Real-Time Water Quality 2016 Annual Report

Voisey's Bay Network

June 16 to October 26, 2016

Government of Newfoundland & Labrador
Department of Municipal Affairs and Environment
Water Resources Management Division

Contents

Acknowledgements

The Real-Time Water Quality Monitoring Network in Voisey's Bay is successful in tracking emerging water quality issues due to the hard work and diligence of certain individuals. The management and staff of Vale work in cooperation with the management and staff of the Department of Municipal Affairs and Environment (MAE) Water Resources Management Division as well as Environment and Climate Change Canada (ECCC) to ensure the protection of ambient water resources in Voisey's Bay, Labrador.

Vale Environmental Coordinators are acknowledged for their hard work during the 2016 deployment period, and ensuring the Real-Time Water Quality Monitoring Network is operating to the standards set by MAE. It is only through their dedication to properly maintain and calibrate the equipment and perform acceptable quality control measures that the data can be viewed as reliable and accurate.

Various individuals from WRMD have been integral in ensuring the smooth operation of such a technologically advanced network. WRMD staff in Goose Bay, Kelly Maher- Environmental Scientist, played a lead role in coordinating and liaising between the major agencies involved, thus, ensuring open communication lines at all times. In addition, WRMD is responsible for the data management/reporting, troubleshooting, along with ensuring the quality assurance/quality control measures are satisfactory. WRMD provides the data to the general public on a near real-time basis through the departmental web page.

Environment and Climate Change Canada staff of the Meteorological Service of Canada: Water Survey Canada play an essential role in the data logging/communication aspect of the network. These individuals visit the site often to ensure the data logging equipment is operating properly and transmitting the data efficiently. Finally, they play the lead role in dealing with hydrological quantity and flow issues.

The managers MAE (Renée Paterson), ECCC (Howie Wills) and Vale (Perry Blanchard) are fully committed to improving this network and ensuring it provides meaningful and accurate water quality/quantity data that can be used in the decision-making process. This network is only successful due to the cooperation of all three agencies involved.

Abbreviations

ECCC	Environment and Climate Change Canada
WSC	Water Survey of Canada
MAE	Department of Municipal Affairs and Environment
DO	Dissolved Oxygen
NL	Newfoundland and Labrador
QAQC	Quality Assurance and Quality Control
RTWQ	Real-time Water Quality
WRMD	Water Resources Management Division
%Sat	Percent Saturation
PTE	Performance Testing and Evaluation

Introduction

The RTWQ network in Voisey's Bay was successfully established by MAE and ECCC in cooperation with Vale in 2003 and further expanded in 2006. The objective of the network is to identify and track emerging water quality or quantity management issues and ensure protection of ambient water resources in and around the Voisey's Bay operations.

The RTWQ network consists of four water quality monitoring stations; Reid Brook at Outlet of Reid Pond, Camp Pond Brook below Camp Pond, Tributary to Reid Brook, and Reid Brook below Tributary. These stations measure water quality parameters including water temperature, pH, specific conductivity, dissolved oxygen, and turbidity. Two additional parameters, total dissolved solids and percent saturation are calculated from measured parameters.

These stations also record continuous stage level and streamflow rate data. These parameters are the responsibility of ECCC, however, if needed, WRMD staff reporting on water quality will have access to water quantity information to understand and explain water quality fluctuations.

Four new Hydrolab Datasonde 5X instruments were purchased in spring 2012 season for this network as well as a new Hydrolab Minisonde 5 for QAQC measurements and an Archer handheld display unit.

This annual deployment report illustrates, discusses and summarizes water quality related events from June 16 to October 26, 2016. During this time, five visits were made to each of the four RTWQ sites. Instruments were deployed for month long intervals referred to as deployment periods.

Maintenance and Calibration

It is recommended that regular maintenance and calibration of the instruments take place on a monthly basis to ensure accurate data collection. This procedure is the responsibility of the Vale Environment staff and is performed preferably every 30 days.

Maintenance includes a thorough cleaning of the instrument and replacement of any small sensor parts that are damaged or unsuitable for reuse. Once the instrument is cleaned, Vale Environment staff carefully calibrates each sensor attachment for pH, specific conductivity, dissolved oxygen and turbidity.

An extended deployment period (>30 days) can result in instrument sensor drift which may result in skewed data. The instrument sensors will still work to capture any water quality event even though the exact data values collected may be inaccurate. Installation and removal dates for each station in the 2016 deployment season are summarized in Table 1.

Table 1: Installation and removal dates for 2016 deployment periods

Installation	Removal	Deployment
June 16	July 16	30 days
July 17	August 15	29 days
August 16	September 19	34 days
September 20	October 25	35 days

Quality Assurance and Quality Control

As part of the Quality Assurance and Quality Control protocol (QAQC), an assessment of the reliability of data recorded by an instrument is made at the beginning and end of the deployment period. The procedure is based on the approach used by the United States Geological Survey.

At deployment and removal, a QAQC Instrument is temporarily deployed alongside the Field Instrument. Values for temperature, pH, conductivity, dissolved oxygen and turbidity are compared between the two instruments**.** Based on the degree of difference between parameters recorded by the Field Instrument and QAQC Instrument at deployment and at removal, a qualitative statement is made on the data quality (Table 2).

Table 2: Ranking classifications for deployment and removal

	Rank				
Parameter	**Excellent**	**Good**	**Fair**	**Marginal**	**Poor**
Temperature (oC)	<=+/-0.2	>+/-0.2 to 0.5	>+/-0.5 to 0.8	>+/-0.8 to 1	<+/-1
pH (unit)	<=+/-0.2	>+/-0.2 to 0.5	>+/-0.5 to 0.8	>+/-0.8 to 1	>+/-1
Sp. Conductance (µS/cm)	<=+/-3	>+/-3 to 10	>+/-10 to 15	>+/-15 to 20	>+/-20
Sp. Conductance > 35 µS/cm (%)	<=+/-3	>+/-3 to 10	>+/-10 to 15	>+/-15 to 20	>+/-20
Dissolved Oxygen (mg/l) (% Sat)	<=+/-0.3	>+/-0.3 to 0.5	>+/-0.5 to 0.8	>+/-0.8 to 1	>+/-1
Turbidity <40 NTU (NTU)	<=+/-2	>+/-2 to 5	>+/-5 to 8	>+/-8 to 10	>+/-10
Turbidity > 40 NTU (%)	<=+/-5	>+/-5 to 10	>+/-10 to 15	>+/-15 to 20	>+/-20

It should be noted that the temperature sensor on any instrument is the most important. All other parameters can be broken down into three groups: temperature dependent, temperature compensated and temperature independent. Because the temperature sensor is not isolated from the rest of the instrument the entire instrument must be at the same temperature before the sensor will stabilize. The values may take some time to climb to the appropriate reading; if a reading is taken too soon it may not accurately portray the water body.

Deployment and removal comparison rankings for the Voisey's Bay Network stations are summarized in Table 3. For additional information and explanations of rankings including "n/a" rankings, please refer to the monthly deployment reports.

Table 3: Comparison rankings for Voisey's Bay Network stations

Station	Date	Action	Instrument #	Temperature	pH	Specific Conductivity	Dissolved Oxygen	Turbidity
Reid Brook at outlet of Reid Pond	16-Jun	Deployment	62884	Excellent	Excellent	Excellent	Poor	Excellent
	16-Jul	Removal		Excellent	Good	Excellent	Good	Excellent
	17-Jul	Deployment	62884	Excellent	Marginal	Excellent	Good	Excellent
	15-Aug	Removal		Excellent	Good	Excellent	Excellent	Excellent
	16-Aug	Deployment	62884	Excellent	Marginal	Excellent	Excellent	Poor
	19-Sep	Removal		Excellent	Fair	Good	Poor	Excellent
	20-Sep	Deployment	62884	Excellent	Fair	Good	Excellent	Excellent
	25-Oct	Removal		Excellent	Good	Excellent	Good	Good
Camp Pond Brook	16-Jun	Deployment	62885	Excellent	Good	Excellent	Excellent	Excellent
	16-Jul	Removal	44175	Excellent	Good	Excellent	Good	Excellent
	17-Jul	Deployment	44175	Excellent	Fair	Excellent	Excellent	Excellent
	15-Aug	Removal		Excellent	Excellent	Good	Excellent	Excellent
	16-Aug	Deployment	44175	Excellent	Good	Good	Excellent	Fair
	19-Sep	Removal		Excellent	Excellent	Poor	Excellent	Excellent
	20-Sep	Deployment	62885	Excellent	Fair	Marginal	Excellent	Excellent
	25-Oct	Removal		Excellent	Excellent	Excellent	Fair	Poor
Reid Brook below Tributary	16-Jun	Deployment	62887	Excellent	Excellent	Excellent	Excellent	Excellent
	16-Jul	Removal		Excellent	Good	Good	Excellent	Excellent
	17-Jul	Deployment	62887	Excellent	Fair	Excellent	Excellent	Excellent
	15-Aug	Removal		Excellent	Good	Excellent	Excellent	Poor
	16-Aug	Deployment	62887	Good	Excellent	Good	Excellent	Fair
	19-Sep	Removal		Excellent	Fair	Marginal	Good	Excellent
	20-Sep	Deployment	62887	Good	Fair	Fair	Good	Excellent
	25-Oct	Removal		Excellent	Good	Good	Fair	Poor
Tributary to Reid Brook	16-Jun	Deployment	62886	Excellent	Excellent	Excellent	Poor	Excellent
	16-Jul	Removal		Excellent	Fair	Excellent	Excellent	Excellent
	17-Jul	Deployment	62886	Excellent	Good	Excellent	Excellent	Excellent
	15-Aug	Removal		Excellent	Good	Good	Excellent	Excellent
	16-Aug	Deployment	62886	Excellent	Fair	Good	Excellent	Poor
	19-Sep	Removal		Excellent	Excellent	Poor	Good	Good
	20-Sep	Deployment	62886	Excellent	Good	Good	Excellent	Excellent
	25-Oct	Removal		Excellent	Good	Excellent	Excellent	Good

Data Interpretation

The following graphs and discussion illustrate significant water quality-related events from June 16 to October 25, 2016 in the Voisey's Bay RTWQ Network.

With the exception of water quantity data (stage), all data used in the preparation of the graphs and subsequent discussion below adhere to this stringent QAQC protocol. WSC is responsible for QAQC of water quantity data. Corrected data can be obtained upon request to WSC.

Reid Brook below Tributary had turbidity data that indicated that there was debris blocking the sensor. Therefore the turbidity data from July 2^{nd} 2016 through to July 16^{th} 2016 and August 7^{th} to August 15^{th}, 2016 was removed from the analysis as it did not represent the brook.

During the data grooming process it was identified that the turbidity data at Tributary to Reid Brook was not representing the brook from October 16^{th} 2016 to October 25^{th}, 2016. This data was removed and not used in the statistical analysis in this report.

All instruments were sent to the St. John's WRMD laboratory at the end of the season for the instruments' yearly PTE. Any necessary repairs and replacement sensors will be addressed before the 2016 season.

Reid Brook at Outlet of Reid Pond

During the 2016 deployment season the water temperature ranged within a minimum of 1.47°C to a maximum of 15.77°C (Table 4). The water temperature minimum and maximum values for 2016 were slightly lower than that of 2015 deployment season. However the median for 2016 at 9.79 °C was slightly higher than 2015 which was 9.5 °C for the deployment season (Figure 1).

Water temperatures start to steadily increase on the onset of June. By the end of July and throughout August the water temperatures were at the highest. As the Fall season started the water temperatures had already started to decrease. This is depicted below in Figure 1.

There are several independent increases and decreases in water temperature. During one evident dip on August 7th, 2016 there is an increase in stage level and a corresponding drop in air temperature at the same time. Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

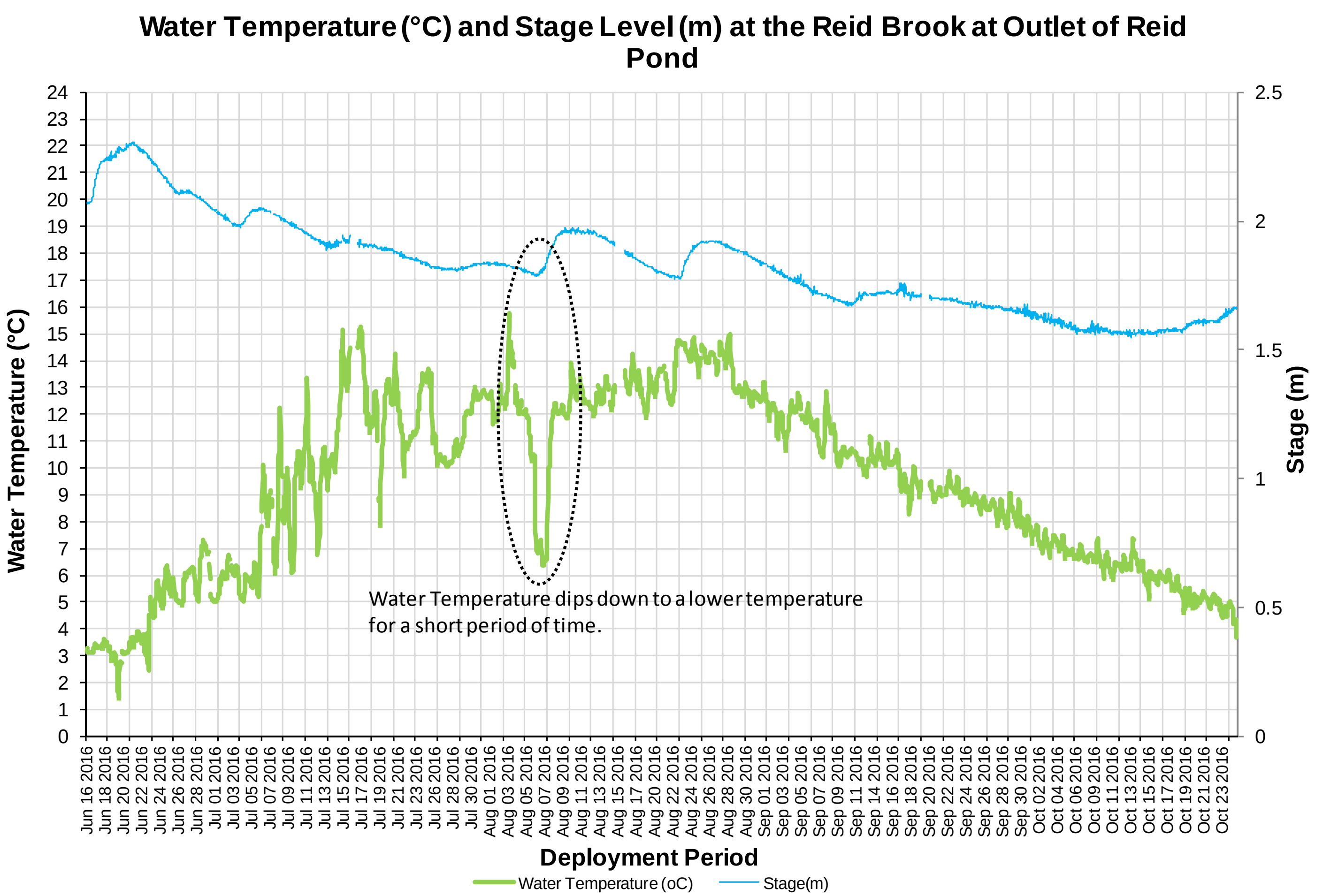

Figure 1: Water Temperature & Stage at Reid Brook at Outlet of Reid Pond

Table 4: Comparisons of Minimum, Maximum and Median from the past three deployment years

Water Temperature	2016	2015	2014
Min	1.47	2.51	2.21
Max	15.77	18.01	19.25
Median	9.79	9.5	7.8

Water temperature values show a close relationship with air temperature (Figure 2). Increases and decreases in air temperatures are reflected in water temperatures. Air temperatures clearly fluctuate at a greater scale each day when compared with water temperatures.

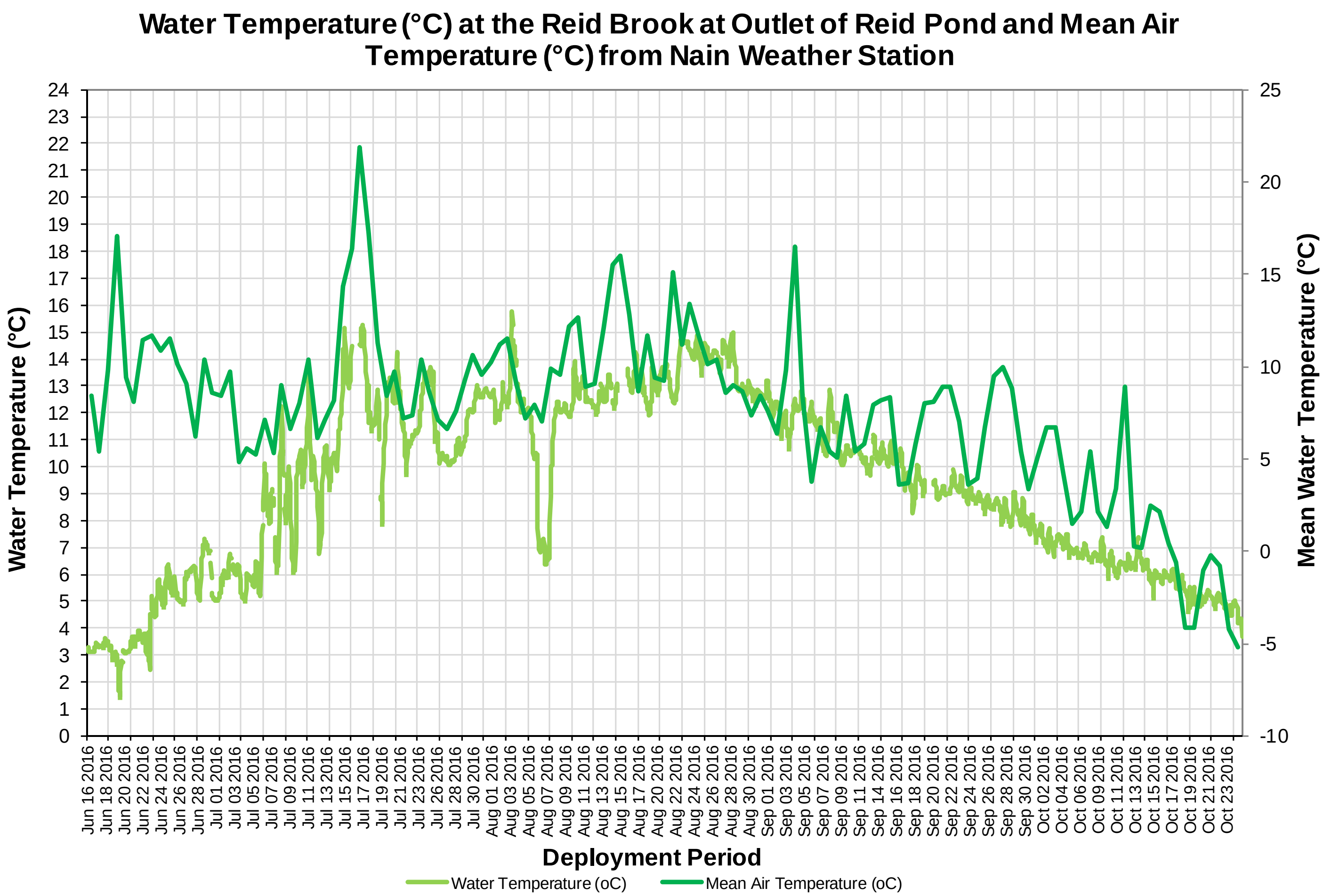

Figure 2: Mean Air Temperature from Nain weather station and Water Temperature at Reid Brook at Outlet of Reid Pond

During the 2016 deployment season the pH data ranged between a minimum of 6.08 pH units and a maximum of 7.54 pH units (Table 5). This station is at the outlet of a pond and the pH data has a wider range compared to that of stream or brook pH. In a pond environment the water parameters take longer to adjust or change after an influence. The pond has a larger volume of water with a slower turnover than a stream or brook.

