fouling error of -0.2% saturation (App A, Table A-1) and a calibration drift error of -0.2% saturation (App A, Table A-2). The results indicated an absolute error for dissolved oxygen at 0.4 % saturation which is above the range provided in the data-correction criteria. Therefore, dissolve oxygen raw data did require correction to ensure 'true' dissolved oxygen measurements. Figure B-4 in Appendix B displays the corrected data against the raw data. Visibly the data corrected for fouling and calibration drift do not appear to be different from the raw dissolved oxygen data. In August, the fouling error is 0.8% saturation (App A, Table A-3) and the calibration drift error was calculated at -0.2% saturation (App A, Table A-4). The absolute value of the errors exceed the data-correction criteria at 0.6 % saturation, therefore the dissolved oxygen dataset required correction. The scatter plots (App B, Figure B-9) display uniform data up until August 8th, where the datasets slightly separate, potentially indicating at this point the probe is being influenced by fouling and/or calibration drift.

Turbidity

According to the statistical analysis of the fouling error for turbidity in July the turbidity probe was not affected by fouling (App A, Table A-1). However, turbidity was affected by a calibration drift of

-0.95 NTU (App A, Table A-2). This led to an absolute error of 0.95 which is outside the criteria for data-correction, therefore turbidity data was corrected based on calibration drift alone. Figure B-5 in Appendix B displays the corrected data against the raw data for turbidity and when graphed it appears there is little or no difference between the datasets. In August, the turbidity fouling error was 2.6 NTU (App A, Table A-3) which is considerably higher than the fouling error in July. Turbidity also has a higher calibration drift error at 1.45 NTU (App A, Table A-4), which provided an absolute total error of 4.05 NTU. The absolute error identifies that the August turbidity data did require correction. The scatter plot represents the differences between the corrected and the raw data (App B, Figure B-10). The fouling error in August is greater compared to that of the error for calibration drift. This may signify that fouling played a greater part in adjusting the readings for this probe during the warmer month of August.

7.2 Minisonde

Water Temperature

During this deployment period the water temperature data had a fouling error of -0.05ºC (App A, Table A-5) and a calibration drift error of 0.13ºC (App A, Table A-6), these calculated an absolute value of the errors of 0.08ºC. The absolute error is below the range of correction and the water temperature data is identified as being close enough to the 'true readings' during this time frame. The errors for fouling and calibration drift indicate that there was greater calibration drift occurring on the probe throughout the time interval than fouling influence. The scatter plot does not display any differences between the corrected readings and the raw data (App B, Figure B-11).

pH

The pH data after a 53 day deployment, calculated a fouling drift of 0.01 pH units (App A, Table A-5) and a calibration drift error of -0.01 pH units (App A, Table A-6). This calculated an absolute value of the errors of 0. While there is evidence of drift from both fouling and calibration, it is not significant enough for the data to be corrected. The scatter plot (App B, Figure B-12) indicates that there is little or no significant difference between the data for fouling and calibration drift and that of the uncorrected (raw) data.

Specific Conductivity

For specific conductivity, the fouling drift error was calculated at 0.1µS/cm (App A, Table A-5), with a considerably high calibration drift error at 9µS/cm (App A, Table A-6). This calculated an absolute value of the errors at 9.1µS/cm, which is outside the criteria for data-correction. The specific conductivity raw data needs to be corrected with the absolute error. When graphed the data demonstrates (App B, Figure B-13) that around August 5th, 2009 the calibration drift started to increase throughout the remainder of the project. Comparing the two errors, it is evident that calibration drift is notably greater than fouling drift, indicating that calibration drift had a larger influence on the specific conductivity probe than fouling.

Dissolved Oxygen

The dissolved oxygen fouling error was calculated at 3% saturation (App A, Table A-5) with a calibration drift error of -1.4% saturation (App A, Table A-6). The dissolved oxygen data was influenced by fouling more so than calibration drift. When calculated, the absolute error of the values is 1.6% saturation and is outside the data-correction criteria. Dissolved oxygen readings do need correction for the absolute error to provide ‘true’ data. When graphed the datasets display differences and from August 3rd, 2009 onwards there is evident adjustments in the corrected fouling data and calibration data from the raw data, with the most prominent difference being the data corrected for fouling (App B, Figure B-14).

The photographs taken of the sondes throughout the duration of the project (Appendix C) were aimed at illustrating the presence of bio-fouling in Leary’s Brook. The Minisonde sensors illustrate an obvious amount of fouling at the end of the 53 days deployment. While the Datasonde displays greater fouling on the outside of the sonde and less fouling on the sensors.

8.0 Opportunities for Error

In the natural environment, conditions are seldom constant. This is most definitely the case when dealing with water bodies and especially those influenced by urban activities, such as Leary’s Brook.

Leary’s Brook has shown over time that it is very susceptible to flash flooding. Over the course of this project there were several flash flood events, immediately changing the characteristics of the water. One of these typical changes temperature: increasing and decreasing temperatures can influence the growth and decay patterns of any biological growth. This activity can adjust the fouling error during the final calculation, which can affect whether the data is being corrected/not corrected, and/or can provide an opportunity for error. Location and position of the sondes in Leary’s Brook was also a variable. With flooding and higher flows, the sondes were moved frequently from the original positions.

Leary's Brook also has a high amount of large debris (litter, leaves, branches, plastic bags, gravel) passing through. Debris can become lodged and block the area of a sensor that takes readings. Blocking the sensors, even temporarily, can affect an accurate reading. The aim of the weekly visits to the investigation site were to prevent and/or reduce debris interfering with the sensors.

The instruments that were deployed within Leary's Brook were under constant monitoring to prevent equipment malfunction or system failures. Even with increased monitoring, the power supply of the sonde failed due to poor battery selection and there was not enough power to take consistent readings. By not being able to record additional data points, it is difficult to determine the exact point in time at which the sondes became influenced by drift and identify the appropriate time to remove the instruments before this occurs.

The instruments went through a routine calibration and cleaning before deployment. The DS 5X was removed for the monthly calibration as per the standard protocol. The effectiveness of calibration relies upon the integrity of the standards such as pH buffer, specific conductance and turbidity solution. There is the possibility of the solution standards becoming contaminated and/or diluted during use; this may affect the calibration drift error.

