Real-Time Water Quality 2019 Annual Report

Voisey's Bay Network

June 10 to October 16, 2019

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 2019 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 10 to October 16, 2019. During this time, five 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 2019 deployment season are summarized in Table 1.

Table 1: Installation and removal dates for 2018 deployment periods

Installation	Removal	Deployment
June 10	July 6	26 days
July 7	August 13	37 days
August 14	September 14	31 days
September 14	October 16	32 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 adjacent to 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 2019 Deployment Season

Station	Date	Action	Temperature	pH	Specific Conductivity	Dissolved Oxygen	Turbidity
Reid Brook at Outlet of Reid Pond	June 10, 2019	Deployment	Excellent	Good	Excellent	Good	Excellent
	July 6, 2019	Removal	Excellent	Fair	Excellent	Fair	Excellent
	July 7, 2019	Deployment	Excellent	Marginal	Excellent	Fair	Excellent
	August 13, 2019	Removal	Excellent	Poor	Excellent	Good	Excellent
	August 14, 2019	Deployment	Excellent	Fair	Excellent	Good	Excellent
	September 14, 2019	Removal	Excellent	Fair	Excellent	Excellent	Excellent
	September 14, 2019	Deployment	Good	Good	Excellent	Excellent	Excellent
	October 16, 2019	Removal	Excellent	Poor	Excellent	Excellent	Excellent
Camp Pond Brook below Camp Pond	June 10, 2019	Deployment	Excellent	Fair	Excellent	Excellent	Excellent
	July 6, 2019	Removal	Excellent	Good	Good	Excellent	Poor
	July 7, 2019	Deployment	Excellent	Fair	Excellent	Fair	Excellent
	August 13, 2019	Removal	Excellent	Good	Excellent	Good	Good
	August 14, 2019	Deployment	Excellent	Marginal	Excellent	Fair	Excellent
	September 14, 2019	Removal	Excellent	Poor	Excellent	Excellent	Poor
	September 14, 2019	Deployment	Excellent	Poor	Marginal	Excellent	Good
	October 16, 2019	Removal	Excellent	Good	Marginal	Excellent	Poor
Reid Brook below Tributary	June 10, 2019	Deployment	Excellent	Excellent	Excellent	Excellent	Excellent
	July 6, 2019	Removal	Excellent	Good	Excellent	Good	Excellent
	July 7, 2019	Deployment	Excellent	Good	Excellent	Excellent	Excellent
	August 13, 2019	Removal	Good	Excellent	Good	Good	Excellent
	August 14, 2019	Deployment	Excellent	Good	Good	Good	Excellent
	September 14, 2019	Removal	Excellent	Good	Good	Excellent	Good
	September 14, 2019	Deployment	Excellent	Excellent	Good	Excellent	Excellent
	October 16, 2019	Removal	Excellent	Poor	Good	Excellent	Good
Tributary to Reid Brook	June 10, 2019	Deployment	Excellent	Excellent	Excellent	Excellent	Excellent
	July 6, 2019	Removal	Excellent	Marginal	Excellent	Good	Good
	July 7, 2019	Deployment	Excellent	Good	Excellent	Marginal	Excellent
	August 13, 2019	Removal	Excellent	Good	Excellent	Good	Excellent
	August 14, 2019	Deployment	Excellent	Fair	Excellent	Fair	Excellent
	September 14, 2019	Removal	Excellent	Excellent	Good	Excellent	Poor
	September 14, 2019	Deployment	Excellent	Good	Good	Excellent	Excellent
	October 16, 2019	Removal	Excellent	Good	Poor	Fair	Excellent

Data Interpretation

The following graphs and discussions illustrate significant water quality-related events from June 10 through October 16, 2019 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 instruments at Tributary to Reid Brook and Reid Brook below Tributary did not transmit data as expected. Water quality data was obtained from each of the instruments' internal log files; however, water quantity data is not available for these stations for that period.

During the third deployment period, the instrument at Tributary to Reid Brook experienced a build-up of sediment around the sensors, which rendered turbidity readings inaccurate for much of the deployment period. As such, the inaccurate 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 2020 season.

Reid Brook at Outlet of Reid Pond

During the 2019 deployment season, water temperature ranged from 2.49°C to a maximum of 13.99°C (Figure 1). Water temperature values for 2019 were similar to data from the 2018 and 2017 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 through late August. Water temperatures started to decrease again from early September 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.

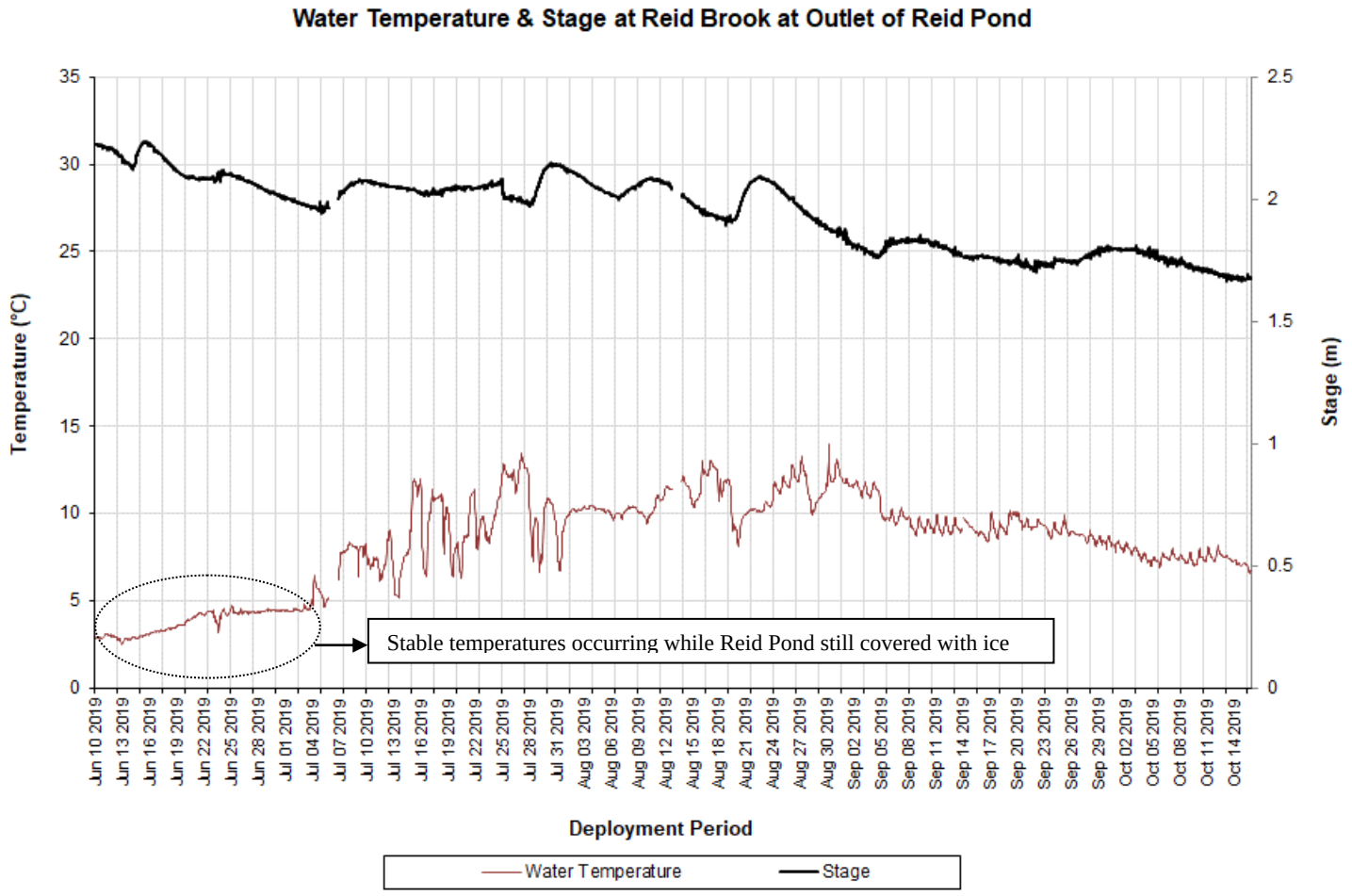

Figure 1: Water Temperature & Stage at Reid Brook at Outlet of Reid Pond

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

Water Temperature	2019	2018	2017
Min	2.49	1.37	0.6
Max	13.99	15.97	14.9
Median	8.90	9.34	9.53

Water temperatures show a close relationship with air temperature (Figure 2). Increases and decreases in air temperatures throughout 2019 were associated with similar changes in water temperature. Air temperatures fluctuate to a greater extent each day when compared to 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 airstrip.