Figure 3, displays the relationship between pH and stage. At the start of deployment the pH levels are elevated along with the stage data. Before an increase in pH there is a dip in the levels. This can indicate rainfall, as the initial onset of rainfall drops (increases acidity) the pH for a short period of time then the pH levels (alkalinity increases) as the stage level increases. During the 2016 deployment the pH data does dip below the minimum CCME guideline. These drops in pH (increased acidity) are for a short period of time with the pH levels returning to above the CCME minimum guideline.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

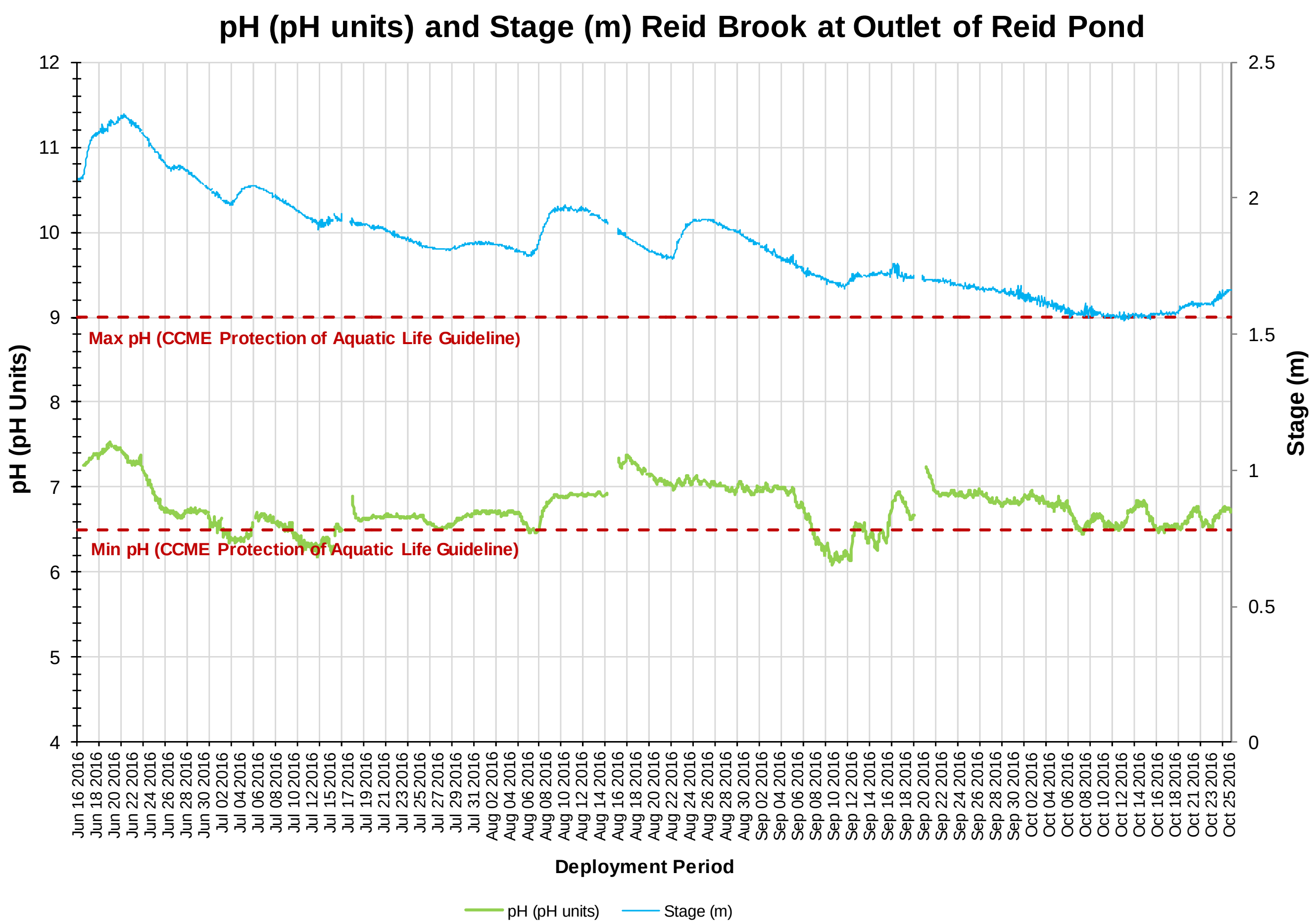

Figure 3: pH and Stage Level at Reid Brook at Outlet of Reid Pond

Table 5: Comparisons of Minimum, Maximum and Median from the past three deployment years

pH	2016	2015	2014
Min	6.08	4.83	5.38
Max	7.54	6.96	8.96
Median	6.72	6.05	6.78

This deployment season had specific conductivity values ranging from a minimum of 9.1µS/cm to a maximum of 15.9µS/cm. The overall conductivity median of 11.6µS/cm indicated that this station naturally has very low conductivity (Table 6).

Specific conductivity was low and stable throughout the deployment season with minimal fluctuation regardless of the changing water level (Figure 4). This trend is to be expected as this station, as it is located at the outflow of a stable lake environment of Reid Pond. There is movement in the specific conductivity at the end of June to beginning of July, this is the time of year of snowmelt and there is likely more runoff from the surrounding natural environment.

The deployment period of July to August has lower conductivity than the rest of the season, there was a total of 17 days that saw some level of precipitation during that deployment period, and it is likely the rainfall diluted the conductivity for that time frame. The data stabilizes for the reminder of the deployment season.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

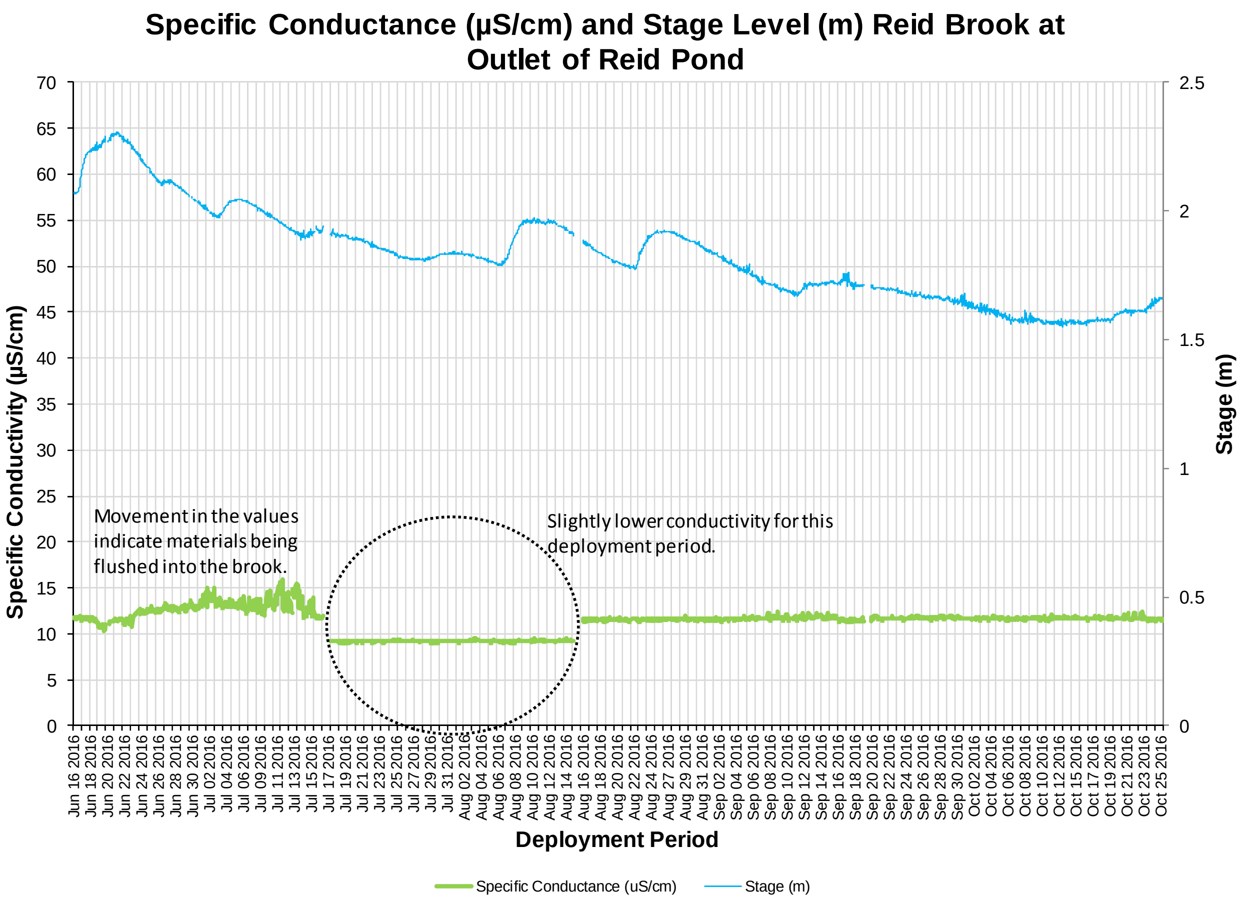

Figure 4: Specific conductivity at Reid Brook at Outlet of Reid Pond

Table 6: Comparisons of Minimum, Maximum and Median from the past three deployment years

Specific Conductivity	2016	2015	2014
Min	9.1	11	9.7
Max	15.9	14	13
Median	11.6	12	12

During this deployment season the dissolved oxygen content ranged between a minimum of 10.79mg/l and a maximum of 12.46mg/l. The overall dataset had a median value of 12.09mg/l (Table 7). The median is higher than that of 2015 deployment season of 10.98mg/L.

Dissolved oxygen content shows a typical seasonal fluctuation in 2016, and is inversely proportional to the changes in water and air temperature (Figure 1 & 2). Dissolved oxygen values were low and consistent through the warmest part of the season and began to increase in mid to late September as water and air temperatures began to cool with the change to the fall season. The lowest dip in dissolved oxygen (mg/L) on July 15 -17th 2016 corresponds with a peak in air temperature (Figure 2).

All values were above both the minimum CCME Guideline for the Protection of Cold Water Biota at Other Life Stages (6.5mg/l) and Early Life Stages (9.5mg/l) during the deployment season (Figure 5).

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

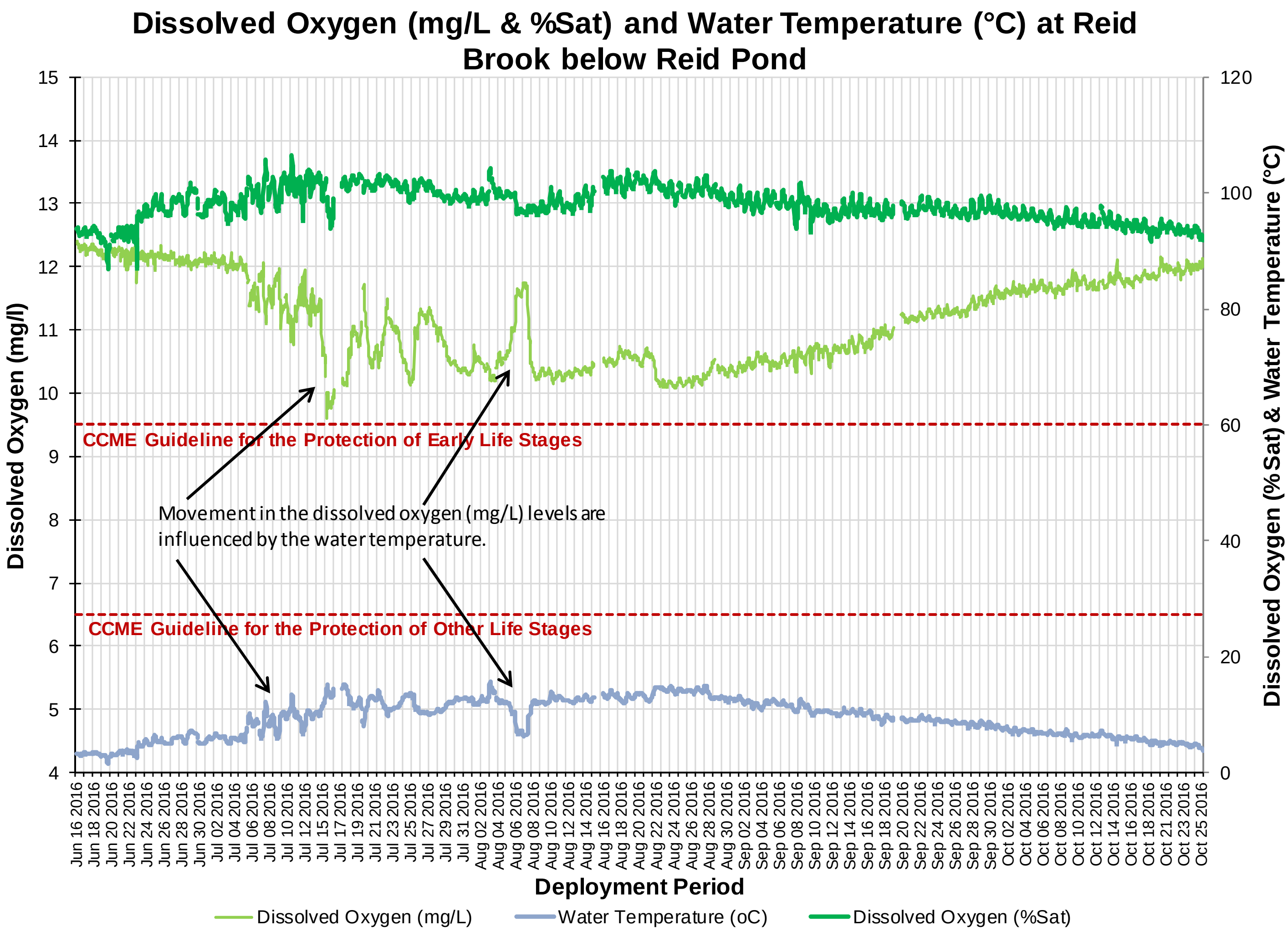

Figure 5: Dissolved oxygen and Water Temperature at Reid Brook at Outlet of Reid Pond

Table 7: Comparisons of Minimum, Maximum and Median from the past three deployment years

Dissolved Oxygen (mg/l)	2016	2015	2014
Min	10.76	9.76	9.54
Max	12.46	12.36	12.82
Median	12.09	10.98	11.66

Turbidity values during this deployment period ranged between a minimum of 0.0NTU and a maximum of 41.3NTU. The median for the turbidity data remained a 0.2NTU. This data range indicates that there is no natural background turbidity at this station (Table 8).

At the initial deployment of this station the turbidity data had a lot of movement. At this time of year there is an increase in particles, minerals and natural material flushed into waterways due to snowmelt and increased runoff. As the deployment period continues the turbidity data settles down to lower levels (Figure 6).

Turbidity levels can be influenced by precipitation and the corresponding runoff that can occur. It is common to see levels increase during these events, it is important that the turbidity levels return to natural levels after such events.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

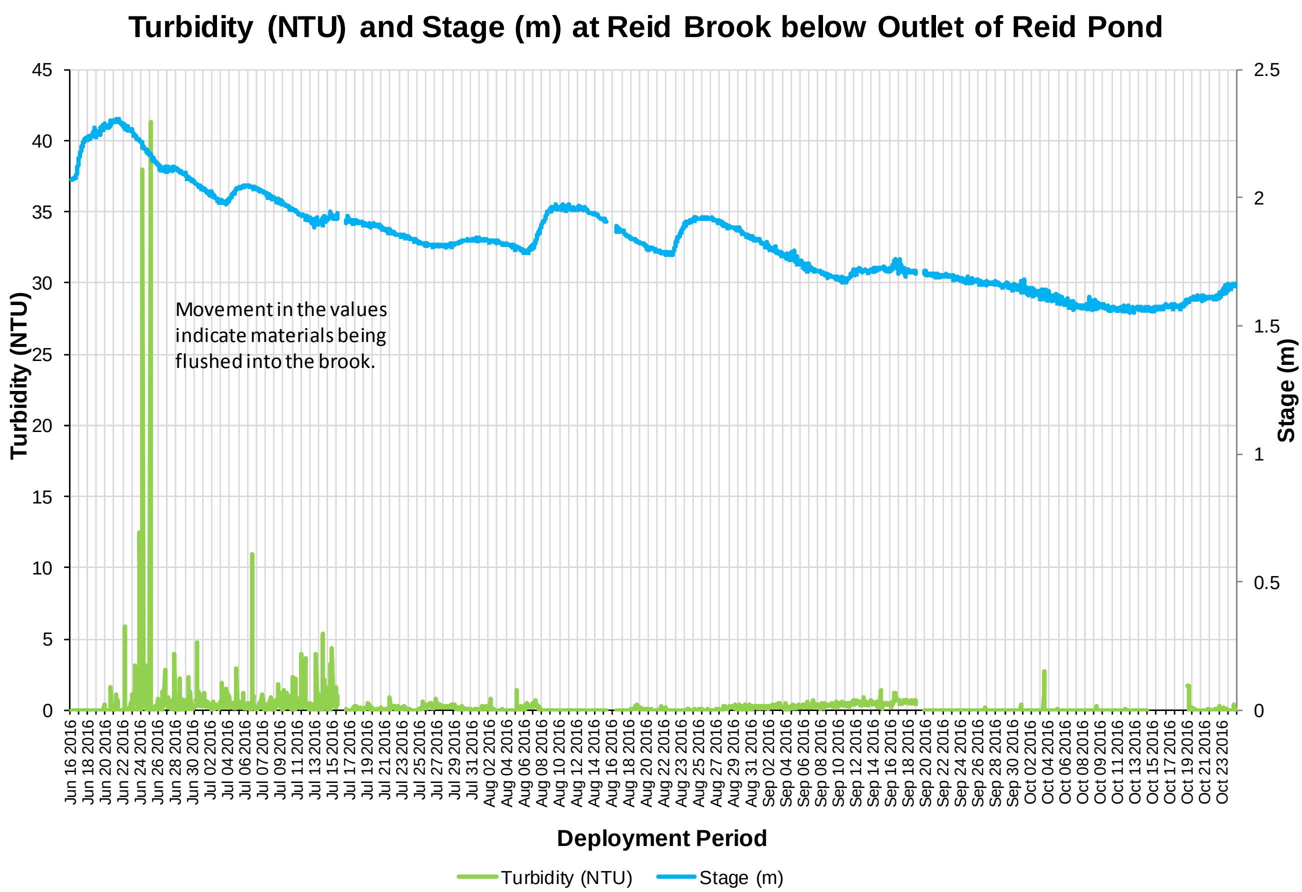

Figure 6: Turbidity and Stage data at Reid Brook at Outlet to Reid Pond

Table 8: Comparisons of Minimum, Maximum and Median from the past three deployment years

Turbidity	2016	2015	2014
Min	0.0	0.0	0.0
Max	41.3	1.2	49.3
Median	0.2	0.0	0.0

Camp Pond Brook below Camp Pond

During this deployment season the water temperature values at Camp Pond Brook below Camp Pond ranged from a minimum of 0.07°C to a maximum of 22.02°C. This station had a median of 12°C which was similar to the previous deployment season median of 11.95°C (Table 9).

The highest temperatures occurred mid-July and toward the end of August (Figure 7). At the end of August the water temperatures drop down to lower levels likely a result of the air temperature changes as Fall and then Winter season starts (Figure 8).

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

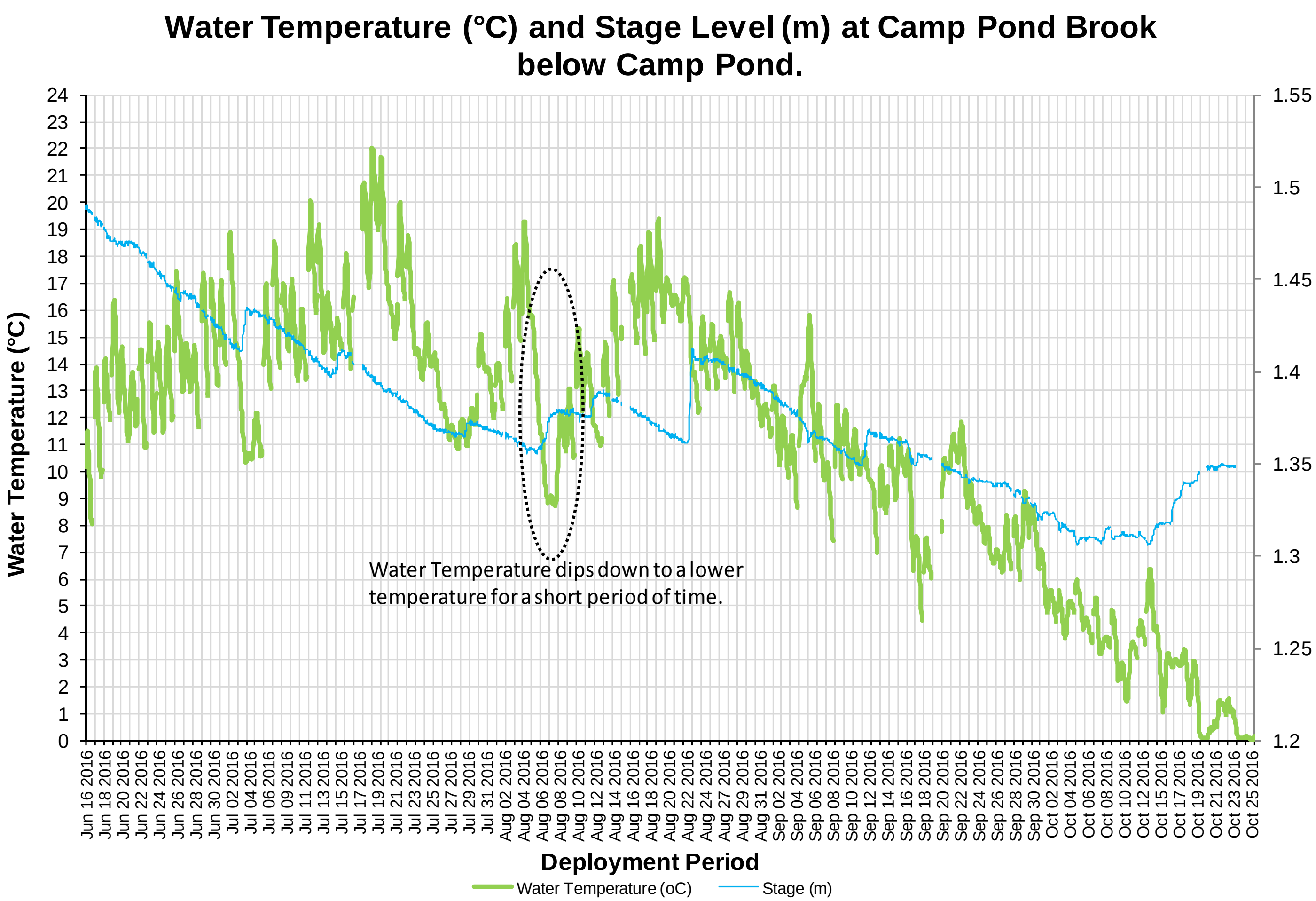

Figure 7: Water temperature and Stage Level at Camp Pond Brook below Camp Pond

Water temperature values show a close relationship with air temperatures (Figure 8). Increases and decreases in air temperatures are reflected in water temperatures. Air temperatures clearly fluctuate at a greater scale each day when compared with water temperatures.