Most importantly, there is an opportunity for error with the statistical processes and methods used during this project. Without careful analysis and accurate input, the results can indicate incompatible findings which may be unrealistic for the WRMD when implementing new practices. Statistical analysis should provide accurate and precise results on which decisions can be based.

To reduce and prevent opportunities for error throughout the duration of this project all handling, calibration and cleaning of the instruments was followed as outlined in the procedures by the WRMD and when applicable the manufacture's specifications. To ensure appropriate statistical analysis was completed the *'Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Operation, Record Computation, and Data'* was utilized (Wagner, Boulger, Oblinger, & Smith, 2006).

9.0 Conclusion

Fouling of instruments is a concern when dealing with water related testing and monitoring. It is necessary to ensure data is as accurate and precise as possible. Water quality data is used by scientists to provide a health assessment of the aquatic ecosystems in the waterways of NL. The data provides critical ranges and normality levels upon which scientists can base findings. Being able to monitor waterways with accurate real-time data ensures that problematic situations can be identified and, if necessary, remedial procedures can be put into effect. If factors such as fouling and calibration drift are affecting water quality data, the data loses its accuracy, thus hindering the ability to effectively manage water resources.

The temperature probe on the Datasonde and Minisonde was influenced more so by calibration drift than fouling drift. The temperature readings did not require correction for absolute error at any stage of this project.

The Minisonde pH probe spent a total of 53 days in Leary's Brook with no data correction required. The Datasonde pH probe did not require any corrections in July. The Datasonde pH probe did require correction in August, and the larger part of the error was attributed to bio-fouling - potentially due to the warmer temperatures and increased aquatic growth at that time.

The Minisonde specific conductivity readings did require correction; calibration drift was a larger contributor to absolute error than fouling. The Datasonde specific conductivity readings indicated higher calibration drift in July, but higher fouling drift in August - likely a result of increased aquatic growth at that time.

The dissolved oxygen probe required correction on both the Datasonde and Minisonde. Based on the results, it could be assumed that fouling drift was more prevalent than calibration drift for the dissolved oxygen probe.

As noted previously in the report, there is no turbidity sensor on the Minisonde. The findings for turbidity are from the Datasonde instrument only. The Datasonde turbidity readings did require correction for absolute error through, July and August. In July, the turbidity sensor was influenced by calibration drift, whereas, in August fouling drift was of greater influence (possibly related to increased aquatic growth and higher water temperatures in general).

While this project cannot accurately determine the most effective length of time between calibration and cleaning for Hydrolab sondes placed within Leary's Brook, it does indicate that some parameters are affected more significantly by bio-fouling growth after approximately 30 days of deployment, while other sensors are impacted by calibration drift.

The findings from the Minisonde data do suggest that the most satisfactory length of time between cleaning and calibration of the sondes would be approximately 30 days. Therefore, the present cleaning and calibration protocols that WRMD are using appear to be sufficient to control the majority of fouling and calibration drift. Following a 30 day deployment schedule would ensure more precise pH and dissolved oxygen readings. During warmer months, the 30 day deployment would ensure the sensors can be cleaned before the bio-fouling negatively impacts the data.

It is also essential to factor in the concept of "available resources" when determining a suitable maintenance and calibration schedule for such a technical program. There are many real-time sites within the network that are not as accessible as Leary's Brook and a deployment interval that is less than 30 days would likely put additional strain on the resources of WRMD. The results of this project provide confidence that the data is accurate and precise after a 30 day deployment, therefore, WRMD should continue to follow the protocols that they have developed.

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APPENDIX A

Table A-1: Fouling Errors Calculated for Datasonde Data in July

Parameter	Before field cleaning		After field cleaning		E_f
	Field Sonde	QAQC	Field Sonde	QAQC	
Temperature (°C)	15.25	15.4	15.24	15.24	0.15
Sp. Conductivity (µS/cm)	699.8	698.7	696.6	695.1	0.4
pH (units)	6.8	6.47	6.88	6.58	-0.03
Turbidity (NTU)	0	0	0	0	0
LDO (% sat)	97.2	94.5	96.9	94.4	-0.2

Table A-2: Calibration Drift Errors Calculated for Datasonde Data in July

Parameter	Standard	Reading		E_d
Temperature (°C)	22.2	22.56		-0.36
Sp. Conductivity (µS/cm)	100	99		1
pH 7 (units)	7	7.01		-0.01
pH 4 (units)	4	3.98		0.02
			Average	0.005
Turbidity 0 (NTU)	0	1.3		-1.3
Turbidity 100 (NTU)	100	100.6		-0.6
			Average	-0.95
LDO (% sat)	100	100.2		-0.2

* pH and Turbidity are averaged as the calibration processes involved two standards.

Table A-3: Fouling Errors Calculated for Datasonde Data in August

Parameter	Before field cleaning		After field cleaning		E_f
	Field Sonde	QAQC	Field Sonde	QAQC	
Temperature (°C)	15.38	15.49	15.42	15.58	-0.05
Sp. Conductivity (µS/cm)	442.7	447.3	441.5	448.4	-2.3
pH (units)	6.33	6.89	6.62	6.87	0.31
Turbidity (NTU)	14	20.9	13.2	17.5	2.6
LDO (% sat)	95.9	95.7	96.6	95.6	0.8

Table A-4: Calibration Drift Errors Calculated for Datasonde Data in August

Parameter	Standard	Reading	E_d
Temperature (ºC)	20.74	20.8	-0.06
Sp. Conductivity (µS/cm)	100	100.6	-0.6
pH 7 (units)	7	6.91	0.09
pH 4 (units)	4	3.99	0.01
		Average	0.05
Turbidity 0 (NTU)	0	0	0
Turbidity 100 (NTU)	100	97.1	2.9
		Average	1.45
LDO (% sat)	100	100.2	-0.2

* pH and Turbidity are averaged as the calibration processes involved two standards.

