Real-Time Water Quality 2018 Annual Report

Voisey's Bay Network

June 17 to October 9, 2018

Newfoundland Labrador

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 (WRMD), 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 2018 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 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 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.

Staff with MAE, ECCC, and Vale 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
QA/QC	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 the spring 2012 season for this network, as well as a new Hydrolab Minisonde 5 for QA/QC measurements and an Archer handheld display unit.

This annual deployment report illustrates, discusses and summarizes water quality related events from June 17 to October 9, 2018. During this time, four visits were made to each of the four RTWQ sites. Instruments were deployed for approximately 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 members carefully calibrate 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. Instrument sensors will still work to capture any water quality event, although exact data values collected may be inaccurate. Installation and removal dates for each station in the 2018 deployment season are summarized in Table 1.

Table 1: Installation and removal dates for 2018 deployment periods

Installation	Removal	Deployment
June 17	August 4	48 days
August 5	September 8	34 days
September 9	October 9	30 days

Quality Assurance and Quality Control

As part of the Quality Assurance and Quality Control protocol (QA/QC), 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 QA/QC 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 QA/QC 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 for 2018 Deployment Season

Station	Date	Action	Temperature	pH	Specific Conductivity	Dissolved Oxygen	Turbidity
Reid Brook at Outlet of Reid Pond	June 17, 2018	Deployment	Good	Poor	Excellent	Excellent	Excellent
	August 4, 2018	Removal	Excellent	Good	Excellent	Excellent	Excellent
	August 5, 2018	Deployment	Good	Marginal	Marginal	Not Ranked	Excellent
	September 8, 2018	Removal	Good	Marginal	Marginal	Good	Excellent
	September 9, 2018	Deployment	Excellent	Marginal	Excellent	Excellent	Excellent
	October 9, 2018	Removal	Excellent	Excellent	Excellent	Good	Good
Camp Pond Brook below Camp Pond	June 17, 2018	Deployment	Excellent	Fair	Good	Excellent	Good
	August 4, 2018	Removal	Excellent	Marginal	Marginal	Excellent	Poor
	August 5, 2018	Deployment	Excellent	Excellent	Excellent	Excellent	Excellent
	September 8, 2018	Removal	Excellent	Good	Excellent	Excellent	Good
	September 9, 2018	Deployment	Excellent	Marginal	Good	Excellent	Poor
	October 9, 2018	Removal	Excellent	Fair	Fair	Excellent	Poor
Reid Brook below Tributary	June 17, 2018	Deployment	Excellent	Poor	Excellent	Good	Excellent
	August 4, 2018	Removal	Excellent	Excellent	Excellent	Excellent	N/A*
	August 5, 2018	Deployment	Excellent	Excellent	Excellent	Excellent	Excellent
	September 8, 2018	Removal	Excellent	Fair	Excellent	Fair	Excellent
	September 9, 2018	Deployment	Excellent	Fair	Excellent	Excellent	Excellent
	October 9, 2018	Removal	Excellent	Poor	Good	Good	Excellent
Tributary to Reid Brook	June 17, 2018	Deployment	Excellent	Good	Excellent	Excellent	Poor
	August 4, 2018	Removal	Excellent	Excellent	Excellent	Excellent	Poor
	August 5, 2018	Deployment	Excellent	Excellent	Good	Good	Excellent
	September 8, 2018	Removal	Excellent	Excellent	Excellent	Excellent	Excellent
	September 9, 2018	Deployment	Excellent	Good	Good	Excellent	Poor
	October 9, 2018	Removal	Excellent	Fair	Poor	Excellent	Poor

Data Interpretation

The following graphs and discussions illustrate significant water quality-related events from June 17 through October 9, 2018 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 QA/QC protocol. WSC is responsible for QA/QC of water quantity data. Corrected data can be obtained upon request to WSC.

During the first deployment period, the instrument at Tributary to Reid Brook recorded a much higher baseline turbidity level than expected. This was likely the result of an error made during calibration; however, the data was not removed from the data set because turbidity events were still observable throughout the deployment period.

During the third deployment period, the instrument at Camp Pond Brook below Camp Pond recorded a much higher baseline turbidity level than expected. This was likely the result of an error made during calibration; however, the data was not removed from the data set because turbidity events were still observable throughout the deployment period. The instrument at Tributary to Reid Brook recorded 100.0NTU turbidity across the entire deployment period with no fluctuations. This was likely the result of a serious error during calibration and therefore all of this turbidity data was removed from the dataset.

All instruments were sent to the St. John's WRMD laboratory at the end of the season for yearly PTE. Any necessary repairs and replacement sensors will be addressed before the 2019 season.

Reid Brook at Outlet of Reid Pond

During the 2018 deployment season, water temperature ranged from 1.37°C to a maximum of 15.97°C (Figure 1). Water temperature minimum and maximum values for 2018 were on par with data from the 2017 and 2016 deployment seasons (Table 4).

Water temperatures were stable at the beginning of deployment due to Reid Pond still being covered in ice. Temperatures started to steadily increase from early July onwards. Water temperatures were at their highest in early August. Water temperatures started to decrease again through mid-August onwards (Figure 1).

Please note that 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.

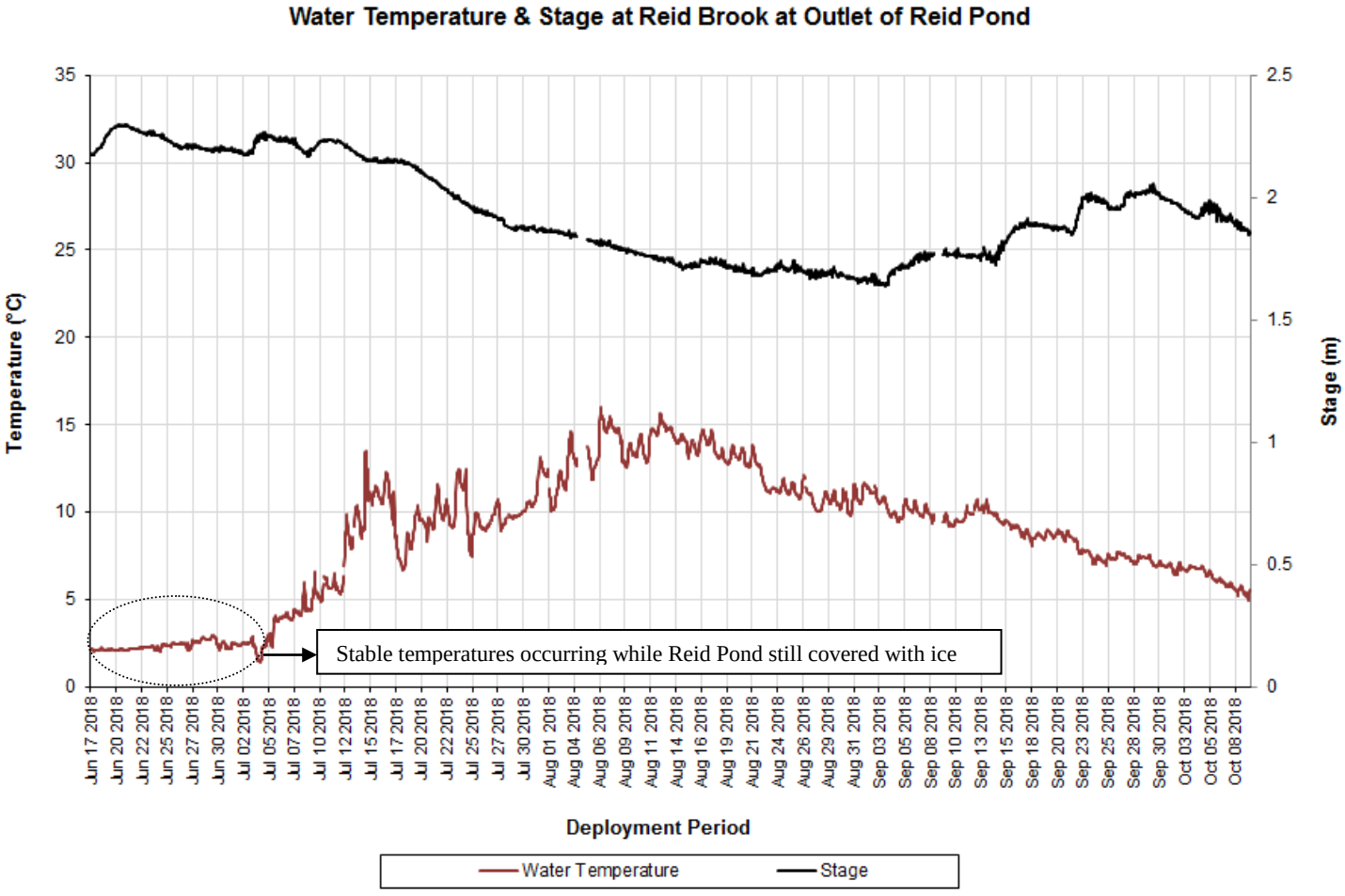

Figure 1: Water Temperature & Stage at Reid Brook at Outlet of Reid Pond

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

Water Temperature	2018	2017	2016
Min	1.37	0.6	1.47
Max	15.97	14.9	15.77
Median	9.34	9.53	9.79

Water temperatures show a close relationship with air temperature (Figure 2). Increases and decreases in air temperatures throughout 2018 were associated with similar changes in water temperature. Air temperatures fluctuate at a greater extent each day when compared with water temperatures. This location is also less susceptible to extreme temperature fluctuations as Reid Pond is a larger body of water. Air temperature data was obtained from the Voisey's Bay Weather Station located at the Air Strip.

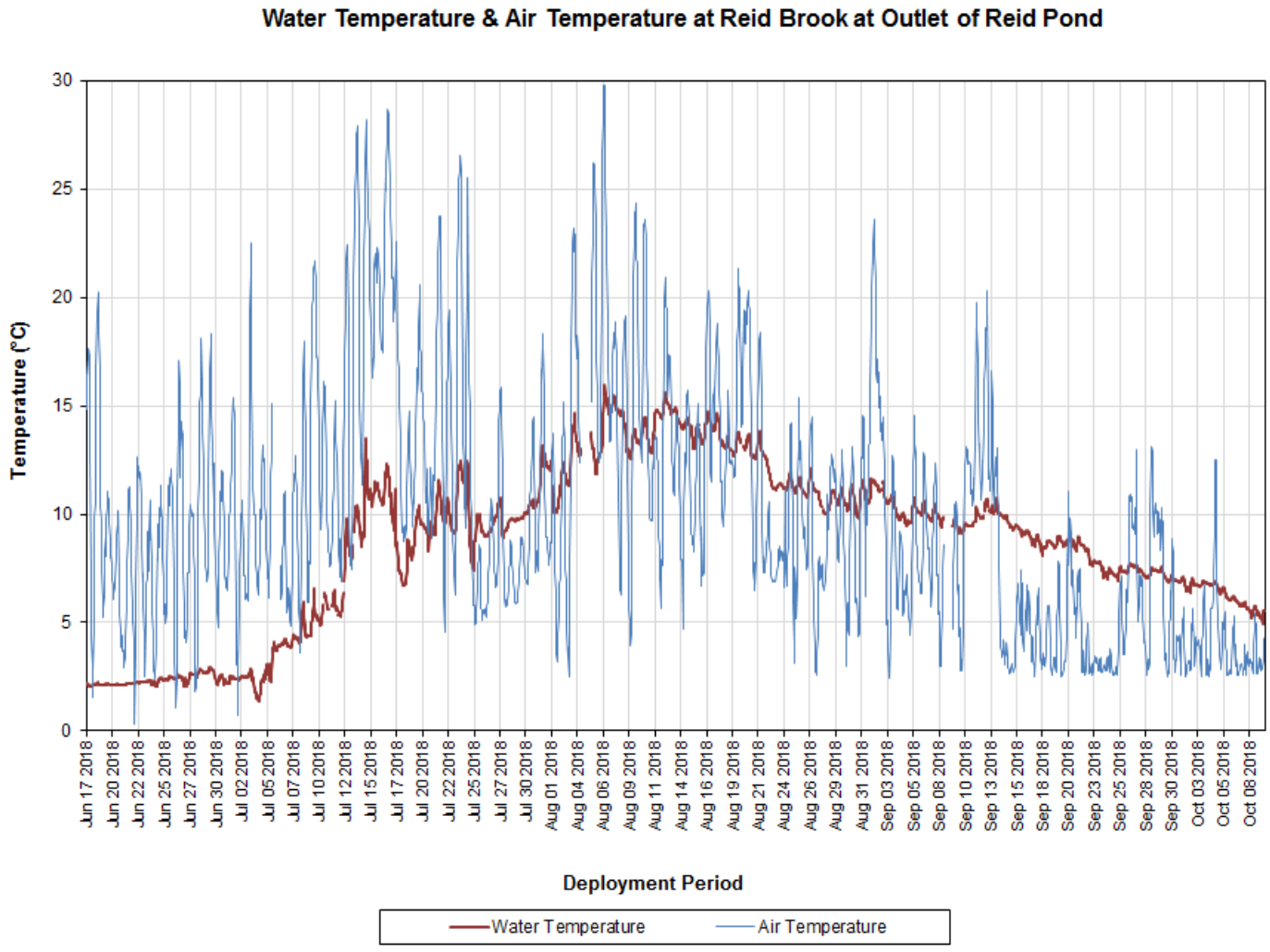

Figure 2: Water Temperature & Air Temperature at Reid Brook at Outlet of Reid Pond

During the 2018 deployment season, pH ranged from 6.36 pH units to a maximum of 8.04 pH units (Table 5). This station is at the outlet of a pond and so pH data has a wider range compared to that of a stream or brook. In a pond environment, water parameters take longer to change after an influence; ponds have a larger volume of water and in turn have a slower turnover rate compared to streams or brooks.

Figure 3 displays the relationship between pH and stage; generally when stage increases, pH decreases slightly. pH remained within the CCME's Guidelines for the Protection of Aquatic Life for the majority of the deployment season, except for a very short period at the end of July.

Please note that 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.

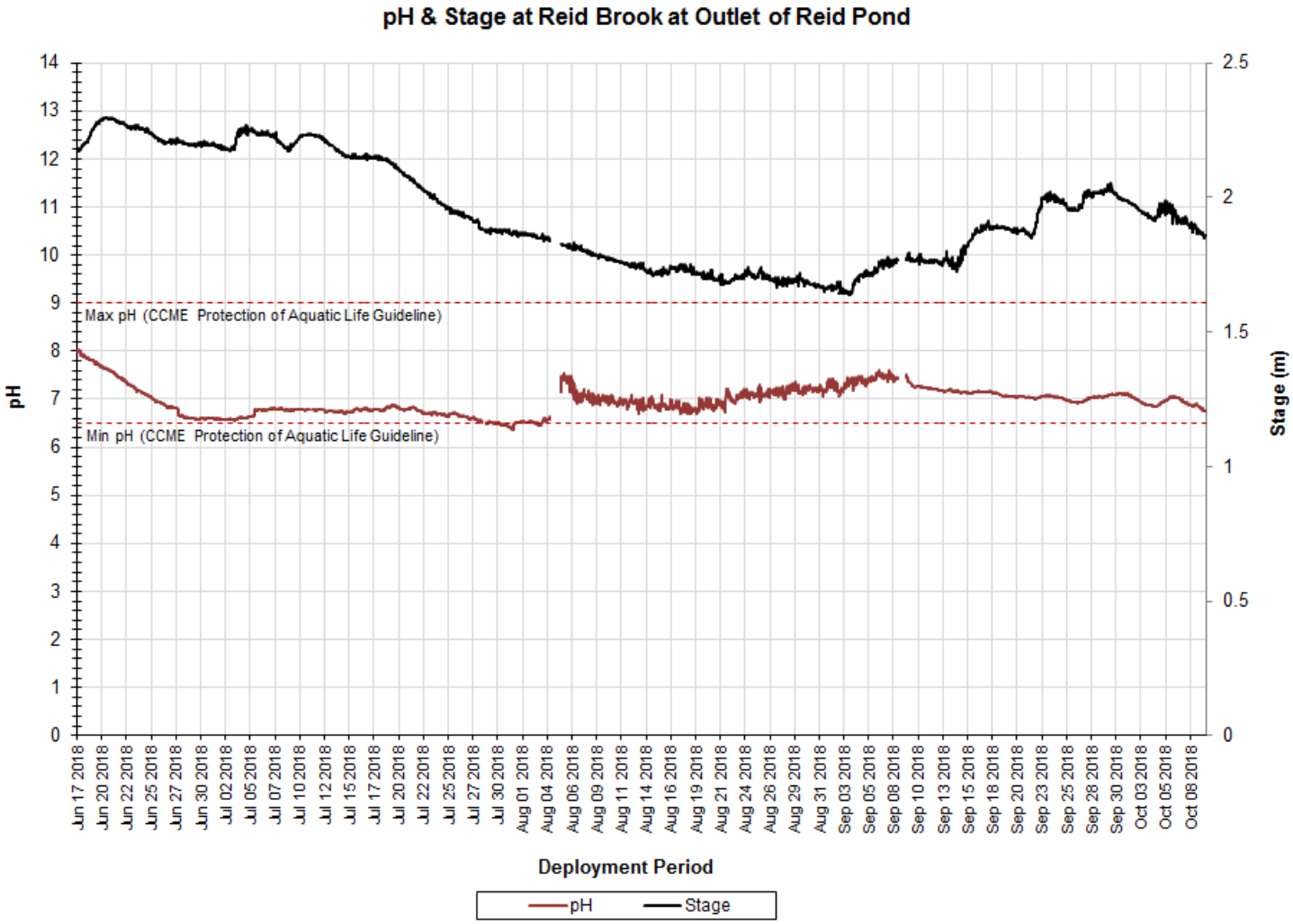

Figure 3: pH & Stage at Reid Brook at Outlet of Reid Pond

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

pH	2018	2017	2016
Min	6.36	5.34	6.08
Max	8.04	7.58	7.54
Median	6.96	6.78	6.72

During the 2018 deployment season, specific conductivity values ranged from 9.1µS/cm to a maximum of 27.5µS/cm. An overall conductivity median of 11.8µS/cm indicates that this station naturally has very low conductivity (Table 6).

Specific conductivity was low and stable throughout the majority of the deployment season with only minimal fluctuation (Figure 4). This trend is to be expected at this station, since it is located at the outflow of the stable environment of Reid Pond. The maximum specific conductivity value recorded for 2018 was higher than those from 2017 and 2016. Based on the graph below, this may have been associated with a calibration error during the second deployment period leading to higher-than-expected specific conductivity levels. There was some movement in specific conductivity towards the end of deployment, which may have been associated with changes in stage.

Please note that 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.