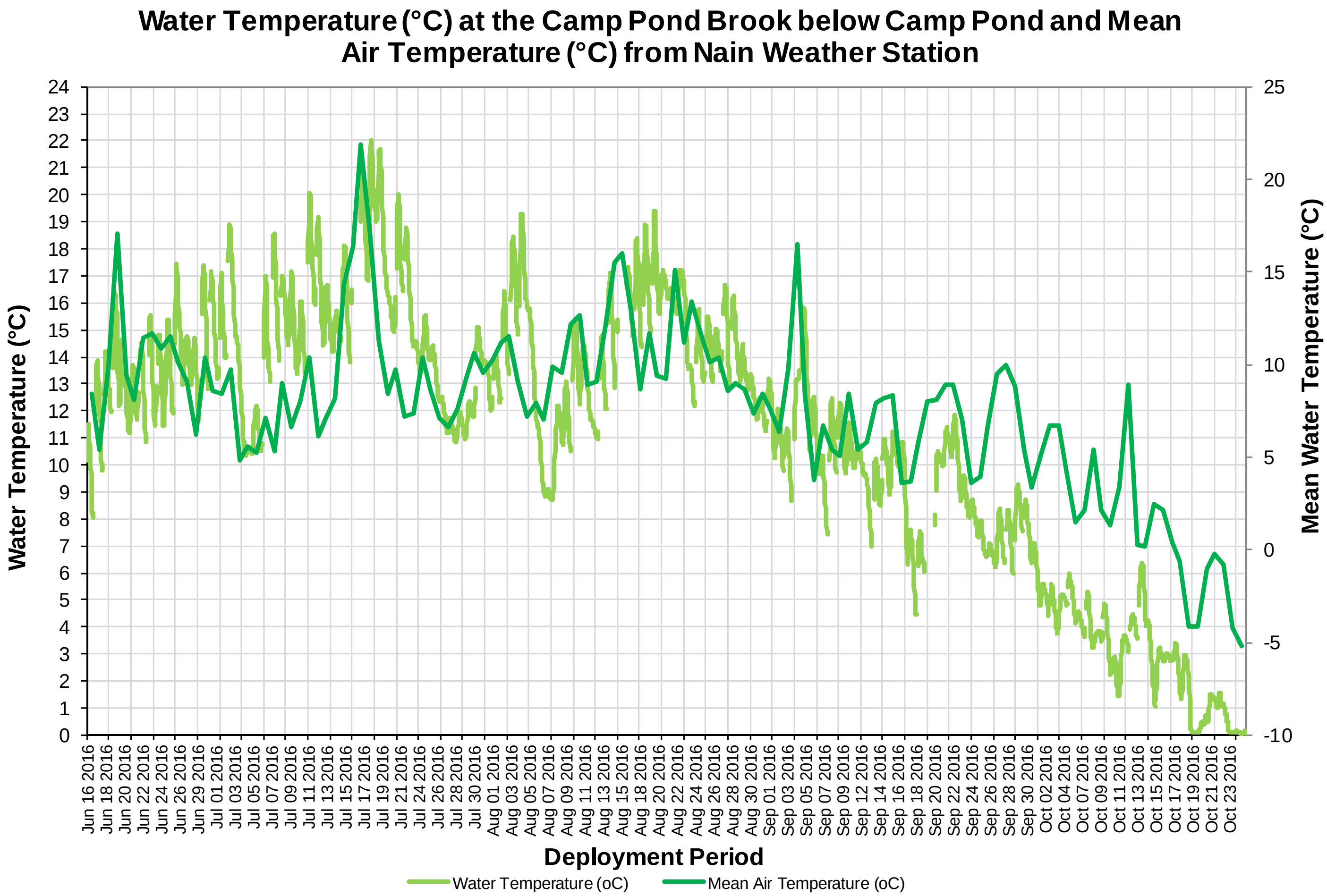

Figure 8: Average Daily Air Temperature from Nain weather station and Water Temperature at Camp Pond Brook below Camp Pond

Table 9: Comparisons of Minimum, Maximum and Median from the past three deployment years

Water Temperature	2016	2015	2014
Min	0.07	0.38	0.39
Max	22.02	21.7	22.90
Median	12	11.95	12.34

During this deployment season the pH data ranged between a minimum of 6.54 and a maximum of 7.2 pH units. The data for 2016 has a median value of 6.90pH units which compares with the median values of 6.92 pH units in 2015 and 6.85 in 2014 (Table 10).

Stage is included on Figure 9 to show the relationship between water level and pH values. Across the deployment the pH data is reasonably stable; there is a small dip on August 23rd, 2016 where the values drop to the minimum guideline for a short span of time. The majority of the events in this deployment season can be linked to precipitation during the same time frames (Figure 9).

The 2016 pH data is within the recommended range that is suggested by the CCME Guidelines for the Protection of Aquatic Life (>6.5 and <9.0 pH units). Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

pH (pH units) and Stage (m) at Camp Pond Brook below Camp Pond

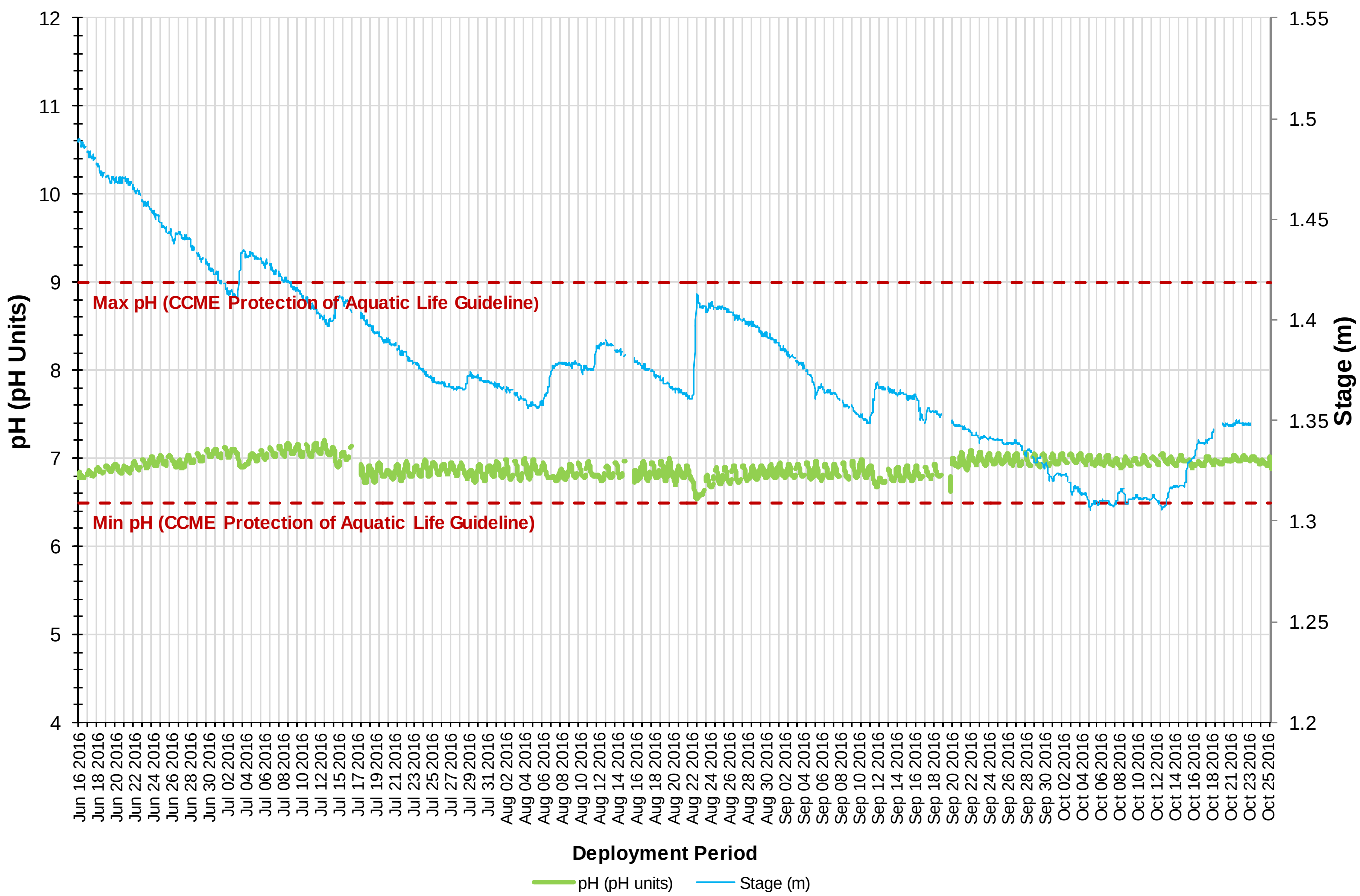

Figure 9: pH and Stage Level at Camp Pond Brook below Camp Pond

Table 10: Comparisons of Minimum, Maximum and Median from the past three deployment years

pH	2016	2015	2014
Min	6.54	6.21	6.40
Max	7.2	7.33	7.08
Median	6.90	6.92	6.85

This deployment season had specific conductivity data within a minimum of 28.7µS/cm and a maximum of 64.0µS/cm (Figure 10). This deployment season had a slightly higher conductivity median of 38.2µS/cm when compared with the 2015 conductivity median of 34.8µS/cm (Table 11).

Stage is included in Figure 10 to illustrate the comparable relationship between conductivity and water level. At this station when stage levels are high the conductivity level also increases. This is generally not the case at other stations, however due to the proximity of this brook to roadways and the mine site this brook is heavily influenced by runoff factors that the other Voisey's Bay real-time stations do not exhibit. The high spikes in conductivity correspond with high peaks in stage for the same time frames, the conductivity levels settle down shortly after.

Over the entire deployment season the conductivity level in the brook increased slightly, while the stage level decreased. This relationship is to be expected as the incidents of rainfall and bank runoff start to decrease as the winter season approaches. Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

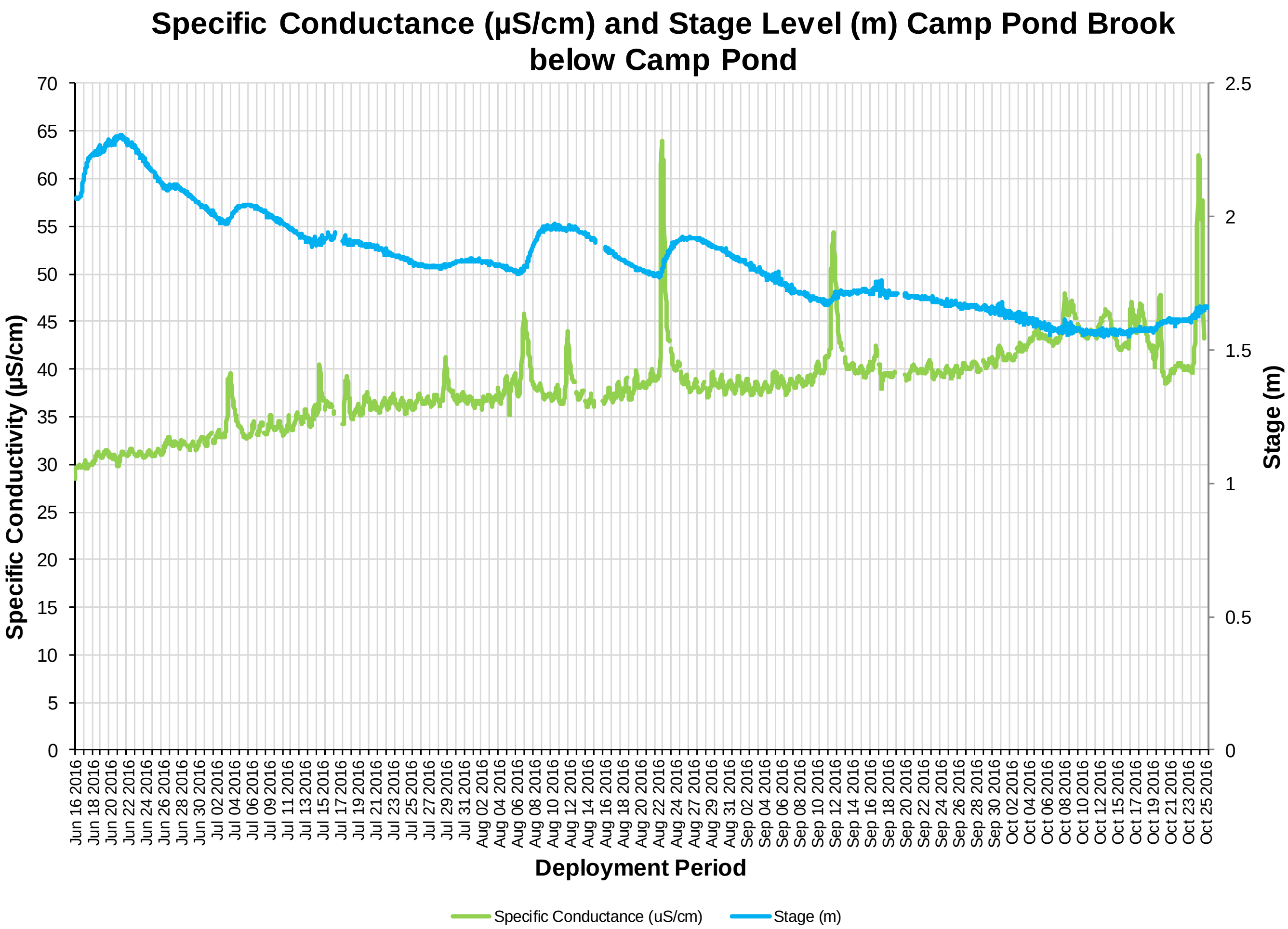

Figure 10: Specific conductivity and Stage Level at Camp Pond Brook below Camp Pond

Table 11: Comparisons of Minimum, Maximum and Median from the past three deployment years

Specific Conductivity	2016	2015	2014
Min	28.7	30.3	27.8
Max	64.0	55.5	56.7
Median	38.2	34.8	35.5

This deployment season at Camp Pond Brook had dissolved oxygen values that ranged between a minimum of 8.22mg/l and a maximum of 14.03mg/l, with a median value of 10.00mg/L comparable with the 2015 median of 10.03mg/l. The saturation of dissolved oxygen ranged from a minimum of 87.9% to 103.3%, with a median value of 93.7% (Table 12).

Dissolved oxygen content showed a typical seasonal trend, inverse to water temperature. Dissolved oxygen content is lower throughout June and July and toward the end of August when water temperatures are the warmest. As water temperatures decrease in the late summer and early fall, dissolved oxygen content begins to increase. There are fluctuations that are concurrent with the changes in water temperature.

There were some dips below the CCME Guideline for the Protection of Aquatic Life at Early Life Stages (9.5mg/l) however the dips correspond with water temperature highs during those same time frames. The guidelines are indicated in red on Figure 11.

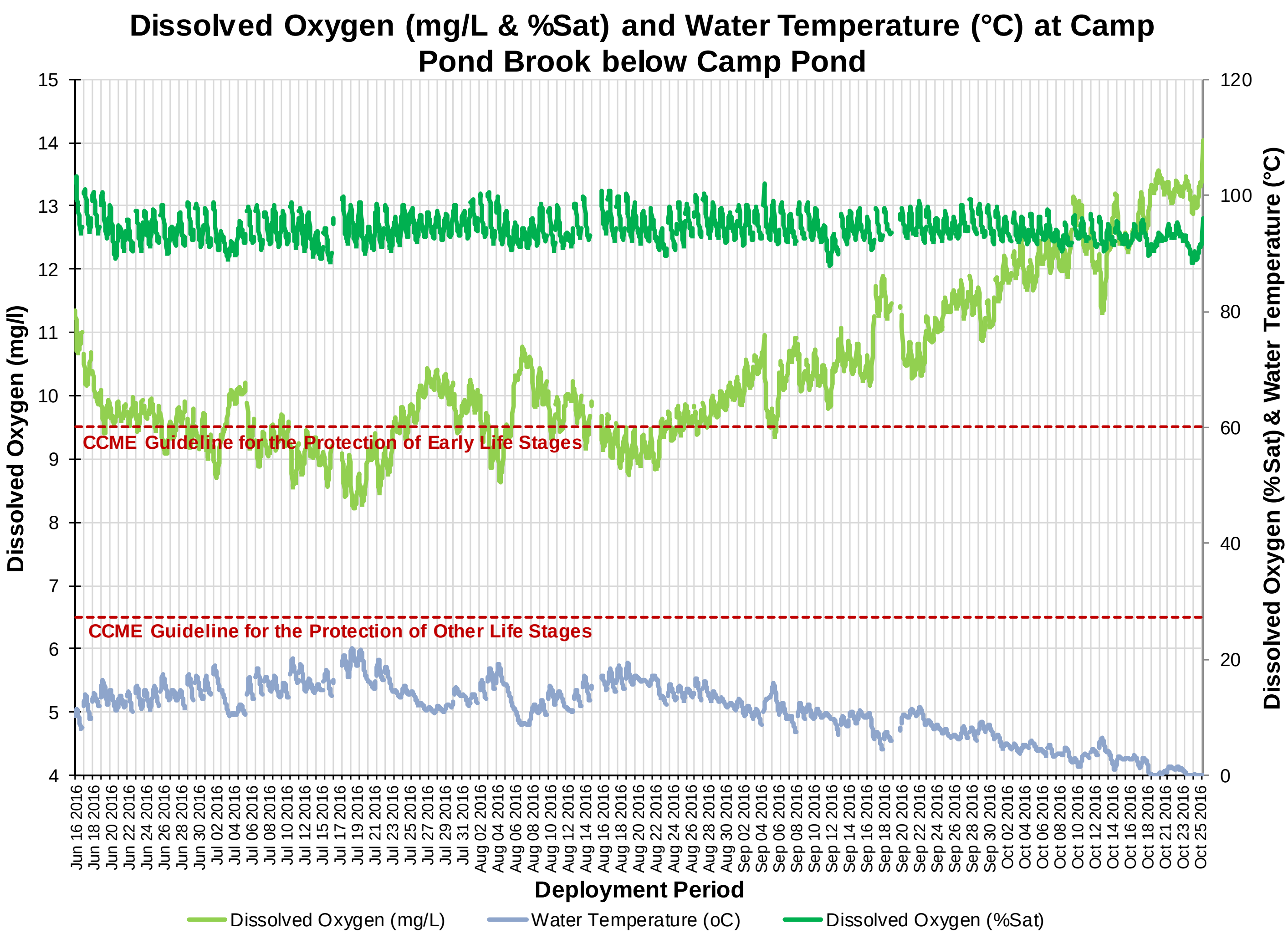

Figure 11: Dissolved Oxygen and Water Temperature at Camp Pond Brook below Camp Pond

Table 12: Comparisons of Minimum, Maximum and Median from the past three deployment years

Dissolved Oxygen (mg/l)	2016	2015	2014
Min	8.22	8.51	8.08
Max	14.03	11.55	13.67
Median	10	10.03	9.86

Camp Pond Brook below Camp Pond had turbidity values that ranged between a minimum of 0.0NTU and a maximum of 3.5NTU during the 2016 deployment season (Figure 12). A median value of 0.0NTU indicates there is very little or no natural background turbidity occurring at this station. This is the case for the previous 3 years with the medians recording no higher than 0.3 NTU (Table 13).

While there are a number of turbidity spikes throughout the four deployment periods from June to October 2016, the majority of these increases correspond with rainfall events. Turbidity events are similar throughout the deployment season. The turbidity events recorded were low in magnitude and short in duration.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

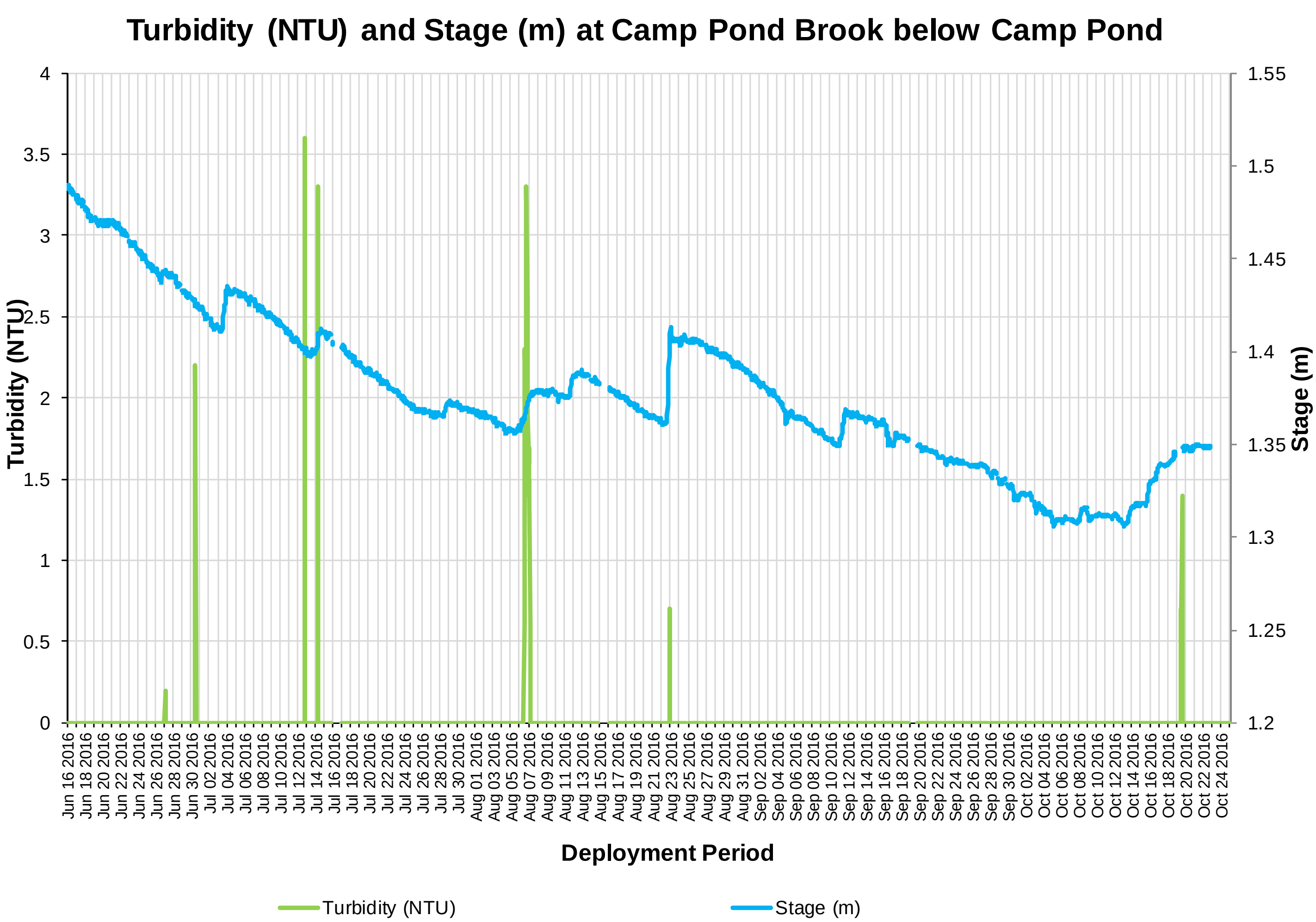

Figure 12: Turbidity and Stage Level at Camp Pond Brook below Camp Pond

Table 13: Comparisons of Minimum, Maximum and Median from the past three deployment years

Turbidity	2016	2015	2014
Min	0.0	0.0	0.0
Max	3.5	31.5	117.7
Median	0.0	0.0	0.3

Tributary to Reid Brook

During this deployment season the water temperatures ranged between a minimum of 0.0°C to a maximum of 15.7°C at Tributary to Reid Brook (Table 14). The water temperatures were highest early July as the air temperatures increased with the summer season (Figure 13 & 14). From the end of August onwards the water temperatures made a steady decline as the ambient air temperatures adjusted to the fall and winter seasons approaching. There doesn't seem to be much variation in the water temperatures at the site over the past 3 years.