Table A-5: Fouling Errors Calculated for Minisonde Data

Parameter	Before field cleaning		After field cleaning		E_f
	Field Sonde	QAQC	Field Sonde	QAQC	
Temperature (ºC)	15.28	15.44	15.27	15.48	-0.05
Sp. Conductivity (µS/cm)	383.1	447.3	382	446.1	0.1
pH (units)	6.41	6.82	6.42	6.82	0.01
LDO (% sat)	95.3	96.3	98	96	3

Table A-6: Calibration Drift Errors Calculated for Minisonde Data

Parameter	Standard	Reading	E_d
Temperature (ºC)	21	20.87	0.13
Sp. Conductivity (µS/cm)	100	91	9
pH 7 (units)	7	6.96	0.04
pH 4 (units)	4	4.06	-0.06
		Average	-0.01
LDO (% sat)	100	101.4	-1.4

* pH and Turbidity are averaged as the calibration processes involved two standards.

APPENDIX B

Figure B-1: Fouling and Calibration Drift graphed against Uncorrected Temperature Data for the Datasonde in July

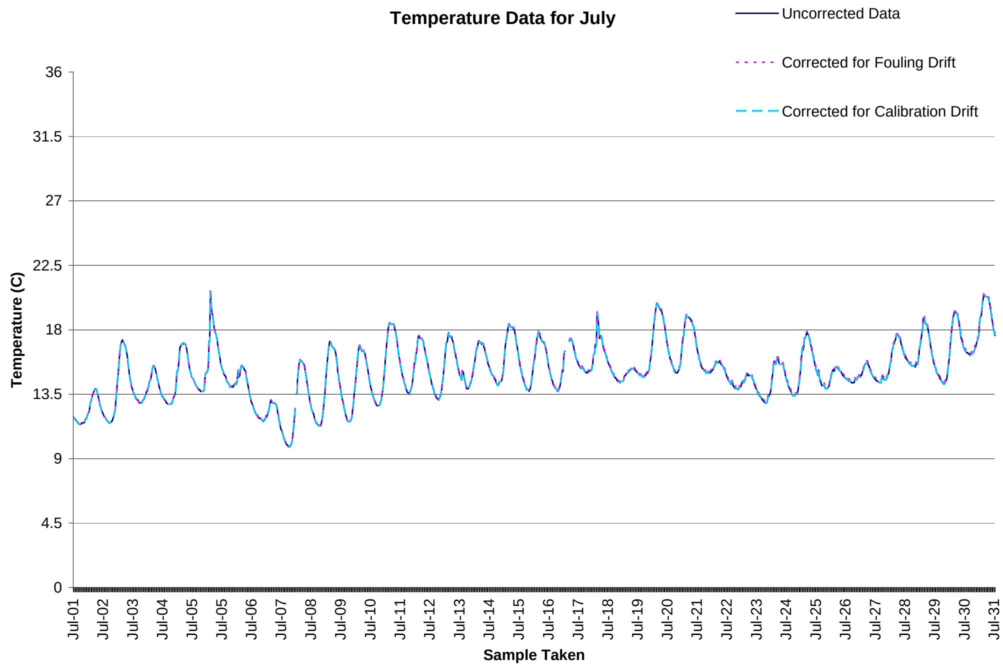


Figure B-2: Fouling and Calibration Drift graphed against Uncorrected pH Data for the Datasonde in July

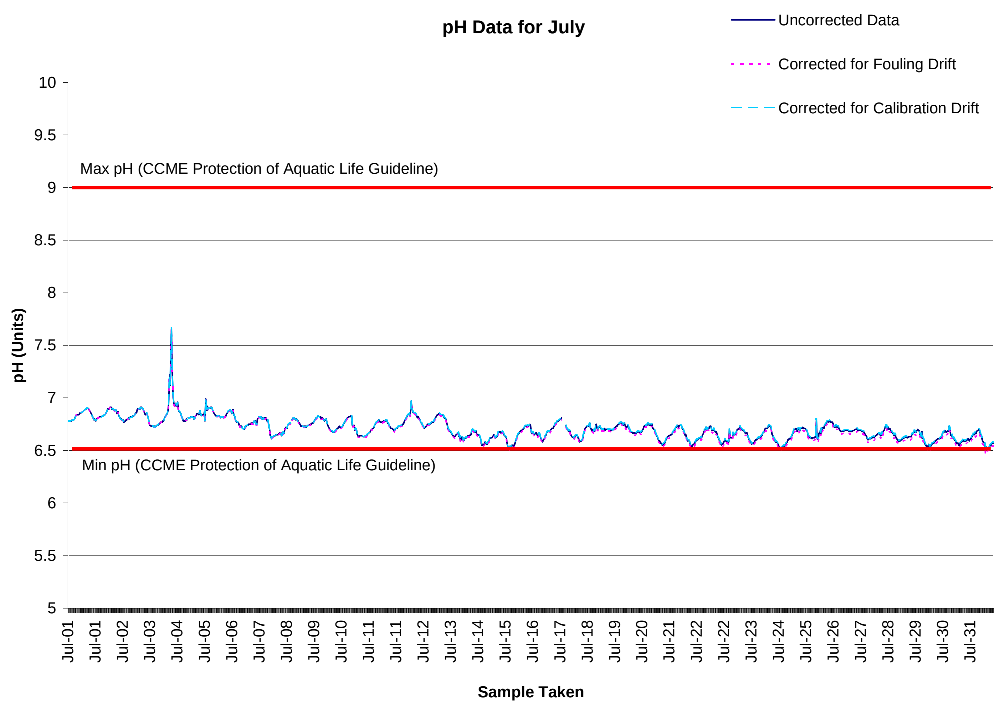


Figure B-3: Fouling and Calibration Drift graphed against Uncorrected Specific Conductivity Data for the Datasonde in July