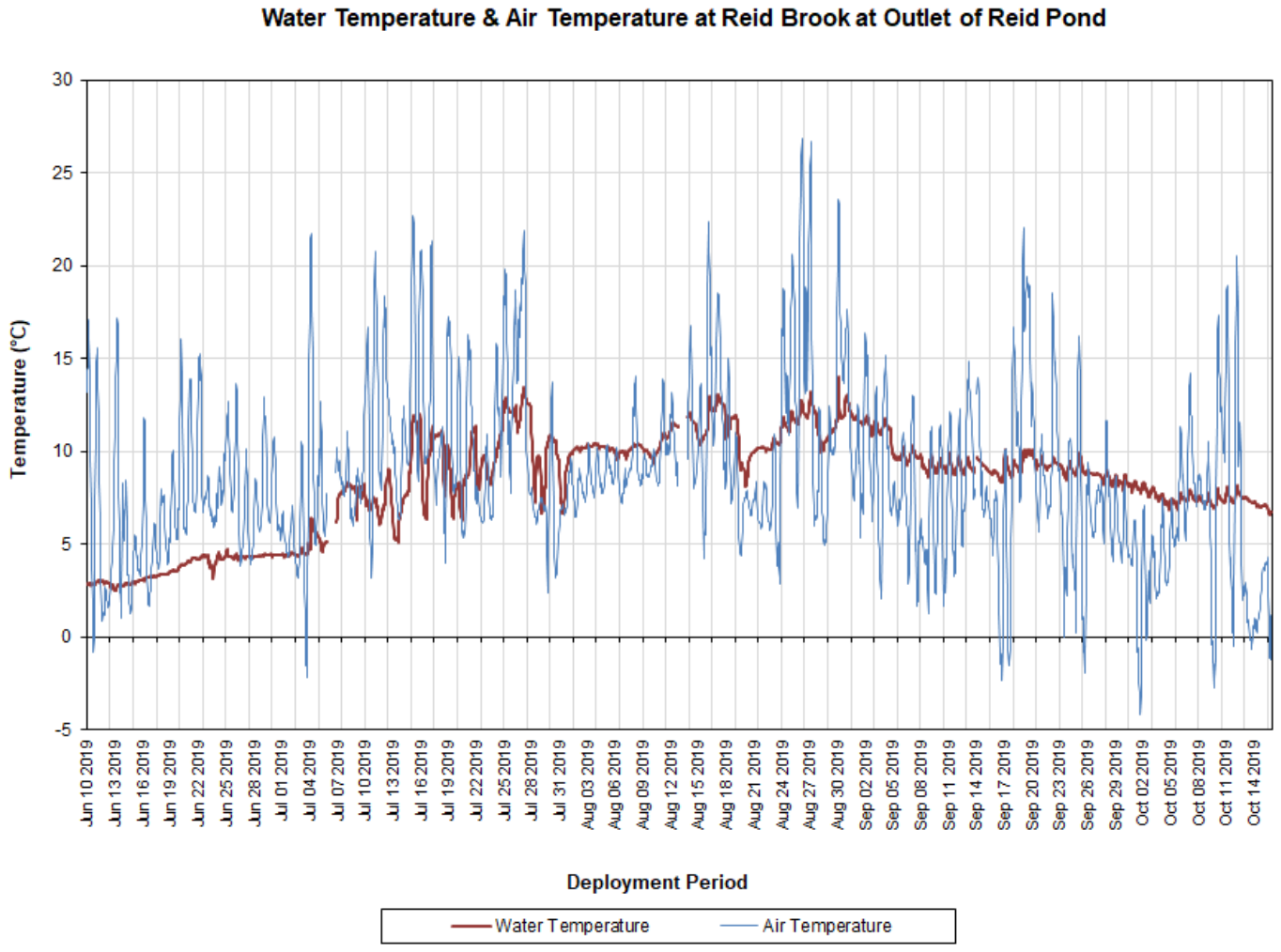

Figure 2: Water Temperature & Air Temperature at Reid Brook at Outlet of Reid Pond

During the 2019 deployment season, pH ranged from 5.21 pH units to a maximum of 10.05 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 brief periods in late June and mid-October.

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.