This station had an overall water temperature median value of 9.3°C which was comparable to that of the 2015 median value of 9.1°C and the 2014 median of 9.30°C (Table 14).

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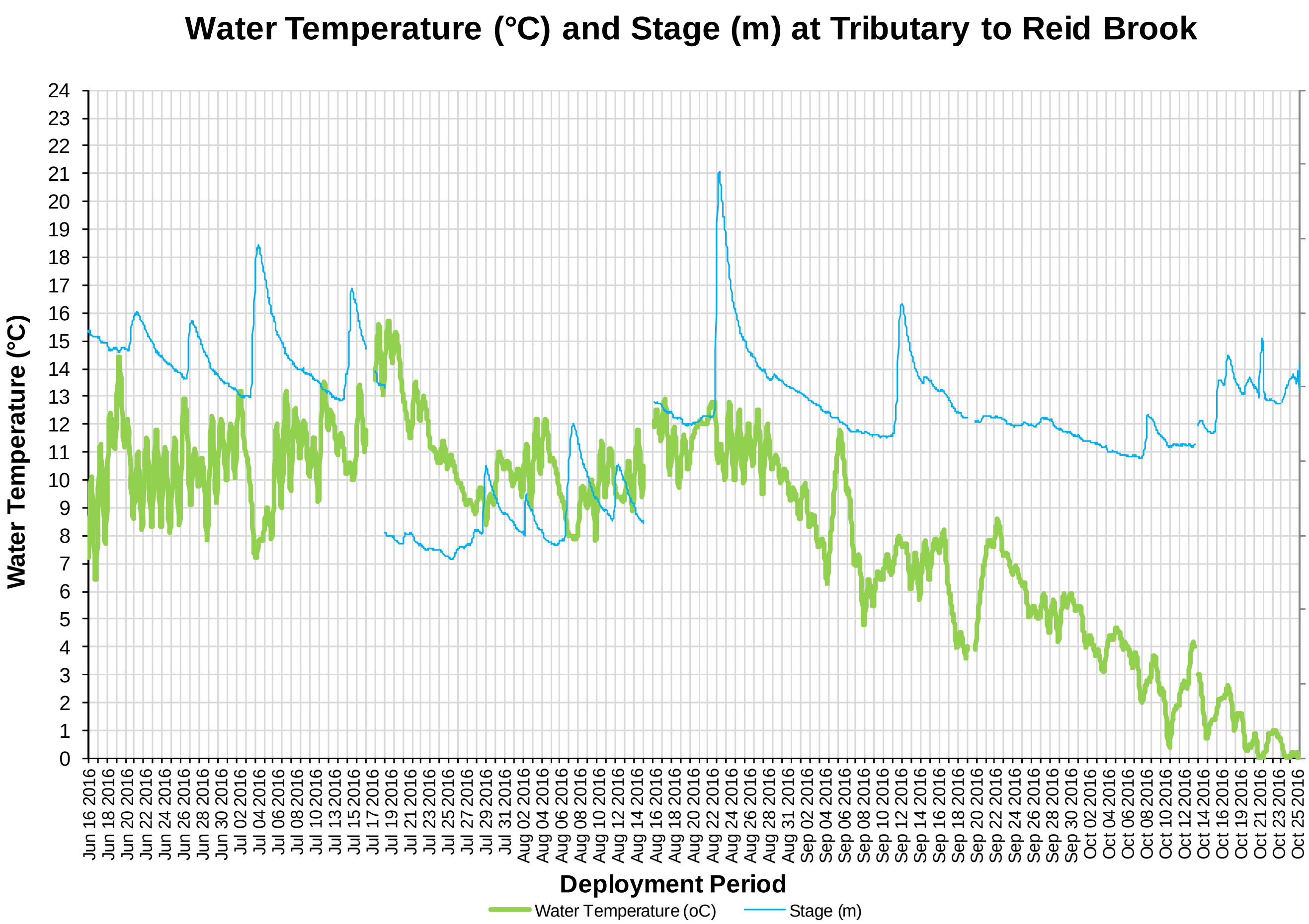

Figure 13: Water temperature and Stage Level at Tributary to Reid Brook

Table 14: Comparisons of Minimum, Maximum and Median from the past three deployment years

Water Temperature	2016	2015	2014
Min	0.0	0.0	0.10
Max	15.7	15.7	18.30
Median	9.3	9.1	9.30

Water temperature values show a close relationship with air temperatures (Figure 14). Increases and decreases in air temperatures are reflected in water temperatures. Air temperatures clearly fluctuate at a greater scale each day when compared with water temperatures.

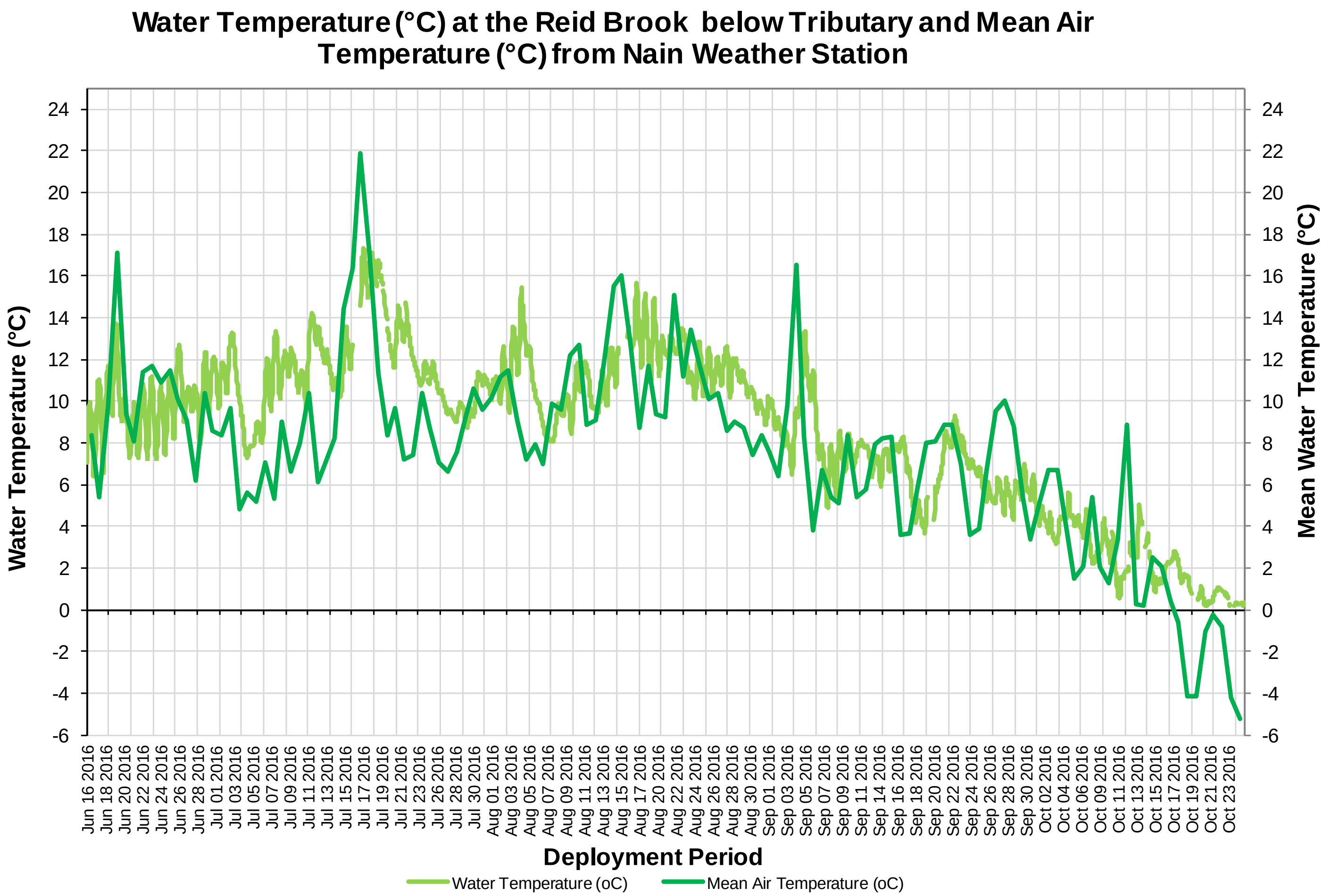

Figure 14: Average Daily Air Temperature from Nain weather station and Water Temperature at Tributary to Reid Brook

The pH data at Tributary to Reid Brook ranged between a minimum of 6.08 pH units and a maximum of 7.22 pH units throughout the 2016 deployment season. This data had a median of 6.89 pH units (Figure 15). The past 3 years of pH data provided medians that were close in range to each other, indicating there is no significant change to pH data over the 3 year time frame (Table 15).

Stage data is included on Figure 15 to present how stage can influence pH values over a period of time. As stage increases pH levels will decrease, this is a normal relationship and is expected in brooks.

pH data at this site are found along the minimum CCME Guideline for the Protection of Aquatic Life. The guidelines are indicated in red on Figure 15. On several occasions, the pH values drop under the suggested guideline however most of these events are during periods of high stage levels. The CCME guidelines are a base to understand the pH data in rivers; all rivers are different and have its own specific range that the pH data will fall within.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

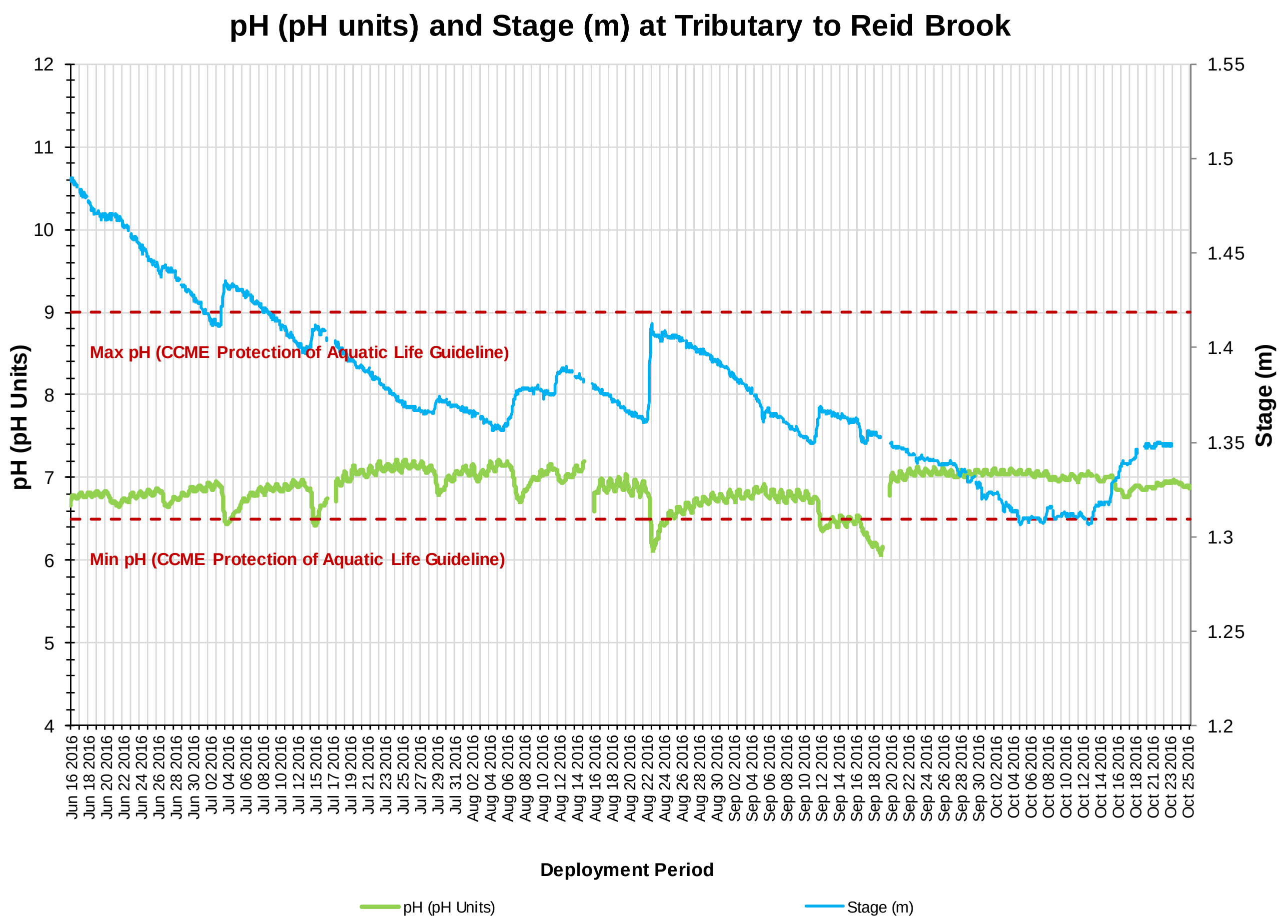

Figure 15: pH and stage level at Tributary to Reid Brook

Table 15: Comparisons of Minimum, Maximum and Median from the past three deployment years

pH	2016	2015	2014
Min	6.08	5.66	6.07
Max	7.22	7.09	7.10
Median	6.89	6.78	6.69

The specific conductivity levels at Tributary to Reid Brook ranged between a minimum of 22.1µS/cm to a maximum amount of 44µS/cm during the deployment season. This deployment period data had a median value of 34.9µS/cm (Figure 16). There is not a significant difference over the past 3 years with the median for each deployment year, 2016, 2015 and 2014 (Table 16).

Specific conductivity changes with the varying water level. As stage increases at this site the specific conductivity decreases, this is due to the dilution of dissolved solids in the water column. Then, as stage decreases, specific conductivity increases as the concentration of dissolved solids increases. Specific conductivity is increasing throughout the entire deployment season with periodic short decreases. The general trend corresponds with the decreasing stage level.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

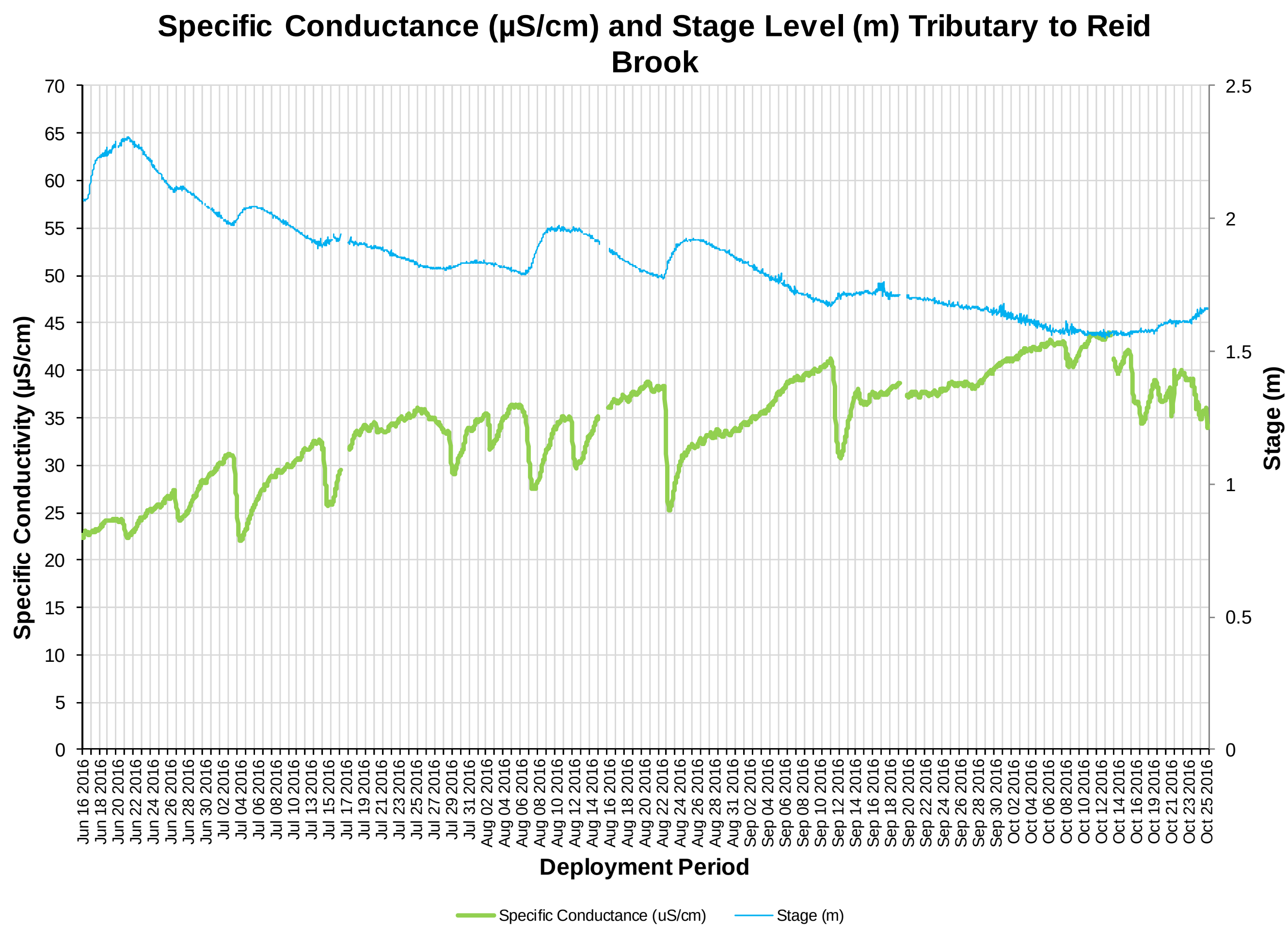

Figure 16: Specific conductivity and stage level at Tributary to Reid Brook

Table 16: Comparisons of Minimum, Maximum and Median from the past three deployment years

Specific Conductivity	2016	2015	2014
Min	22.1	16.6	18.4
Max	44	41.4	42.6
Median	34.9	32.2	32.2

Tributary to Reid Brook deployment season had dissolved oxygen content that ranged between a minimum of 9.29mg/l and a maximum of 14.21mg/l, with a median value of 11.01mg/l (Table 17). The saturation of dissolved oxygen ranged from 92.8% to 100.4%, with a median value of 96.9% (Figure 17).

Dissolved oxygen concentrations were lower in the early summer months of June and July as the water temperatures are increasing. Highs in water temperature result in less dissolved oxygen present in the brook. With the change in the water temperature at the end of August and into September the dissolved oxygen also responds by increasing.

Outside of a dip in dissolved oxygen concentration on July 17th to July 19th, 2016 the dissolved oxygen values were above the CCME Guideline for the Early Life Stages (9.5mg/l). The dip below the guideline corresponds with an increase in water temperature for the same time frame.