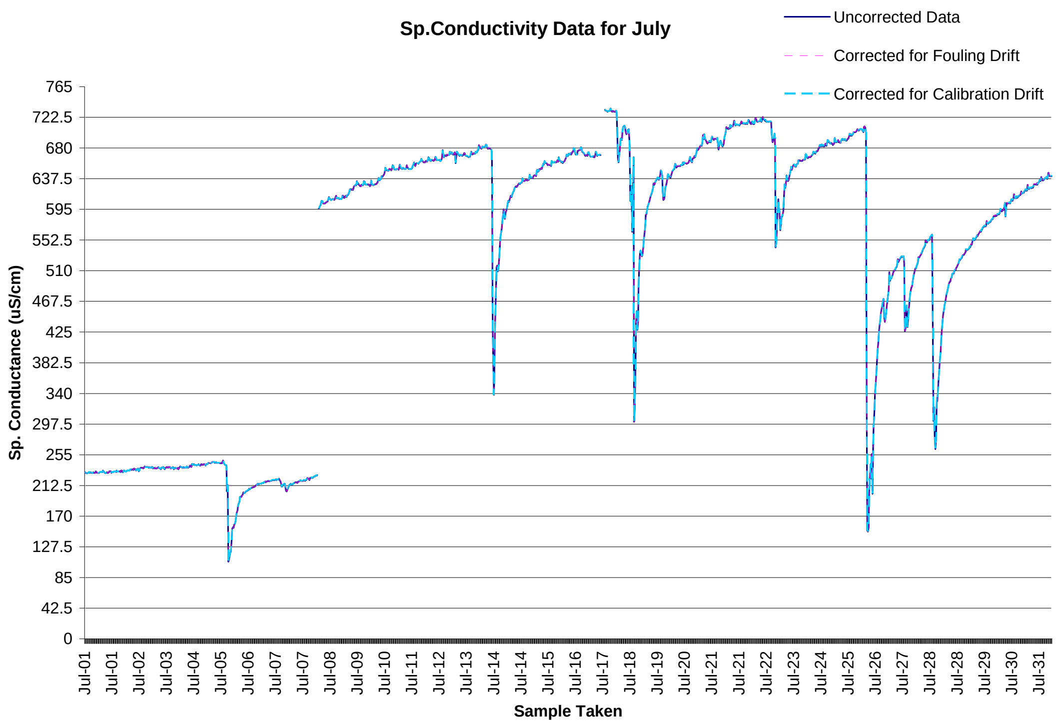


Figure B-4: Fouling and Calibration Drift graphed against Uncorrected Dissolved Oxygen Data for the Datasonde in July

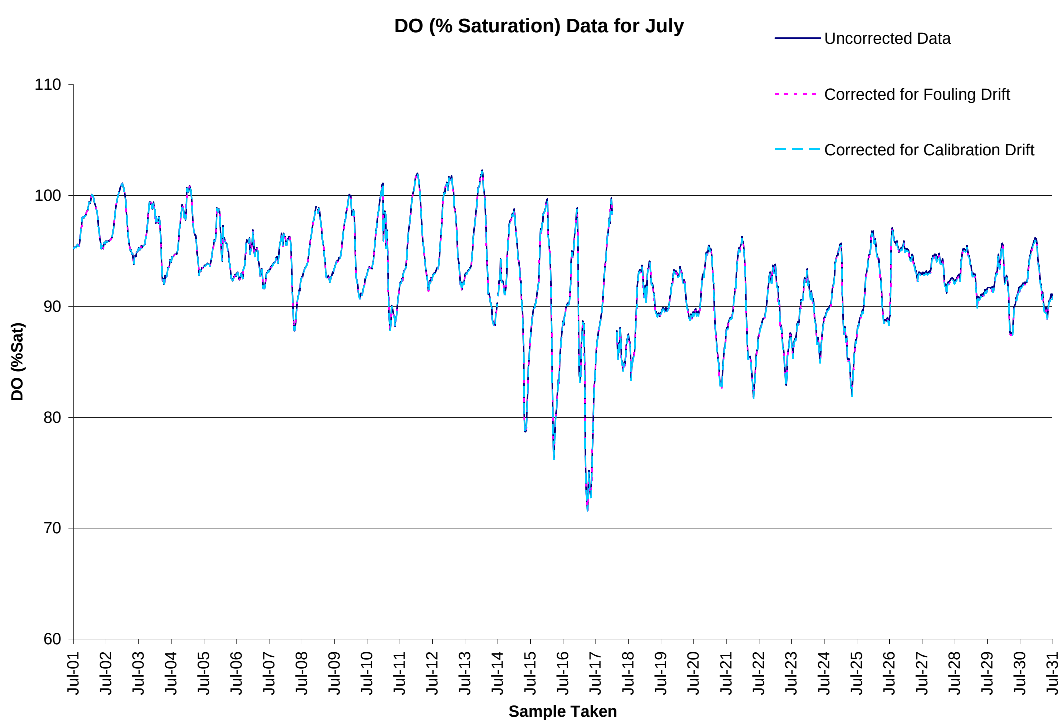


Figure B-5: Fouling and Calibration Drift graphed against Uncorrected Turbidity Data for the Datasonde in July