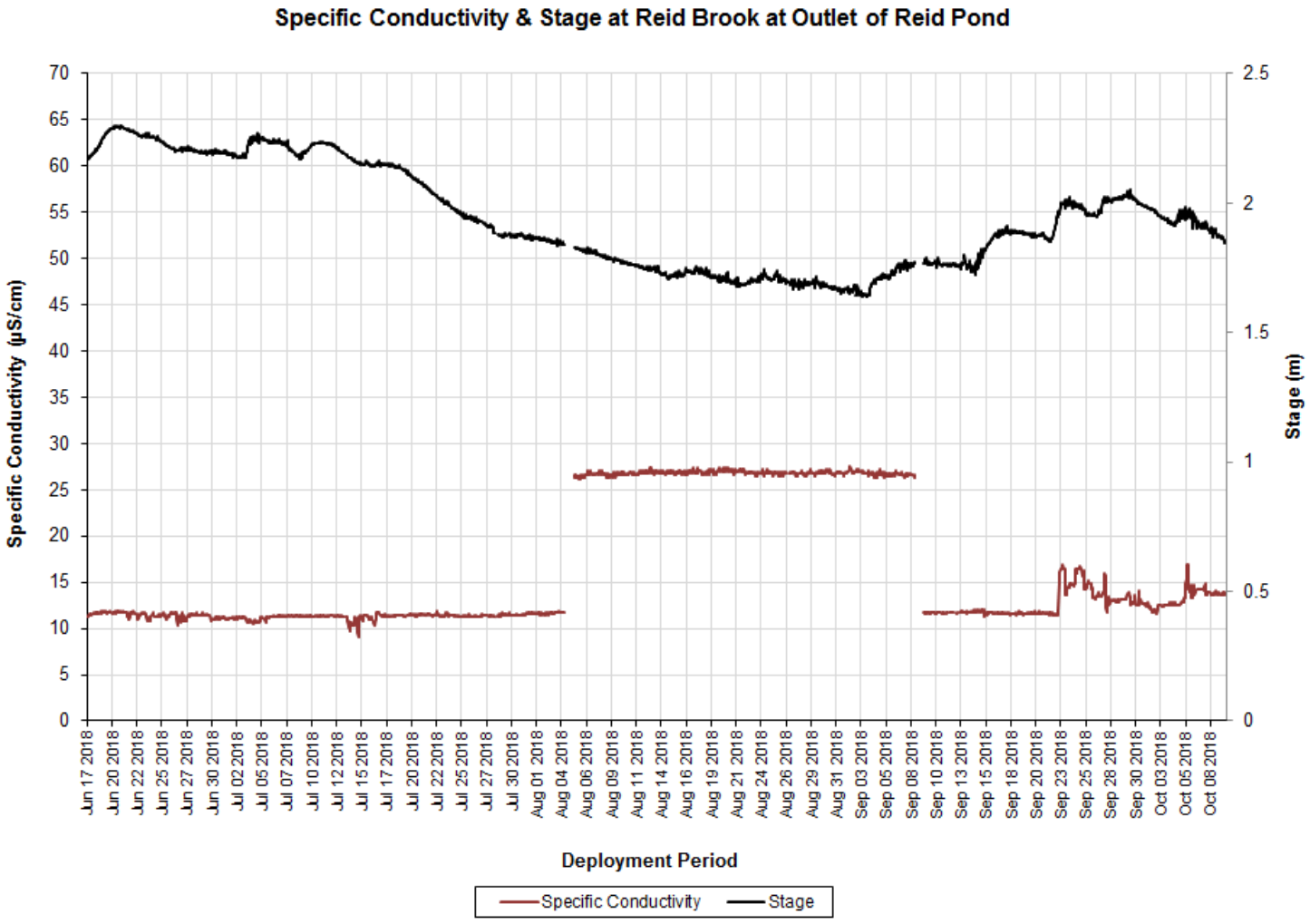

Figure 4: Specific Conductivity & Stage at Reid Brook at Outlet of Reid Pond

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

Specific Conductivity	2018	2017	2016
Min	9.1	9.4	9.1
Max	27.5	22.3	15.9
Median	11.8	12.1	11.6

During the 2018 deployment season, dissolved oxygen concentrations ranged from 9.63mg/L to a maximum of 12.92mg/L, with a median value of 11.23mg/L. Saturation of dissolved oxygen ranged from 86.6% to 110.4%, with a median value of 95.6% (Table 7).

Dissolved oxygen concentrations displayed typical seasonal fluctuations throughout the deployment season, and exhibited an inverse relationship with water temperature (Figure 5). Dissolved oxygen values were consistently high at the beginning of deployment when Reid Pond was covered by ice and water temperatures were low. Dissolved oxygen values decreased steadily until mid-August, after which they began to increase again through the remainder of deployment as water temperatures decreased into the fall season.

Dissolved oxygen values remained above the CCME's Minimum Guideline for the Protection of Other Life Stages (6.5mg/L) and Early Life Stages (9.5mg/L) for the duration of the deployment season.

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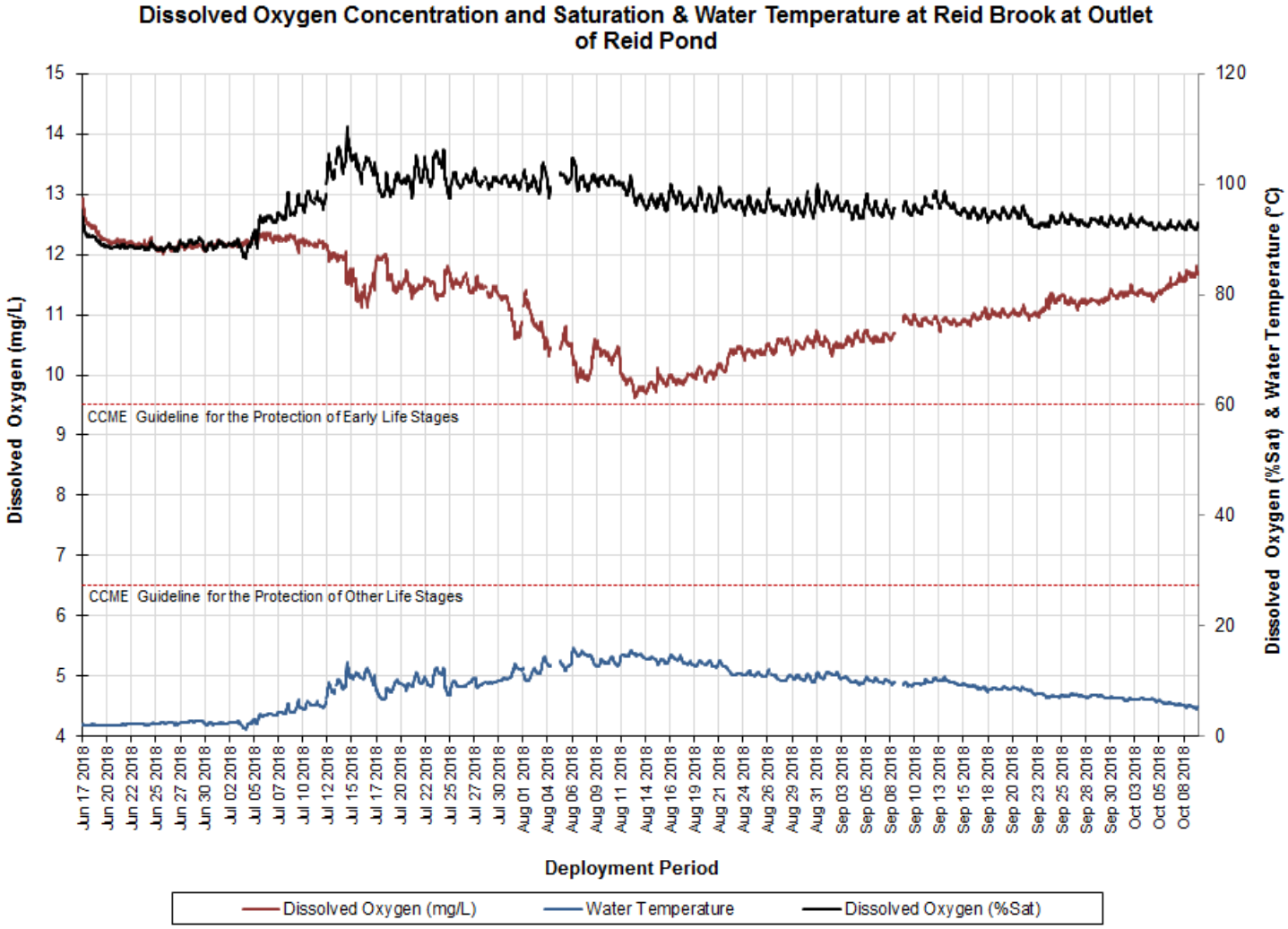

Figure 5: Dissolved Oxygen Concentration and Saturation & Water Temperature at Reid Brook at Outlet of Reid Pond

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

Dissolved Oxygen (mg/L)	2018	2017	2016
Min	9.63	10.22	10.76
Max	12.92	12.39	12.46
Median	11.23	11.265	12.09

Percent Saturation (%)	2018	2017	2016
Min	86.6	82.2	95.9
Max	110.4	107.6	106.5
Median	95.6	97.1	97.9

During the 2018 deployment season, turbidity values ranged from 0.7NTU to a maximum of 196.4NTU. A median value of 0.7NTU indicates that there is very little background turbidity at this station (Table 8).

There were very few turbidity events at this station over the course of deployment (Figure 6). This is to be expected, as this site is pristine in nature and far removed from the Voisey's Bay mine site.

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

Please note that 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.

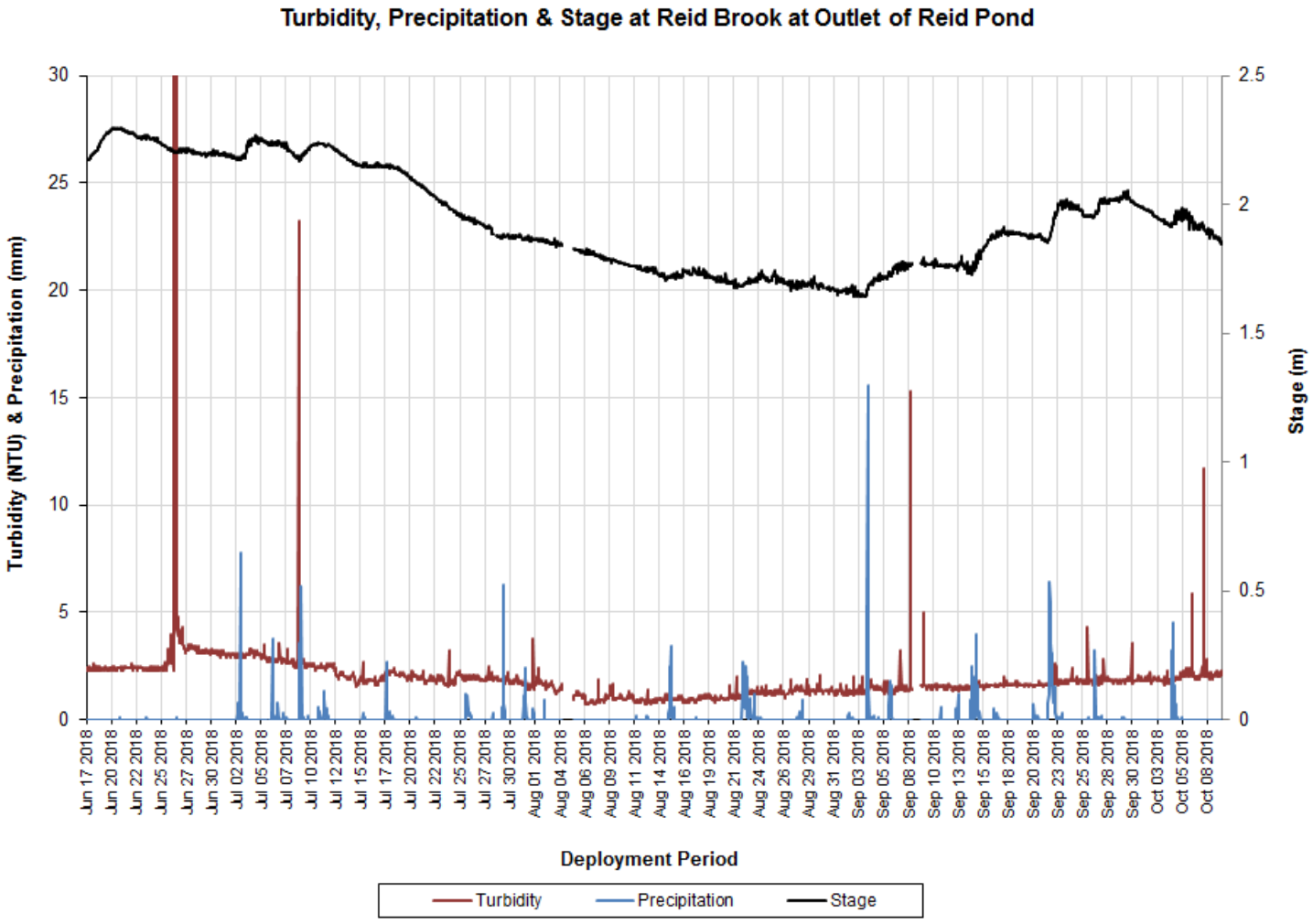

Figure 6: Turbidity & Stage at Reid Brook at Outlet of Reid Pond

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

Turbidity	2018	2017	2016
Min	0.7	0.0	0.0
Max	196.4	78	41.3
Median	1.8	0.0	0.2

Camp Pond Brook below Camp Pond

During the 2018 deployment season, water temperature ranged from 1.18°C to a maximum of 21.42°C. The median temperature of 11.34°C was slightly lower than that from the 2017 deployment season (Table 9).

Water temperature was highest from mid-July to mid-August (Figure 7), after which water temperatures decreased steadily as ambient air temperatures also decreased (Figure 8).

Please note that 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.

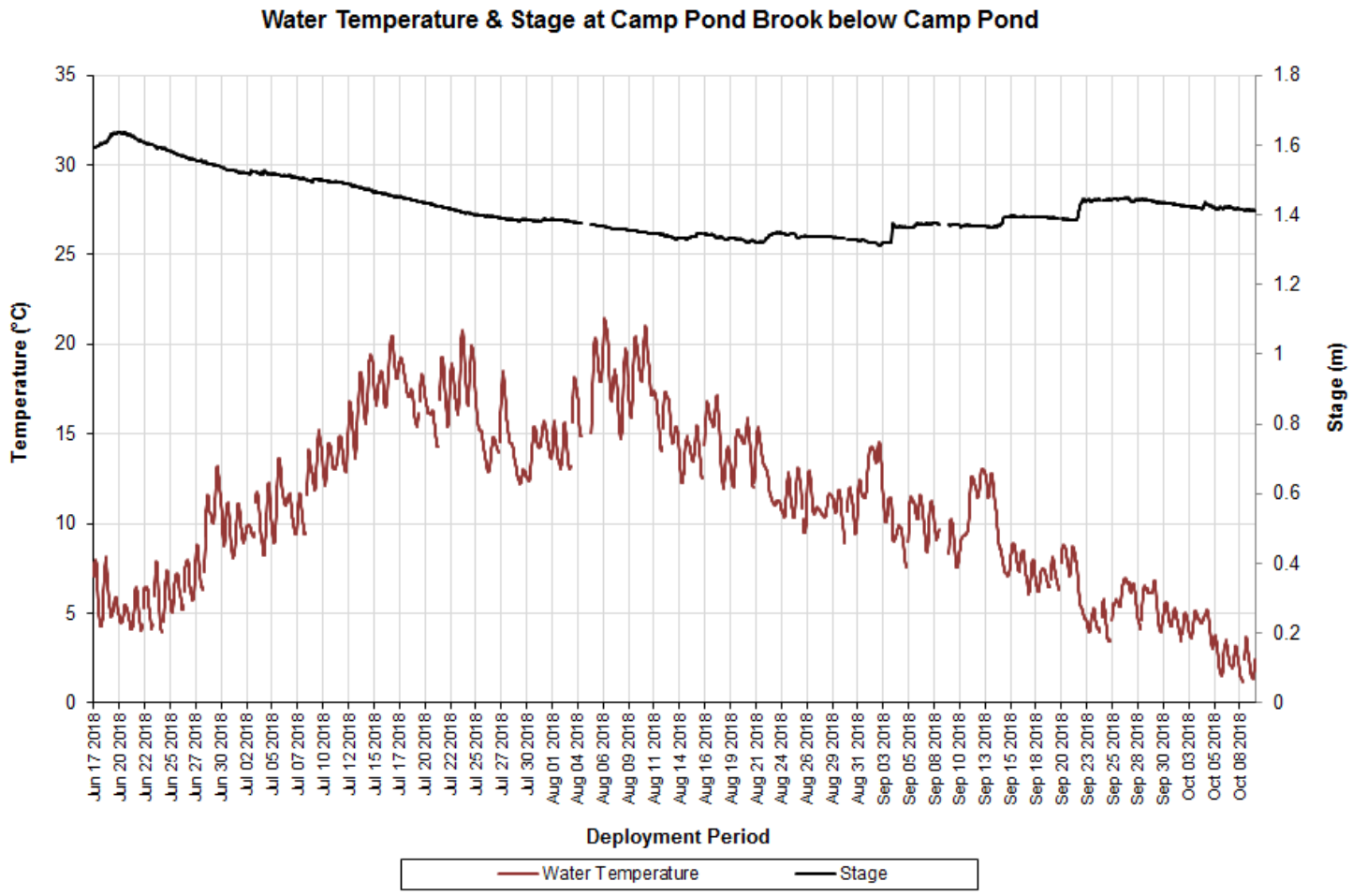

Figure 7: Water Temperature & Stage at Camp Pond Brook below Camp Pond

Water temperature values showed a close relationship with ambient air temperatures (Figure 8); increases and decreases in air temperatures were reflected in similar changes in water temperatures. Air temperatures fluctuate to a greater extent compared to water temperatures. Air temperature data was obtained from the Voisey's Bay Weather Station located at the Air Strip.