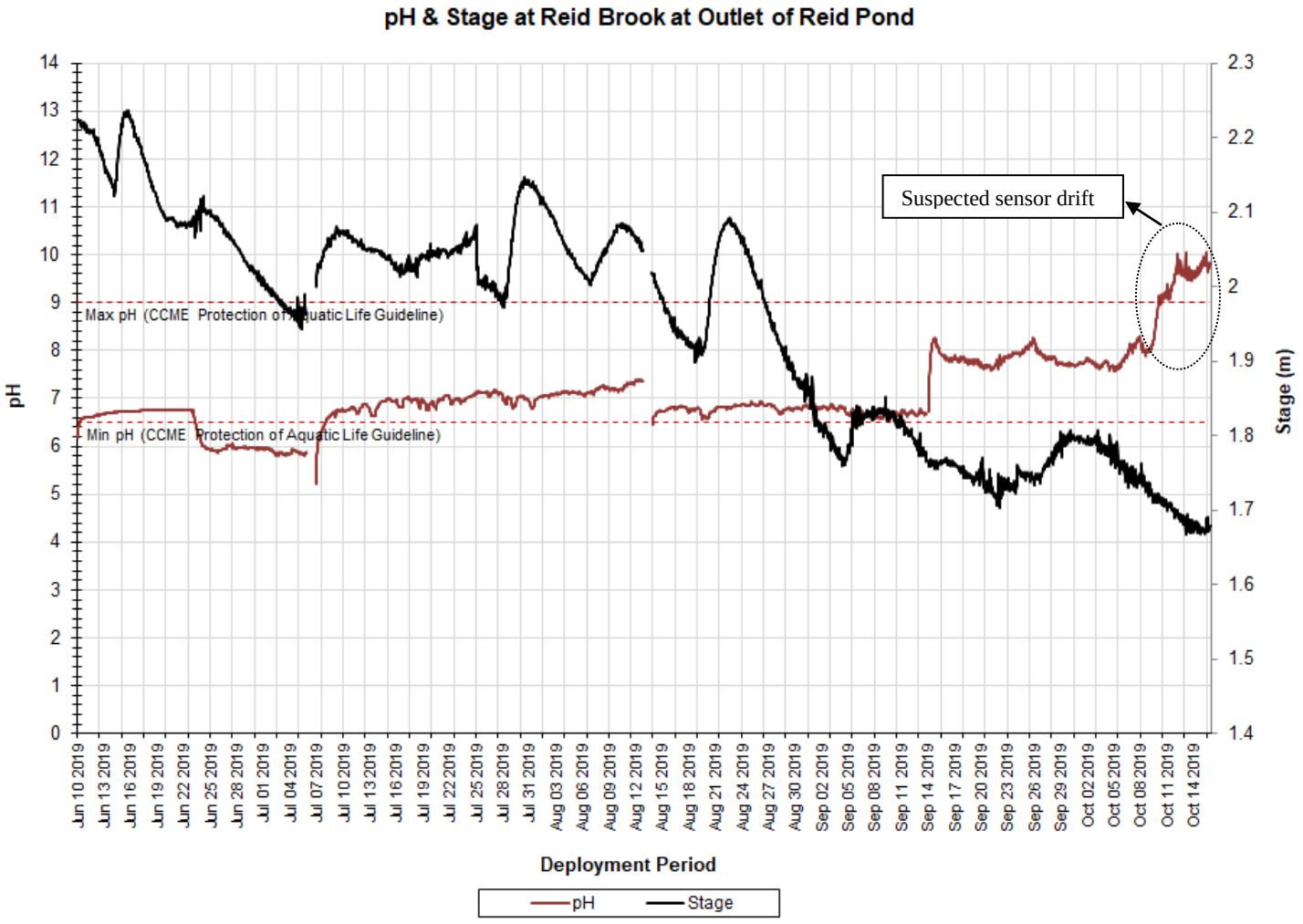

Figure 3: pH & Stage at Reid Brook at Outlet of Reid Pond

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

pH	2019	2018	2017
Min	5.21	6.36	5.34
Max	10.05	8.04	7.58
Median	6.86	6.96	6.78

During the 2019 deployment season, specific conductivity values ranged from 8.5µS/cm to a maximum of 13.8µS/cm. An overall conductivity median of 11.6µS/cm indicates that this station naturally has very low conductivity, and was very similar to previous deployment seasons (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.

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.

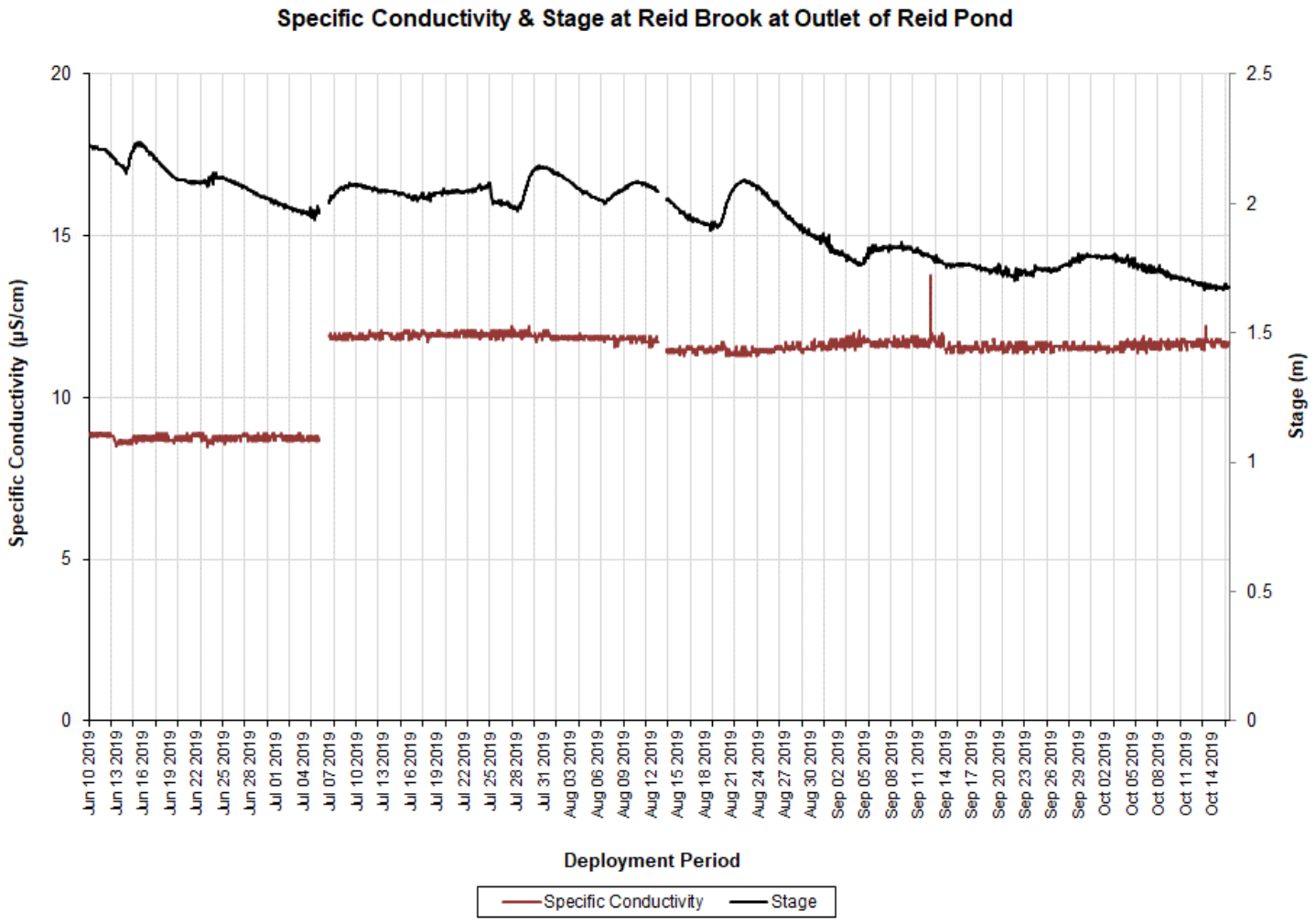

Figure 4: Specific Conductivity & Stage at Reid Brook at Outlet of Reid Pond

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

Specific Conductivity	2019	2018	2017
Min	8.5	9.1	9.4
Max	13.8	27.5	22.3
Median	11.6	11.8	12.1

During the 2019 deployment season, dissolved oxygen concentrations ranged from 10.37mg/L to a maximum of 12.52mg/L, with a median value of 11.00mg/L. Saturation of dissolved oxygen ranged from 90.3% to 106.7%, with a median value of 97.0% (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 late 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.

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.