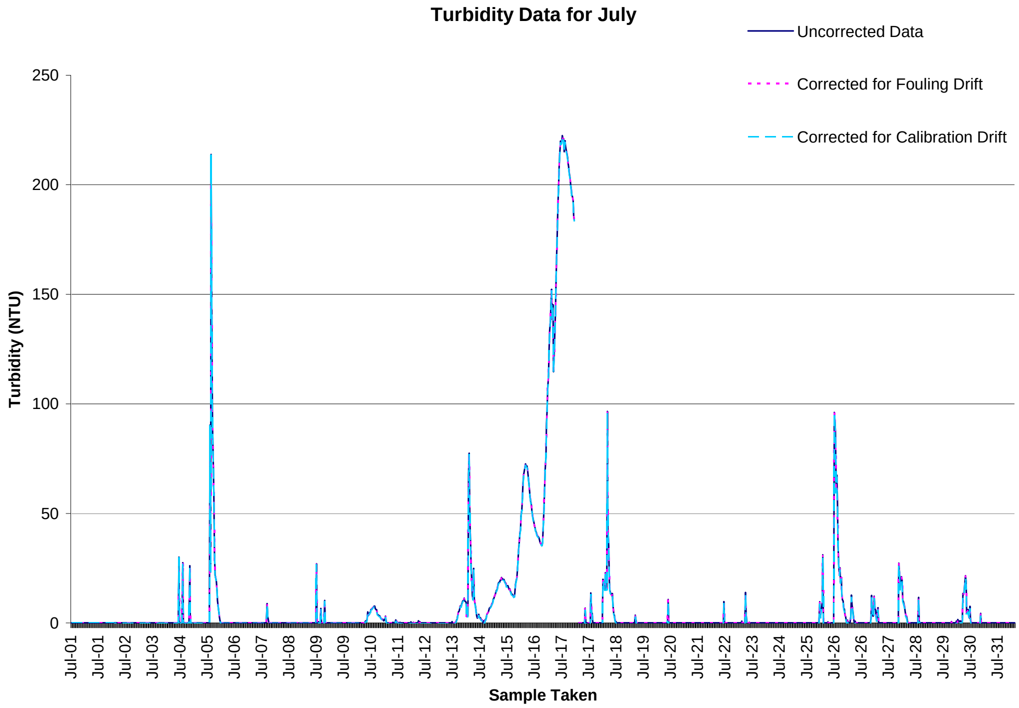


Figure B-6: Fouling and Calibration Drift graphed against Uncorrected Temperature Data for the Datasonde in August

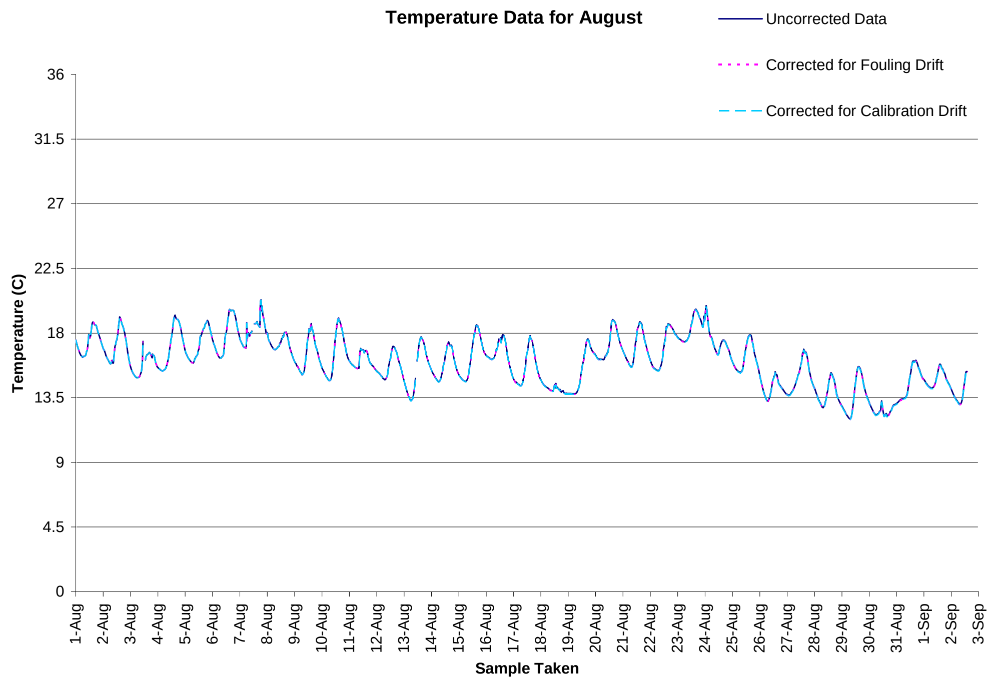


Figure B-7: Fouling and Calibration Drift graphed against Uncorrected pH Data for the Datasonde in August

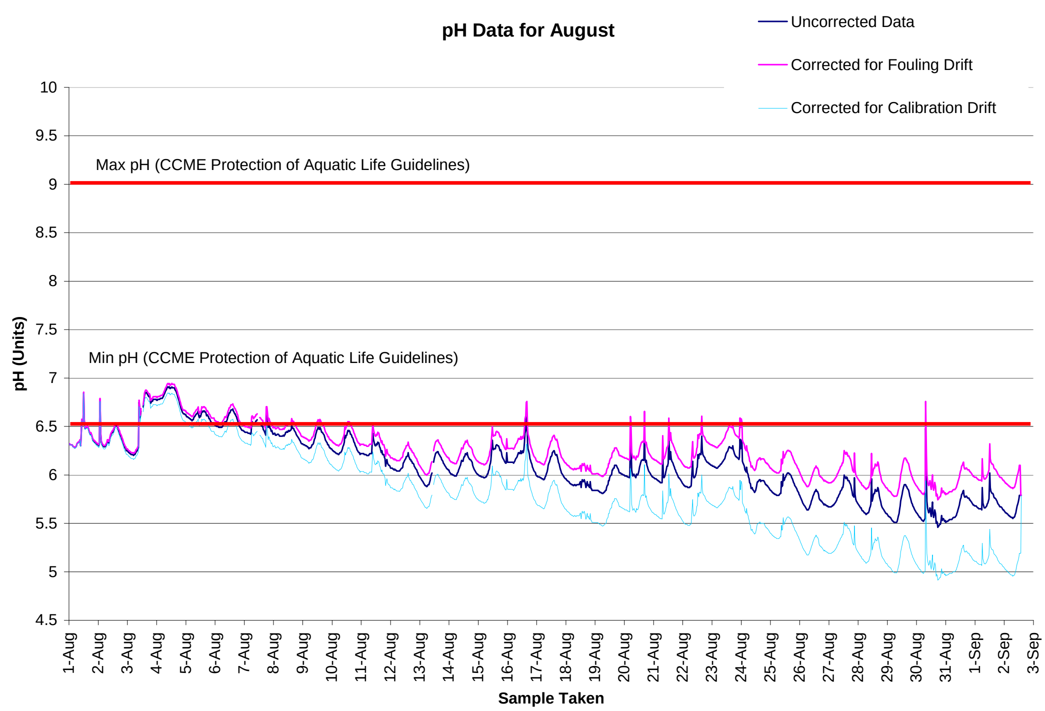


Figure B-8: Fouling and Calibration Drift graphed against Uncorrected Specific Conductivity Data for the Datasonde in August