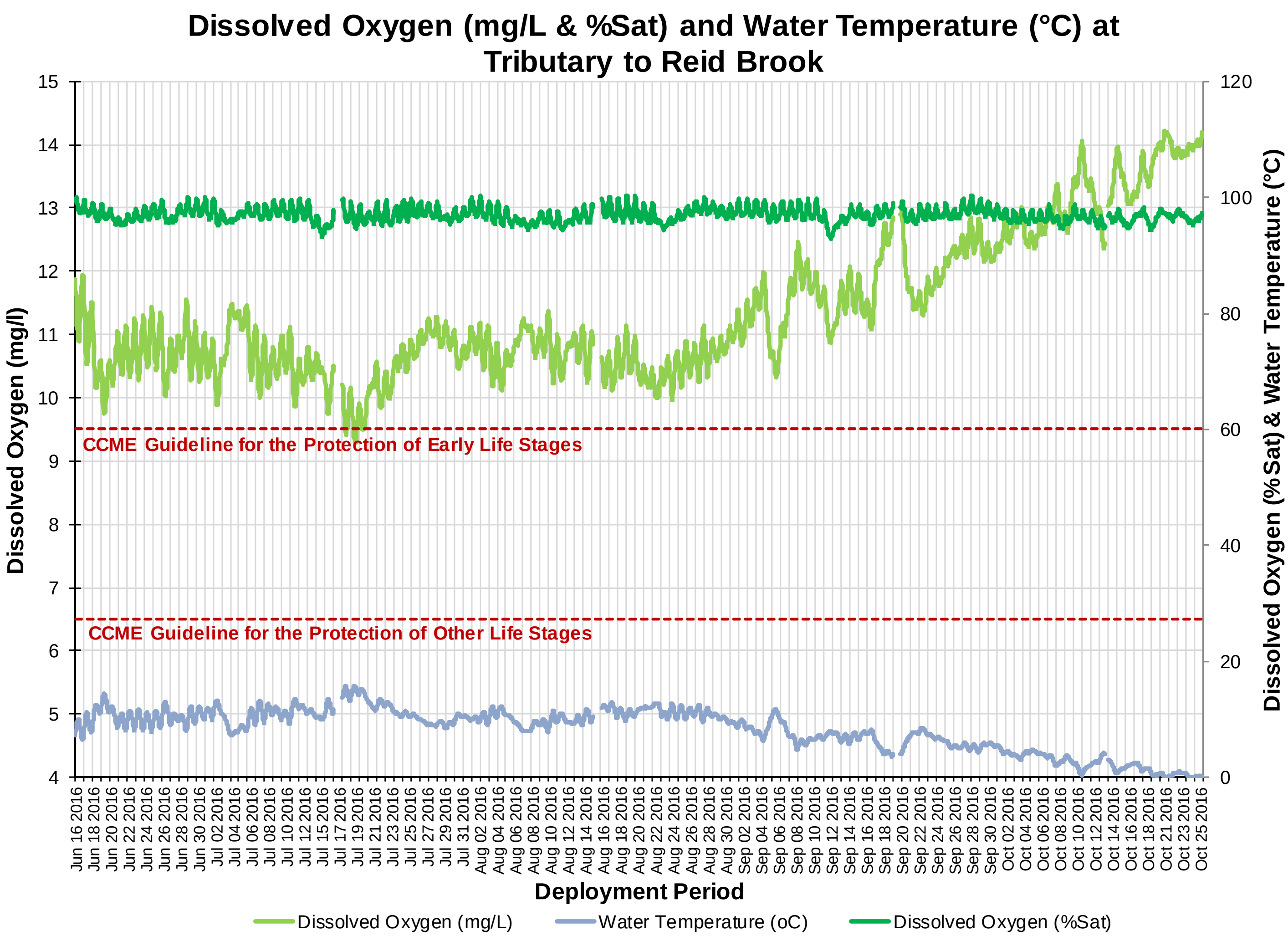

Figure17: Dissolved oxygen (mg/l & %Sat) and Water Temperature at Tributary to Reid Brook

Table 17: Comparisons of DO (mg/L) Minimum, Maximum and Median from the past three deployment years

Dissolved Oxygen (mg/l)	2016	2015	2014
Min	9.29	9.63	8.99
Max	14.21	12.65	14.12
Median	11.01	11.05	10.88

Tributary to Reid Brook station had turbidity data that ranged within a minimum of 0.0NTU to a maximum of 100.2NTU during the 2016 deployment season (Figure 18). This data had a median value of 0.0NTU. Across the 3 years noted in Table 18, the deployment medians for 2016, 2015 and 2014 were all 0.0 NTU indicating that there is little to no significant turbidity events at this site.

Many of the turbidity increases corresponded with rainfall and subsequent runoff. The events that were captured were generally low in magnitude and short in duration. It is not uncommon to see turbidity fluctuate in a brook relating to environmental factors, such as changes in stage level, flow rates and precipitation. During the data grooming process it was identified that the turbidity data at Tributary to Reid Brook was not representing the brook from October 16th 2016 to October 25th, 2016. This data was removed and not used in the statistical analysis in this report.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

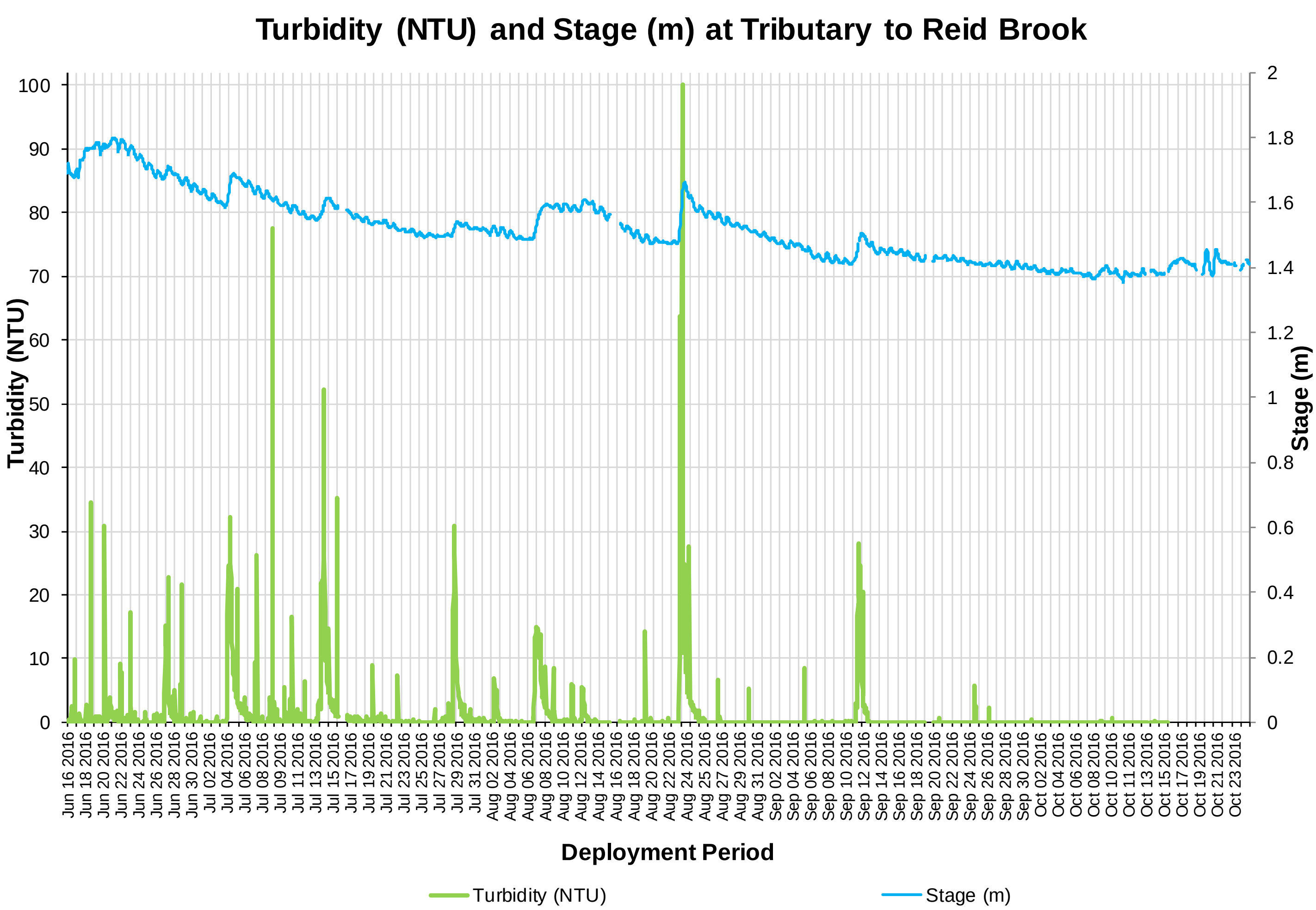

Figure 18: Turbidity and Stage level at Tributary to Reid Brook

Table 18: Comparisons of Minimum, Maximum and Median from the past three deployment years

Turbidity	2016	2015	2014
Min	0.0	0.0	0.0
Max	100.2	738	125.3
Median	0.0	0.0	0.0

Reid Brook below Tributary

During the deployment season the water temperature ranged between a minimum of 0.19°C to a maximum of 17.34°C. This station had a median of 9.52°C which was slightly higher than 2015 median of 9.39°C (Table 19).

This site had several peaks in water temperature, some of the higher temperatures corresponded with higher air temperature occurring during those days. The majority of the higher water temperatures were occurring in July and August, while at the end of August the temperatures started to decline almost immediately as the climate changed into fall and winter seasons (Figure 19).

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

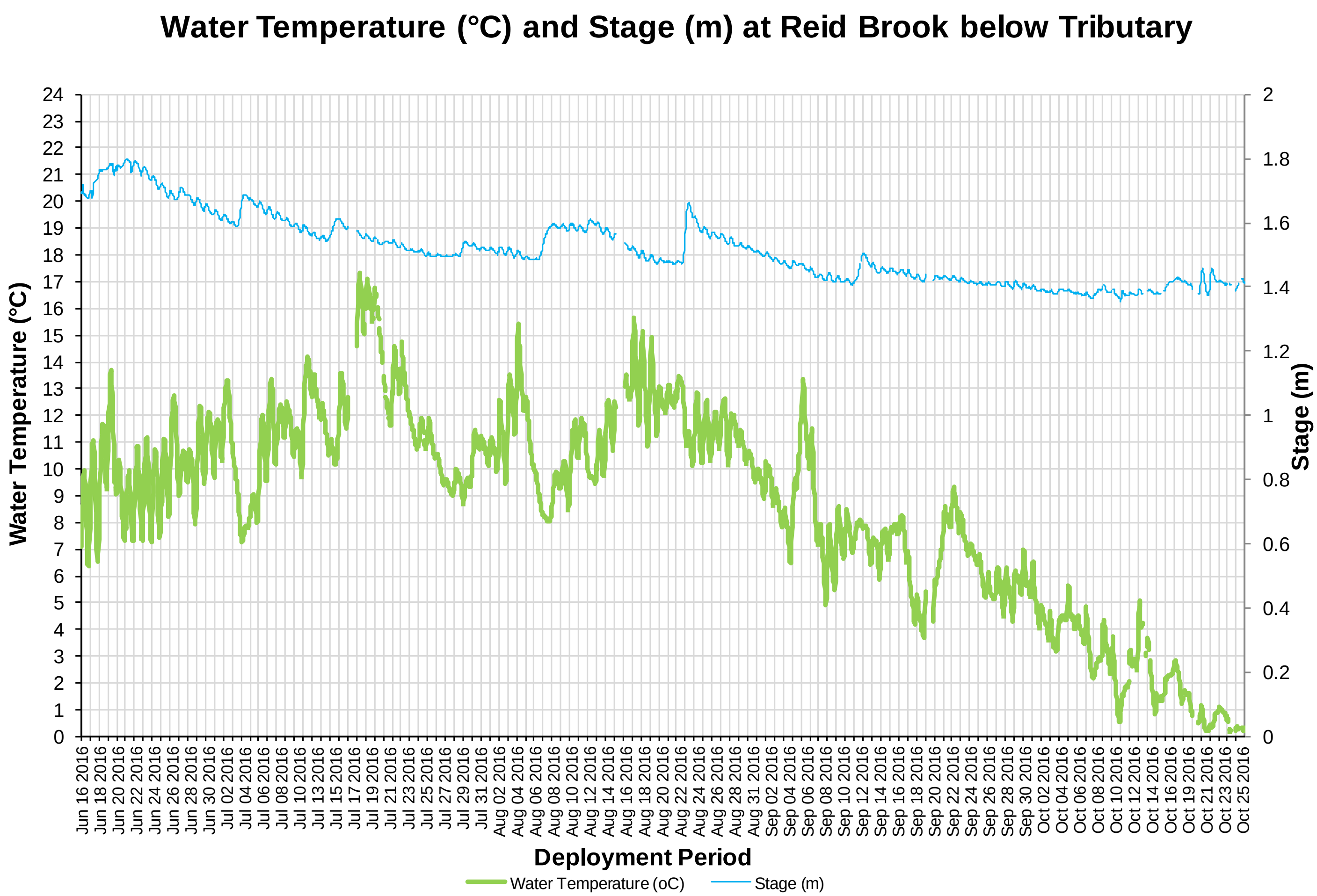

Figure 19: Water temperature at Reid Brook below Tributary

Table 19: Comparisons of Minimum, Maximum and Median from the past three deployment years

Water Temperature	2016	2015	2014
Min	0.19	0.16	0.15
Max	17.34	16.11	19.44
Median	9.52	9.39	9.39

Water temperature values show a close relationship with air temperatures (Figure 20). Increases and decreases in air temperatures are reflected in water temperatures. Air temperatures clearly fluctuate at a greater scale each day when compared with water temperatures.

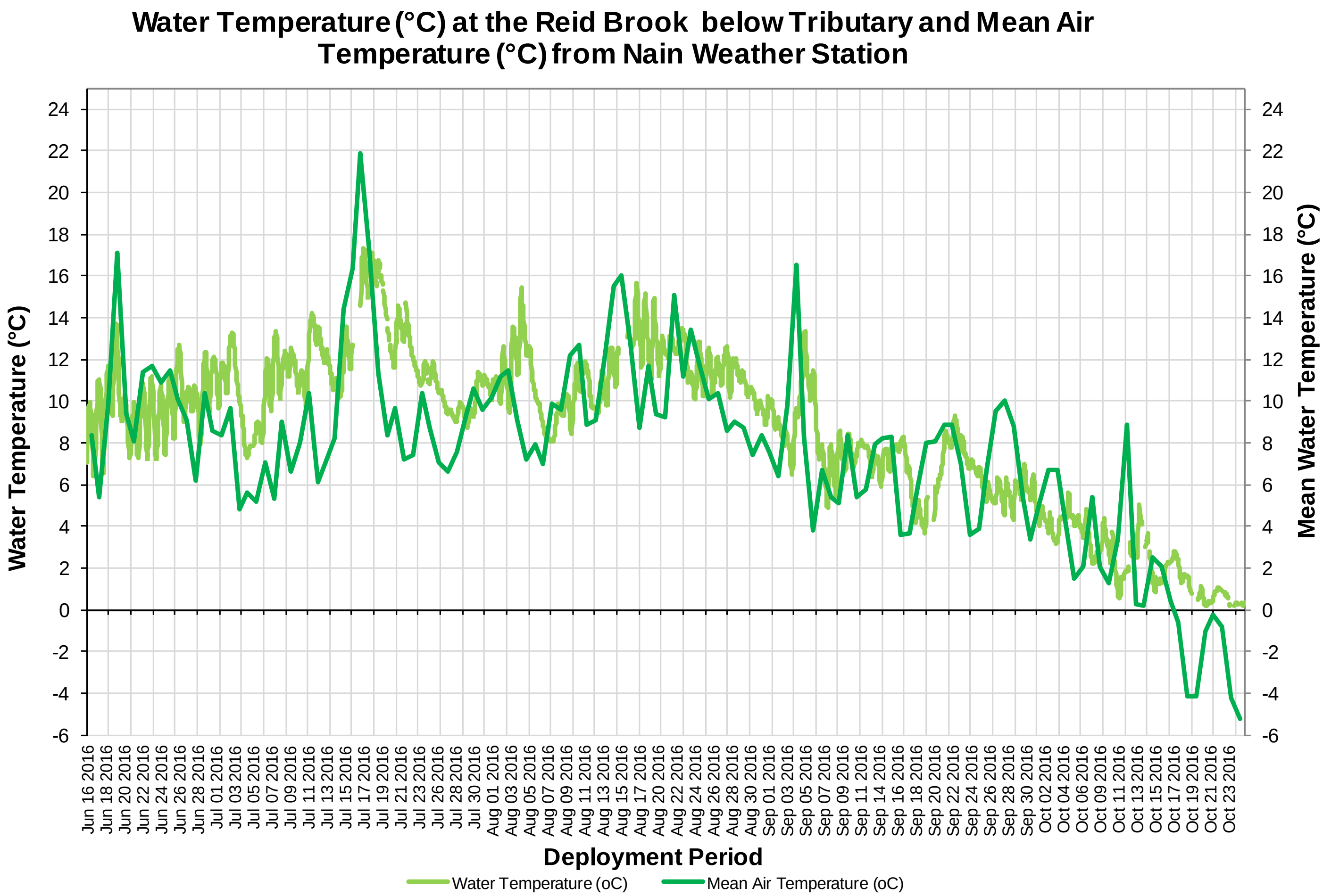

Figure 20: Water temperatures at Reid Brook below Tributary and Average Daily Air Temperatures at Nain Weather Station

At Reid Brook below Tributary the pH data during the deployment season ranged between a minimum of 6.31 to a maximum of 7.58 pH units during the deployment season, with a median value of 6.72 pH units (Table 20).

Most of the values were just within the recommended range for pH as suggested by the CCME Guidelines for the Protection of Aquatic Life (>6.5 and <9.0 pH units). The pH data for the deployment period of August 16 to September 19, 2019 the pH values were slightly higher than the other deployments. This could be a result of a change in stage level (Figure 21).

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

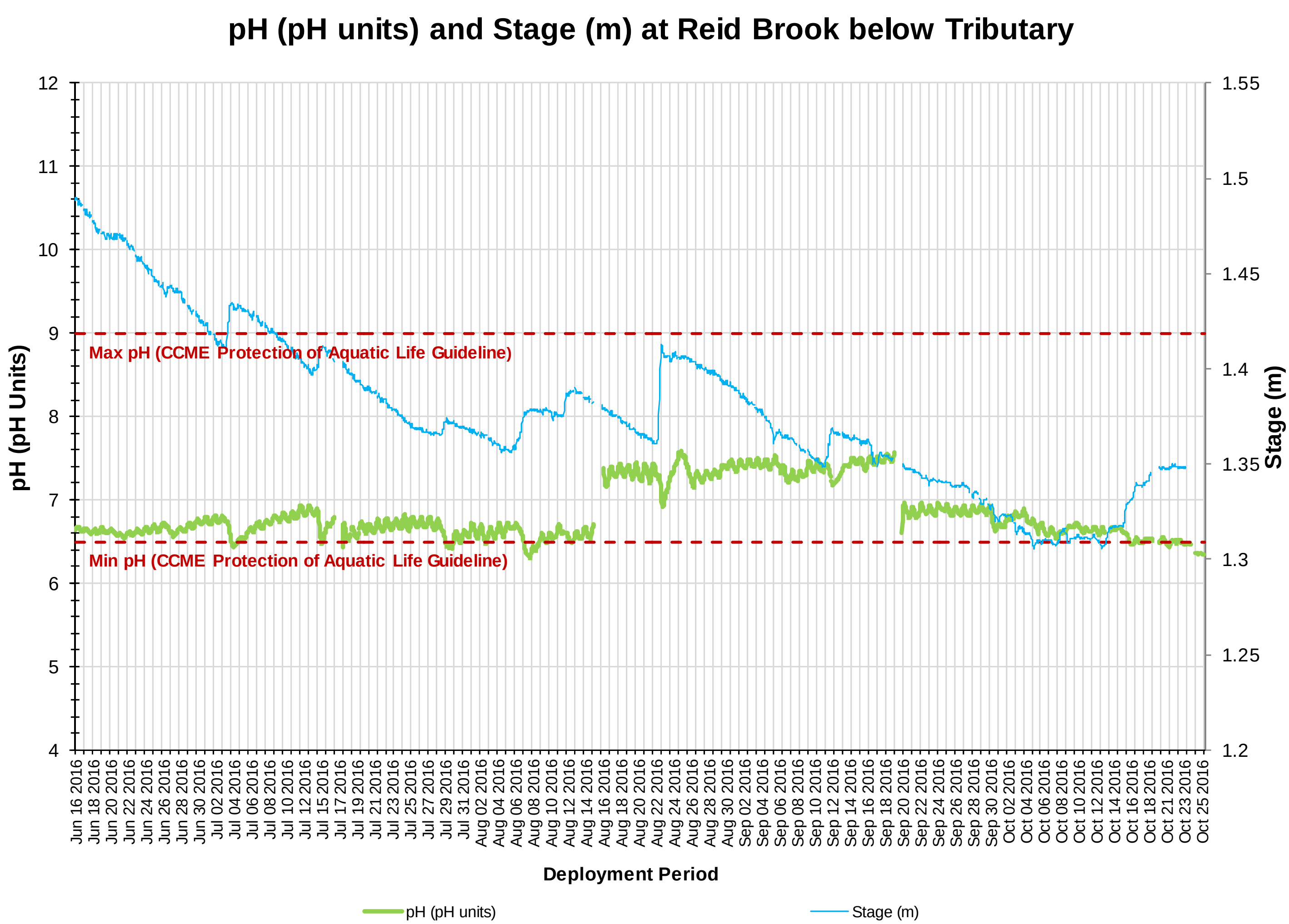

Figure 21: pH and stage level at Reid Brook below Tributary

Table 20: Comparisons of Minimum, Maximum and Median from the past three deployment years

pH	2016	2015	2014
Min	6.31	5.79	6.07
Max	7.58	9.8	7.42
Median	6.72	6.89	6.77

The specific conductivity data ranged between a minimum of 18.5µS/cm to a maximum of 44.9µS/cm during the deployment season. The specific conductivity data had a median of 32.2µS/cm which was just slightly higher than 2015 deployment season which had a median value of 28.9µS/cm (Table 21).

Over the deployment period the conductivity increased gradually, generally, specific conductivity levels do change with the varying water level. During the stage level increases at this station the specific conductivity decreased for short period of times. Increases in stage level dilute the dissolved solids in the water column reducing the conductivity. Inversely, as stage decreased, specific conductivity increased as the concentration of dissolved solids rose (Figure 22).