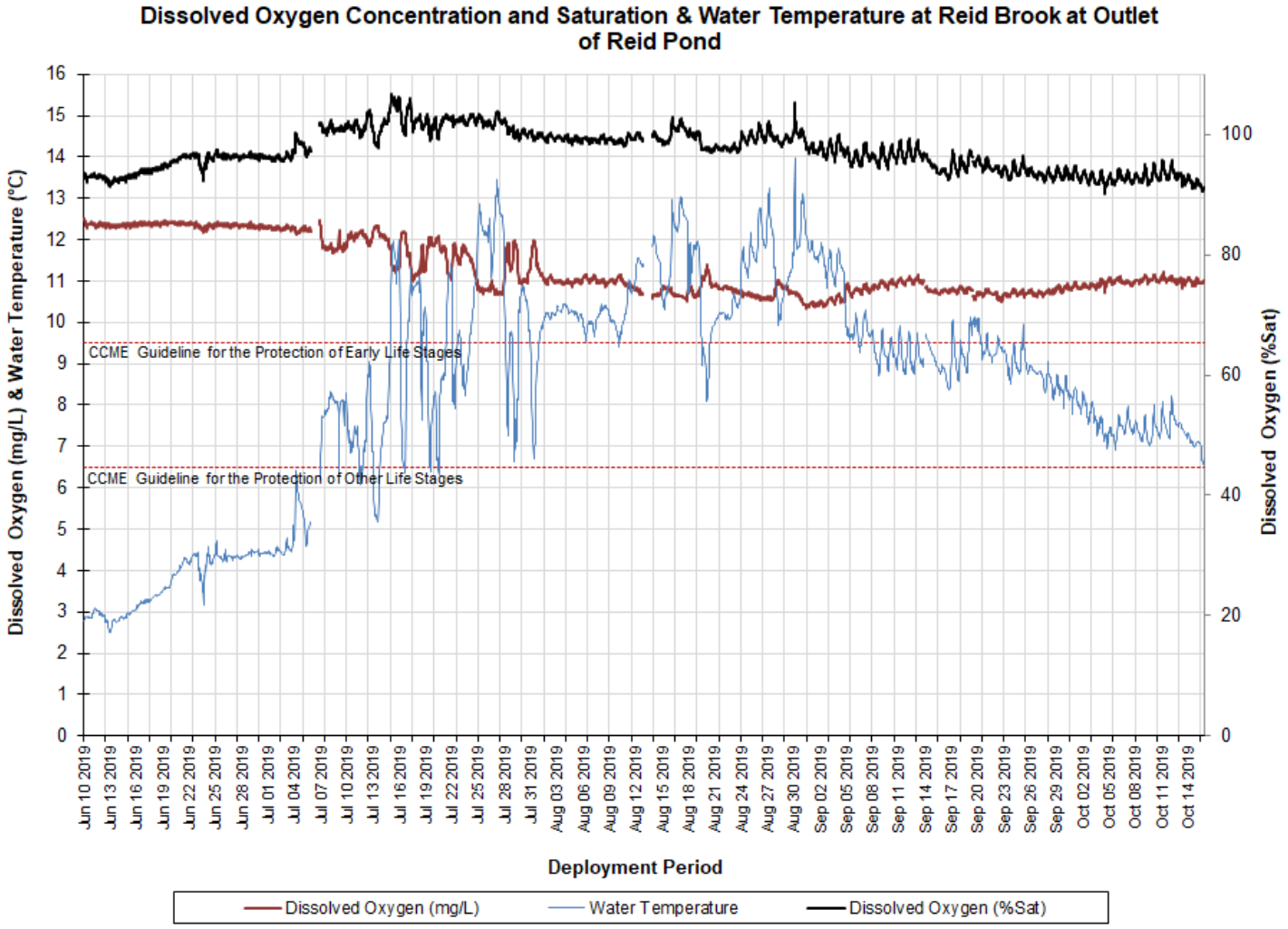

Figure 5: Dissolved Oxygen Concentration and Saturation & Water Temperature at Reid Brook at Outlet of Reid Pond

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

Dissolved Oxygen (mg/L)	2019	2018	2017
Min	10.37	9.63	10.22
Max	12.52	12.92	12.39
Median	11.00	11.23	11.265

Percent Saturation (%)	2019	2018	2017
Min	90.3	86.6	82.2
Max	106.7	110.4	107.6
Median	97.0	95.6	97.1

During the 2019 deployment season, turbidity values ranged from 0.0NTU to a maximum of 484.0NTU. A median value of 0.0NTU 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 subsequent 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.

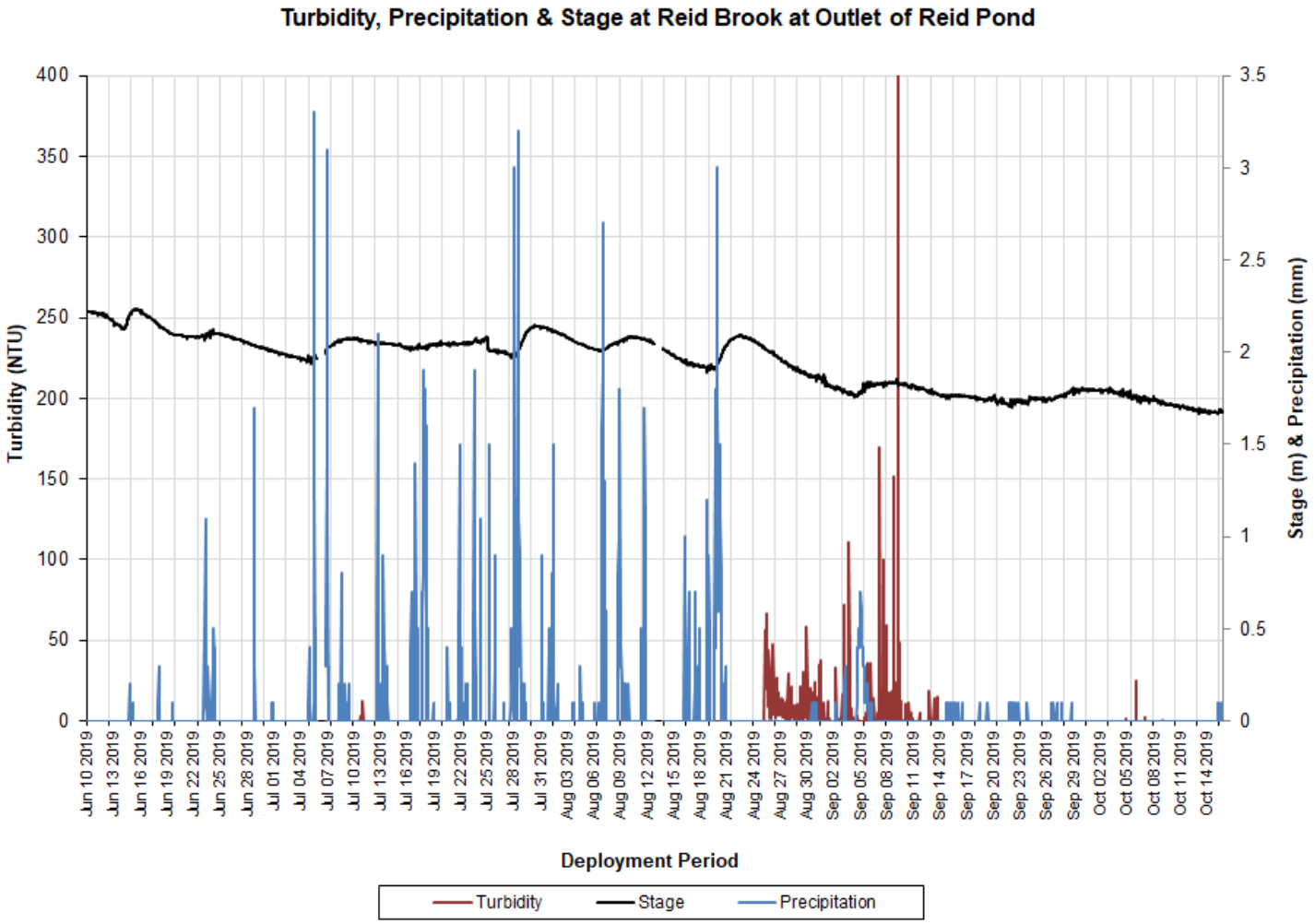

Figure 6: Turbidity & Stage at Reid Brook at Outlet of Reid Pond

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

Turbidity	2019	2018	2017
Min	0.0	0.7	0.0
Max	484.0	196.4	78
Median	0.0	1.8	0.0

Camp Pond Brook below Camp Pond

During the 2019 deployment season, water temperature ranged from 2.99°C to a maximum of 18.76°C. The median temperature of 11.22°C was slightly lower than that from the 2018 deployment season (Table 9).

Water temperature was highest during late July (Figure 7). Water temperatures started to noticeably decrease from early September onwards 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.