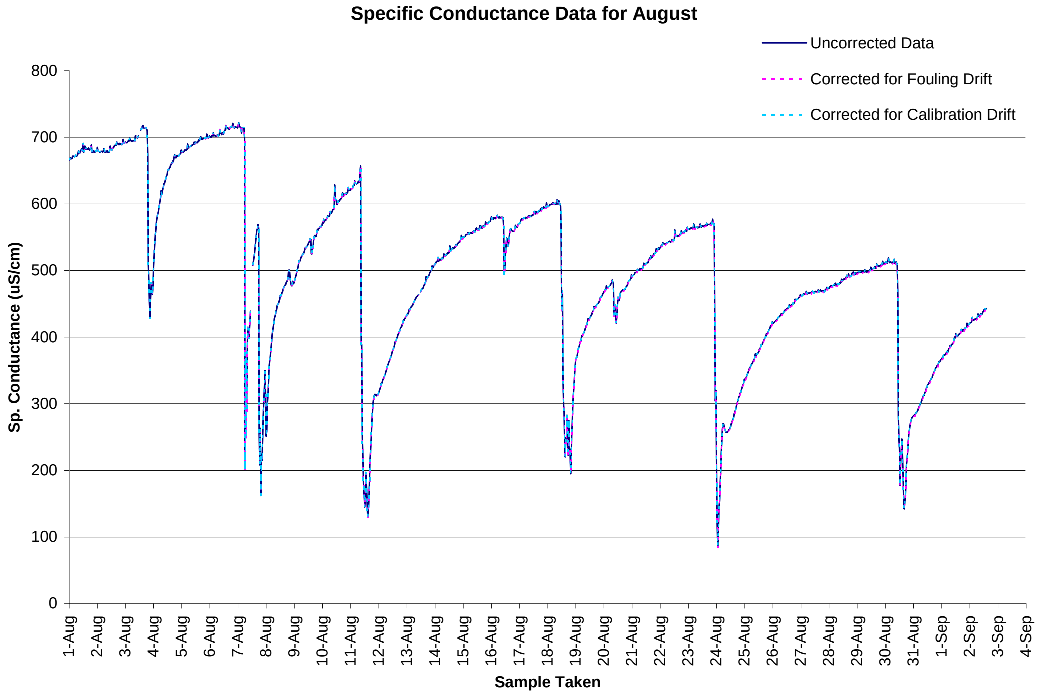


Figure B-9: Fouling and Calibration Drift graphed against Uncorrected Dissolved Oxygen Data for the Datasonde in August

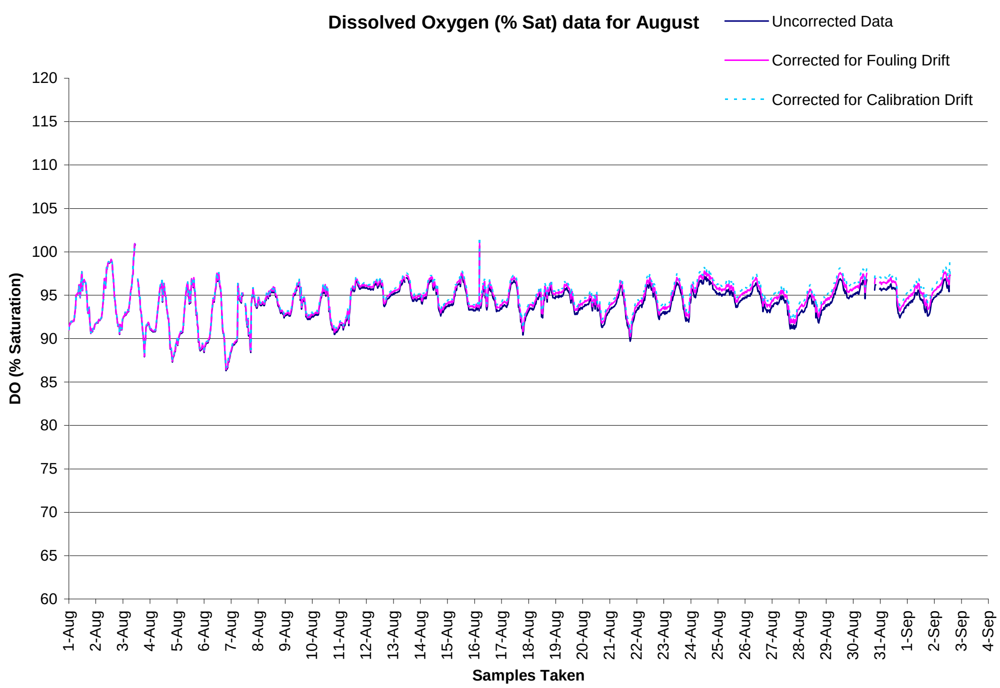


Figure B-10: Fouling and Calibration Drift graphed against Uncorrected Turbidity Data for the Datasonde in August