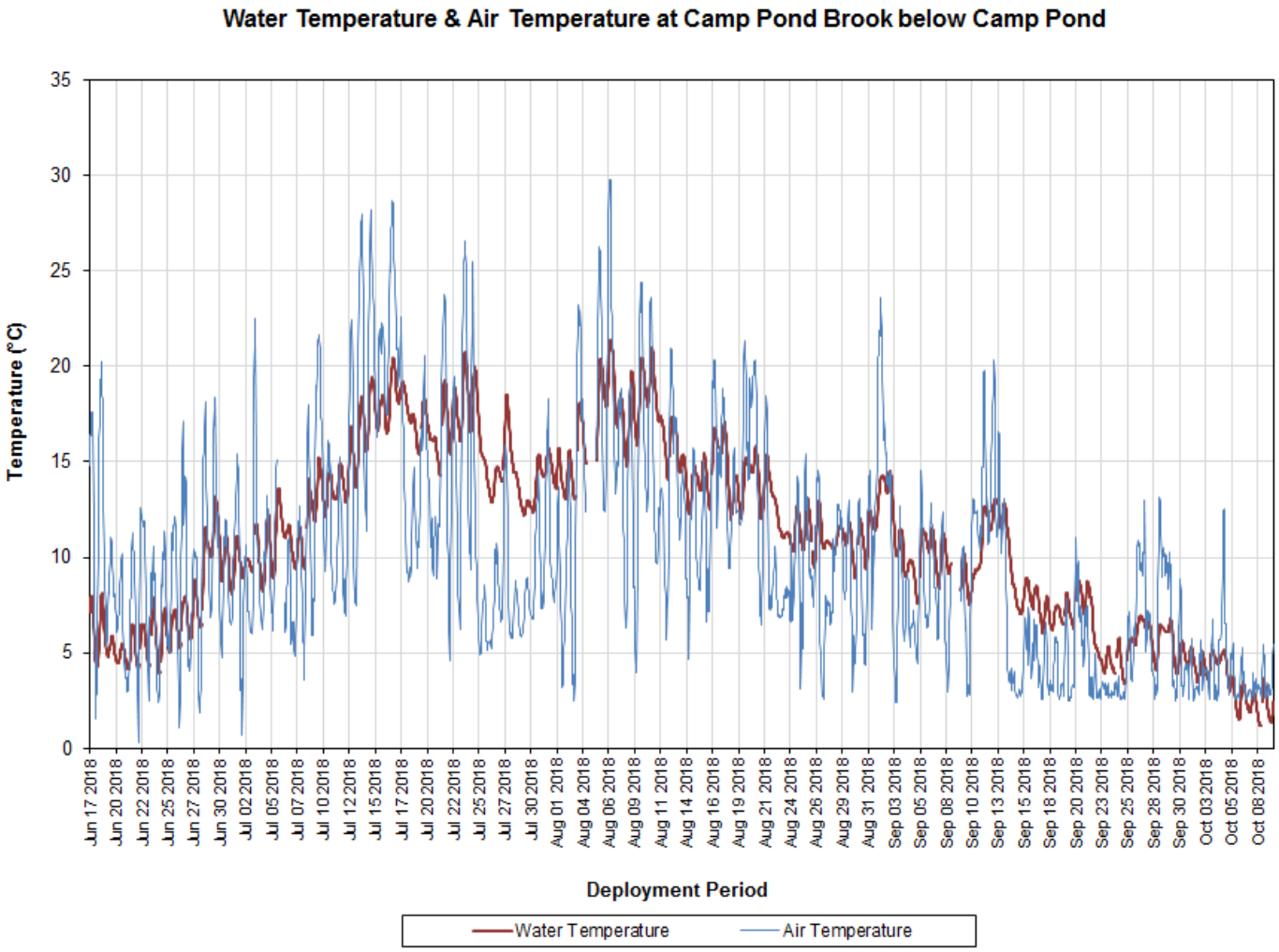

Figure 8: Water Temperature & Air Temperature at Camp Pond Brook below Camp Pond

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

Water Temperature	2018	2017	2016
Min	1.18	0.22	0.07
Max	21.42	20.52	22.02
Median	11.34	11.86	12

During the 2018 deployment season, pH ranged from 5.68 pH units to a maximum of 7.47 pH units. The median value of 6.94 was very similar to those from both 2017 (6.87) and 2016 (6.90) (Table 10).

Stage is included in the graph below to show the relationship between water level and pH values. Across the deployment season, pH data was reasonably stable. pH values were below the CCME's Minimum Guideline for the Protection of Aquatic Life for a short period at the beginning of deployment, but increased through mid-June and remained mostly within the guidelines for the remainder of the deployment season (Figure 9).

Please note that 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.

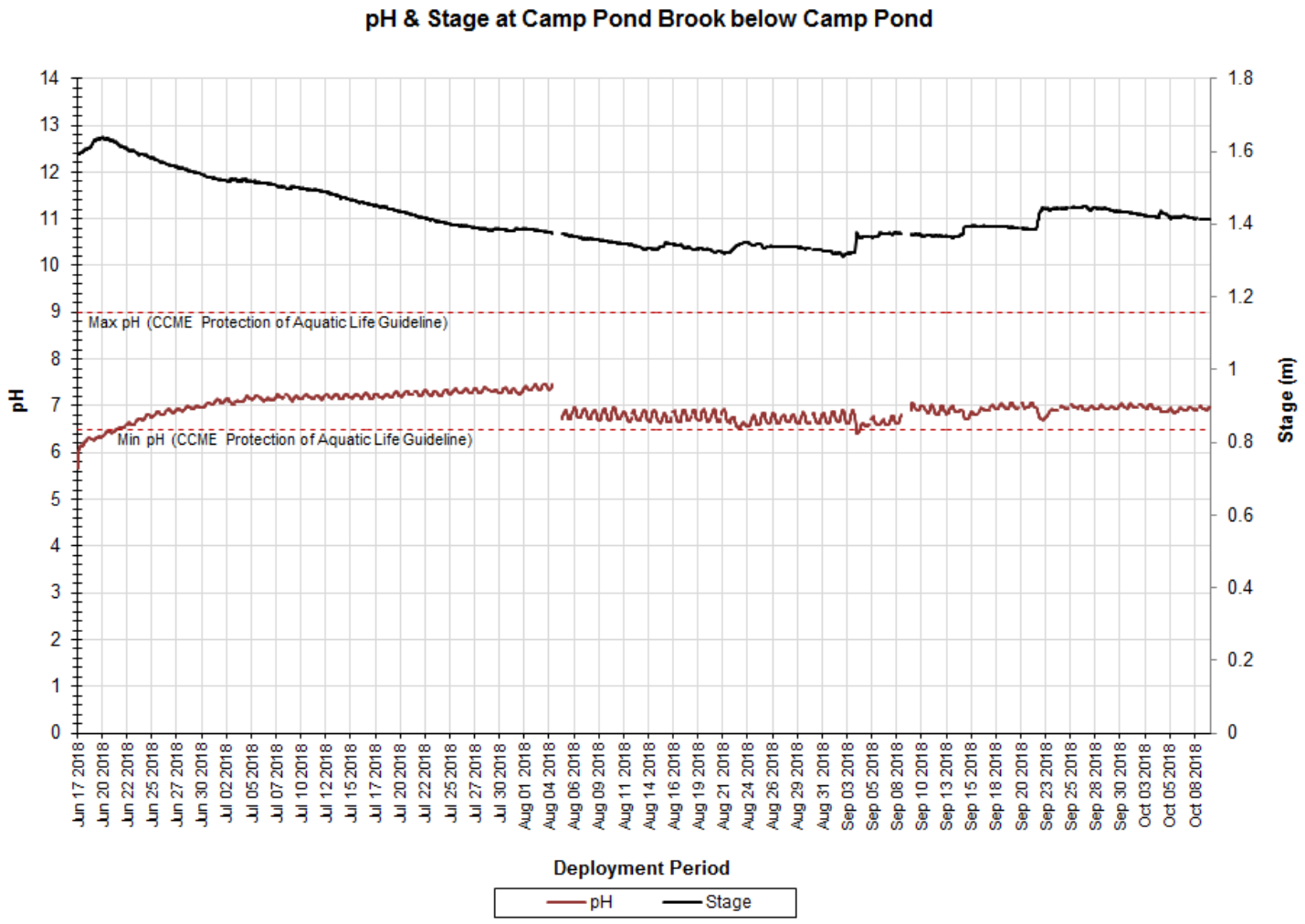

Figure 9: pH & Stage at Camp Pond Brook below Camp Pond

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

pH	2018	2017	2016
Min	5.68	6.02	6.54
Max	7.47	7.12	7.2
Median	6.94	6.87	6.90

During the 2018 deployment season, specific conductivity ranged from 16.4µS/cm to a maximum of 111µS/cm (Figure 10). The median value of 35.9µS/cm was slightly lower than the 2017 median of 39.5µS/cm (Table 11).

Stage is included in the graph below to illustrate the relationship between conductivity and water level (Figure 10). In general, stage and conductivity exhibit an inverse relationship: when one parameter increases, the other decreases. In some instances, however, sharp increases in stage correlate with similar increases in conductivity, which is likely due to increased rainfall and runoff. This site is in close proximity to the mine site and so is heavily influenced by runoff factors that the other Voisey's Bay real-time stations do not experience.

Over the deployment season, conductivity levels in Camp Pond Brook increased slightly, while stage decreased. This relationship is to be expected as rainfall events, and subsequent bank runoff, generally decrease as the winter season approaches.

Please note that 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.

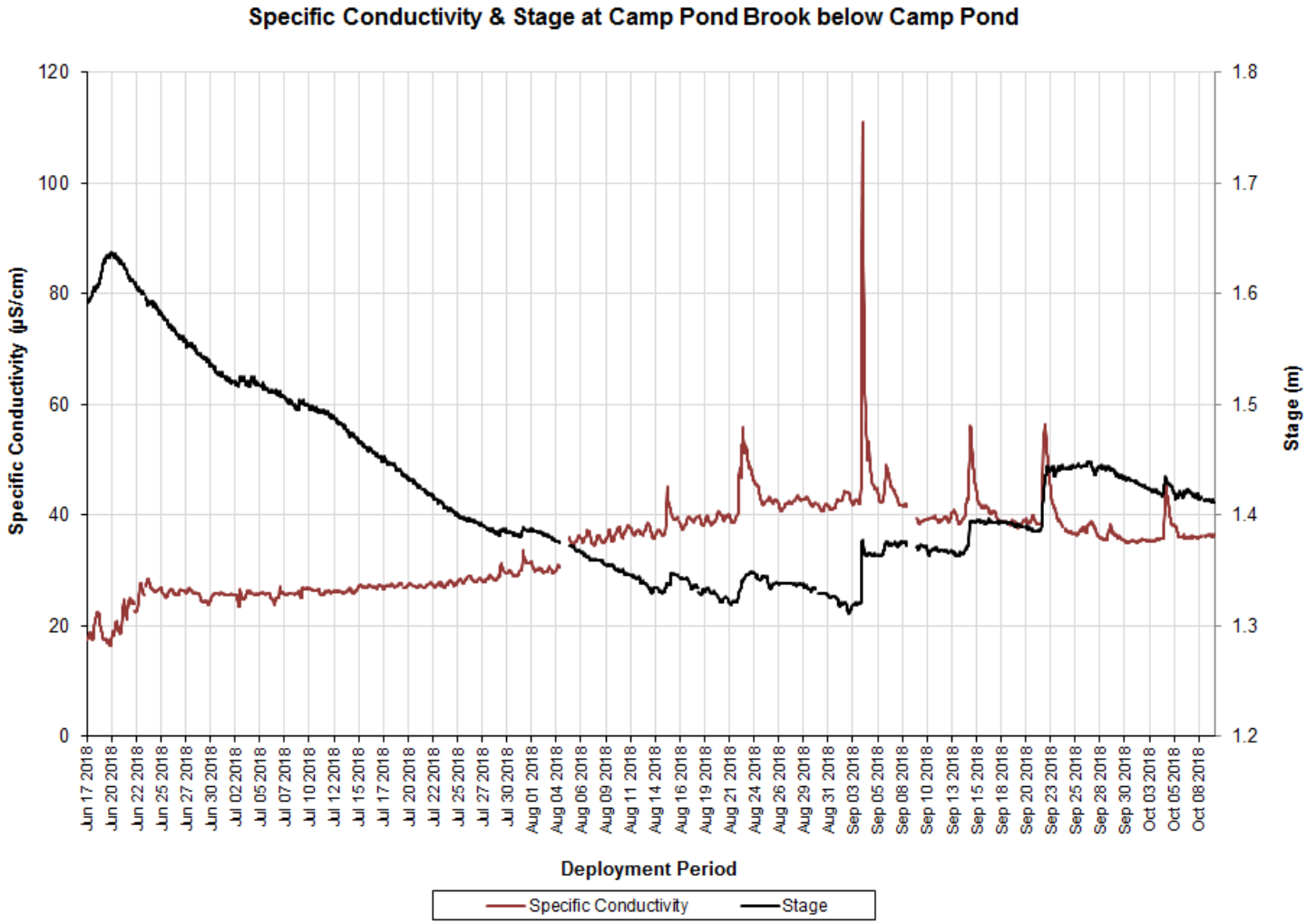

Figure 10: Specific Conductivity & Stage at Camp Pond Brook below Camp Pond

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

Specific Conductivity	2018	2017	2016
Min	16.4	21.2	28.7
Max	111	61.1	64.0
Median	35.9	39.5	38.2

During the 2018 deployment season, dissolved oxygen concentrations ranged from 8.27mg/L to a maximum of 13.48mg/L, with a median value of 10.38mg/L that was very close to the 2017 median of 10.37mg/L. Saturation of dissolved oxygen ranged from 84.4% to 102.2%, with a median value of 95.2% (Table 12).

Dissolved oxygen concentrations exhibited typical seasonal trends, and were inversely related to water temperature. Dissolved oxygen concentrations were lowest throughout July and most of August when water temperatures were warmest. As water temperatures decreased into late summer and early fall, dissolved oxygen concentrations began to increase. Frequent fluctuations in dissolved oxygen levels are consistent with smaller daily changes in water temperature (Figure 11).

Dissolved oxygen concentrations occasionally dipped below the CCME's Guideline for the Protection of Early Life Stages (9.5mg/L) from mid-July through late August; these dips are to be expected as they correspond closely with increased water temperatures during the same time frames.

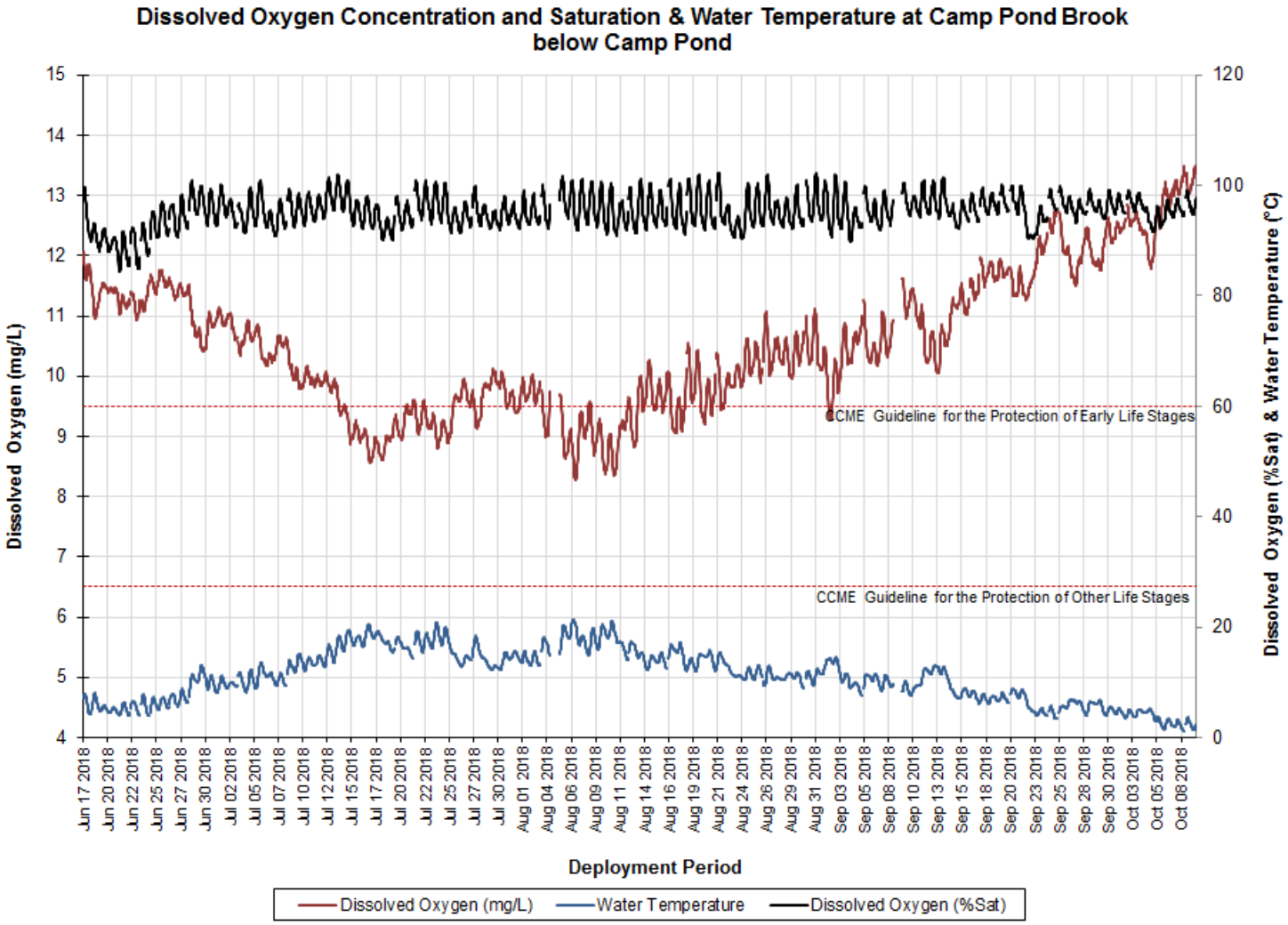

Figure 11: Dissolved Oxygen Concentration and Saturation & Water Temperature at Camp Pond Brook below Camp Pond

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

Dissolved Oxygen (mg/L)	2018	2017	2016
Min	8.27	8.61	8.22
Max	13.48	13.6	14.03
Median	10.38	10.37	10

Percent Saturation (%)	2018	2017	2016
Min	84.4	87.7	87.9
Max	102.2	103.9	103.3
Median	95.2	94.9	93.7

During the 2018 deployment season, turbidity values ranged from 0.0NTU to a maximum of 446NTU, with a median value of 0.0NTU (Figure 12). A median value of 0.0NTU indicates that there is very little natural background turbidity at this station. Turbidity values at this station have been fairly consistent over recent deployment seasons (Table 13).

Turbidity is graphed to a maximum of 80NTU in the graph below in order to show the relationship between turbidity and precipitation. There were a number of turbidity spikes throughout the deployment season, the majority of which corresponded with precipitation events and subsequent increases in stage.

Please note that 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.