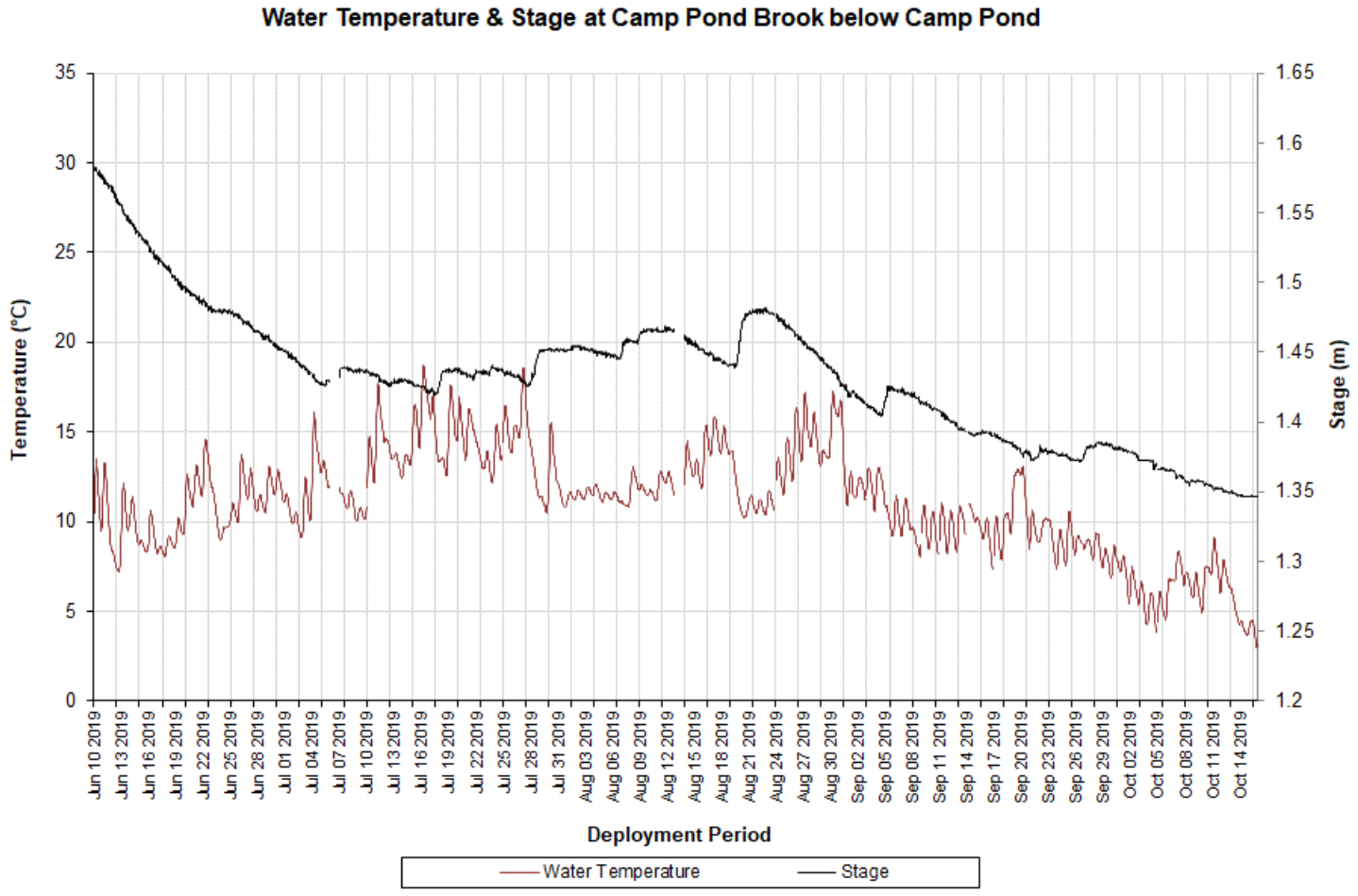

Figure 7: Water Temperature & Stage at Camp Pond Brook below Camp Pond

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

Water Temperature	2019	2018	2017
Min	2.99	1.18	0.22
Max	18.76	21.42	20.52
Median	11.22	11.34	11.86

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 than water temperatures. Air temperature data was obtained from the Voisey's Bay Weather Station located at the airstrip.

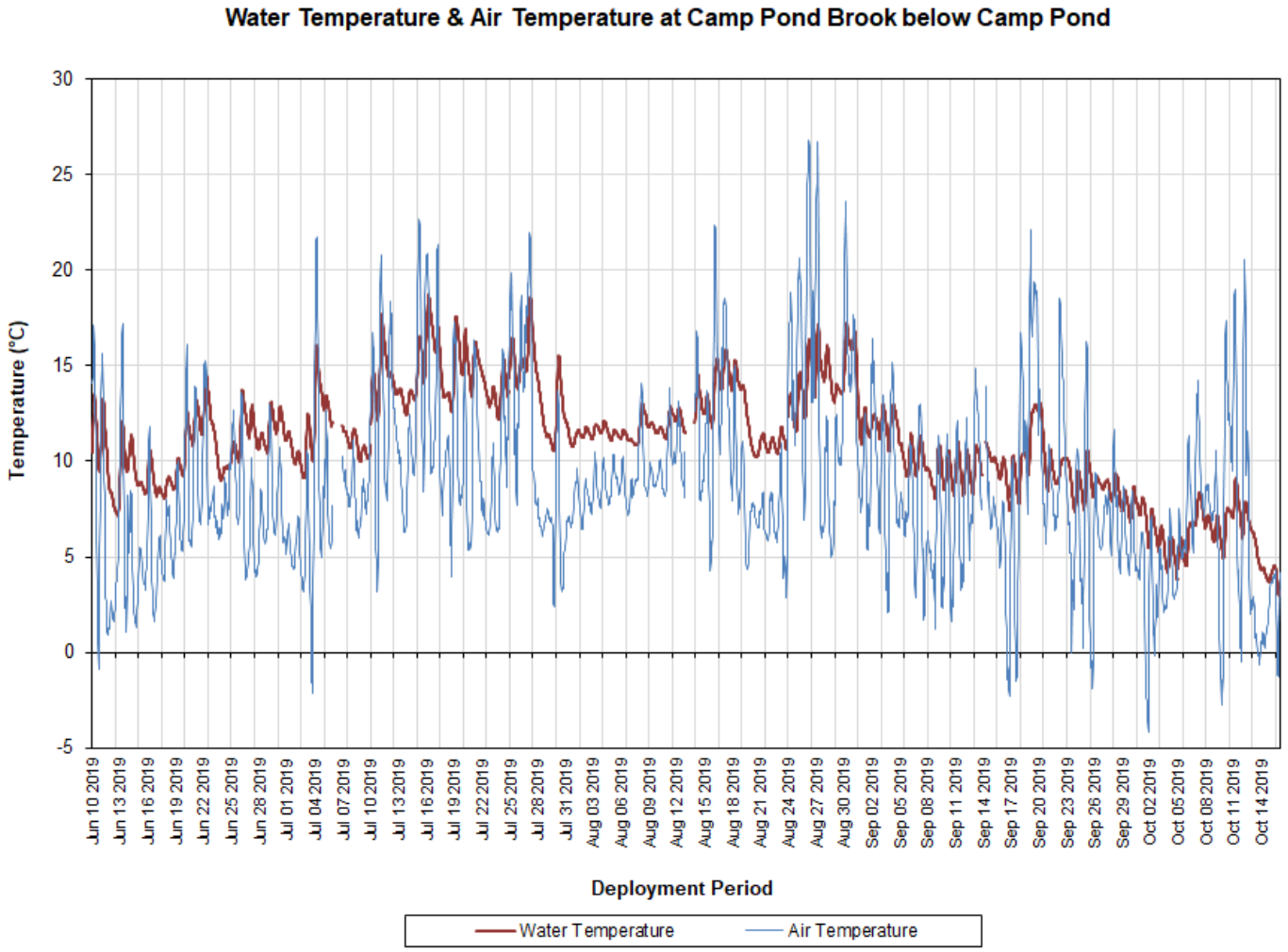

Figure 8: Water Temperature & Air Temperature at Camp Pond Brook below Camp Pond

During the 2019 deployment season, pH ranged from 5.70 pH units to a maximum of 7.07 pH units. The median value of 6.58 was slightly lower than those from both 2018 (6.94) and 2017 (6.87) (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 most of the first half of the deployment season. pH values remained within the CCME's Guidelines from mid-August onwards (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.