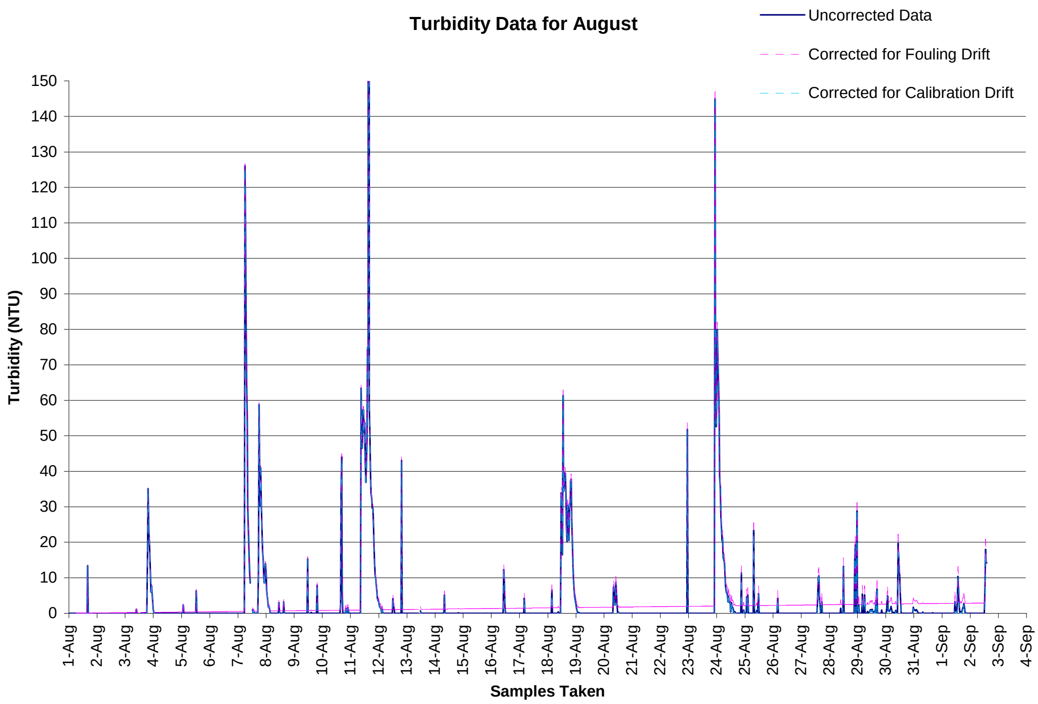


Figure B-11: Fouling and Calibration Drift graphed against Uncorrected Temperature Data for the Minisonde

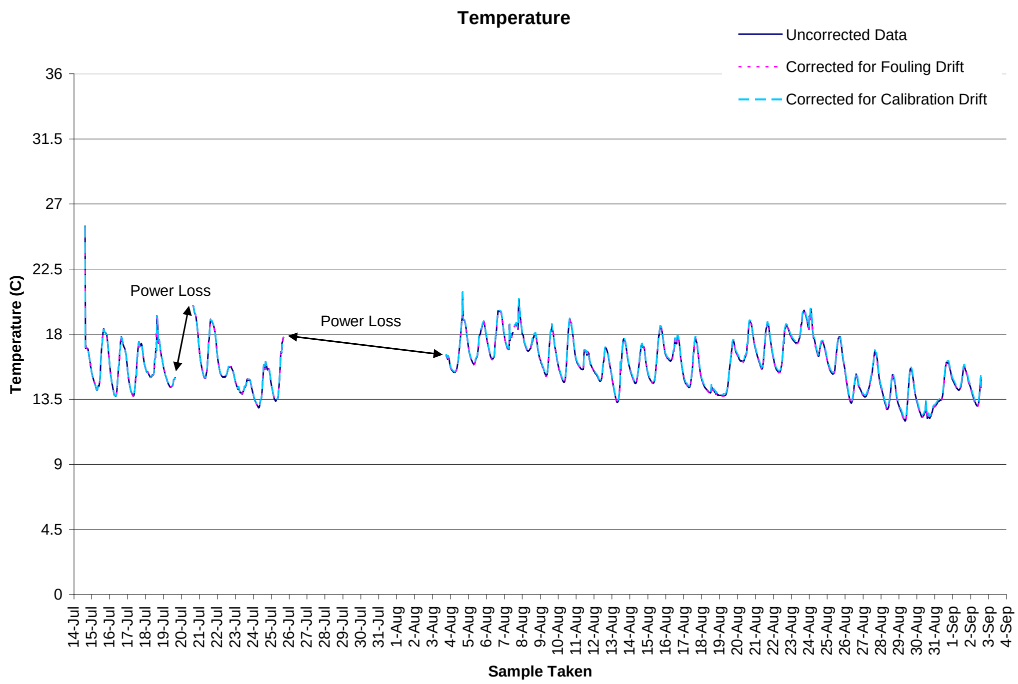


Figure B-12: Fouling and Calibration Drift graphed against Uncorrected pH Data for the Minisonde

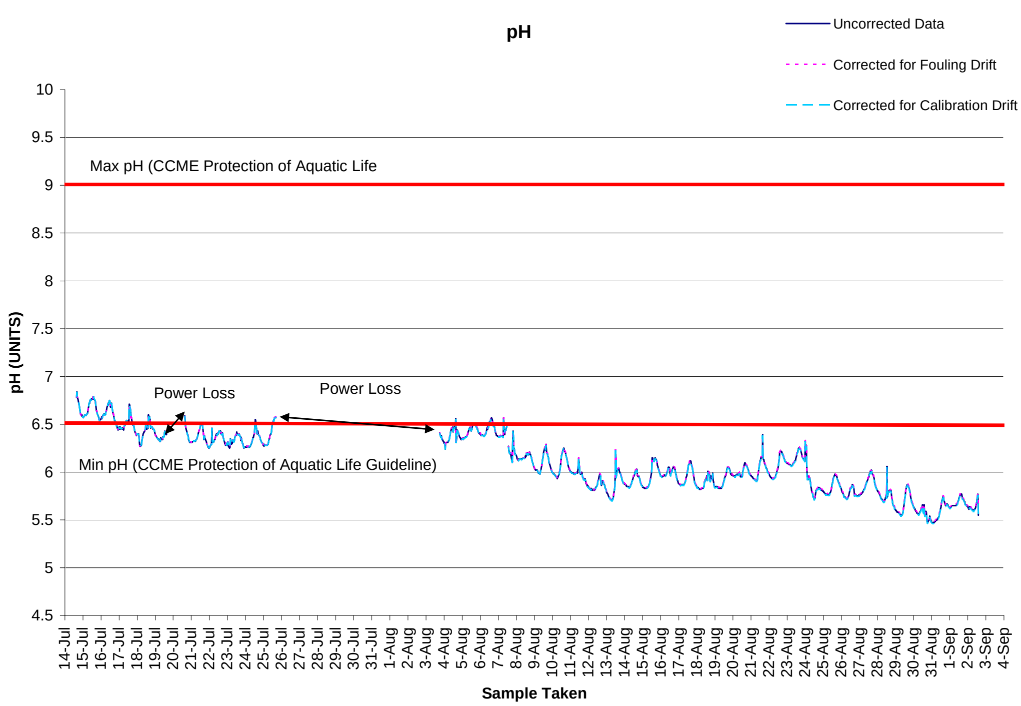


Figure B-13: Fouling and Calibration Drift graphed against Uncorrected Specific Conductivity Data for the Minisonde