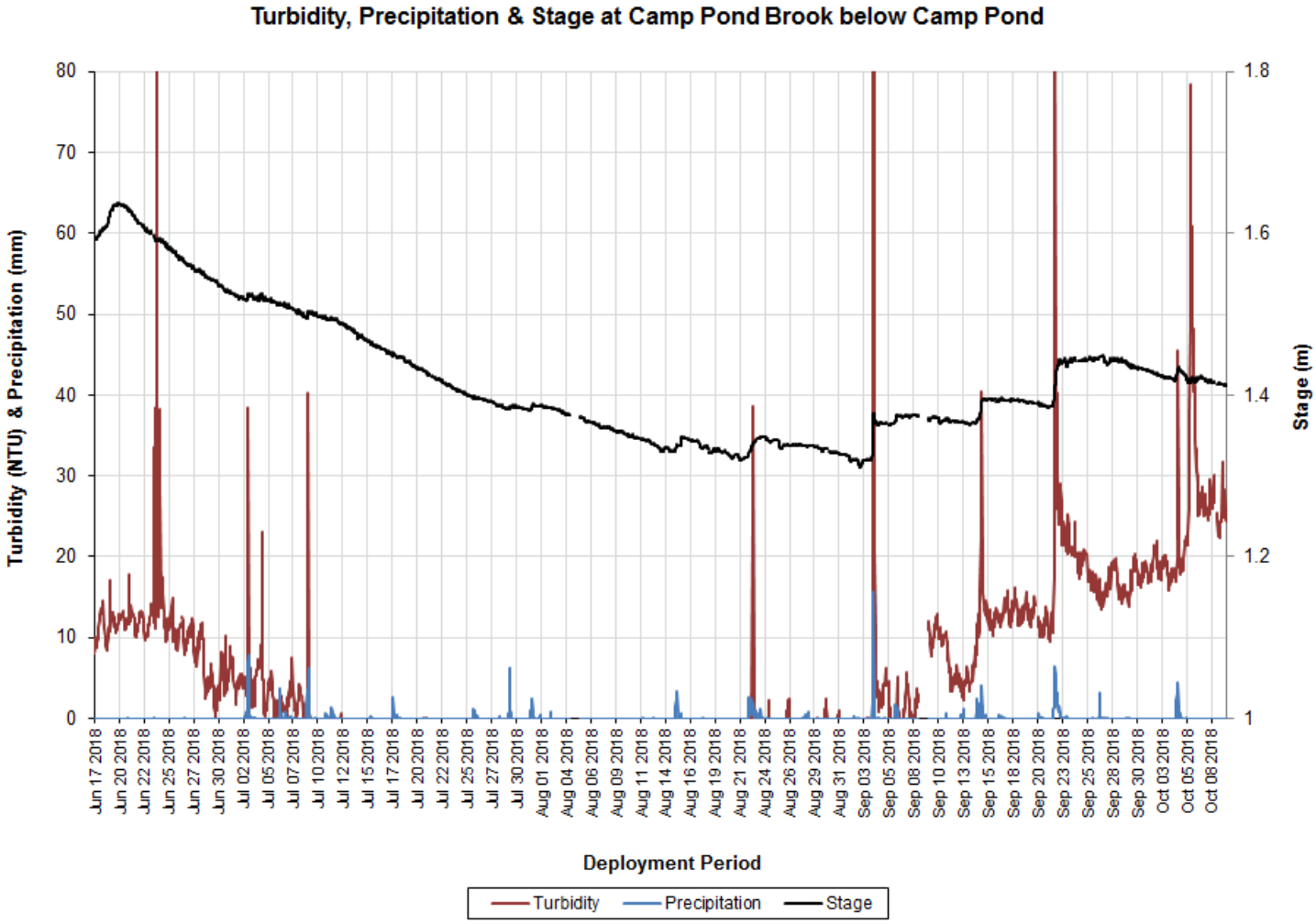

Figure 12: Turbidity & Stage at Camp Pond Brook below Camp Pond

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

Turbidity	2018	2017	2016
Min	0.0	0.0	0.0
Max	446	1509	3.5
Median	0.0	1.7	0.0

Tributary to Reid Brook

During the 2018 deployment season, water temperature ranged from 1.7°C to a maximum of 17.4°C, with a median value of 9.2°C (Table 14). Water temperatures were highest through late July and early August as air temperatures increased with the summer season. From the middle of August onwards, water temperatures steadily declined as ambient air temperatures also declined (Figure 13 & 14).

Water temperatures have been very consistent at this station over recent years (Table 14).

Please note that 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.

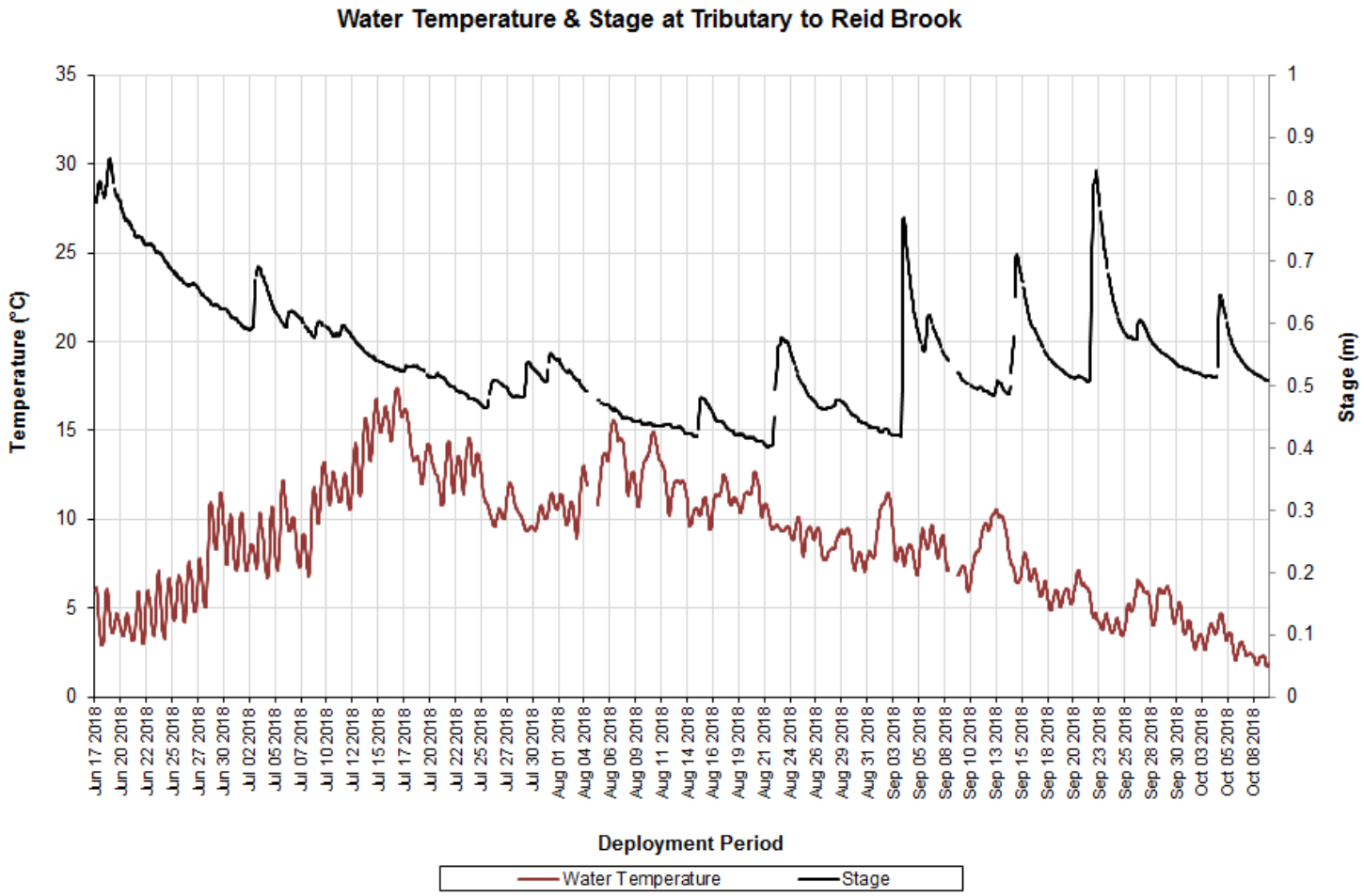

Figure 13: Water Temperature & Stage at Tributary to Reid Brook

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

Water Temperature	2018	2017	2016
Min	1.7	0	0.0
Max	17.4	14.5	15.7
Median	9.2	9.3	9.3

Water temperatures closely correlate with ambient air temperatures, with increases and decreases in ambient air temperatures being reflected in water temperatures (Figure 14). Air temperatures fluctuate to a greater extent each day as compared to water temperatures. Air temperature data was obtained from the Voisey's Bay Weather Station located at the Air Strip.

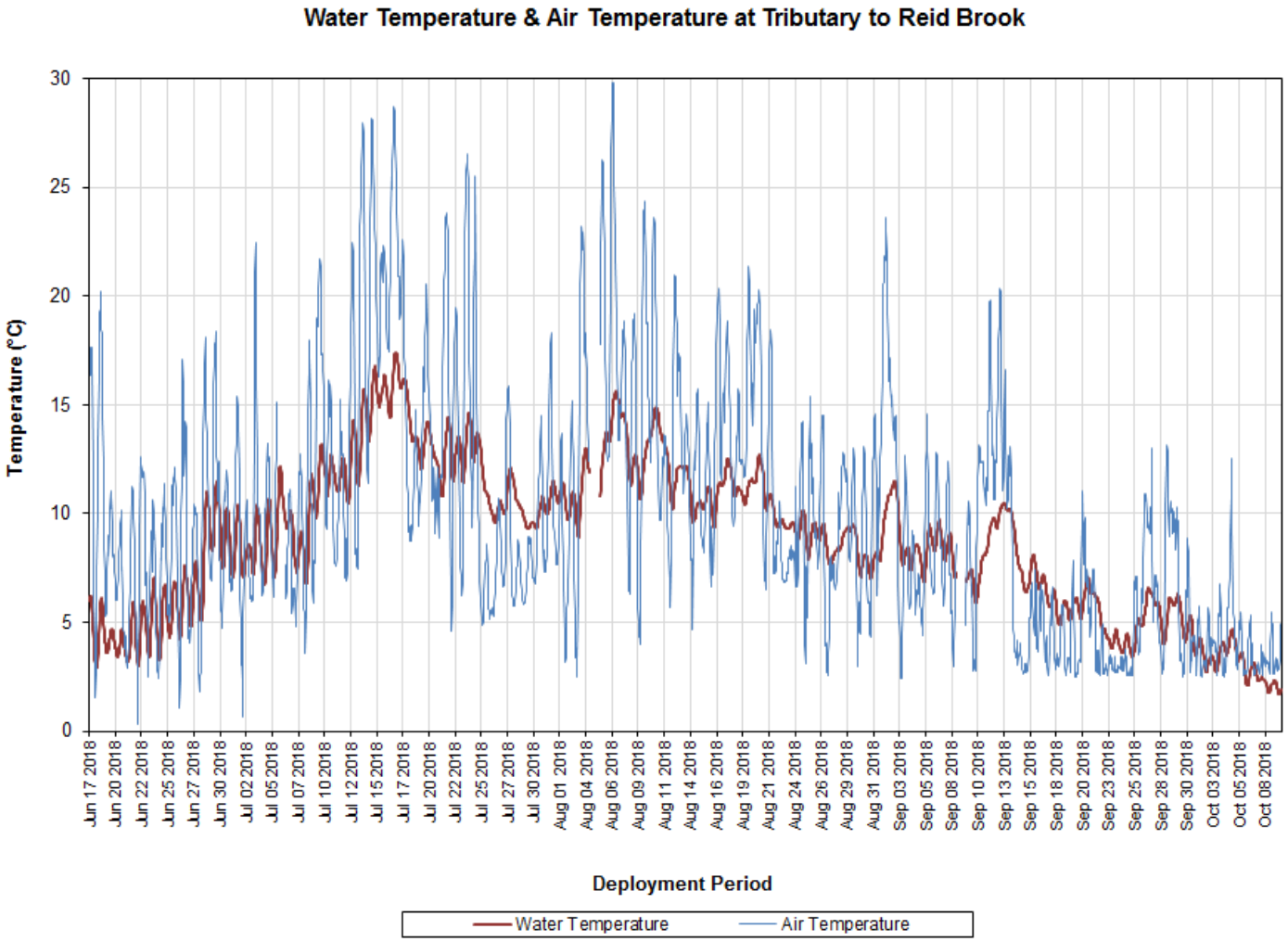

Figure 14: Water Temperature & Air Temperature at Tributary to Reid Brook

During the 2018 deployment season, pH ranged from 6.15 pH units to a maximum of 7.28 pH units, with a median value of 6.83 (Figure 15). pH data at this station has been consistent over recent years with median values of 6.74 in 2017 and 6.89 in 2016 (Table 15).

Stage data is included in Figure 15 to show how stage influences pH over time. In general, as stage decreases pH increases, and vice versa. This is a normal relationship and is expected in brooks.

pH values at this site were within the CCME's Guidelines for the Protection of Aquatic Life for the majority of the deployment season. On several occasions, pH values fell below the suggested minimum guideline; however, most of these events correlated closely with significant increases in stage.

Please note that 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.

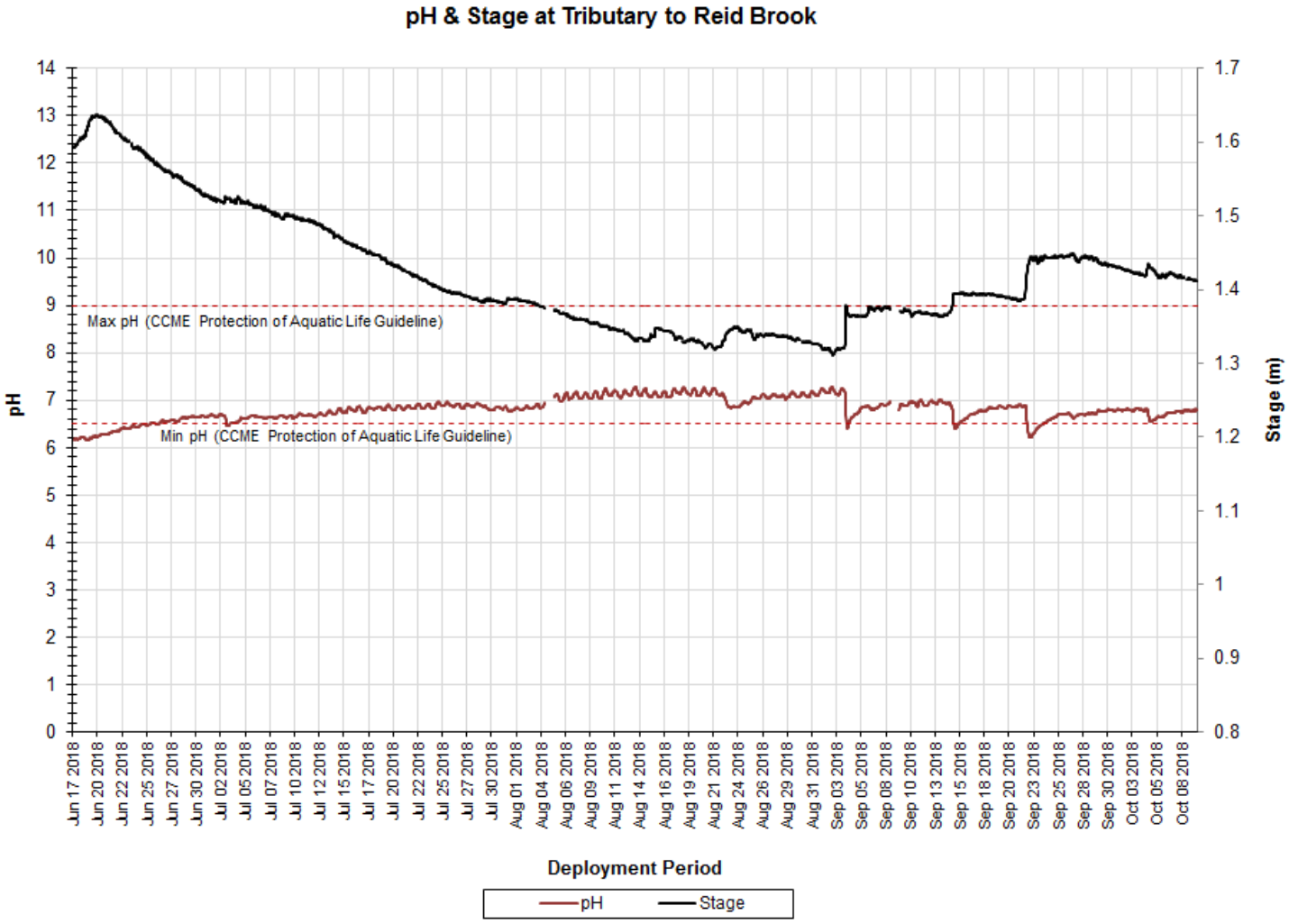

Figure 15: pH & Stage at Tributary to Reid Brook

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

pH	2018	2017	2016
Min	6.15	6.11	6.08
Max	7.28	7.09	7.22
Median	6.83	6.74	6.89

During the 2018 deployment season, specific conductivity levels ranged from 14µS/cm to a maximum of 40.3µS/cm, with a median value of 27.8µS/cm (Figure 16). Specific conductivity levels have been consistent at this site over recent years, with median values of 28.6µS/cm in 2017 and 34.9µS/cm in 2016 (Table 16).

Specific conductivity changes with varying water levels: as stage increases, specific conductivity decreases. This is due to dilution of dissolved solids in the water column; as stage decreases, the concentration of dissolved solids increases, in turn increasing specific conductivity.

Please note that 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.

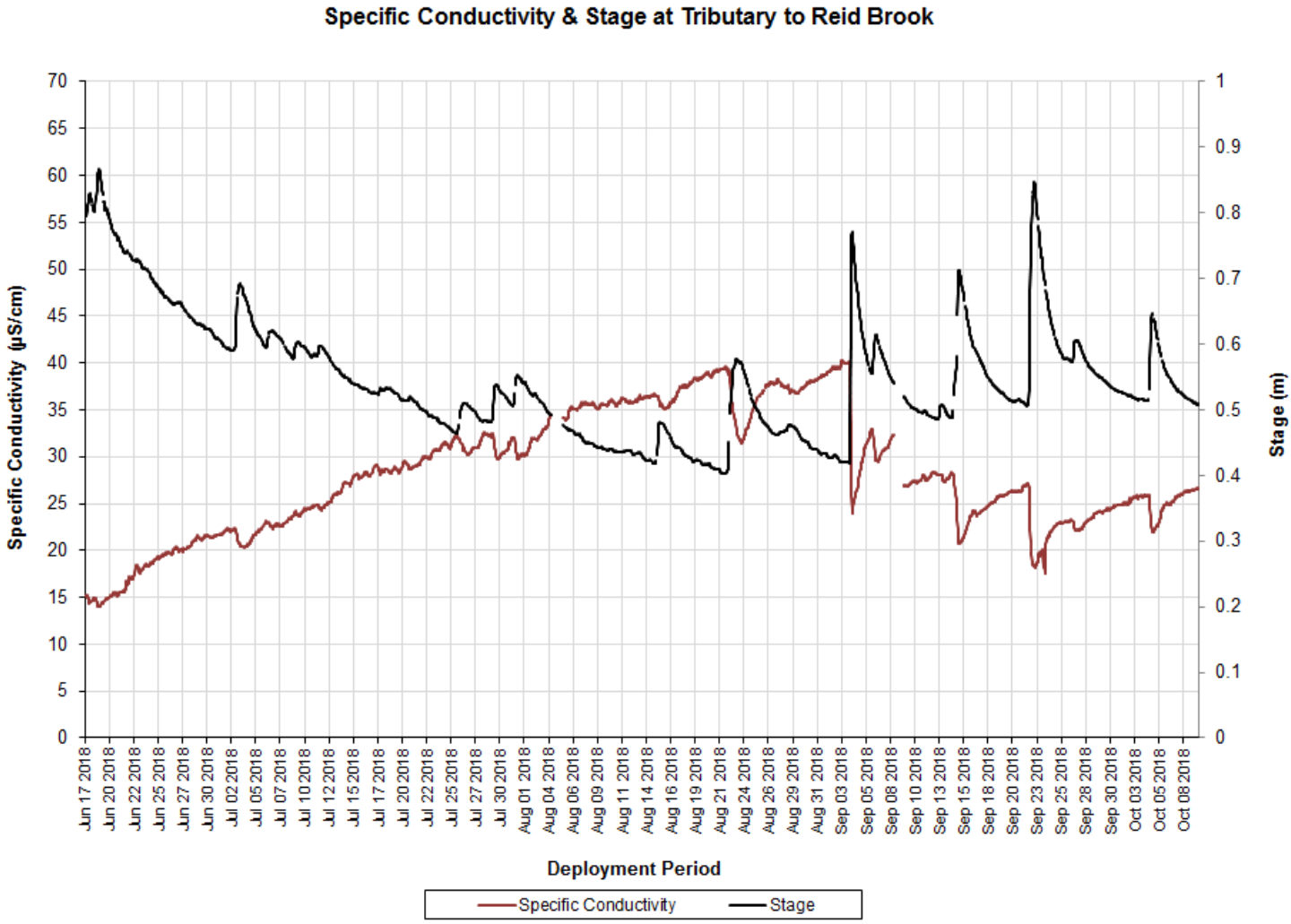

Figure 16: Specific Conductivity & Stage at Tributary to Reid Brook

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

Specific Conductivity	2018	2017	2016
Min	14	2.5	22.1
Max	40.3	40.9	44
Median	27.8	28.6	34.9

During the 2018 deployment season, dissolved oxygen concentrations ranged from 9.05mg/L to a maximum of 13.26mg/L, with a median value of 10.95mg/L. The saturation of dissolved oxygen ranged from 90.9% to 102.6%, with a median value of 94.8% (Figure 17). Dissolved oxygen values have been very consistent at this site over recent years (Table 17).