Specific conductivity values generally increase throughout the entire deployment season. The relationship between stage level and specific conductivity values was evident throughout the entire deployment season. Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

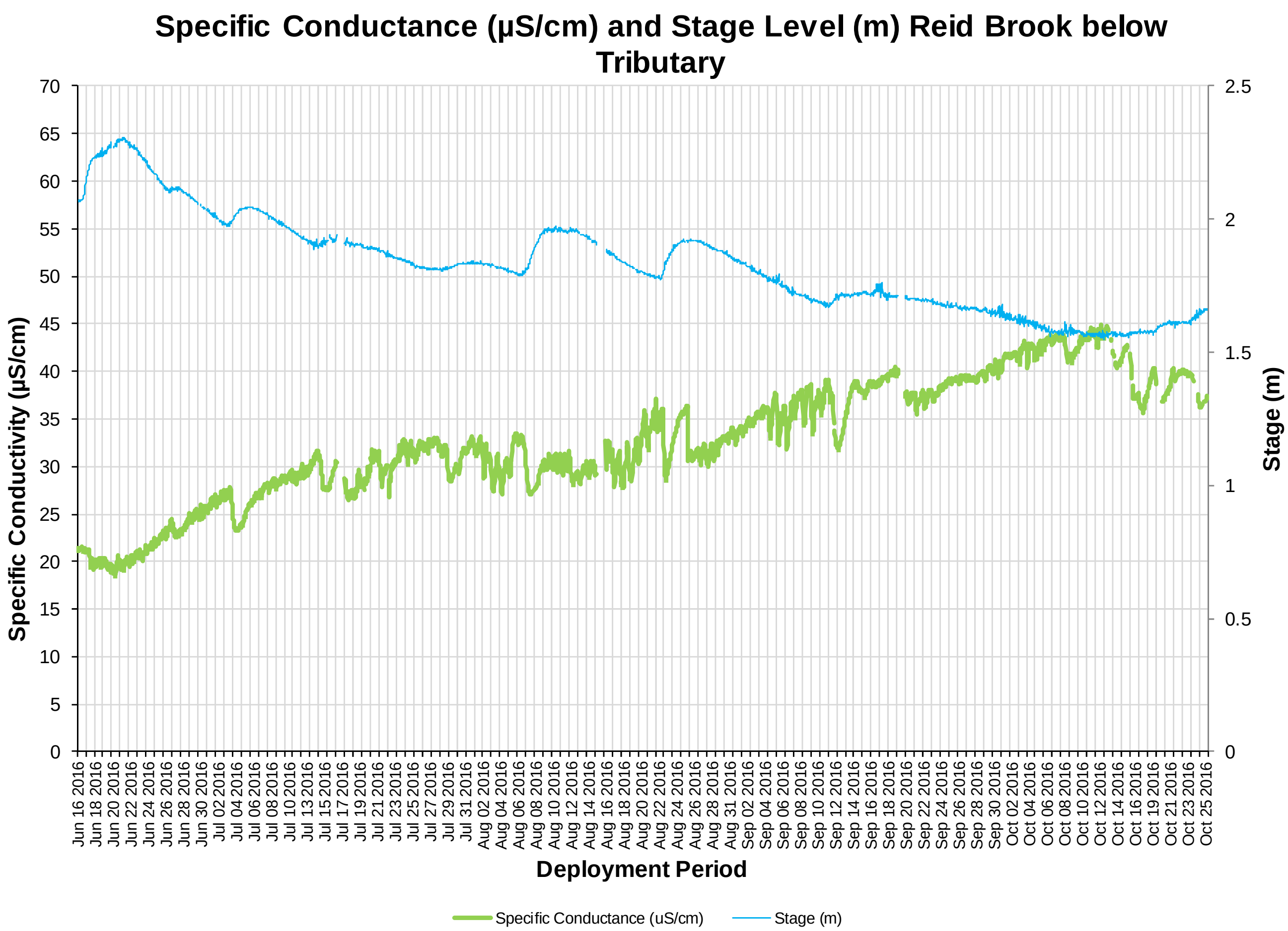

Figure 22: Specific conductivity and stage level at Reid Brook below Tributary

Table 21: Comparisons of Minimum, Maximum and Median from the past three deployment years

Specific Conductivity	2016	2015	2014
Min	18.5	15.7	15.1
Max	44.9	38.5	41.5
Median	32.2	28.9	31.7

The dissolved oxygen content at Reid Brook below Tributary ranged between 9.1mg/l to 13.88mg/l, with a median value of 10.9mg/l during this deployment season. The saturation of dissolved oxygen ranged within 91.6% to 103.9%, with a median value of 96.1% (Table 22).

Dissolved oxygen content indicated a typical seasonal trend, inverse to water temperature. Dissolved oxygen content was lower throughout the latter half of June and the month of July reaching a seasonal low in late July. As water temperatures decrease in the late summer and early fall, dissolved oxygen content begins to increase (Figure 23).

All the dissolved oxygen concentration values were above the minimum CCME Guideline for the Protection of Other Life Stages (6.5mg/l). During warmer temperature the dissolved oxygen did drop below the Guideline for the Protection of Early Life Stages (9.5mg/L) on July 17th to July 21st for a brief period of time.

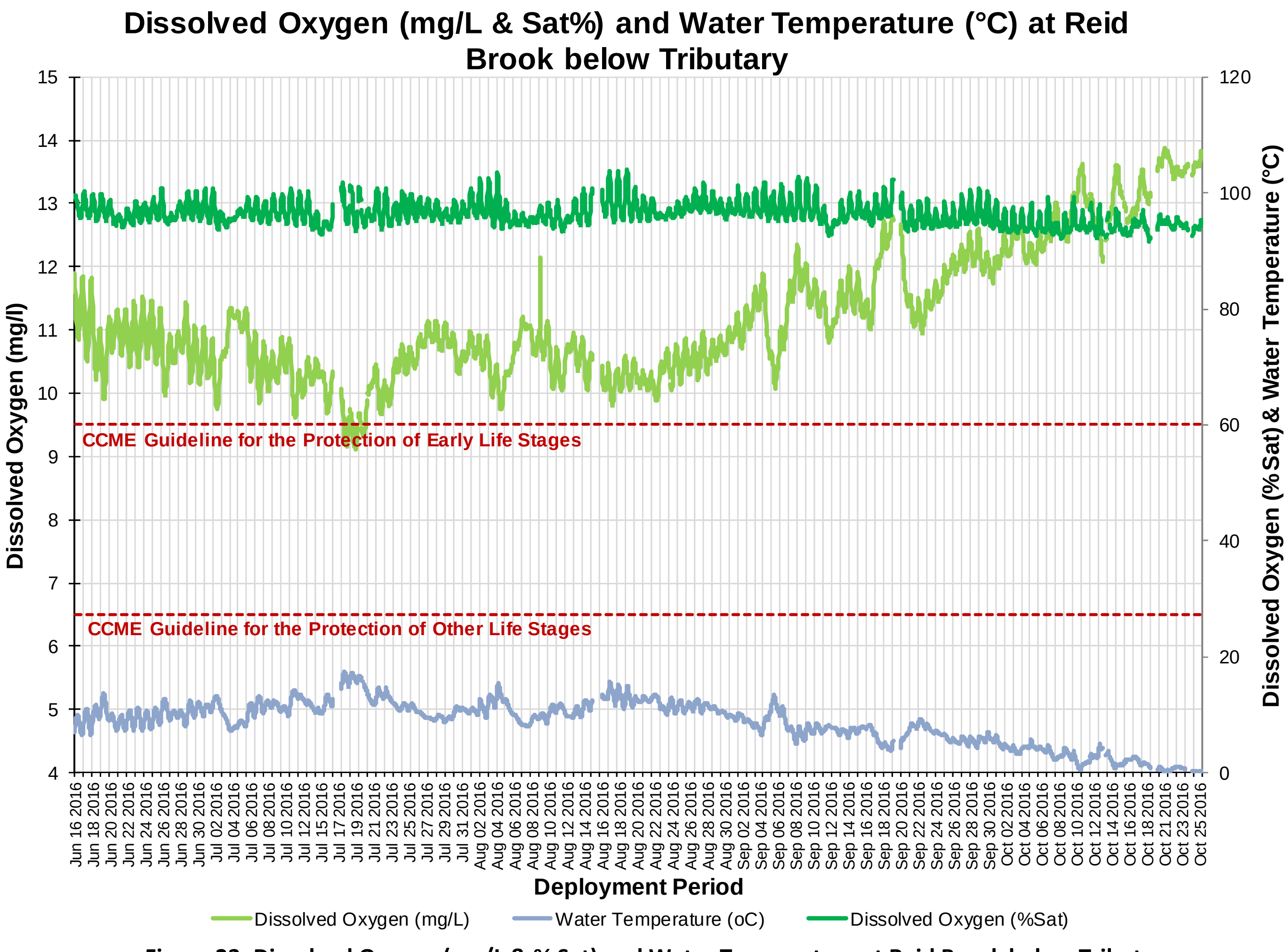

Figure 23: Dissolved Oxygen (mg/L & % Sat) and Water Temperature at Reid Brook below Tributary

Table 22: Comparisons of Minimum, Maximum and Median from the past three deployment years

Dissolved Oxygen (mg/l)	2016	2015	2014
Min	9.1	9.36	8.91
Max	13.88	14.25	13.93
Median	10.90	11.00	10.70

The turbidity data at Reid Brook below Tributary ranged between a minimum of 0.0NTU and a maximum of 64.5NTU during the 2016 deployment season (Figure 24). This data set had a median value of 0.0NTU which indicated that there was little to no natural turbidity present at this station. The maximum turbidity value of 64.5 NTU was recorded during an increase in stage level, likely a result of rainfall which influenced the amount of suspended particles in the brook for that time frame (Table 23).

Reid Brook below Tributary had turbidity data that indicated that there was debris blocking the sensor. Therefore the turbidity data from July 2nd 2016 through to July 16th 2016 and August 7th to August 15th, 2016 was removed from the analysis as it did not represent the brook (Figure 24).

Over the course of the deployment the turbidity spikes corresponded with increases in stage level. It is to be expected to see an increase in turbidity during an increase in stage. Shortly after each event the data returned to a lower value, this would be expected at this site as the background turbidity is very low.

Please note the stage data on the graph below, is raw data. It has not been corrected for backwater effect. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

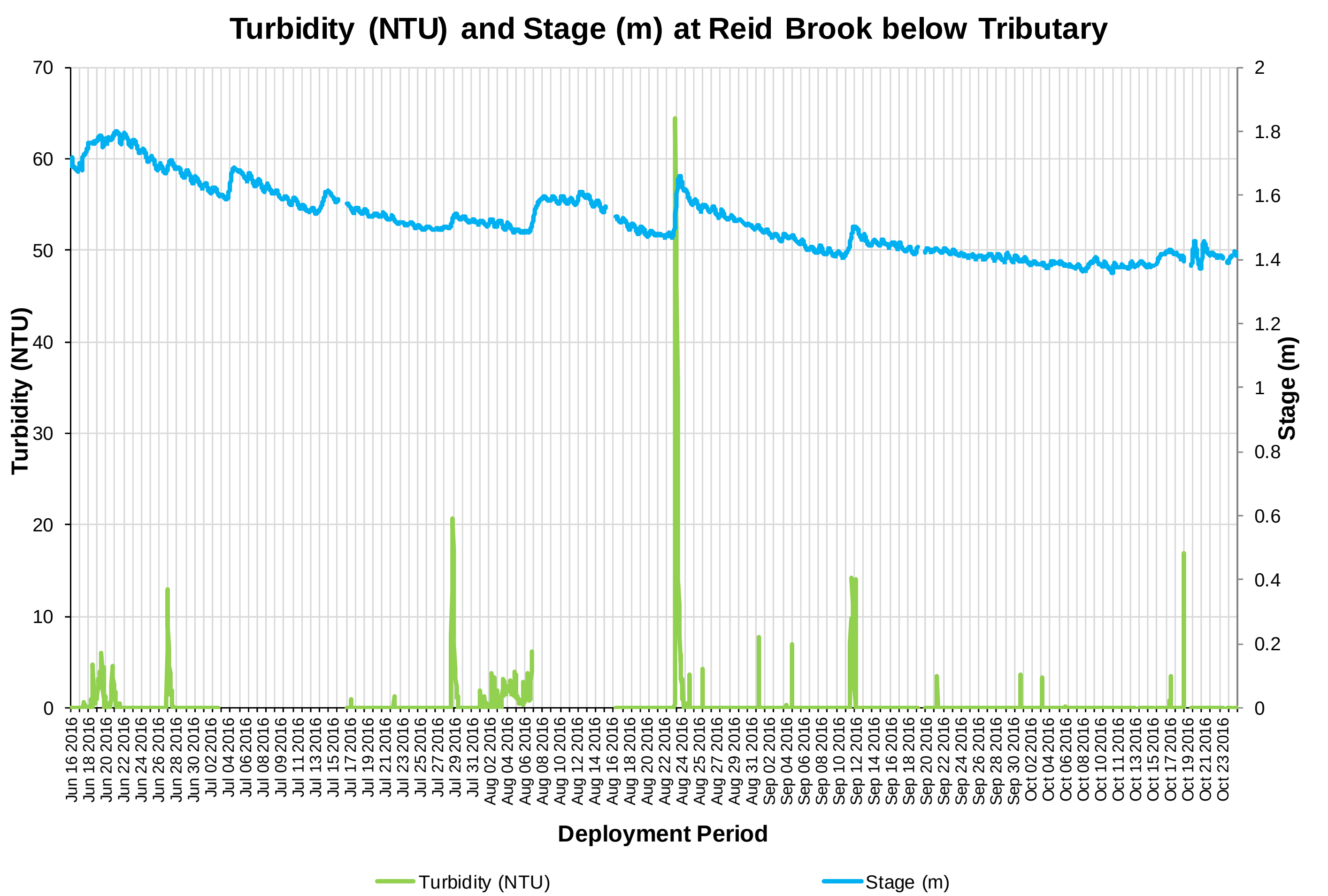

Figure 24: Turbidity and Stage Level at Reid Brook below Tributary

Table 23: Comparisons of Minimum, Maximum and Median from the past three deployment years

Turbidity	2016	2015	2014
Min	0.0	0.0	0.0
Max	64.5	705	48.1
Median	0.0	0.0	0.0

Multi-Station Comparison

This section of the 2016 annual report focuses on the comparisons between the four real-time stations.

Temperature

Water temperature trends at each of the four stations are comparable with one another (Figure 25). There is clear seasonal trend at all stations with water temperatures. Water temperatures at Camp Pond Brook, Reid Brook below Tributary and Tributary to Reid Brook peak around July 16th to July 20th, Camp Pond Brook water temperatures are close to that of the air temperatures recorded in Nain. Reid Brook at outlet of Reid Pond is slower to respond to the air temperatures however this is to be expected in a pond environment as the larger volume of water takes longer to acclimatize. Water temperatures start to decrease toward the end of August and again Reid Brook below Reid Pond decreases the slowest out of the four stations.

Tributary to Reid Brook and Reid Brook below Tributary have very similar water temperature data. This is to be expected as the Tributary to Reid Brook station directly flows into Reid Brook below Tributary. Both are fast flowing sites with similar environmental influences. Camp Pond Brook stands out on the graph as having some of the larger changes in water temperatures than that of the other stations. Camp Pond Brook recorded the highest temperature in the network at 22.02°C. Camp Pond also had the highest median value for temperature at 12°C (Table 24).

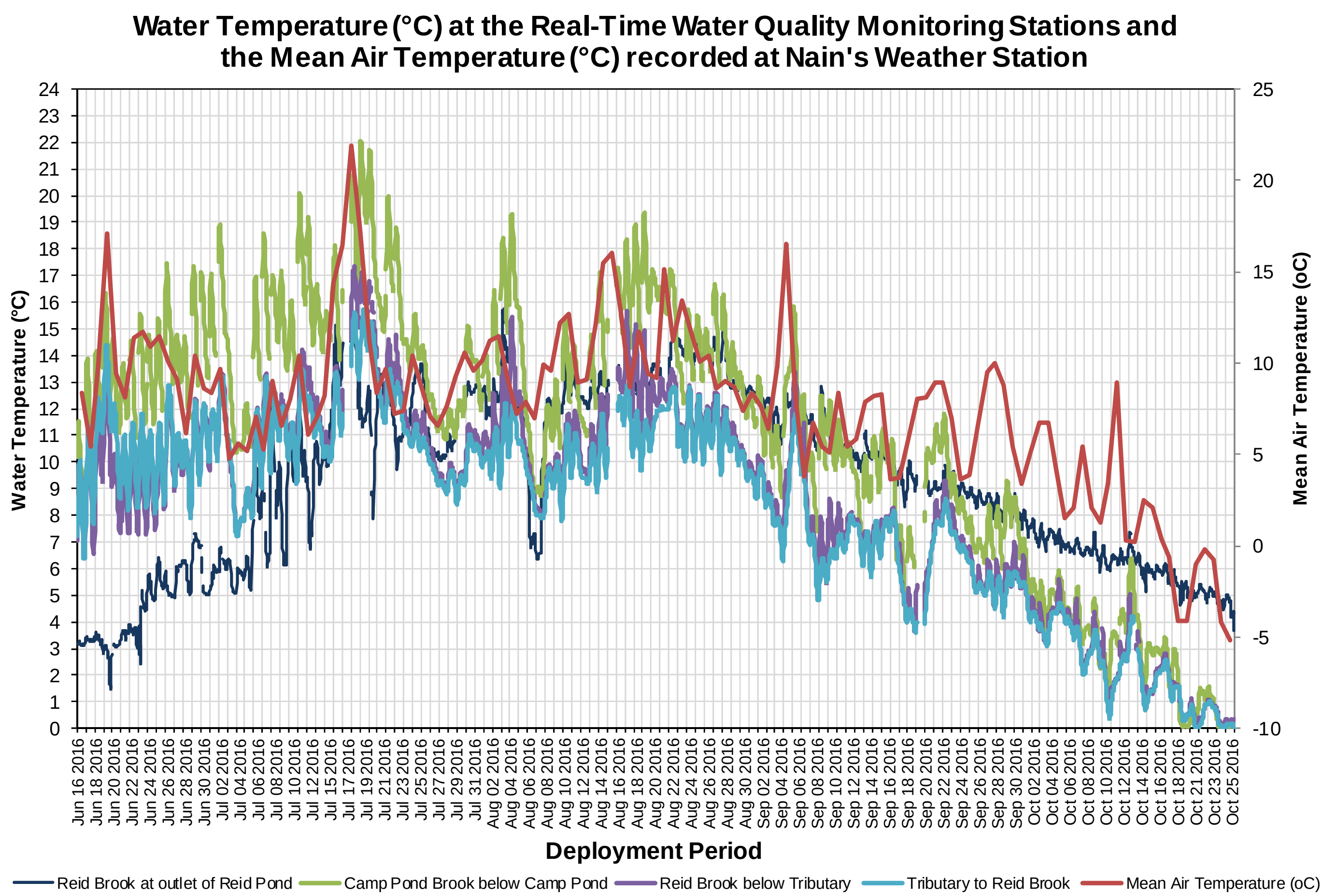

Figure 25: Water temperature at all stations

Table 24: Comparisons of Minimum, Maximum and Median from the four real-time stations

Temperature (°C)	Reid Brook	Camp Pond	Below Tributary	Tributary to Reid
Min	1.47	0.07	0.19	0.0
Max	15.77	22.02	17.34	15.7
Median	9.79	12	9.52	9.3

pH

During the 2016 deployment period the pH medians of the four Real-Time stations were within 6.08 pH units to 7.58 pH units (Table 25).

Reid Brook at Outlet of Reid Pond pH data displayed differently on the graph than the other stations. There is a lot more movement in the data at this site. This station is at the outlet of a pond and does have different factors influencing the pH than the other brook sites. Camp Pond, Reid Brook below Tributary and Tributary to Reid Brook has similar pH movements across the deployment (Figure 26).

There were several events where pH data dips down below the pH minimum CCME guideline for the Protection of Aquatic Life Guideline. When compared to the precipitation, graphed on Figure 26, there is an evident change in pH levels during the higher and longer precipitation events. The largest precipitation event on August 22nd, 2016 influenced the dip in pH at Camp Pond Brook, Reid Brook below Tributary and Tributary to Reid Brook. Reid Brook below Reid Pond responds with a slower smaller decrease.

Most of the fluctuations in the pH data across the real-time stations are responding to precipitation events.