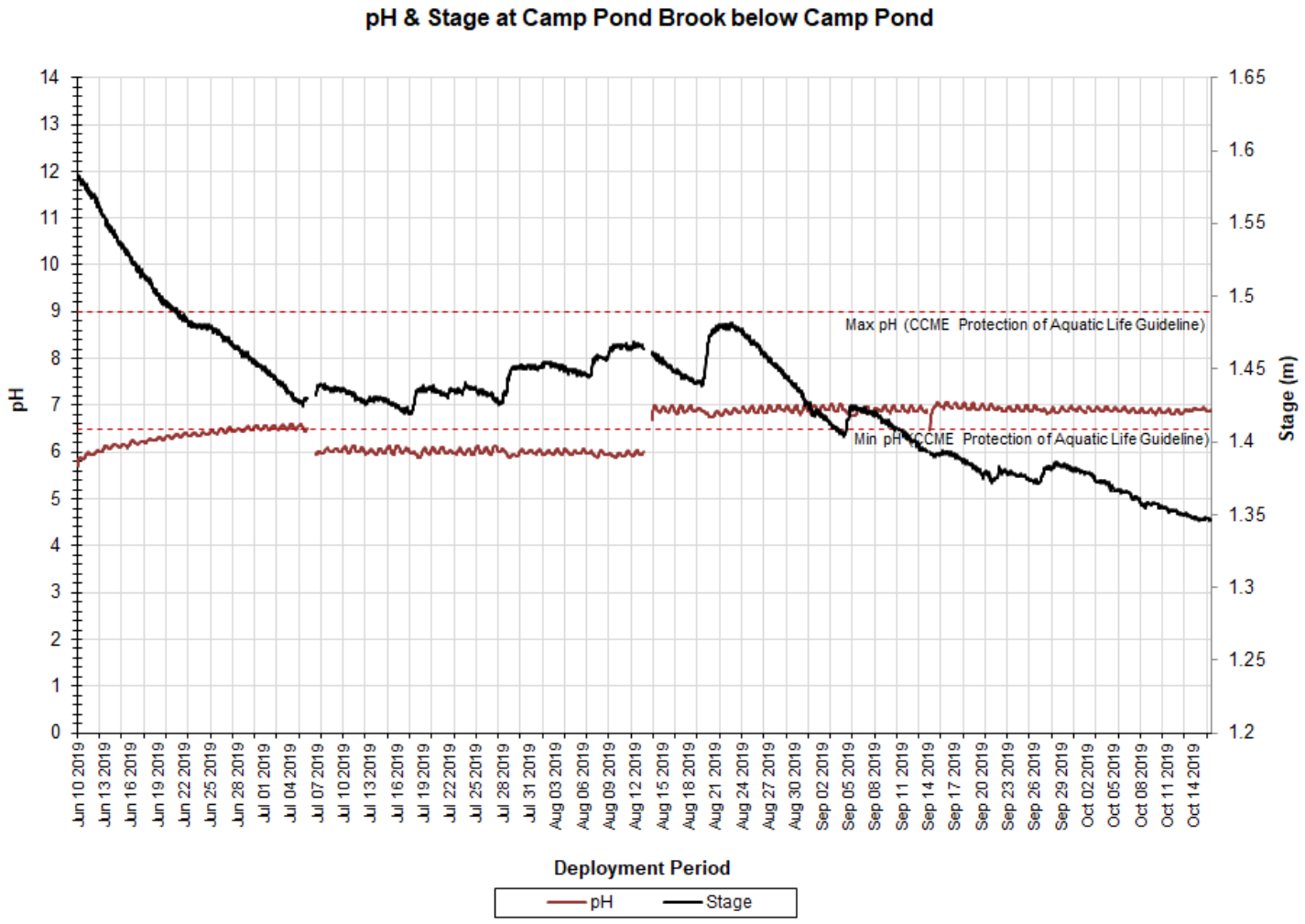

Figure 9: pH & Stage at Camp Pond Brook below Camp Pond

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

pH	2019	2018	2017
Min	5.70	5.68	6.02
Max	7.07	7.47	7.12
Median	6.58	6.94	6.87

During the 2019 deployment season, specific conductivity ranged from 25.6µS/cm to a maximum of 49.7µS/cm (Figure 10). The median value of 34.8µS/cm was very similar to the 2018 median of 35.9µS/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.