Dissolved oxygen concentrations were lowest through July and early August when water temperatures were highest. Increases in water temperature result in less dissolved oxygen being present in a water body. As water temperatures started to decrease from the middle of August onwards, dissolved oxygen concentrations started to increase.

Dissolved oxygen concentrations remained above the CCME's Guideline for the Protection of Early Life Stages (9.5mg/L) for the majority of the deployment season, with exceptions closely correlating with periods of high water temperature.

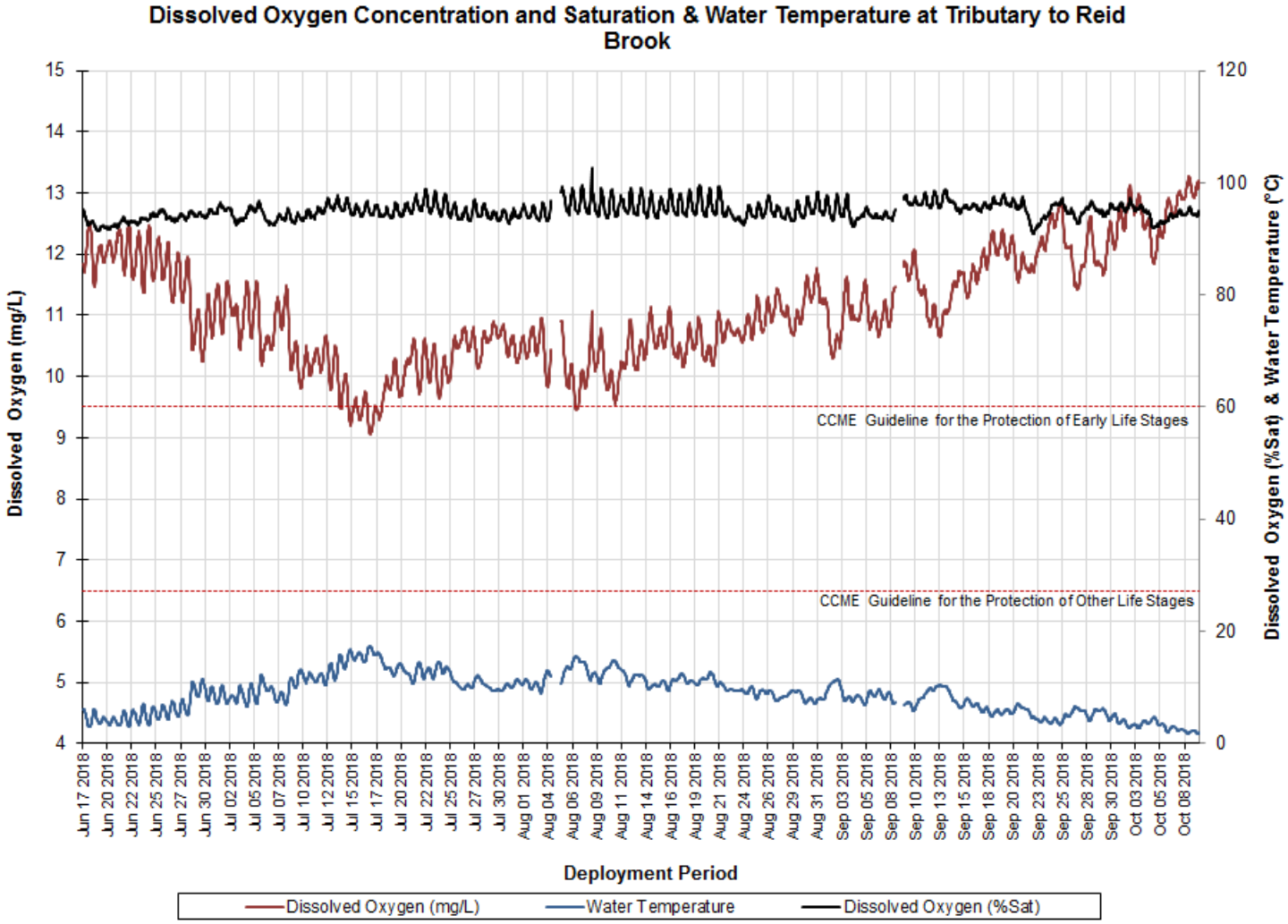

Figure17: Dissolved Oxygen Concentration and Saturation & Water Temperature at Tributary to Reid Brook

Table 17: Comparisons of Minimum, Maximum and Median from the past three deployment years

Dissolved Oxygen (mg/L)	2018	2017	2016
Min	9.05	9.66	9.29
Max	13.26	14.19	14.21
Median	10.95	11.04	11.01

Percent Saturation (%)	2018	2017	2016
Min	90.9	90.5	92.8
Max	102.6	100.6	100.4
Median	94.8	95.8	96.9

During the 2018 deployment season, turbidity ranged from 0.0NTU to a maximum of 52.8NTU, with a median value of 16.8NTU (Figure 18). A median value of 16.8NTU is much higher than expected for this station, as median values were 0.0NTU for both 2017 and 2016 (Table 18). This is the result of a suspected calibration error affecting baseline turbidity values recorded during the first deployment period. Data was maintained for reporting purposes because turbidity events were still observable. Data from the third deployment period was removed from the report due to a serious calibration error, which caused turbidity values to remain constant at 100.0NTU for the entire deployment period.

Many of the turbidity increases at this site corresponded with rainfall events and subsequent runoff. Observed turbidity events 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 and precipitation.

Please note that 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.

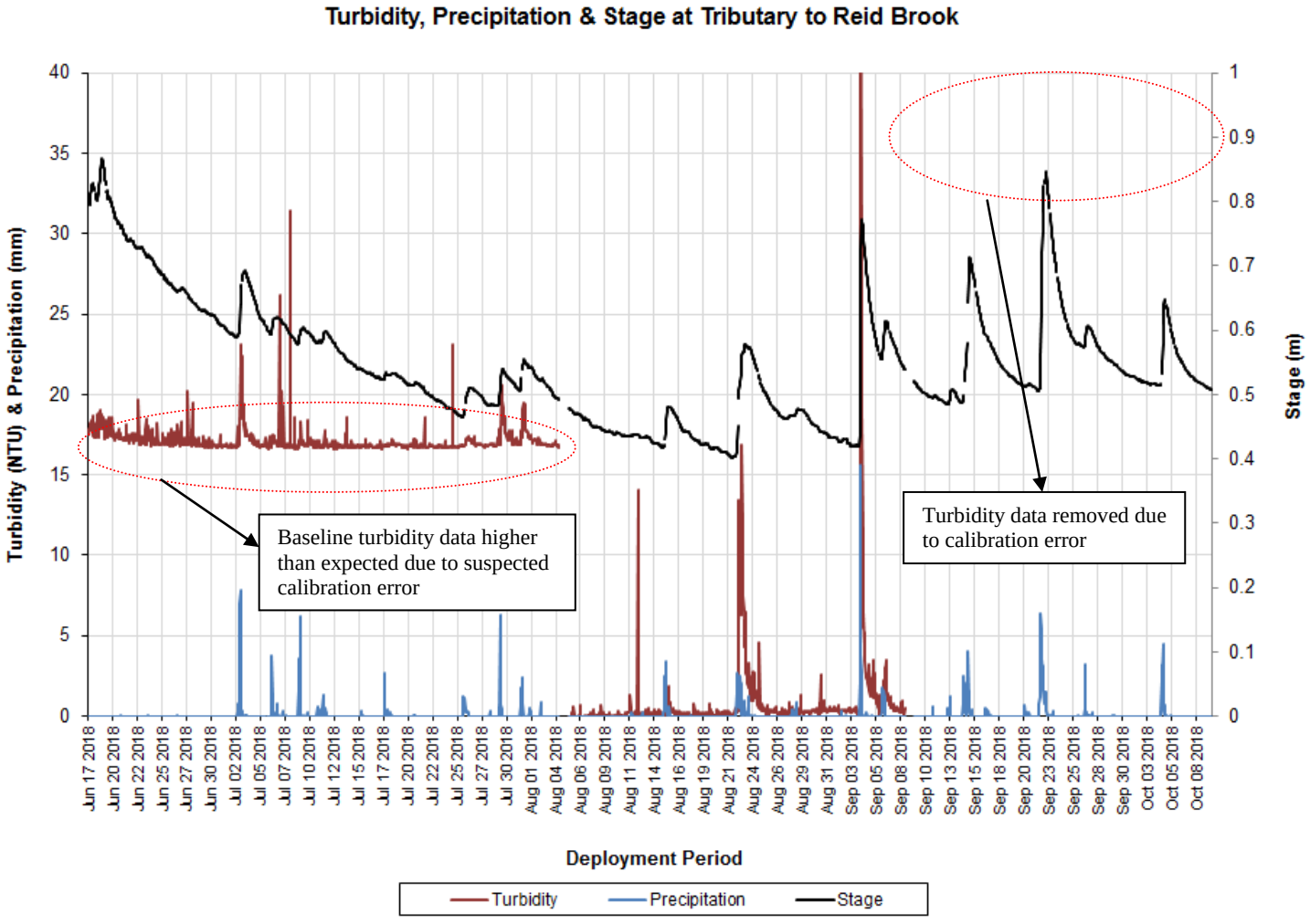

Figure 18: Turbidity, Precipitation & Stage at Tributary to Reid Brook

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

Turbidity	2018	2017	2016
Min	0.0	0.0	0.0
Max	52.8	287.2	100.2
Median	16.8*	0.0	0.0

Reid Brook below Tributary

During the 2018 deployment season, water temperature ranged from 1.86°C to a maximum of 18.02°C, with a median value of 9.39°C (Figure 19). Water temperature at this site has been quite consistent over recent years, with median values of 9.21°C in 2017 and 9.52°C in 2016 (Table 19).

Water temperatures were highest through mid-July and early August as air temperatures increased with the summer season (Figure 19 & 20). From the middle of August onwards, water temperatures steadily declined as ambient air temperatures also declined (Figure 20)

Please note that 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.

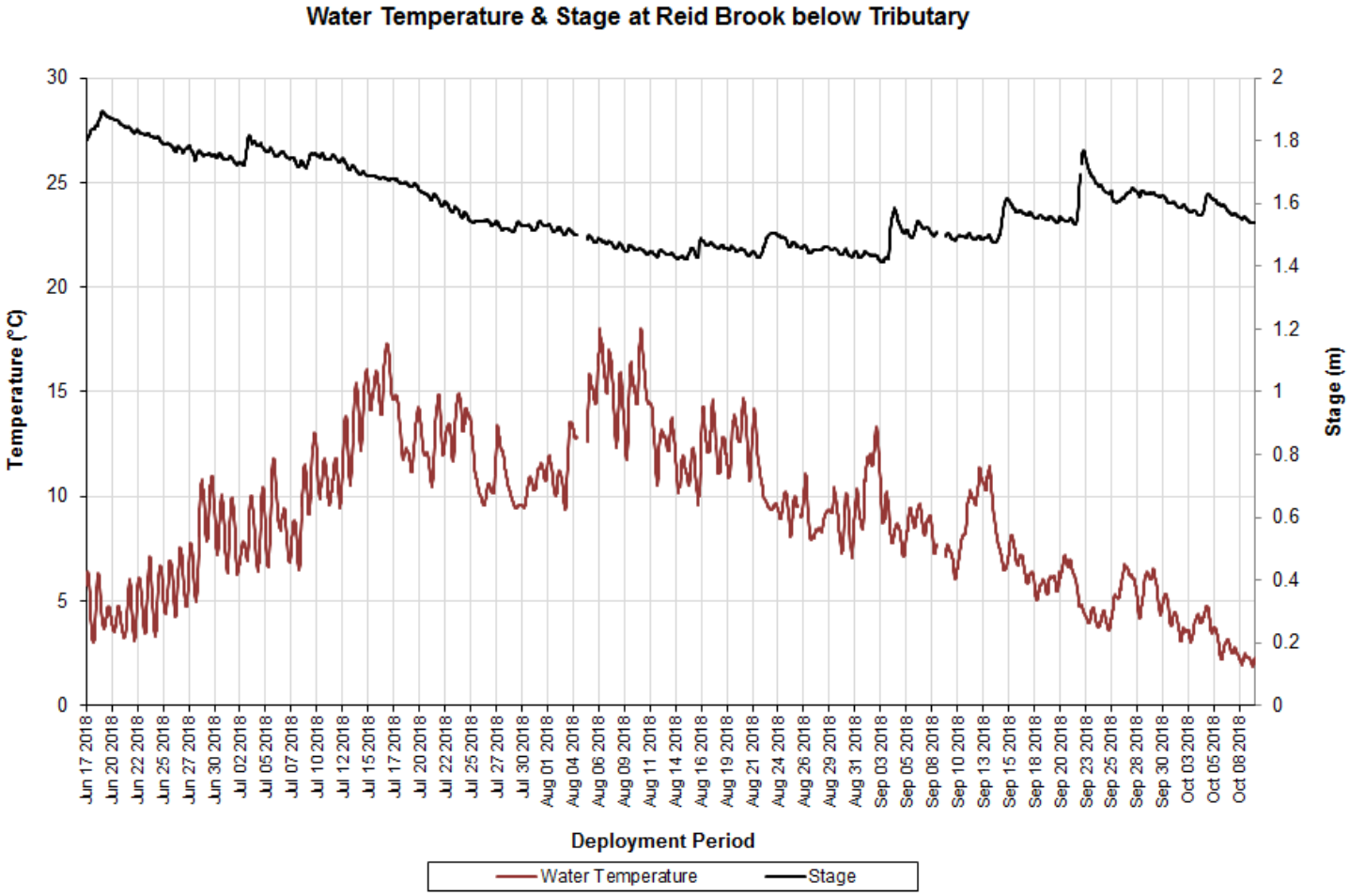

Figure 19: Water Temperature & Stage at Reid Brook below Tributary

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

Water Temperature	2018	2017	2016
Min	1.86	0.17	0.19
Max	18.02	16.81	17.34
Median	9.39	9.21	9.52

Water temperatures showed a close relationship with air temperatures (Figure 20). Increases and decreases in air temperatures were reflected in water temperatures. Air temperatures fluctuate to a greater extent each day when compared with water temperatures.

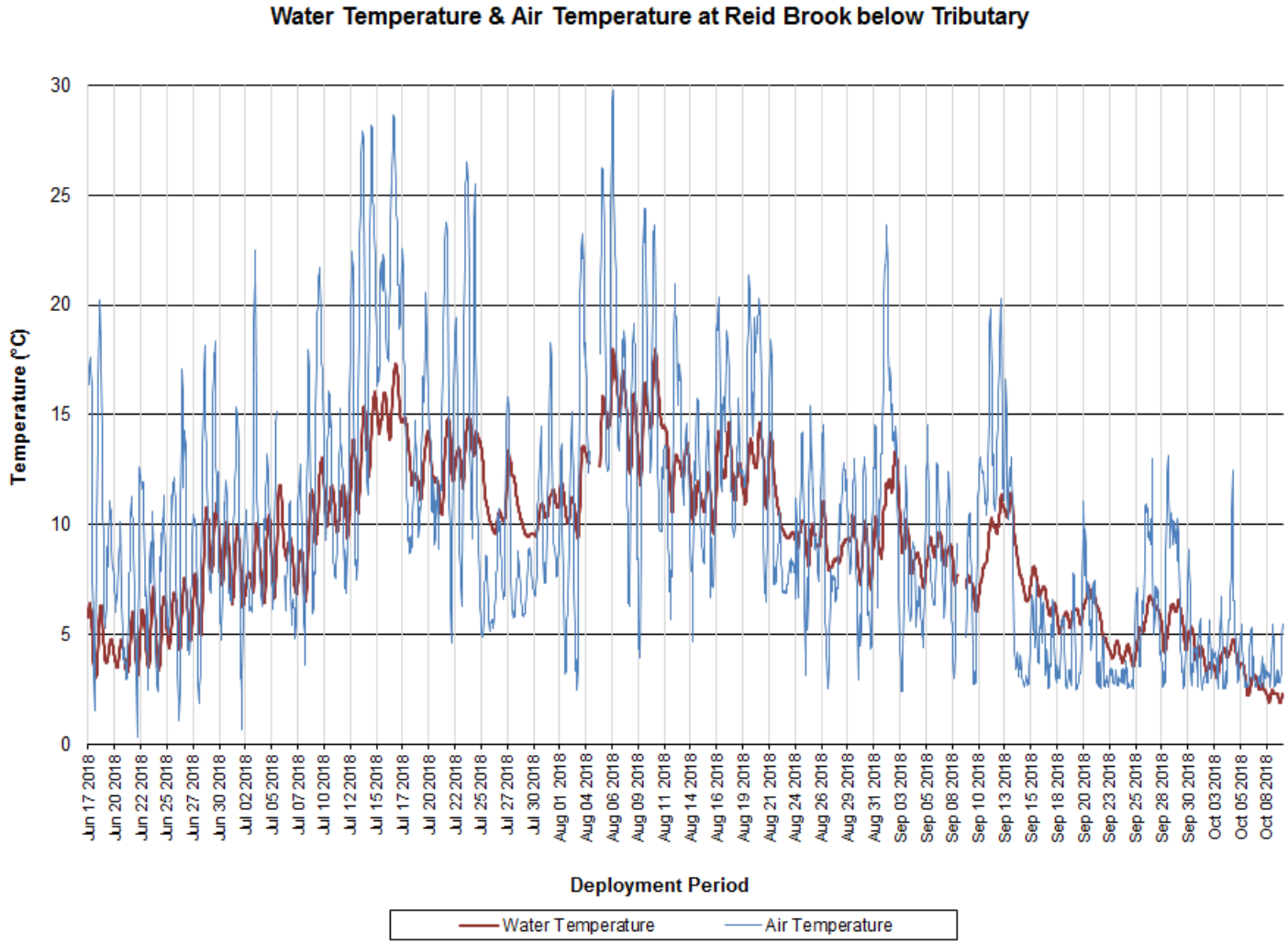

Figure 20: Water Temperature & Air Temperature at Reid Brook below Tributary

During the 2018 deployment season, pH data ranged from 5.31 to a maximum of 7.84 pH units, with a median value of 7.33 pH units (Table 20).

pH values were below the CCME's Guideline for the Protection of Aquatic Life during the first deployment period, but were within the guidelines for the remainder of the deployment season (Figure 21). This could be attributed to a slight calibration error with the field sonde during the first deployment period, steadily decreasing stage levels, or a combination of the two.