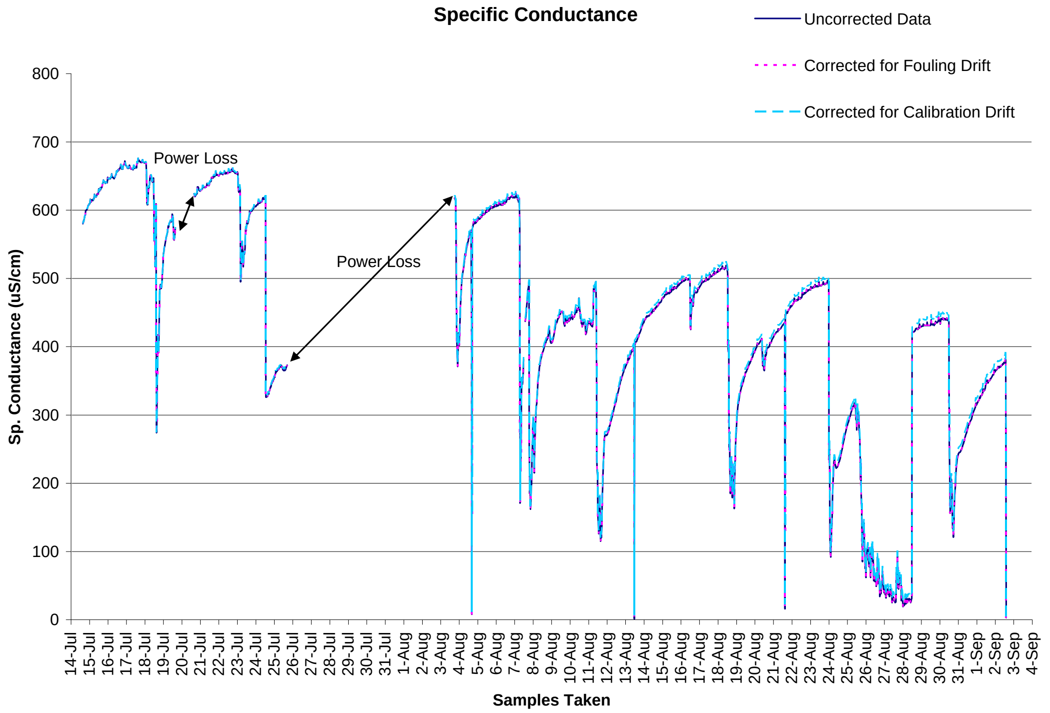
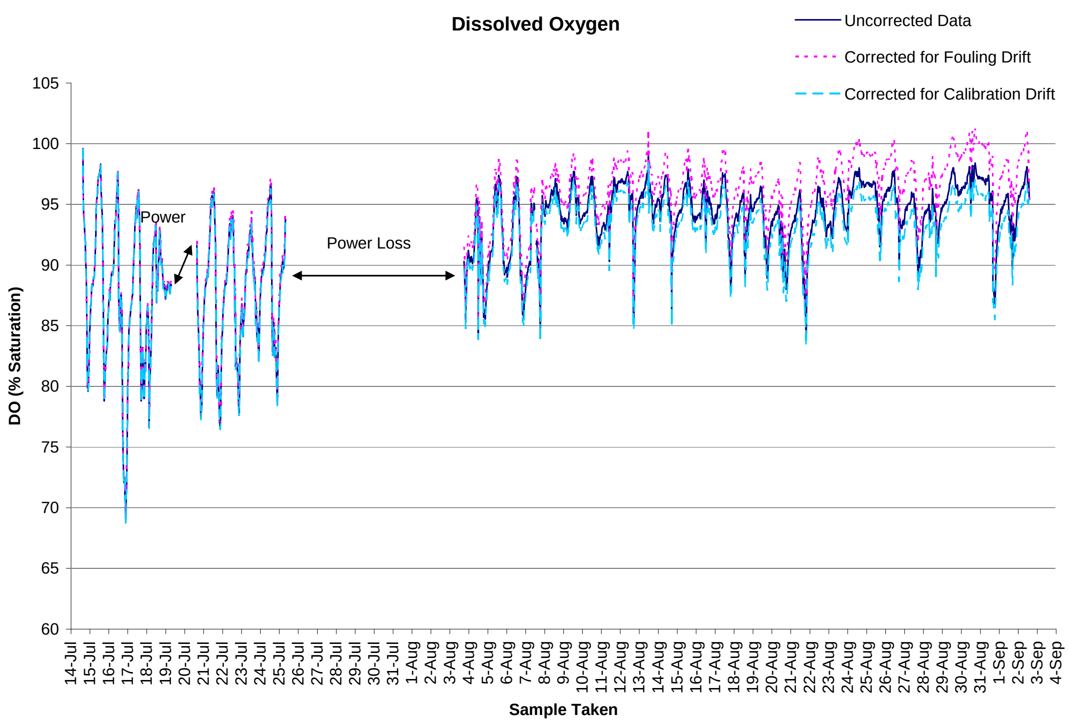


Figure B-14: Fouling and Calibration Drift graphed against Uncorrected Dissolved Oxygen Data for the Minisonde



APPENDIX C

Images of the Sondes during the Project

Figure C-1: Picture taken on July 17, 2009

Figure C-2: Picture Taken on July 31, 2009

Figure C-3: Picture Taken on August 3, 2009

Figure C-4: Picture Taken on August 7, 2009

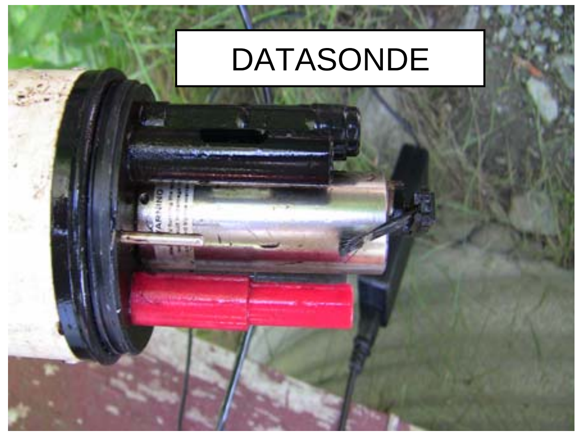


Figure C-5: Picture Taken on August 13, 2009

Figure C-6: Picture Taken on August 21, 2009