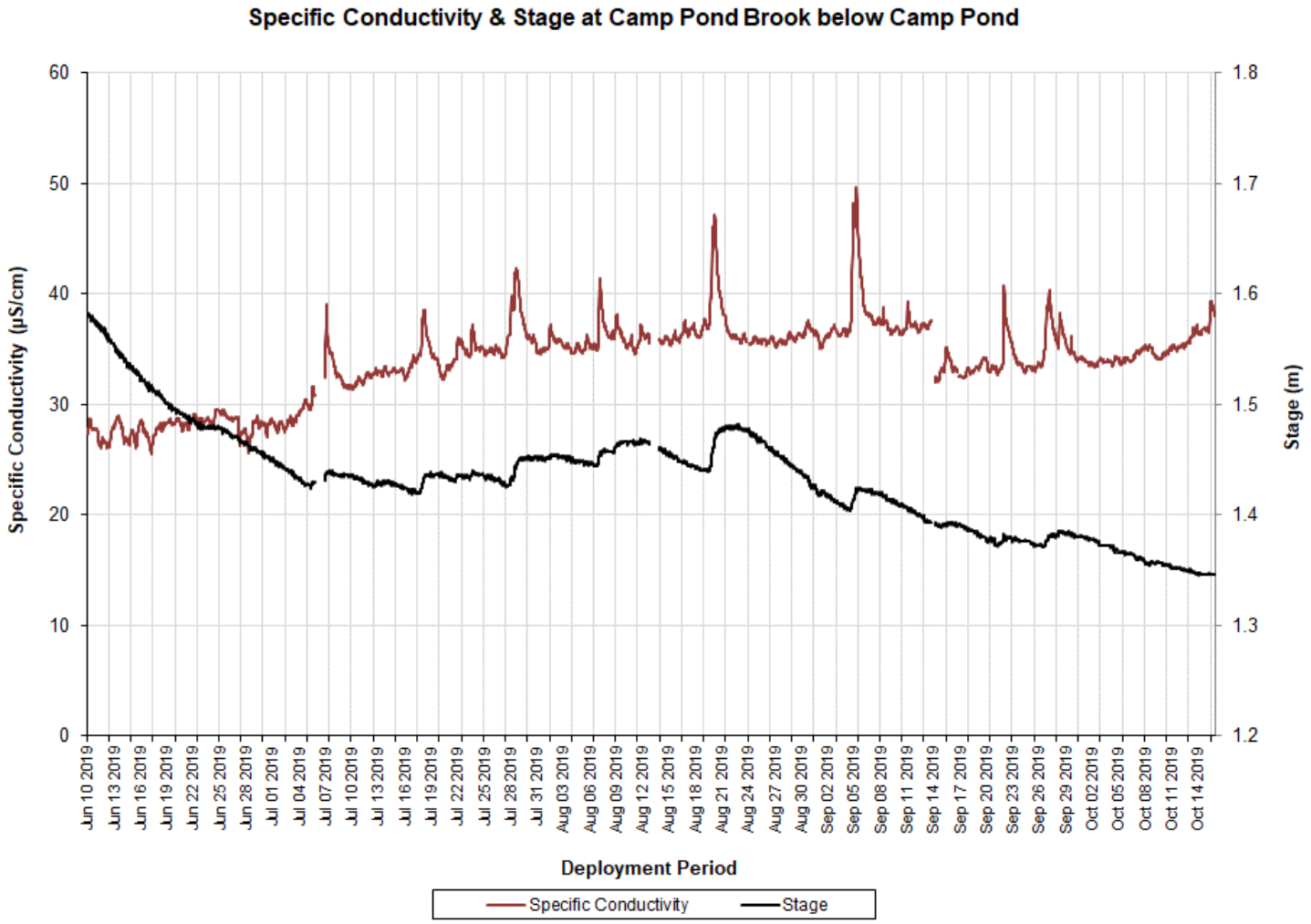

Figure 10: Specific Conductivity & Stage at Camp Pond Brook below Camp Pond

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

Specific Conductivity	2019	2018	2017
Min	25.6	16.4	21.2
Max	49.7	111	61.1
Median	34.8	35.9	39.5

During the 2019 deployment season, dissolved oxygen concentrations ranged from 9.00mg/L to a maximum of 12.42mg/L, with a median value of 10.46mg/L that was very close to the 2018 median of 10.38mg/L. Saturation of dissolved oxygen ranged from 90.3% to 104.4%, with a median value of 96.2% (Table 12).

Dissolved oxygen concentrations exhibited typical seasonal trends, and were inversely related to water temperature. Dissolved oxygen concentrations were lowest throughout July when water temperatures were warmest. As water temperatures decreased into late summer and 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. Dissolved oxygen concentrations remained above the CCME's Guideline for the Protection of Other Life Stages (6.5mg/L) for the duration of the deployment season.

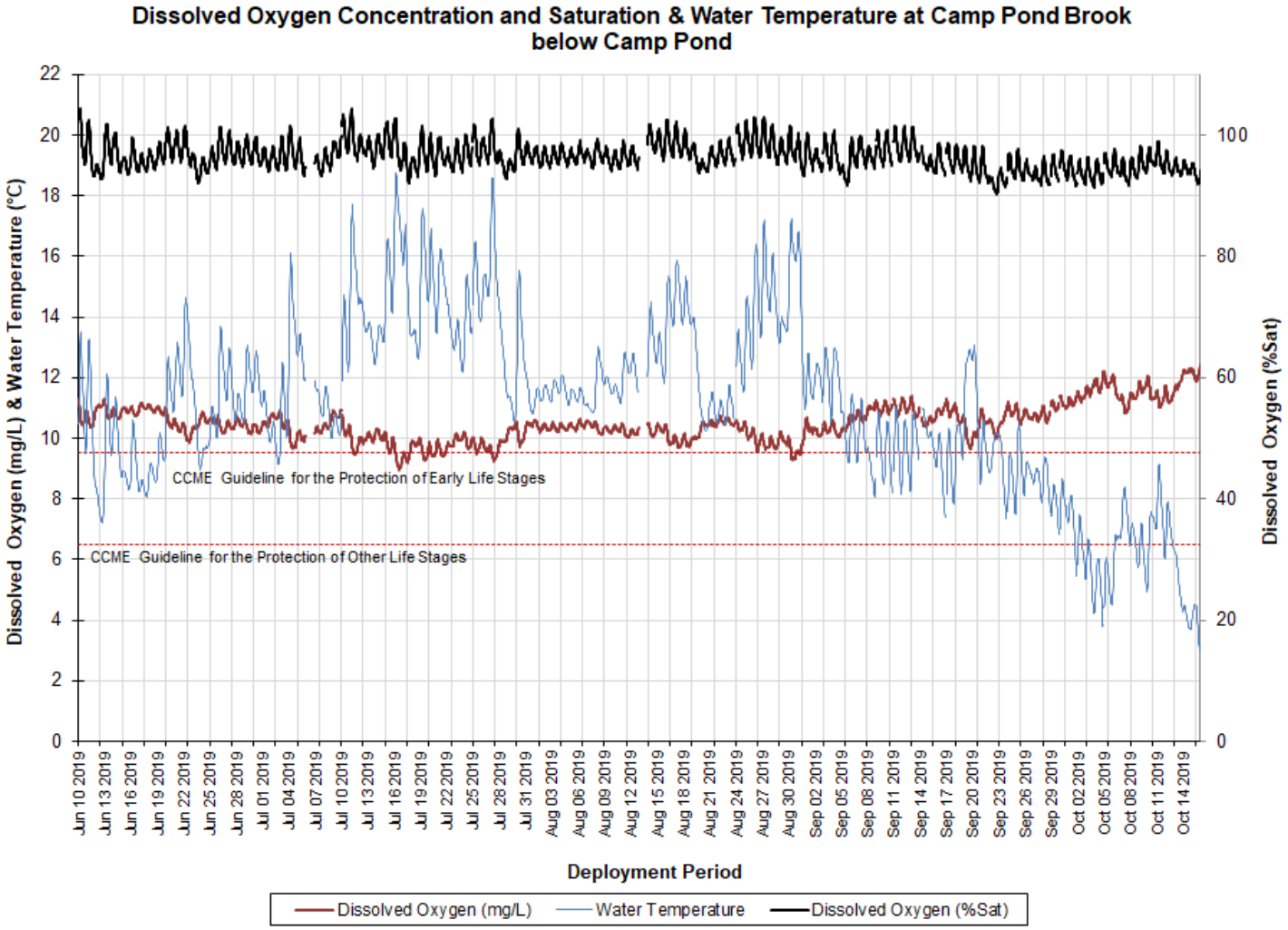

Figure 11: Dissolved Oxygen Concentration and Saturation & Water Temperature at Camp Pond Brook below Camp Pond

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

Dissolved Oxygen (mg/L)	2019	2018	2017
Min	9.00	8.27	8.61
Max	12.42	13.48	13.6
Median	10.46	10.38	10.37

Percent Saturation (%)	2019	2018	2017
Min	90.3	84.4	87.7
Max	104.4	102.2	103.9
Median	96.2	95.2	94.9

During the 2019 deployment season, turbidity values ranged from 0.0NTU to a maximum of 46.5NTU, with a median value of 4.7NTU (Figure 12). A median value of 4.7NTU indicates that there is a small amount of natural background turbidity at this station. The median turbidity value for 2019 was higher than those from both the 2018 (0.0) and 2017 (0.7) deployment seasons (Table 13).

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.