Please note that 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.

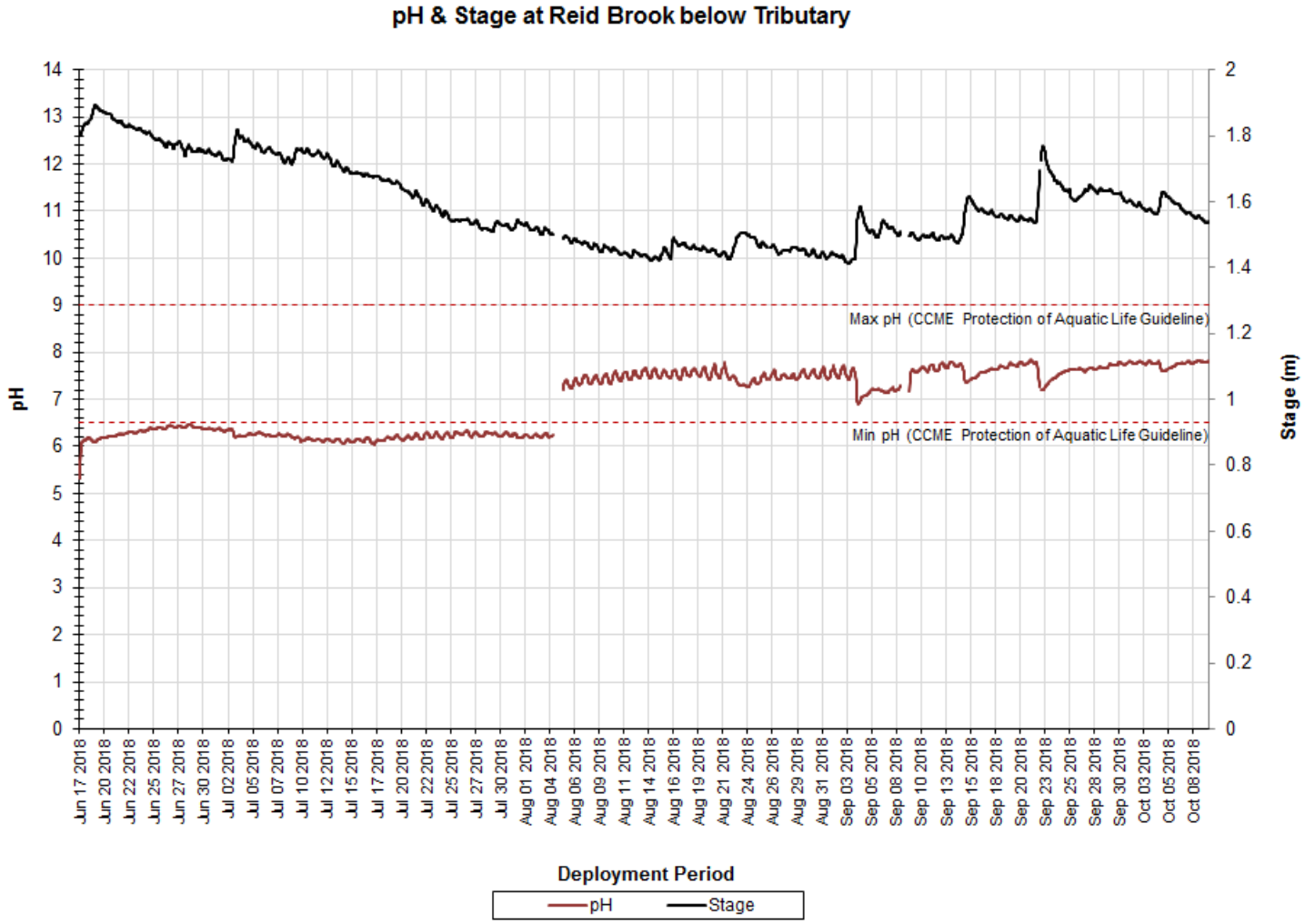

Figure 21: pH & Stage at Reid Brook below Tributary

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

pH	2018	2017	2016
Min	5.31	6.06	6.31
Max	7.84	7.48	7.58
Median	7.33	6.85	6.72

During the 2018 deployment season, specific conductivity ranged from 14.3µS/cm to a maximum of 38.1µS/cm, with a median value of 29.2µS/cm (Table 21).

Specific conductivity generally increased over the course of deployment, exhibiting an inverse relationship with stage. As stage decreased at this station, specific conductivity increased. Increases in stage level dilute dissolved solids in the water column, in turn reducing specific conductivity. Inversely, as stage decreases specific conductivity increases as dissolved solids become more concentrated in the water column (Figure 22).

Please note that 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.

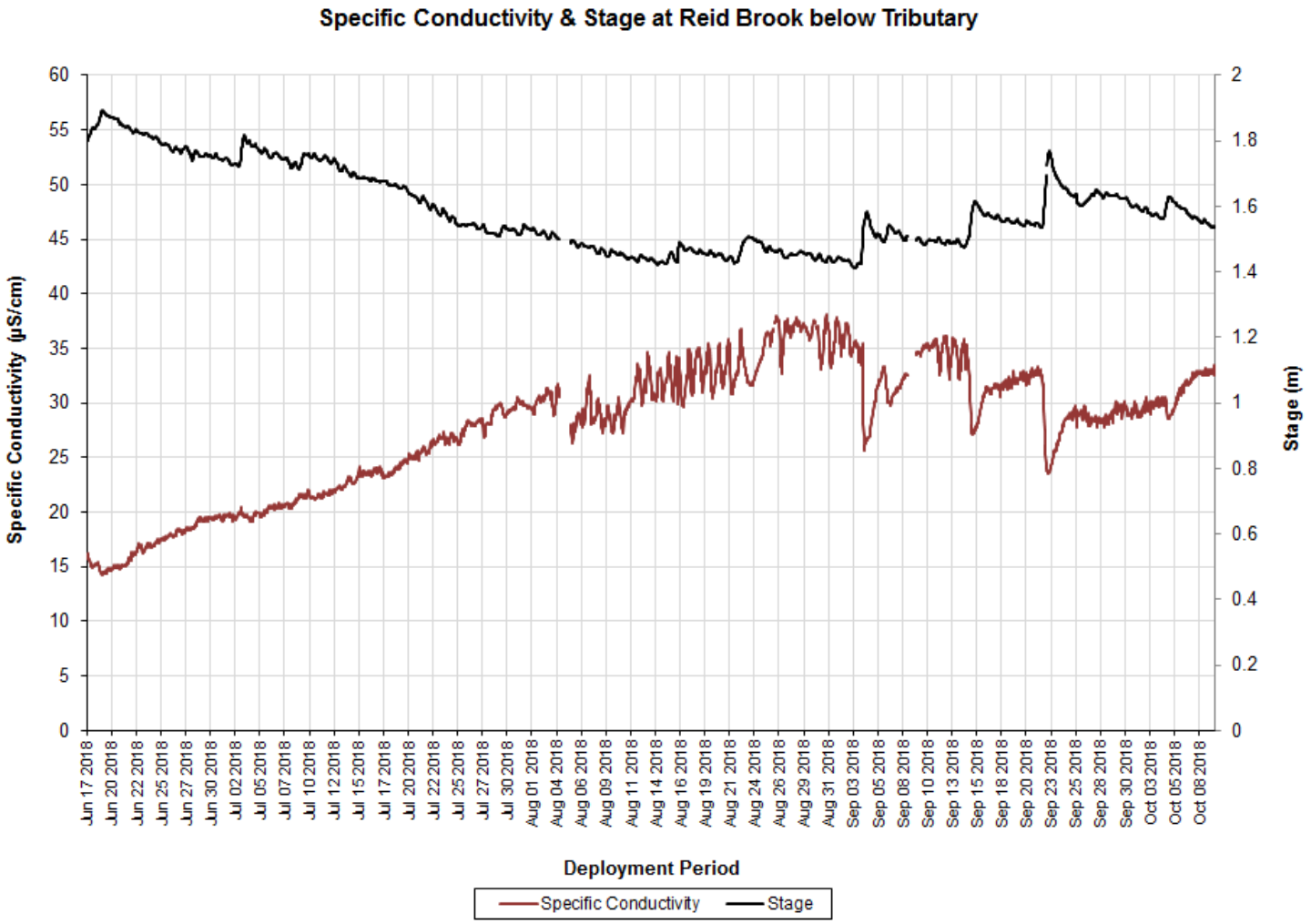

Figure 22: Specific Conductivity & Stage at Reid Brook below Tributary

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

Specific Conductivity	2018	2017	2016
Min	14.3	16.1	18.5
Max	38.1	43	44.9
Median	29.2	28.7	32.2

During the 2018 deployment season, dissolved oxygen concentration ranged from 9.03mg/L to a maximum of 13.22mg/L, with a median value of 10.89mg/L. Saturation of dissolved oxygen ranged from 91.4% to 103.9%, with a median value of 95.6% (Figure 23). Median values for both dissolved oxygen concentration and percent saturation were consistent with values from previous deployment seasons (Table 22).

Observed dissolved oxygen concentrations exhibited typical seasonal trends and were inversely related to water temperature. Dissolved oxygen concentration decreased through June and early July as water temperatures warmed, was lowest throughout late July and early August, then began to increase again through September and October as water temperature decreased (Figure 23).

Dissolved oxygen concentrations remained above the CCME's Guideline for the Protection of Early Life Stages (9.5mg/L) for the majority of the deployment season, with exceptions correlating closely with periods of higher water temperatures.

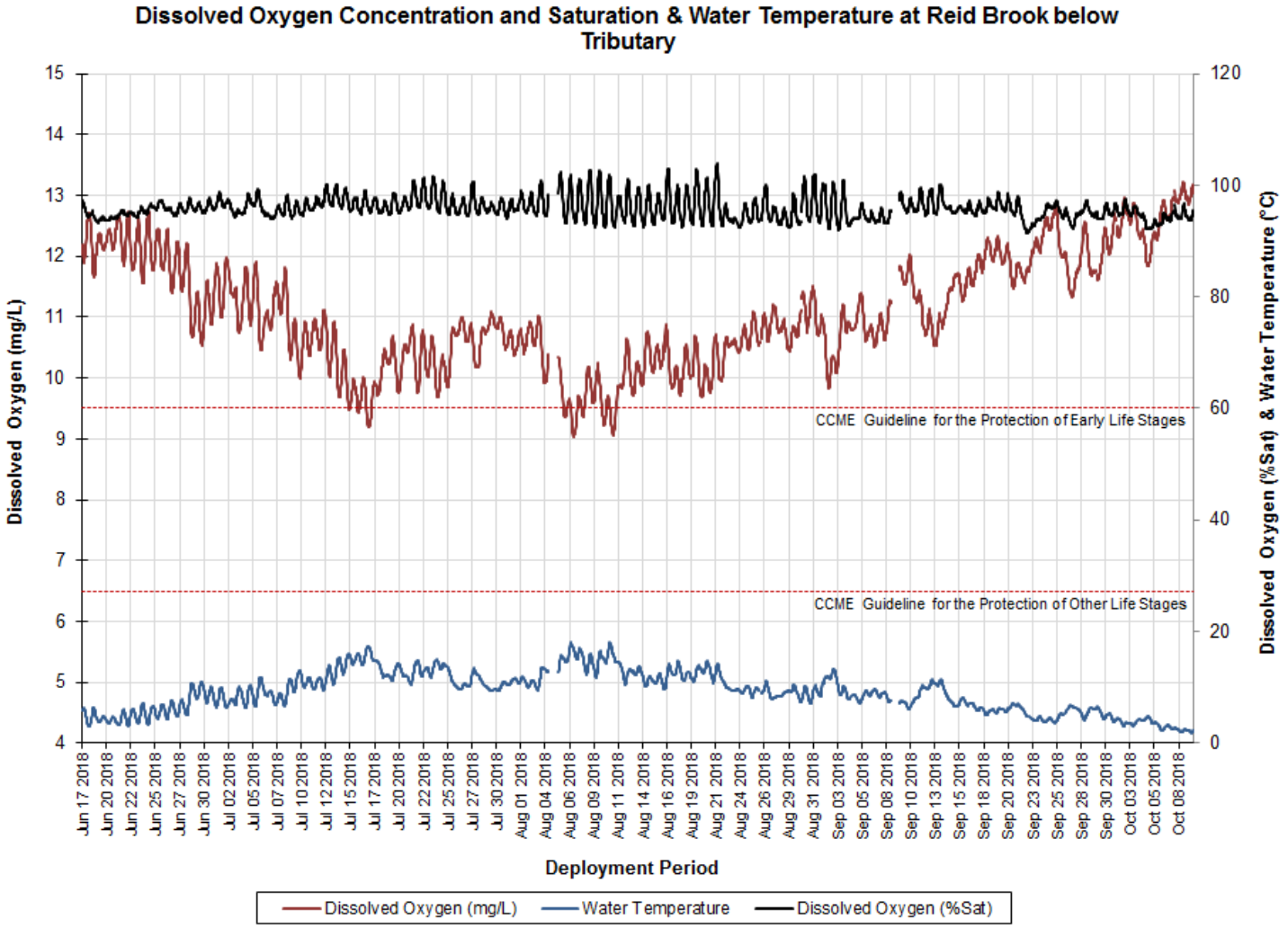

Figure 23: Dissolved Oxygen Concentration and Saturation & Water Temperature at Reid Brook below Tributary

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

Dissolved Oxygen (mg/L)	2018	2017	2016
Min	9.03	9.78	9.1
Max	13.22	13.56	13.88
Median	10.89	11.22	10.90

Percent Saturation (%)	2018	2017	2016
Min	91.4	89.4	91.6
Max	103.9	108.9	103.9
Median	95.6	96.8	96.1

During the 2018 deployment season, turbidity ranged from 0.0NTU to a maximum of 366.1NTU, with a median value of 0.0NTU (Table 23).

Over the course of the deployment season, increases in turbidity generally corresponded with increases in stage and precipitation events. This is to be expected as increased precipitation and run-off may introduce natural organic matter into the water column. Turbidity levels quickly returned to background levels following stage increases and precipitation events (Figure 24). Turbidity is graphed to a maximum of 20NTU below to allow better observation of the relationship between turbidity and precipitation.

Please note that 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.

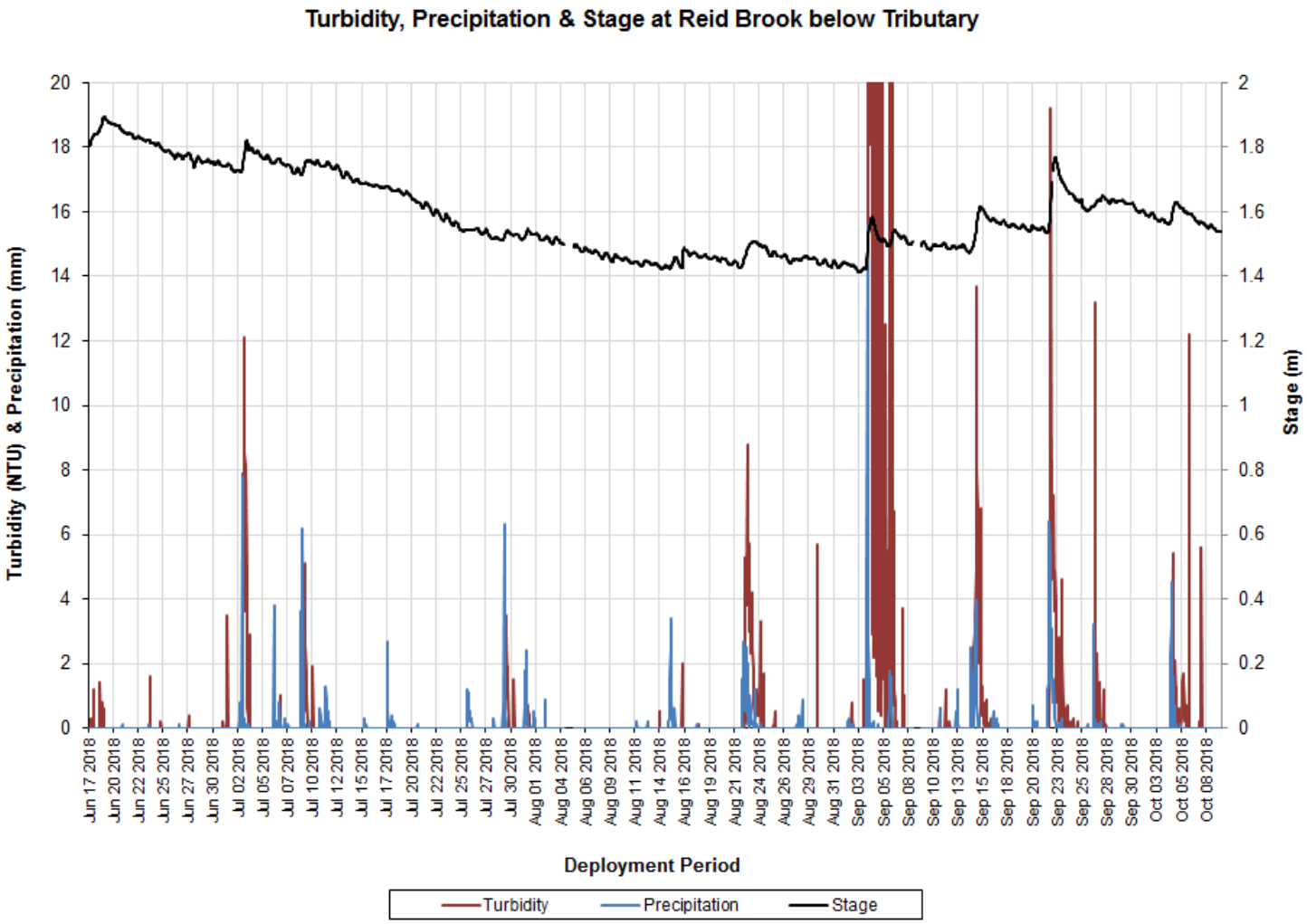

Figure 24: Turbidity, Precipitation & Stage at Reid Brook below Tributary

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

Turbidity	2018	2017	2016
Min	0.0	0	0.0
Max	366.1	54.6	64.5
Median	0.0	0.8	0.0

Multi-Station Comparison

The following section of this report focuses on comparisons between the four stations in the Voisey's Bay real-time network.

Temperature

During the 2018 deployment season, water temperatures at all four real-time stations ranged from 1.18°C to a maximum of 21.42°C, both at Camp Pond Brook below Camp Pond.

Water temperature trends were similar at each of the four RTWQ stations, and closely resembled ambient air temperatures (Figure 25). Water temperatures at Camp Pond Brook below Camp Pond, Reid Brook below Tributary and Tributary to Reid Brook all followed a similar trend, peaking in late July/early August. Reid Brook at Outlet of Reid Pond is generally slower to respond to changes in air temperatures since it is a larger volume of water and takes longer to acclimatize. Water temperature at Reid Brook at Outlet of Reid Pond was also very stable through the end of June while Reid Pond was still covered in ice.

Tributary to Reid Brook and Reid Brook below Tributary had very similar water temperature data. This is to be expected as Tributary to Reid Brook flows directly into Reid Brook below Tributary. Both are fast flowing sites with similar environmental influences. Camp Pond Brook below Camp Pond exhibits more pronounced changes in water temperature compared to the other stations, recording the highest single temperature in the network of 21.42°C, as well as the highest median temperature of 11.34°C (Table 24).