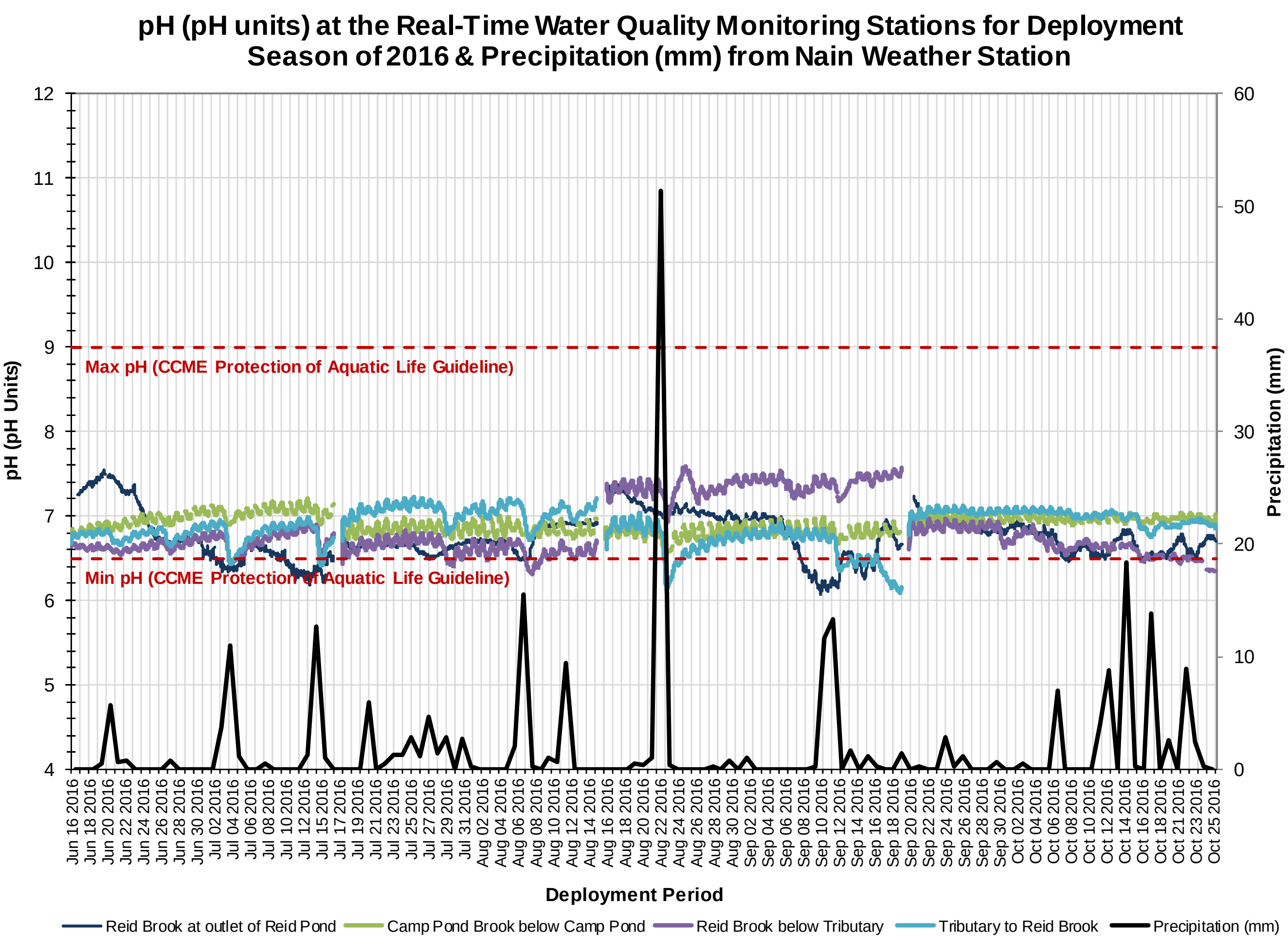

Figure 26: pH at all stations

Table 25: Comparisons of Minimum, Maximum and Median from the four real-time stations

pH (units)	Reid Brook	Camp Pond	Below Tributary	Tributary to Reid
Min	6.08	6.54	6.31	6.08
Max	7.54	7.2	7.58	7.22
Median	6.71	6.92	6.72	6.89

Specific Conductivity

Specific conductivity levels across all four stations ranged within a minimum of 9.1 µS/cm and a maximum of 64 µS/cm. Reid Brook below Reid Pond had the lowest minimum conductivity at 9.1 µS/cm and Camp Pond Brook below Camp Pond had the highest maximum at 64 µS/cm (Table 26).

Reid Brook below Reid Pond maintains a steady conductivity level to be expected in a stable pond environment. Reid Brook below Tributary and Tributary to Reid Brook had similar conductivity. Camp Pond Brook below Camp Pond displayed a reverse response than the other sites. Although this association is not typically expected, this is the relationship most often seen at this station. Specific conductivity is also on average higher at this station than at the other stations in the network (Figure 27).

Reid Brook below Tributary, Tributary to Reid Brook and Camp Pond Brook all display increasing conductivity levels across the deployment. This would be expected as the stage levels decrease and the suspended solids increase in the water column. Median values for specific conductivity for these three stations are 38.2 µS/cm, 34.9 µS/cm and 32.2 µS/cm, respectively. As Reid Brook below Reid Pond is a steadier water quality environment the conductivity data remained reasonably consistent across the deployment.

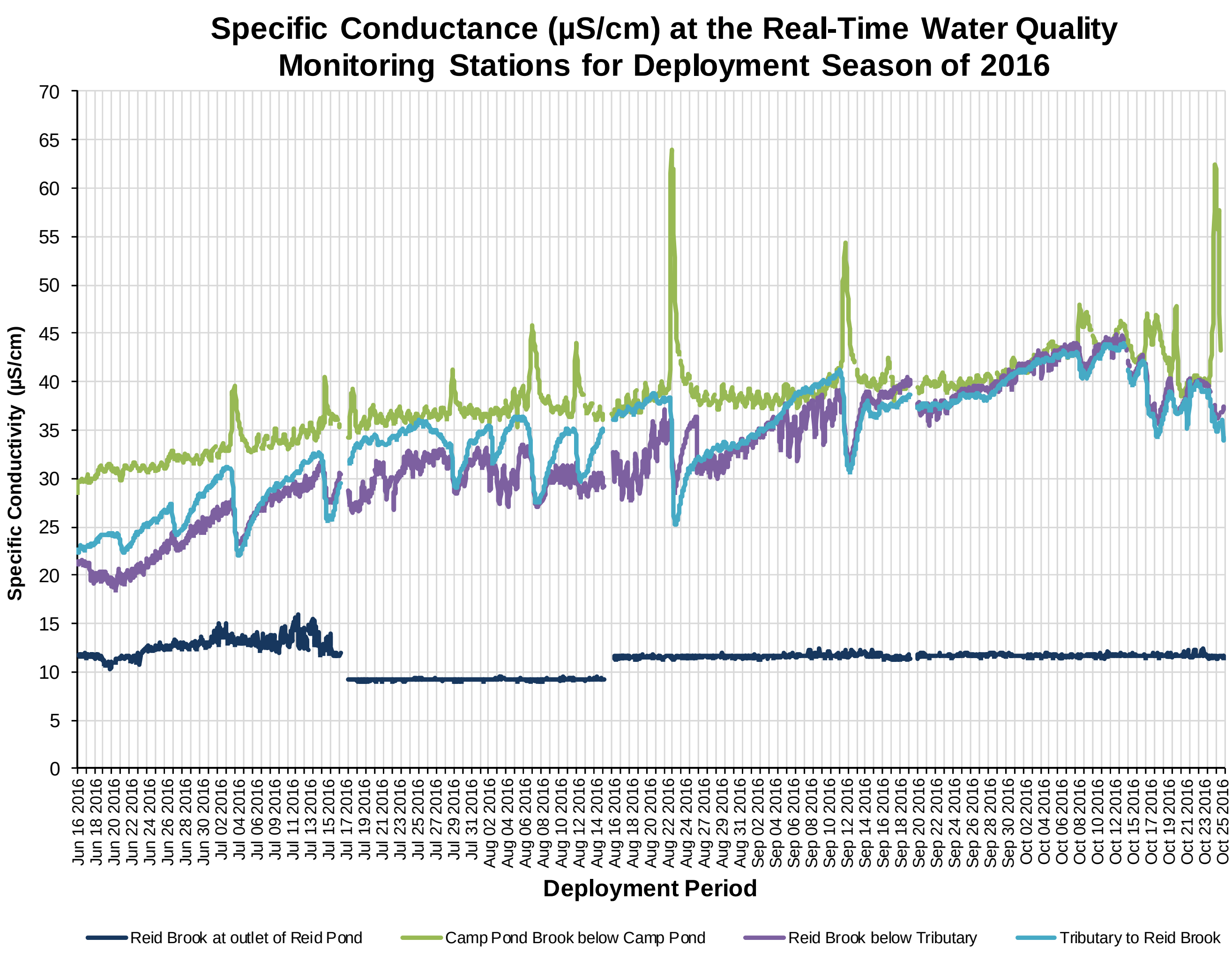

Figure 27: Specific Conductivity at all stations

Table 26: Comparisons of Minimum, Maximum and Median from the four real-time stations

Specific Conductivity	Reid Brook	Camp Pond	Below Tributary	Tributary to Reid
Min	9.1	28.7	18.5	22.1
Max	15.9	64.0	44.9	44.0
Median	11.6	38.2	32.2	34.9

Dissolved Oxygen (mg/L) and Dissolved Oxygen (% Saturation)

Dissolved oxygen concentration ranged within a minimum of 8.22 mg/L to a maximum of 14.21 mg/L across all four stations for 2016 deployment (Table 27). Dissolved oxygen (mg/L) content showed a typical inverse relationship with water temperature at all stations. Air temperature levels from the Nain weather station are included on the graph to demonstrate the relationship with dissolved oxygen mg/L. The most stable dissolved oxygen levels were at Reid Brook below Reid Pond. There was greater fluctuation in levels at the three other Real-Time stations (Figure 28a).

During the high air temperatures on July 15th to July 17th, dissolved oxygen levels (mg/L) at all stations dipped below the CCME guideline of 9.5mg/L for the Protection of Early Life Stages (Figure 28a) for a short period of time. However the dissolved oxygen concentration (mg/L) remained above the CCME Guideline for the Protection of Aquatic Life at Early Life Stages (6.5mg/l) for the entire deployment of 2016.

These changes in dissolved oxygen are not unusual and are to be expected during the warmer temperatures. As the deployment continues into the Fall and start of Winter seasons, the air temperatures dip and the dissolved oxygen levels start to increase.

Figure 28b displays the percent saturation in dissolved oxygen in the four real-time stations.

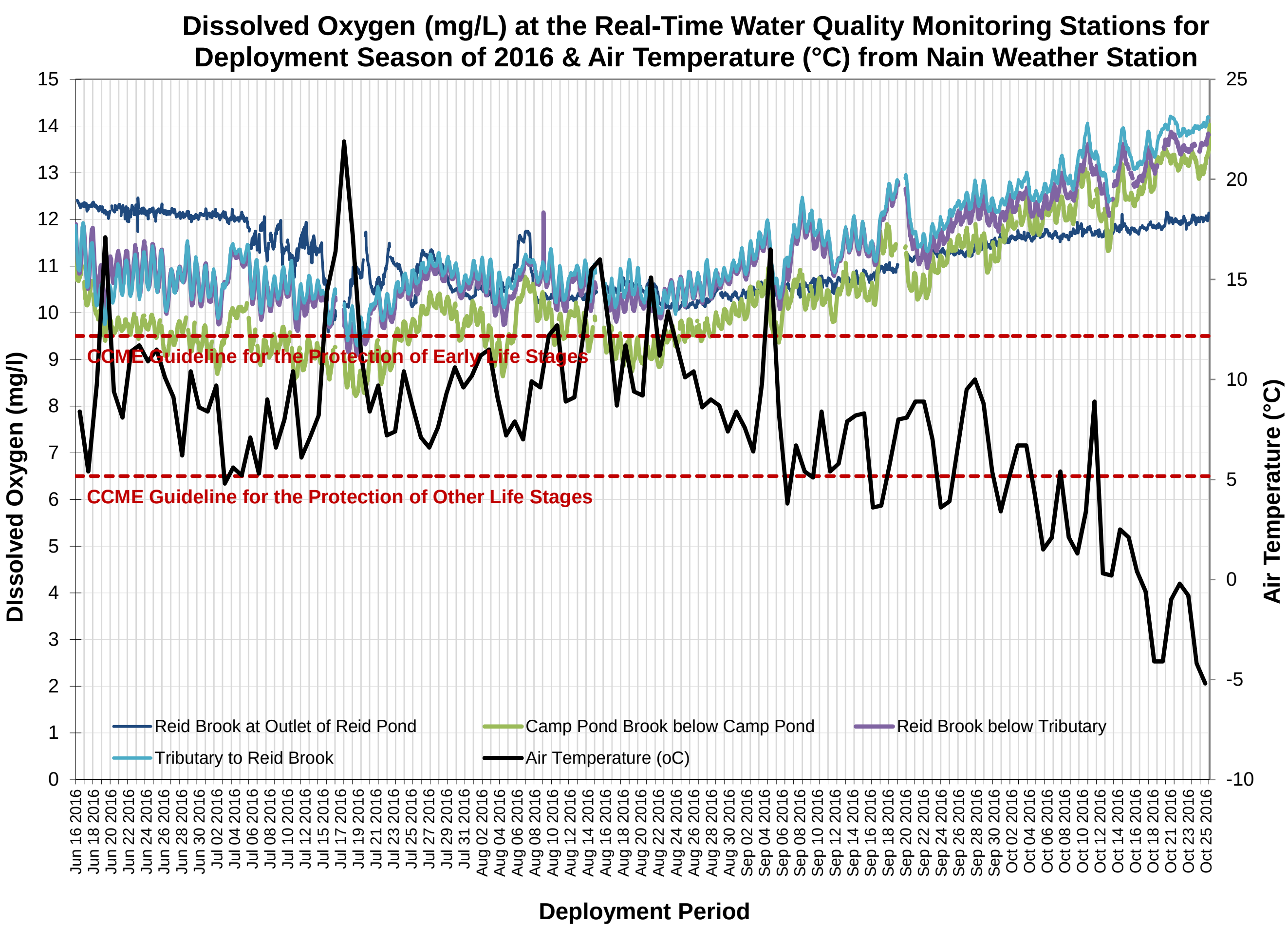

Figure 28a: Dissolved Oxygen (mg/L) at all stations

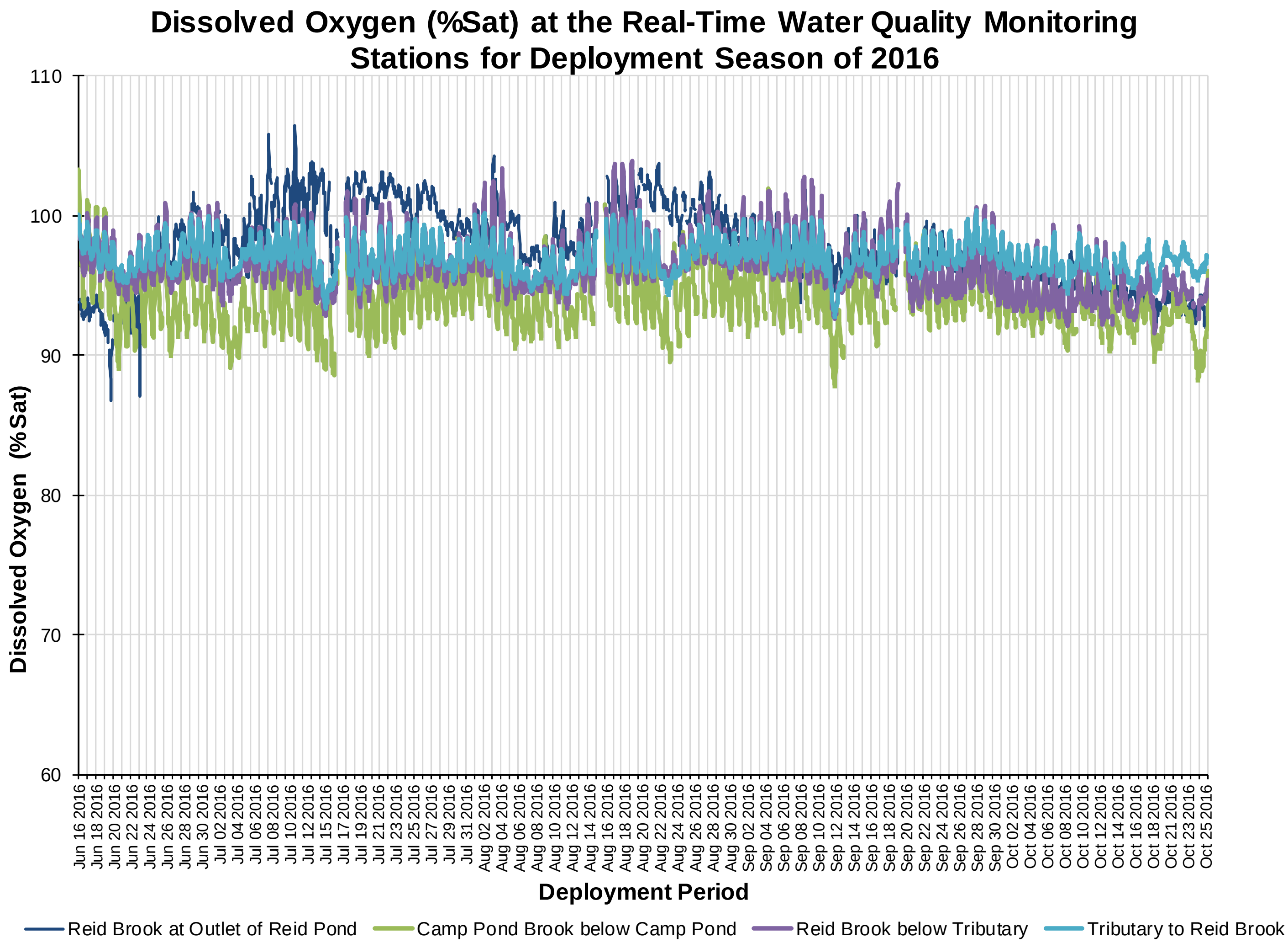

Figure 28b: Dissolved Oxygen (% Saturation) at all stations

Table 27: Comparisons of Minimum, Maximum and Median from the four real-time stations

	Dissolved Oxygen (mg/l)				Dissolved Oxygen (% Saturation)			
	Reid Brook	Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook	Reid Brook	Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	9.59	8.22	9.1	9.29	86.8	87.9	91.6	92.8
Max	12.46	14.03	13.88	14.21	106.5	103.3	103.9	100.4
Median	11.20	10	10.9	11.01	97.9	93.7	96.1	96.9

Turbidity

Turbidity data ranged within a minimum of 0.0 NTU to 100.2 NTU as the maximum recorded at Tributary to Reid Brook (Table 28). It is not unusual to see variability in turbidity data, this parameter is influenced by precipitation, runoff from surrounding environments, high water flow (bubbles) and debris, such as leaf litter. The median values calculated for the four real-time stations were 0.0 NTU this indicates that there is little to no background turbidity at these stations and turbidity events are not frequent.

Figure 29a displays all the turbidity data for the four real-time stations. Figure 29b displays the turbidity data but scales the events just to 40 NTU to portray the separate station data clearer. Figure 29c provides the turbidity data alongside the total precipitation that was recorded at the Nain weather station; there is an association between the high precipitation events and turbidity events on the graphs.

The majority of turbidity increases are at the beginning of the deployment period. This is likely a result of the ground thawing, and ice and snow melting increasing the organic matter, suspended particles and material that is carried into surrounding water bodies. The turbidity spikes cluster the month of June into early July and as the deployment continues the turbidity settles, seeming to increase only during the precipitation events (Figure 29c).