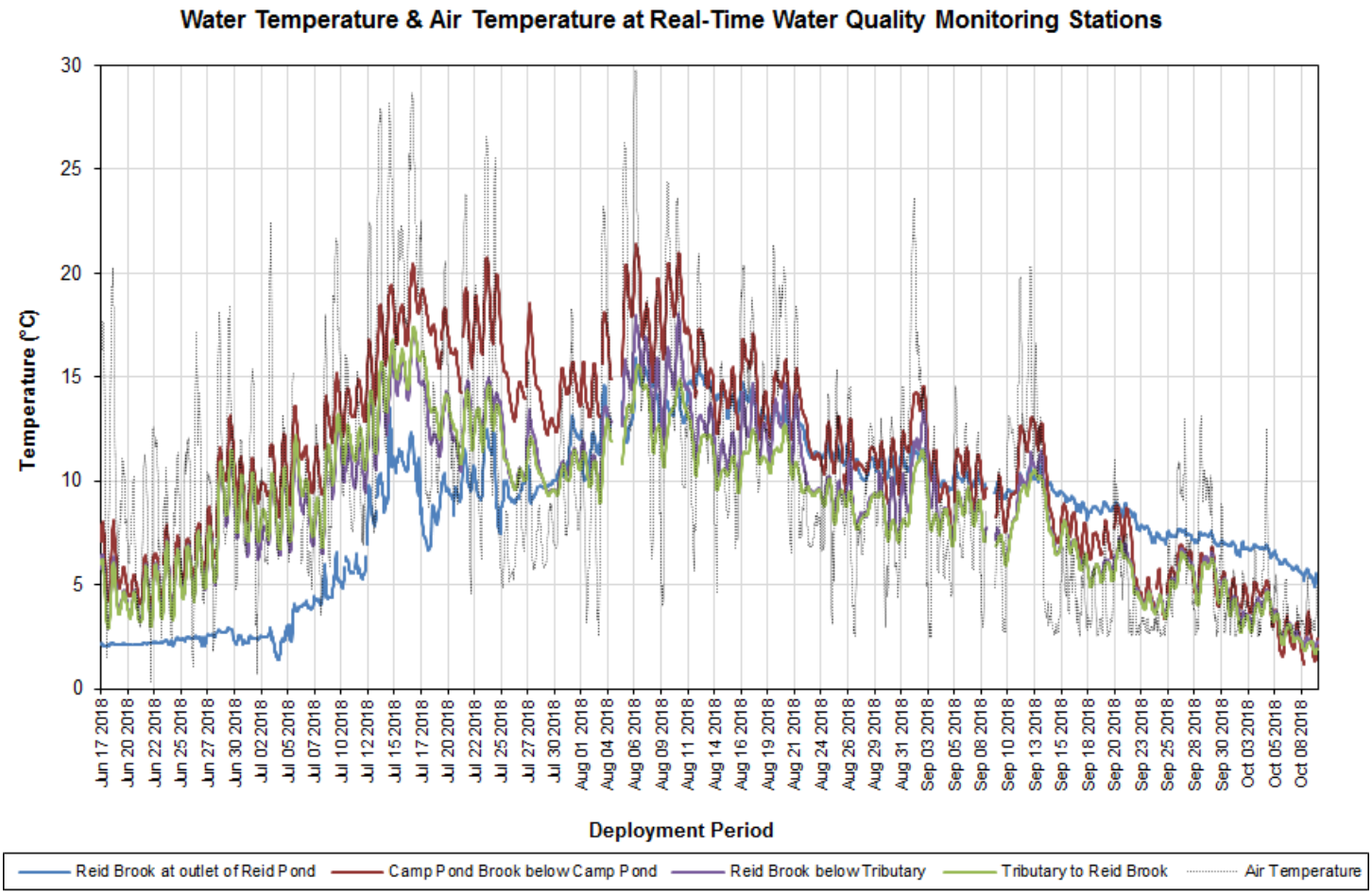

Figure 25: Water Temperature & Air Temperature at all RTWQ Stations

Table 24: Comparisons of Minimum, Maximum and Median from all RTWQ stations

Temperature (°C)	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	1.37	1.18	1.86	1.7
Max	15.97	21.42	18.02	17.4
Median	9.34	11.34	9.39	9.2

pH

During the 2018 deployment season, median pH values at all four real-time stations ranged from 6.83 pH units at Tributary to Reid Brook to 7.33 pH units at Reid Brook below Tributary (Table 25).

pH data for all stations followed a similar trend. The Reid Brook at Outlet of Reid Pond station is at the outlet of a pond and has different factors influencing pH as compared to the other sites, and tends to exhibit a wider range of pH values. Camp Pond Brook below Camp Pond, Reid Brook below Tributary, and Tributary to Reid Brook all showed similar pH movements across the deployment season (Figure 26).

There were several events where pH fell below the minimum CCME Guideline for the Protection of Aquatic Life. When compared to precipitation data (Figure 26), there is an evident change in pH levels during higher and longer precipitation events. Many of the fluctuations in the pH data across the real-time stations corresponded closely with precipitation events.

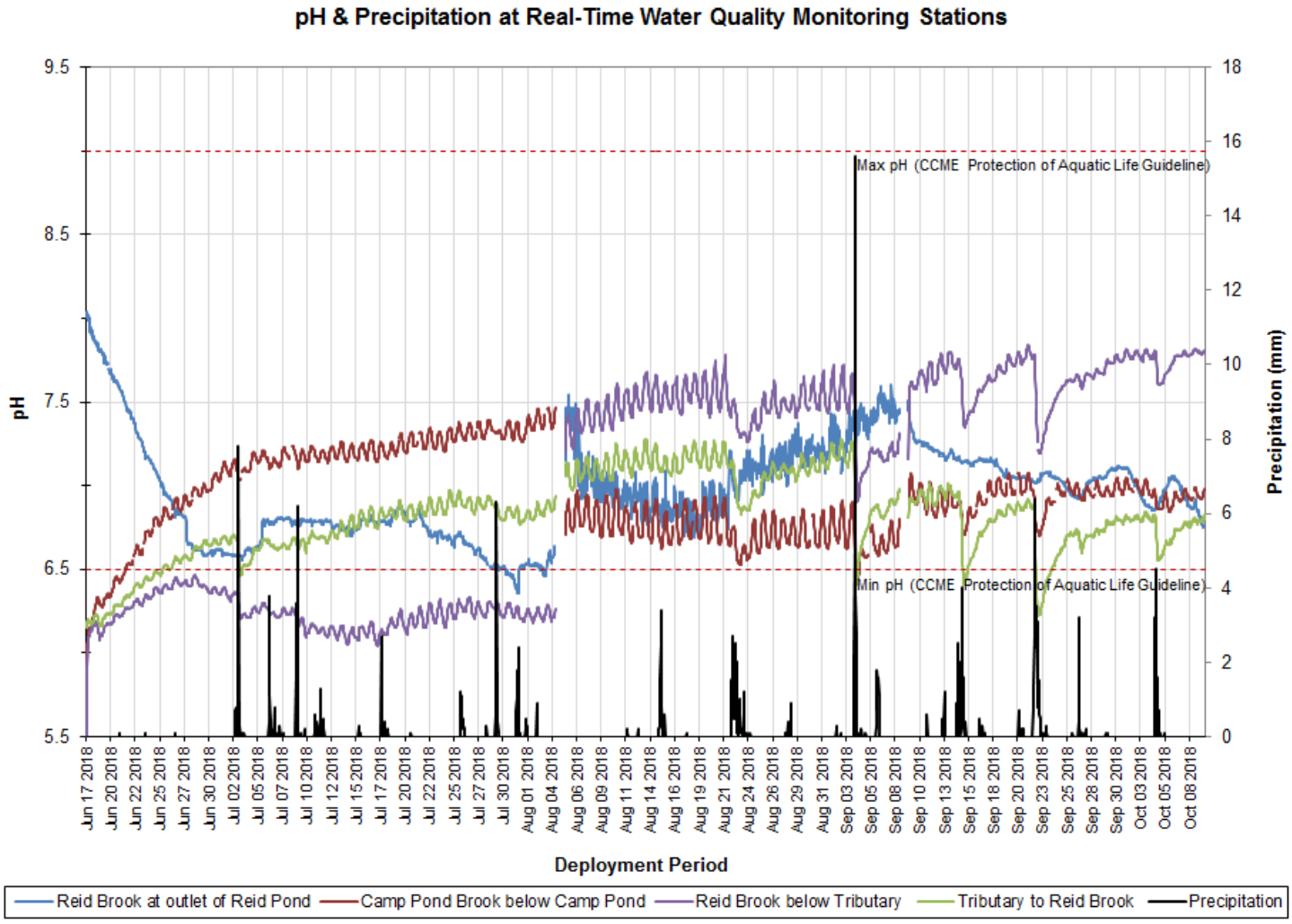

Figure 26: pH & Precipitation at all RTWQ Stations

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

pH (units)	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	6.36	5.68	5.31	6.15
Max	8.04	7.47	7.84	7.28
Median	6.96	6.94	7.33	6.83

Specific Conductivity

During the 2018 deployment season, specific conductivity medians at all stations ranged from 11.8µS/cm at Reid Brook at Outlet of Reid Pond to a maximum of 35.9µS/cm at Camp Pond Brook below Camp Pond (Table 26).

Reid Brook at Outlet of Reid Pond maintained a stable specific conductivity level across the deployment season; the higher level recorded during the second deployment period is being attributed to a calibration error. Stable conductivity levels are to be expected at this station since it is located in an established pond environment. Reid Brook below Tributary and Tributary to Reid Brook had similar conductivity levels and followed a similar trend. Camp Pond Brook below Camp Pond displayed greater and more fluctuating specific conductivity levels. This trend is typical of this station, as it is located closer to the Voisey's Bay mine site than the other stations (Figure 27).

Reid Brook below Tributary, Tributary to Reid Brook and Camp Pond Brook all generally displayed increasing conductivity levels across the deployment season. This is to be expected as stage levels decrease and suspended solids become more concentrated in the water column. As Reid Brook at Outlet of Reid Pond is a more stable water quality environment, conductivity data remained reasonably consistent across the deployment season.

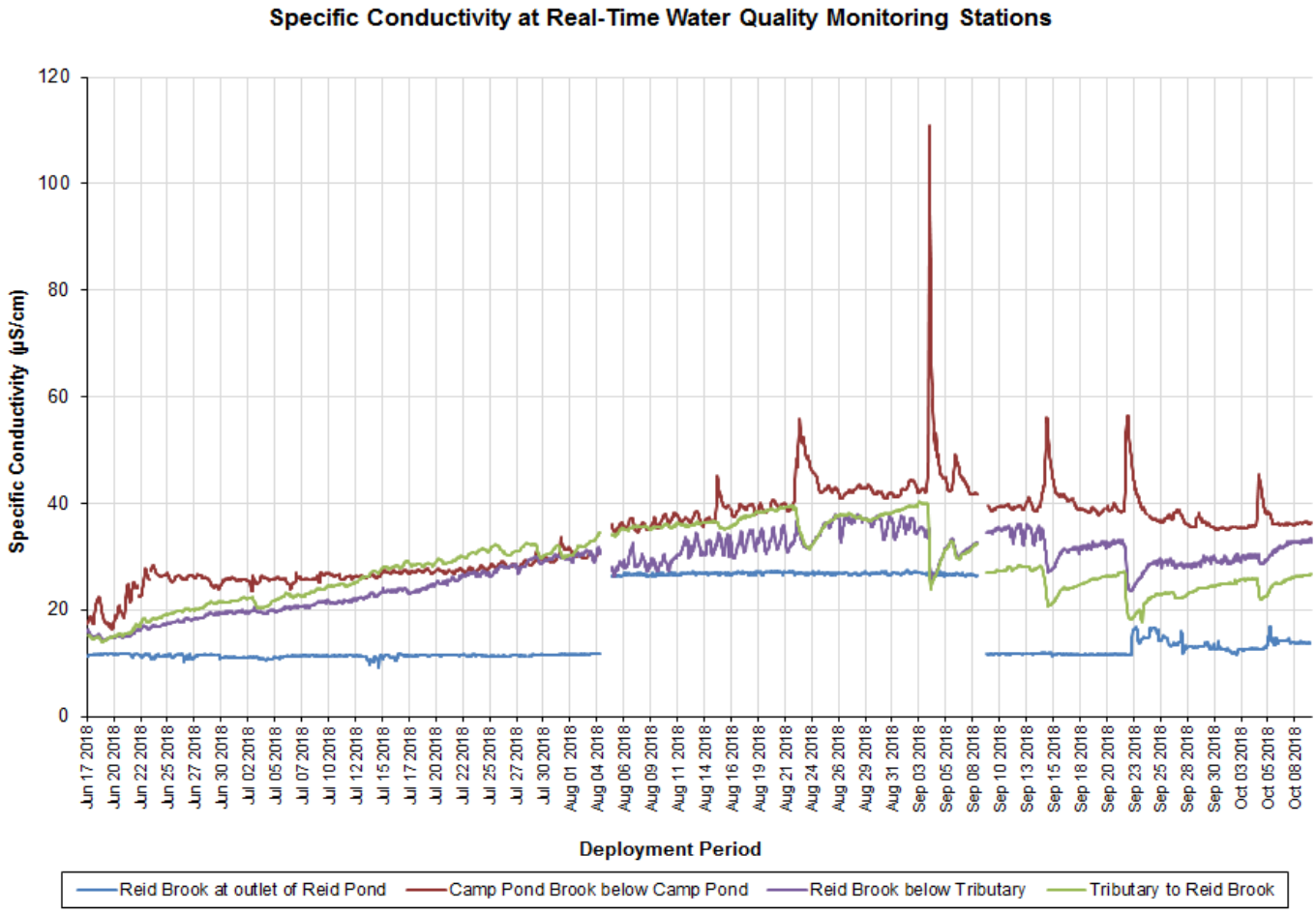

Figure 27: Specific Conductivity at all RTWQ Stations

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

Specific Conductivity	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	9.1	16.4	14.3	14
Max	27.5	111	38.1	40.3
Median	11.8	35.9	29.2	27.8

Dissolved Oxygen Concentration and Saturation of Dissolved Oxygen

During the 2018 deployment season, dissolved oxygen concentration medians ranged from 10.38mg/L at Camp Pond Brook below Camp Pond to a maximum of 11.23mg/L at Reid Brook at Outlet of Reid Pond (Table 27). Dissolved oxygen concentrations displayed a typical inverse relationship with both water and ambient air temperatures at all stations (Figure 28a). Dissolved oxygen levels were most stable at Reid Brook below Reid Pond, whereas there was greater fluctuation at the other three stations.

During the warmer summer season from early July to late August, dissolved oxygen levels at Camp Pond Brook below Camp Pond, Reid Brook below Tributary, and Tributary to Reid Brook occasionally fell below the CCME's Guideline of 9.5mg/L for the Protection of Early Life Stages (Figure 28a).

The observed changes in dissolved oxygen levels are not unusual and are to be expected during warmer temperatures. As air temperatures decreased into the cooler fall season, dissolved oxygen levels began to steadily increase.

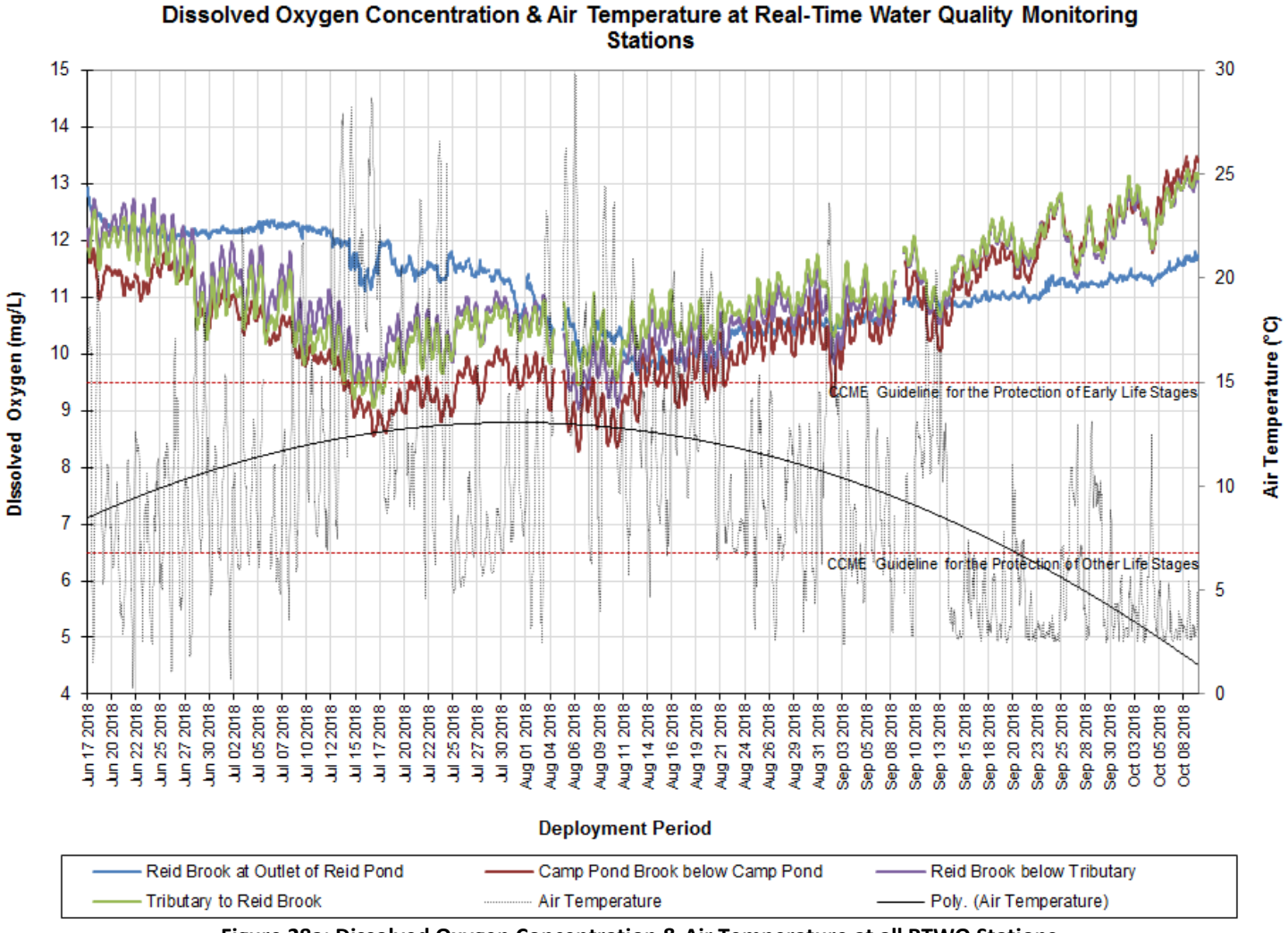

Figure 28a: Dissolved Oxygen Concentration & Air Temperature at all RTWQ Stations

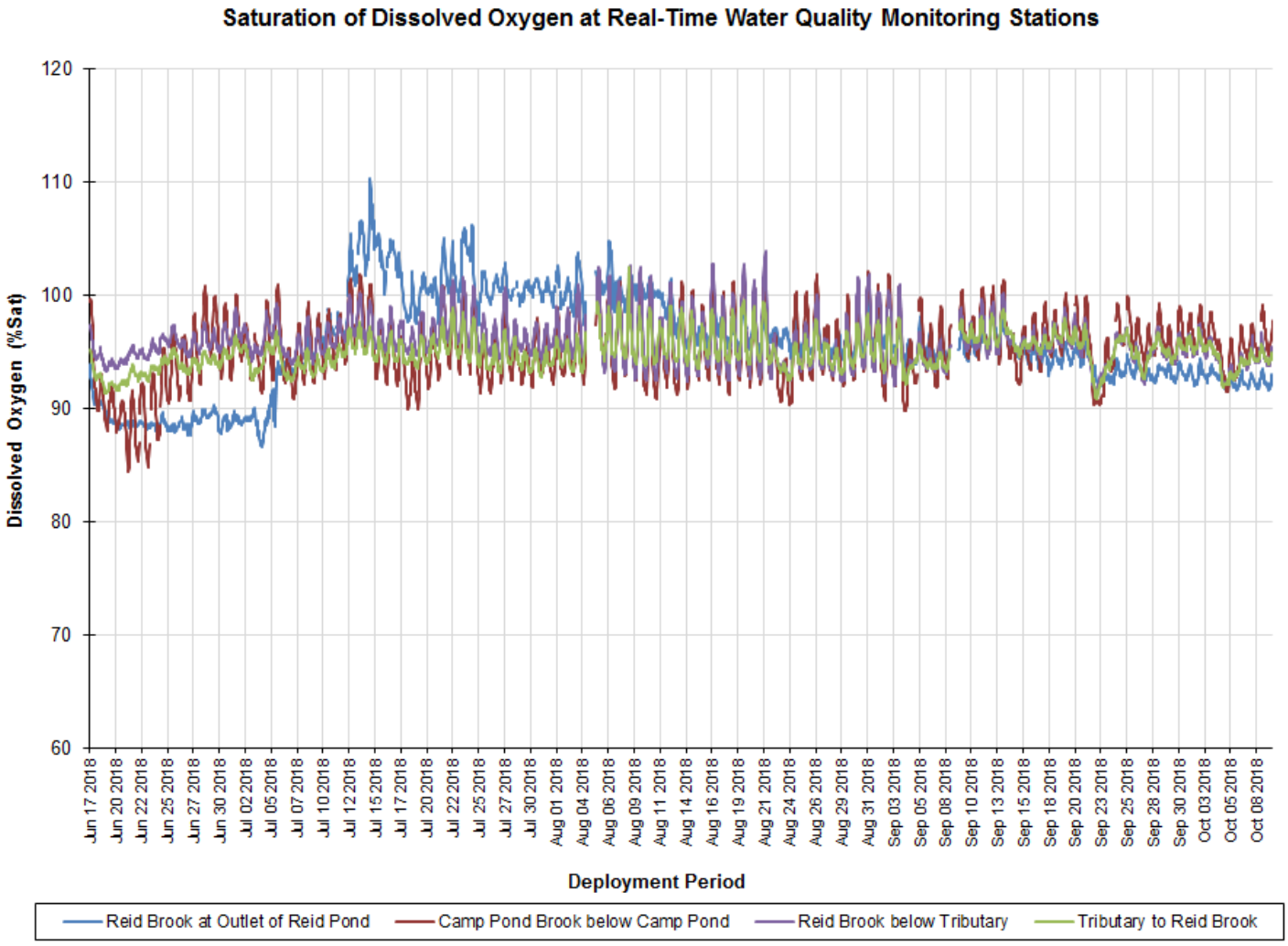

Figure 28b: Saturation of Dissolved Oxygen at all RTWQ Stations

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

	Dissolved Oxygen (mg/L)				Dissolved Oxygen (% Saturation)			
	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	9.63	8.27	9.03	9.05	86.6	84.4	91.4	90.9
Max	12.92	13.48	13.22	13.26	110.4	102.2	103.9	102.6
Median	11.23	10.38	10.89	10.95	95.6	95.2	95.6	94.8

Turbidity

During the 2018 deployment season, turbidity ranged from 0.0NTU to a maximum of 446NTU (Table 28). It is not unusual to see significant variability in turbidity data, as this parameter is influenced by many factors (e.g. precipitation, runoff from surrounding environments, high water flow (bubbles) and debris, such as leaf litter). Median turbidity values at Reid Brook at Outlet of Reid Pond, Camp Pond Brook below Camp Pond and Reid Brook below Tributary indicate that there is very little background turbidity at these stations, which is to be expected. The higher-than-expected median turbidity value observed at Tributary to Reid Brook is being attributed to a calibration error with the field sonde during the first deployment period (Figure 29b).

Figure 29a displays all turbidity data for the four real-time stations, as well as precipitation data. In contrast, Figure 29b displays turbidity data on a scale of 100NTU. The use of a smaller scale allows for more accurate comparison of turbidity events between the different stations, and clearly shows the relationship between precipitation events and increased turbidity levels.

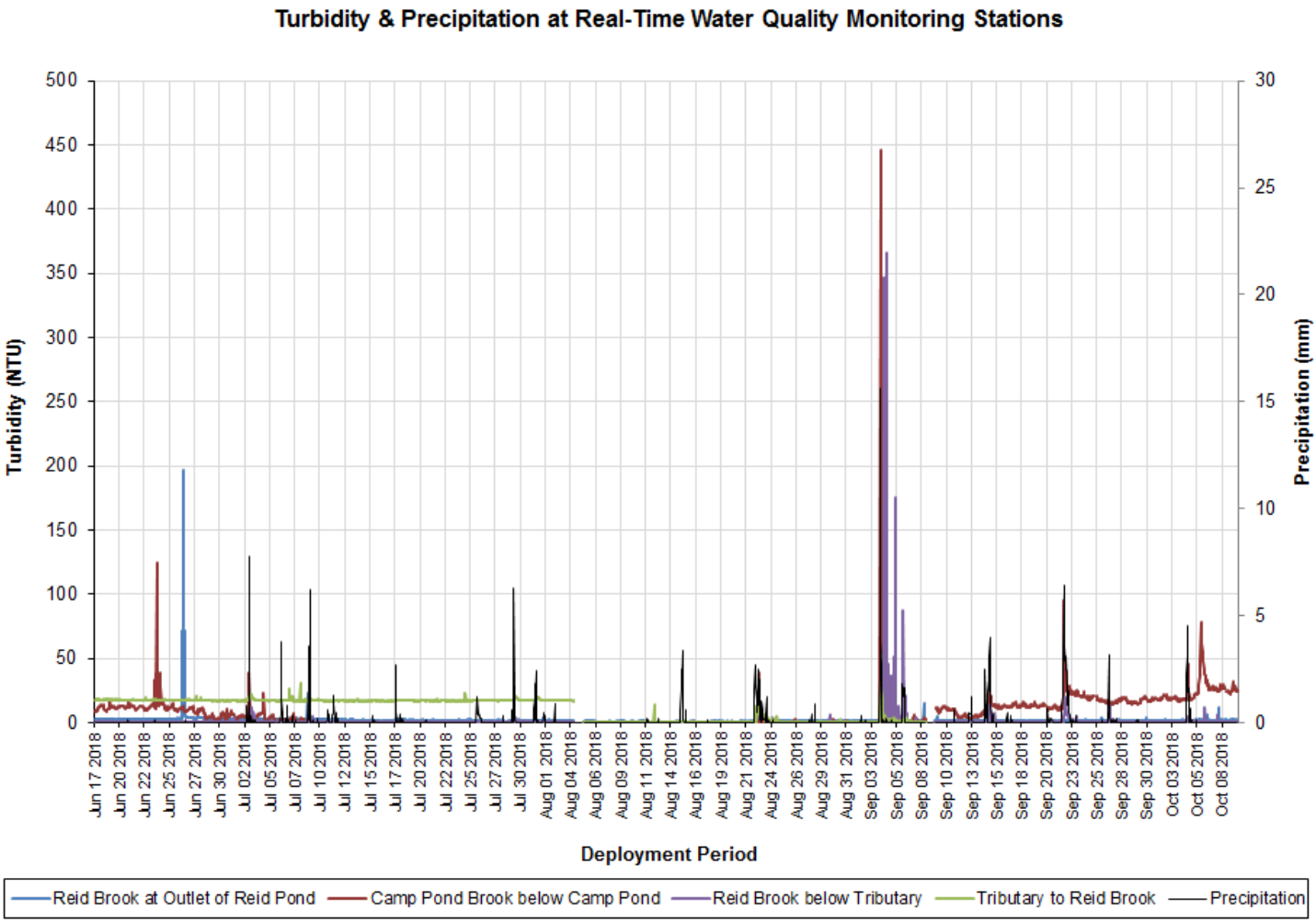

Figure 29a: Turbidity & Precipitation at all RTWQ Stations

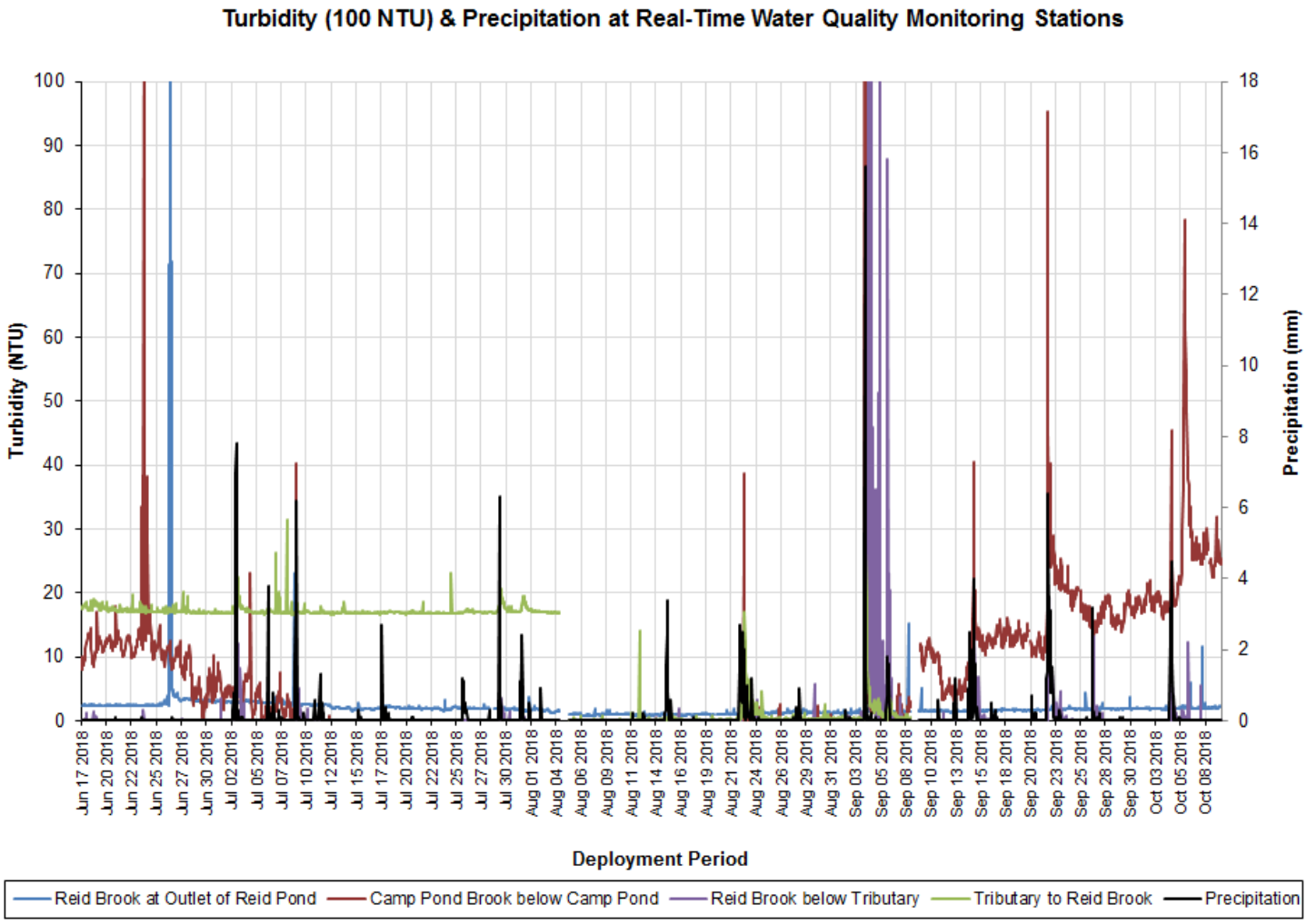

Figure 29b: Turbidity & Precipitation at all RTWQ Stations (graphed to 100 NTU)

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

Turbidity (NTU)	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	0.7	0.0	0.0	0.0
Max	196.4	446	366.1	52.8
Median	1.8	0.0	0.0	16.8*

Stage

During the 2018 deployment season, stage levels started high and generally decreased over the course of deployment at all stations. This was likely the result of ground thaw and snow/ice melt from the surrounding river banks. Camp Pond Brook below Camp Pond exhibited the least variation in stage level, but did react to high precipitation events (Figure 30).

There is an obvious relationship between precipitation and stage. Tributary to Reid Brook, Reid Brook below Tributary, and Reid Brook at Outlet of Reid Pond had very obvious responses to precipitation events. Precipitation events had slightly less influence at Camp Pond Brook below Camp Pond as this station is in close proximity to the lake, but the relationship is still evident (Figure 30).

Please be advised that WSC is responsible for the QA/QC of water quantity data. Corrected data can be obtained upon request. Stage data is included in this report to highlight the relationship with water quality parameters.

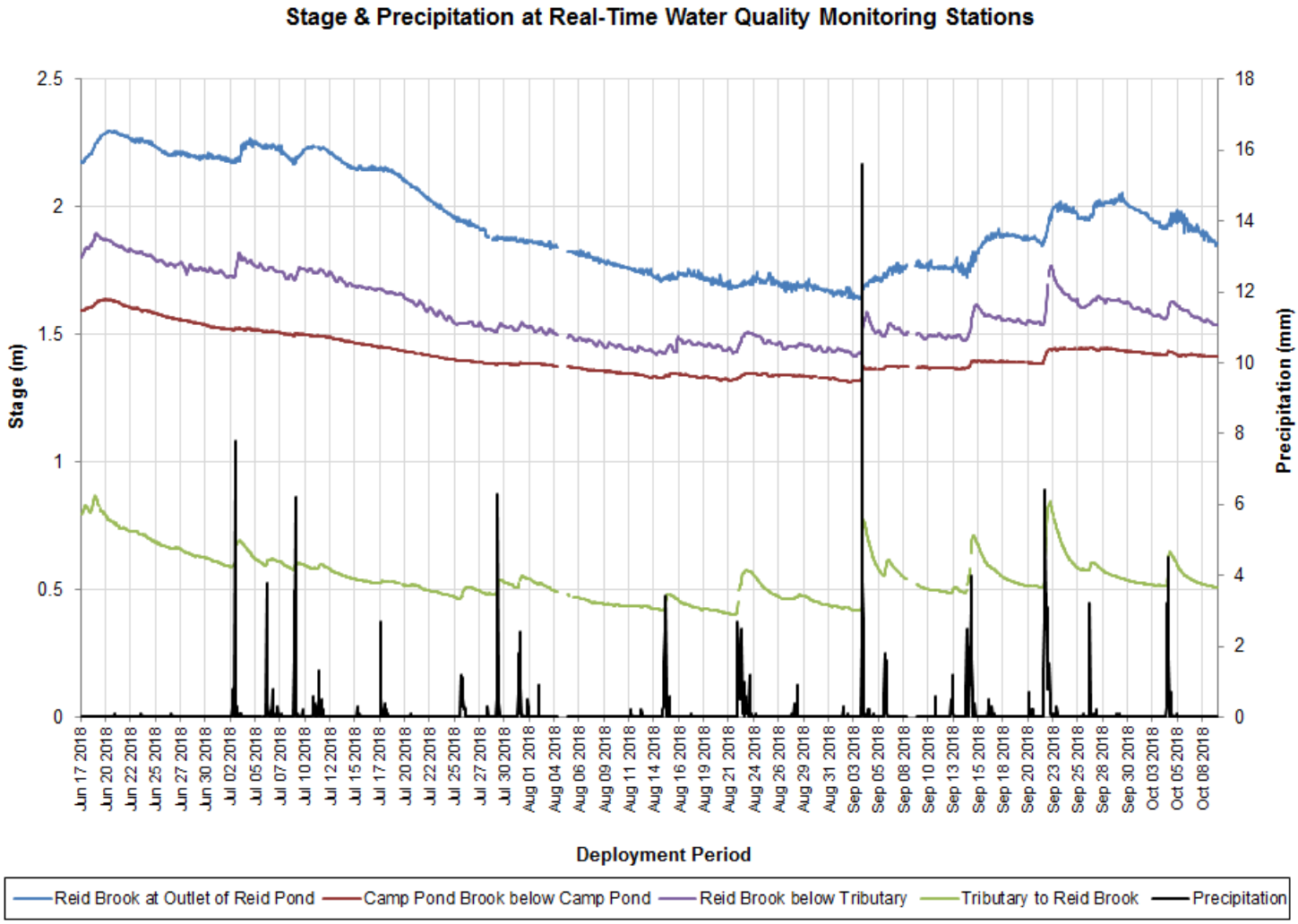

Figure 30: Stage & Precipitation at all RTWQ Stations

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

Stage (m)	Reid Brook at Outlet of Reid Pond	Camp Pond Brook below Camp Pond	Reid Brook below Tributary	Tributary to Reid Brook
Min	1.639	1.311	1.413	0.402
Max	2.297	1.638	1.895	0.867
Median	1.906	1.396	1.561	0.528
Difference (Max/Min)	0.658	0.327	0.482	0.465

Conclusions

The 2018 deployment season ran from June 17 until October 9, and consisted of three deployment periods.

The majority of water quality events at the four RTWQ stations can be explained by precipitation events, spring thaw influences, and/or changes in air temperature as the seasons moved from spring to summer to fall.

Water temperature and dissolved oxygen were directly influenced by typical seasonal trends, increasing or decreasing with warming or cooling air temperatures. pH levels were maintained throughout deployment, except during high stage events or precipitation events when pH values decreased for a short period of time.

Three RTWQ stations had specific conductivity levels that increased across the deployment season; Reid Brook at Outlet of Reid Pond was the exception with relatively stable conductivity levels, which are attributed to the stable pond environment nearby.

Turbidity data showed significant variation across the network; however, the majority of turbidity increases were associated with precipitation events occurring at the same time. Observed turbidity events were short in duration and turbidity readings quickly returned to background levels.

Path Forward

The success of the real-time water monitoring network is largely due to 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 area's characteristics. Data collected within this network is essential for identifying the difference between natural and anthropogenic events. As this agreement progresses into the 2019 deployment period for the Voisey's Bay stations, the following is a list of planned activities to be carried out. This list also includes some multi-year activities planned in the previous year that are still in progress.

- 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.
- 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 2019 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 deployment reports outlining the events that occurred in the previous deployment period and a 2019 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*.).
- 2019 deployments will recommence in the Spring.

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