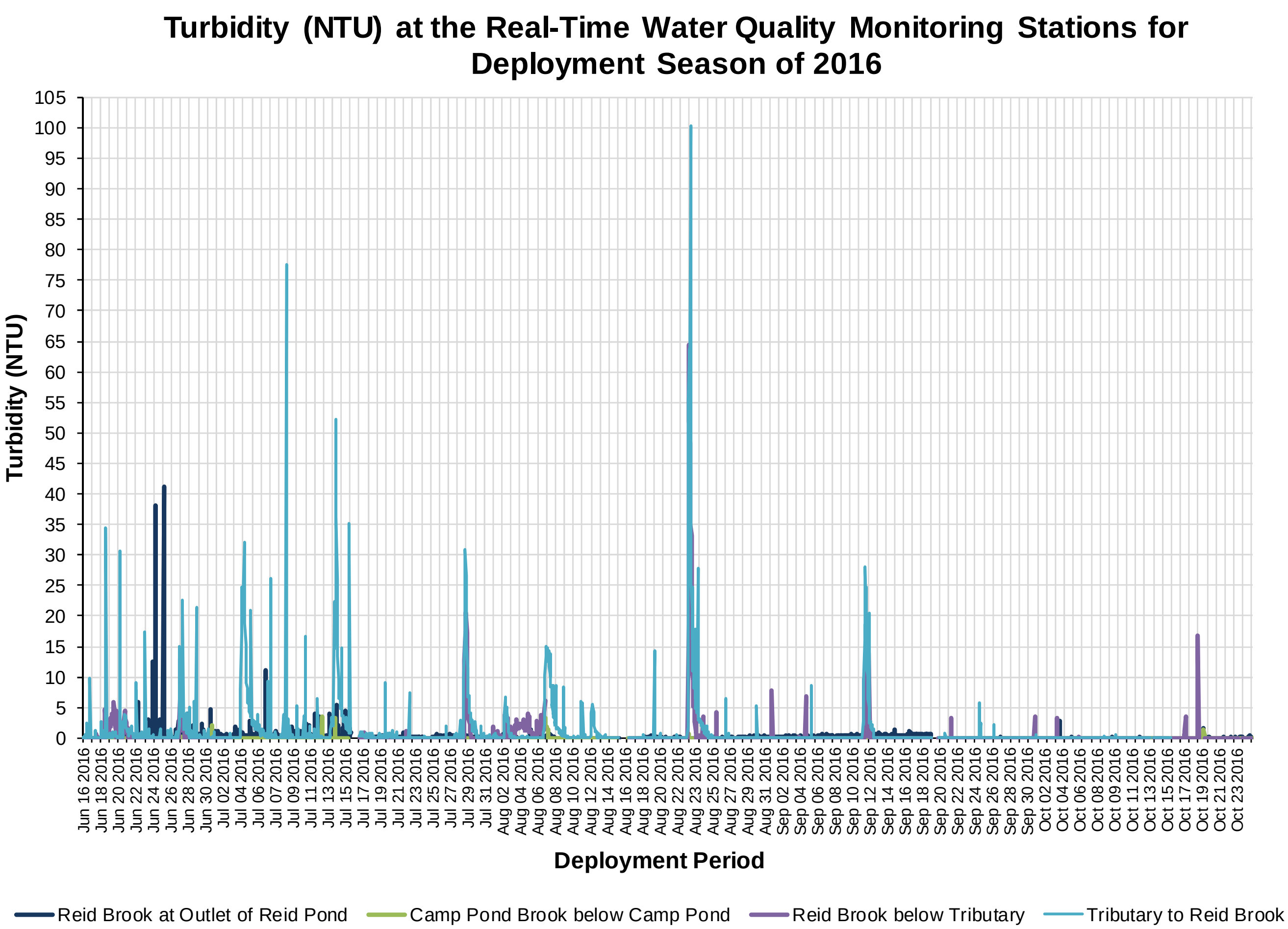

Figure 29a: Turbidity (NTU) recorded at all stations

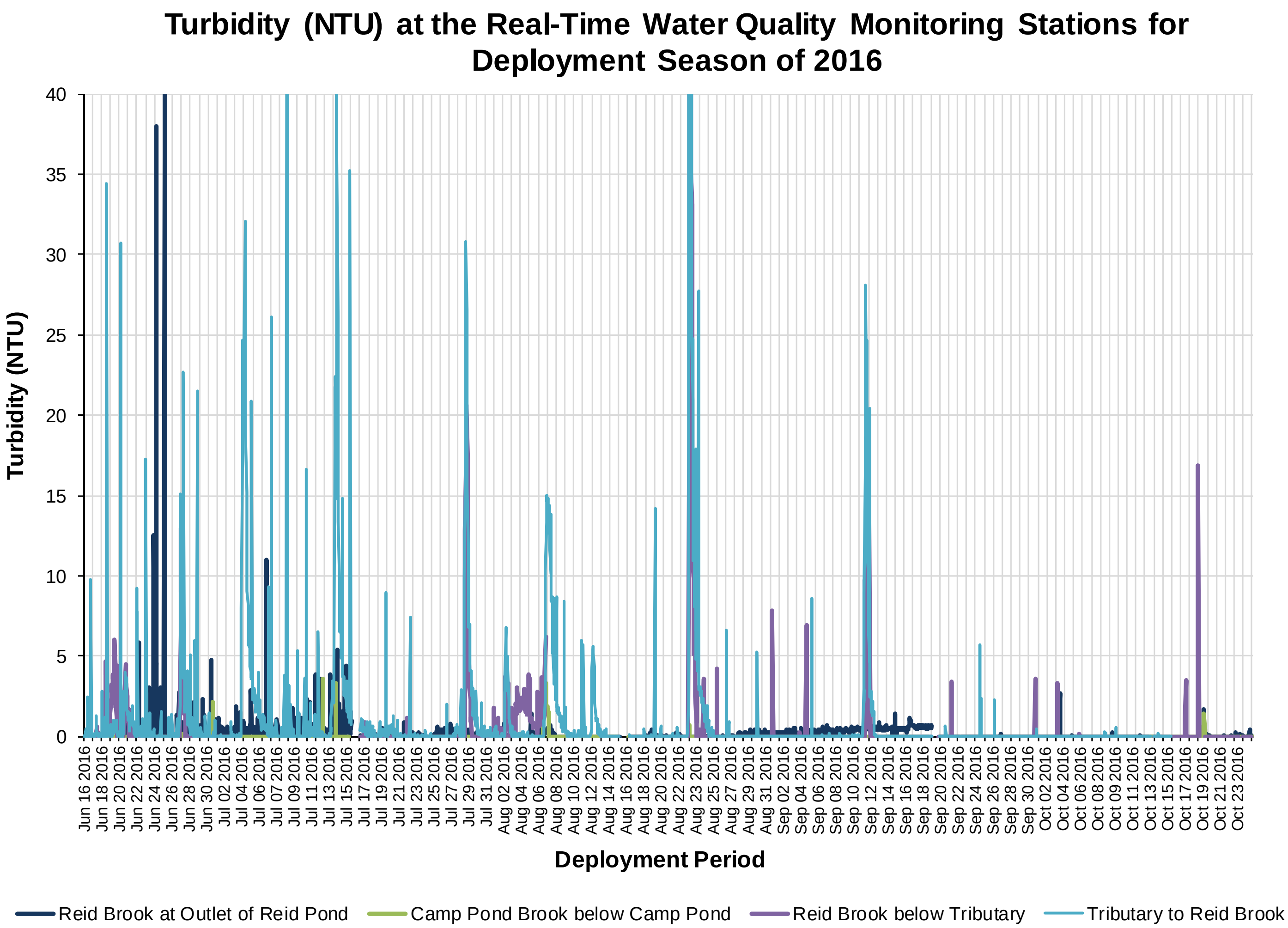

Figure 29b: Turbidity (NTU) at all stations graphed to 40 NTU

Table 28: Comparisons of Minimum, Maximum and Median from the four real-time stations

Turbidity (NTU)	Reid Brook	Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	0.0	0.0	0.0	0.0
Max	41.3	3.6	64.5	100.2
Median	0.0	0.0	0.0	0.0

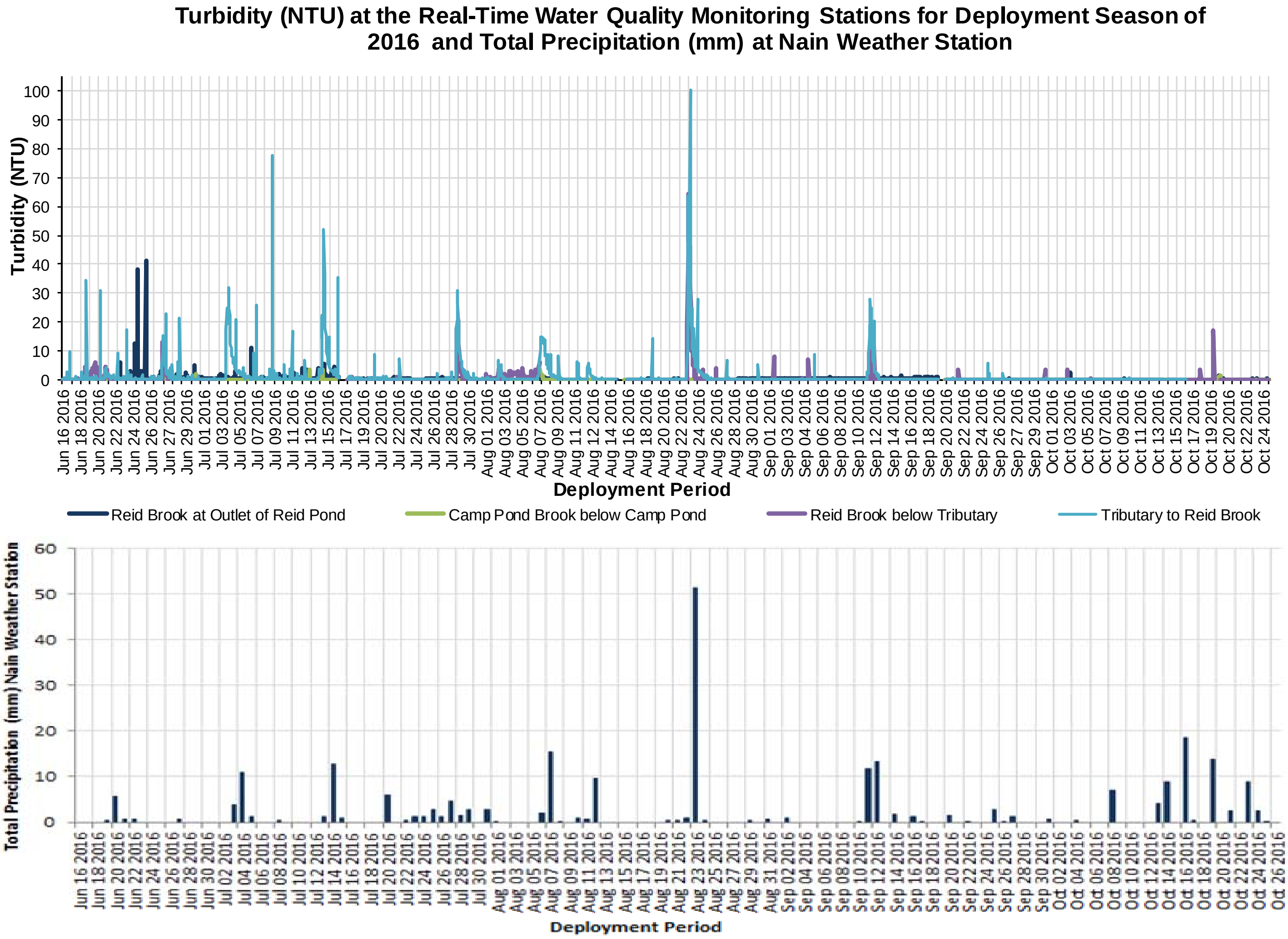

Figure 29c: Turbidity (NTU) at all stations and Total Precipitation (mm) recorded at Nain Weather Station

Stage

Please be advised that the WSC is responsible for the QAQC of water quantity data (stage and flow). Corrected data can be obtained upon request to Water Survey of Canada team. Stage data is included in this report to display the relationship with water quality parameters.

Stage starts out high at the beginning of the 2016 deployment for all stations. This is likely a result of the ground thaw and snow/ice melt from the surrounding river banks. As the season continues the stage level gradually decreases for the sites, Reid Brook at Outlet of Reid Pond, Camp Pond brook below Camp Pond and Reid Brook below Tributary. Tributary to Reid Brook maintains a more consistent stage although does react during high precipitation events (Figure 30).

Precipitation recorded at Nain weather station was included in this graph to explain several of the high stage increases over the deployment. Tributary to Reid Brook, Reid Brook below Tributary and Reid Brook at Outlet of Reid Pond have obvious responses to the precipitation that occurs. The influences of precipitation events are not as evident at Camp Pond Brook below Camp Pond and the stage increases are somewhat less significant at this station due to its vicinity to the lake.

The greatest difference in stage level of the deployment season was at Reid Brook at outlet of Reid Pond with a difference of 0.758m between its highest stage and its lowest stage for 2016.

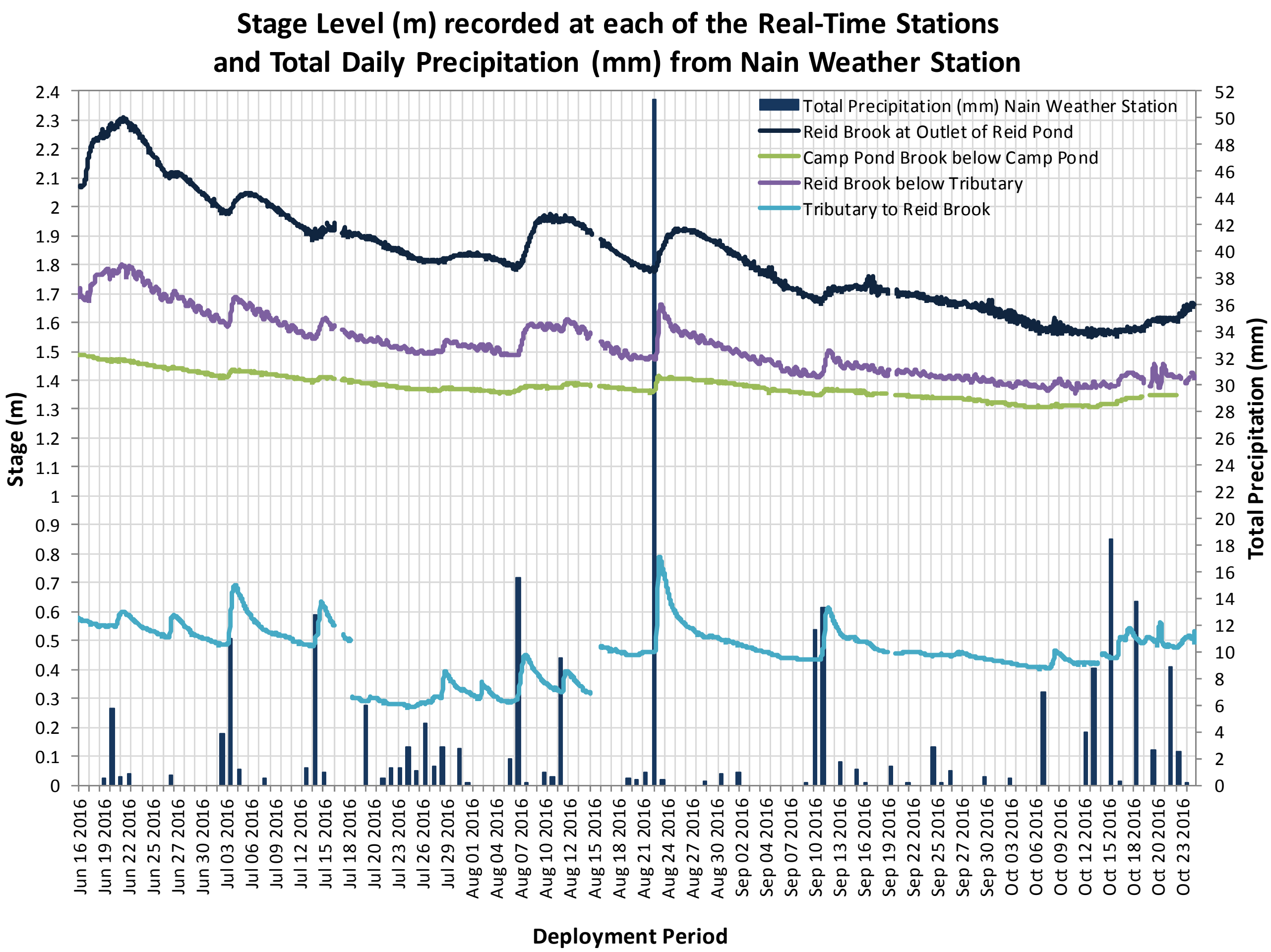

Figure 30: Stage levels at all stations

Table 29: Comparisons of Minimum, Maximum and Median from the four real-time stations

Stage (m)	Reid Brook	Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	1.55	1.306	1.356	0.268
Max	2.308	1.49	1.8	0.791
Median	1.821	1.371	1.503	0.461
Difference (Max/Min)	0.758	0.184	0.444	0.523

Conclusions

The deployment period generally consists of four months; this deployment ran from June 16th to October 25th, 2016.

Almost all changes in water quality at these four stations can be explained by precipitation events, spring thaw influences or changes in air temperature as the seasons move through summer, fall and winter.

Water temperature and dissolved oxygen are directly influenced by the typical seasonal trends, increasing or decreasing with warming and cooling air temperatures. The four real-time stations indicated such with changes in the data graphed in this report. pH levels were maintained throughout deployment, except during high stage events or precipitation events when the pH values decreased for a short period of time.

Three stations had specific conductivity levels increasing as deployment continued, except for Reid Brook below Reid Pond which being a pond is capable of maintaining a more stable conductivity. Camp Pond Brook below Camp Pond did display increases during precipitation events rather than decreases as the other sites did. However based on the proximity of this station to the mine site and roadways, it would be expected to see anthropogenic influences on this brook. The conductivity events that did occur at Camp Pond Brook below Camp Pond were short in duration and the levels returned to lower values within a short period of time.

There was a lot of movement in turbidity data, at the beginning of this deployment period, with all real-time sites. However as the deployment continued, turbidity levels settled down and the majority of turbidity increases were a result of precipitation occurring at the same time. These turbidity events that were recorded were short in duration.

The majority of the changes in water quality could be explained by natural occurring events and those changes, such as conductivity levels, that were an influence of anthropogenic events did not last long allowing the levels to return to its previous range.

Path Forward

The success of the real-time water monitoring network is largely due to the Environmental staff maintaining and monitoring the Voisey's Bay RTWQ network. This network has been improving since 2003 and continues to advance annually in background knowledge and awareness of the rivers' characteristics. The data collected is essential for identifying the difference between natural and anthropogenic events. As this agreement progresses into the 2017 deployment period for the Voisey's Bay stations, the following is a list of planned activities to be carried out in the upcoming year. The list also includes some multi-year activities planned in the previous year that are still in progress.

- In the 2017 deployment season, staff from Vale will be responsible for monthly maintenance and calibration (as was the case in the past). MAE staff will perform regular site visits to audit and assist in the maintenance and calibration procedures from time to time. WSC staff will perform regular site visits to ensure water quantity instrumentation is functioning correctly, calibrated and providing accurate measurements.
- WRMD staff will update Voisey's Bay staff on any changes to processes and procedures with handling, maintaining and calibrating the RTWQ instruments. WRMD is organizing a maintenance and calibration training session available for all industry partners to attend. The details and content of the training session will be communicated with Vale closer to the scheduled timeframe.
- If necessary, changes or improvements to deployment techniques will be adapted to each specific site, ensuring secure and suitable conditions for RTWQ.
- WRMD will work with Vale Environment staff to reassess the network design (station location) and plan for any necessary or desired changes in 2017 or in future seasons.
- Open communication lines will continue to be maintained between WRMD, ECCC and Vale employees involved with the agreement in order to respond to emerging issues on a proactive basis.
- Vale will receive 30 day deployment reports outlining the events that occurred in the previous deployment period and a 2017 annual report summarizing the events of the entire deployment season.
- WRMD will continue to work on Automatic Data Retrieval System to incorporate new capabilities when applicable.
- WRMD will continue to work on the creation of value added products using the RTWQ data, remote sensing and water quality indices.
- WRMD will begin development of models using RTWQ data and grab sample data to estimate a variety of additional water quality parameters (*i.e.* TSS, major ions *etc*.).
- 2017 deployments will recommence in the Spring

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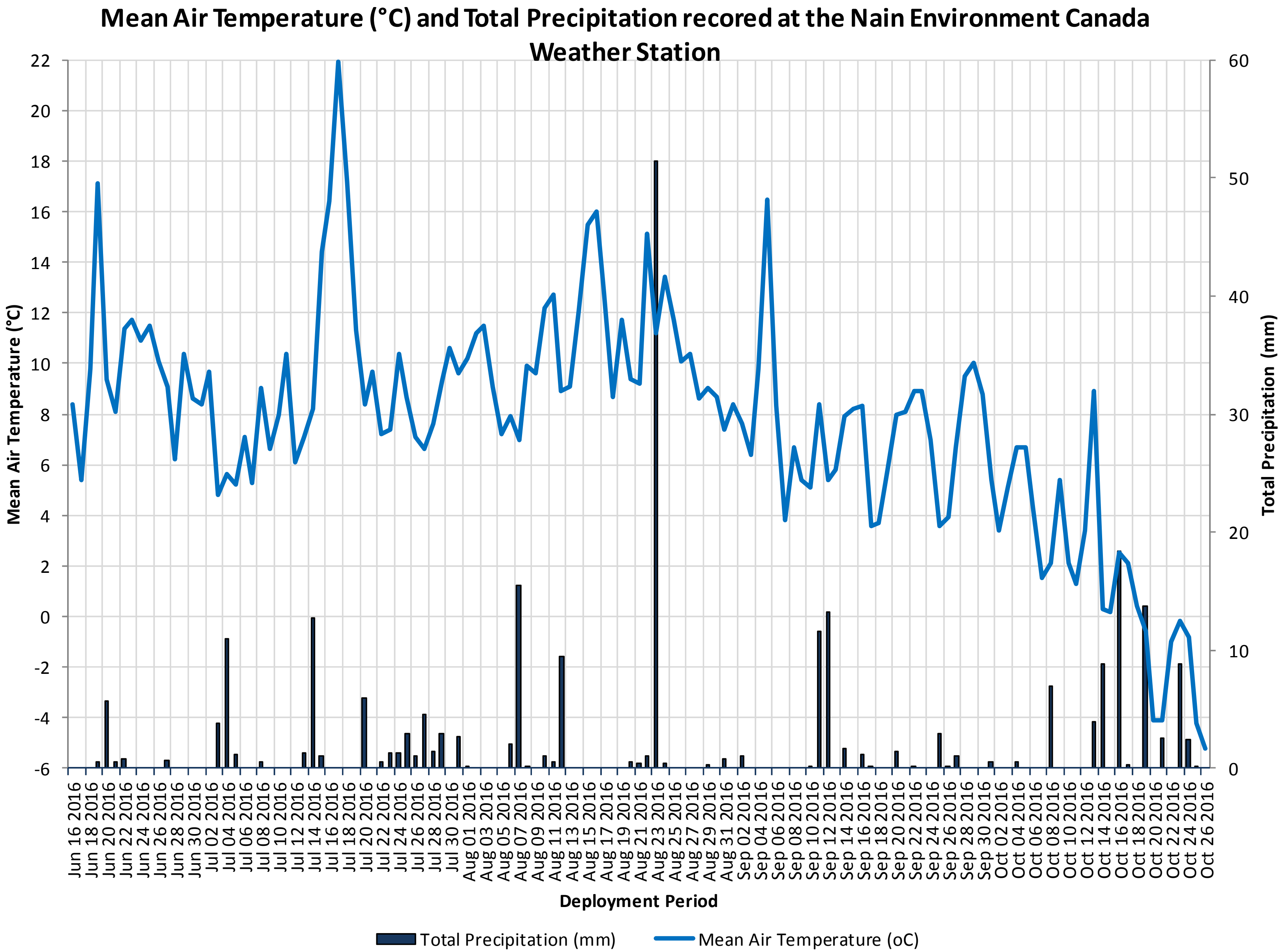
Appendix 1



Mean Air Temperature (°C) and Total Precipitation recored at the Nain Environment Canada Weather Station
Mean Air Temperature (°C)
Total Precipitation (mm)
Deployment Period
Total Precipitation (mm)
Mean Air Temperature (oC)