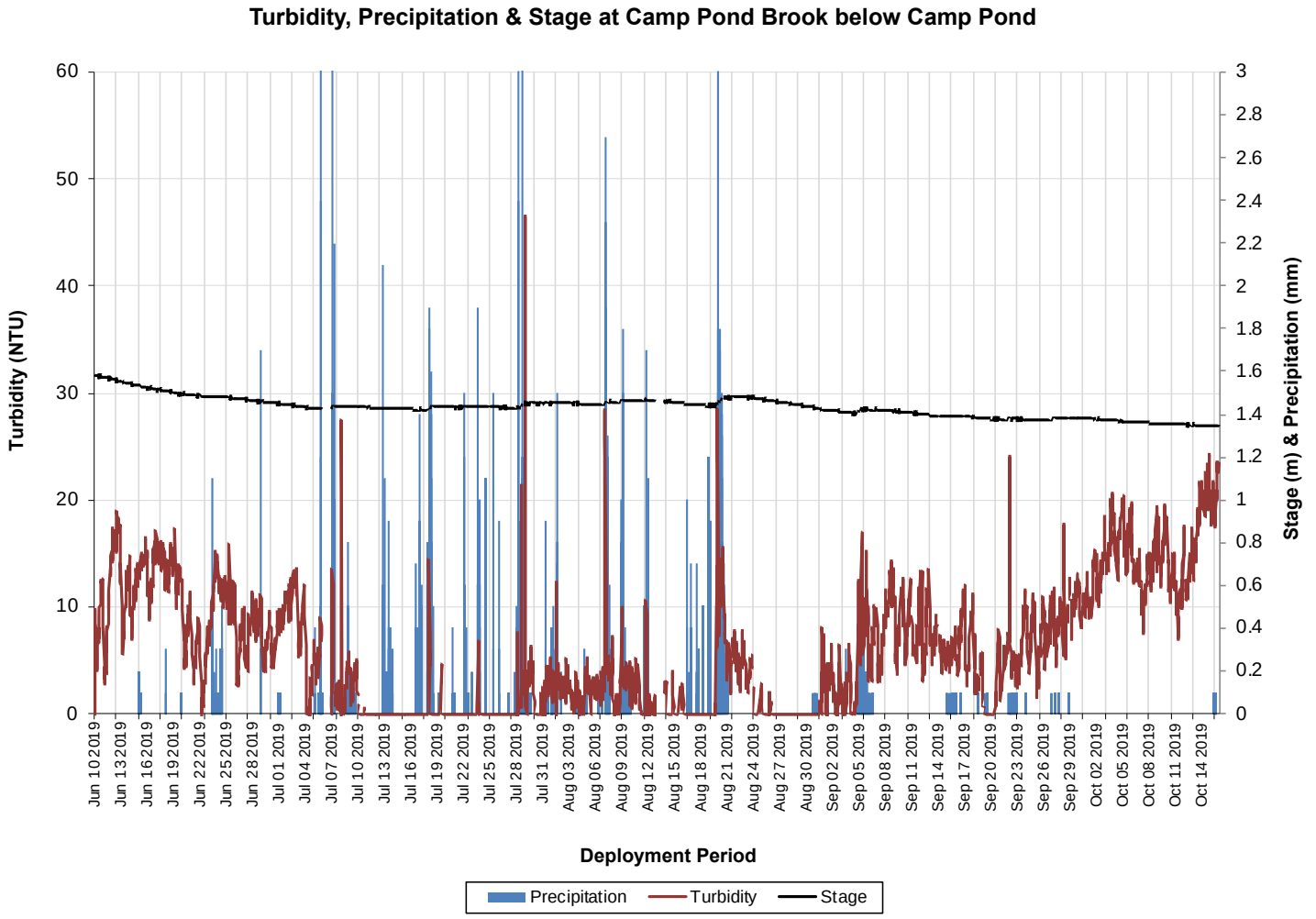

Figure 12: Turbidity & Stage at Camp Pond Brook below Camp Pond

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

Turbidity	2019	2018	2017
Min	0.0	0.0	0.0
Max	46.5	446	1509
Median	4.7	0.0	1.7

Reid Brook below Tributary

During the 2019 deployment season, water temperature ranged from 3.4°C to a maximum of 15.2°C, with a median value of 9.2°C (Table 14). Water temperatures were highest through late July and late August as air temperatures increased with the summer season. From the beginning of September 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.

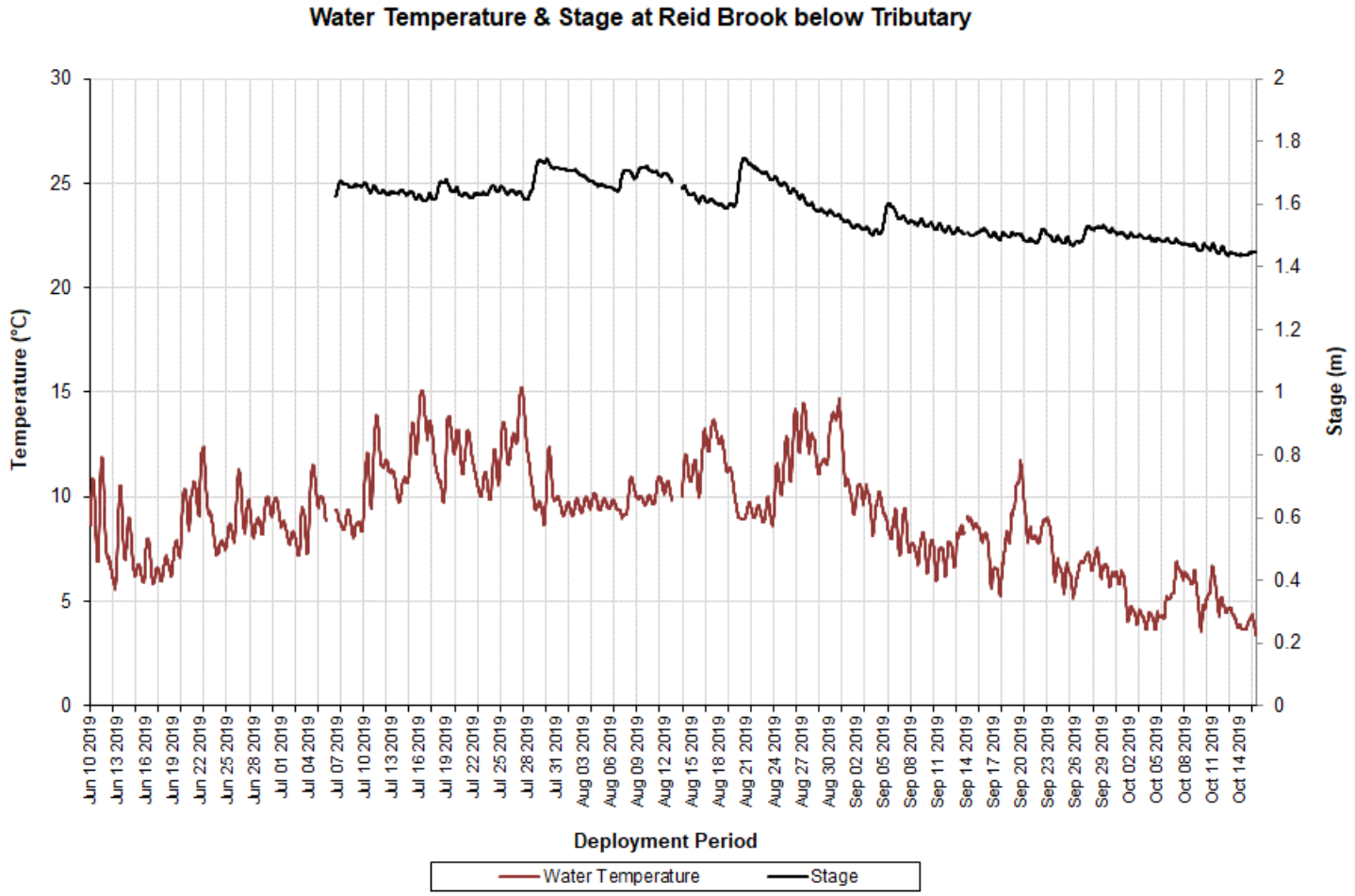

Figure 13: Water Temperature & Stage at Reid Brook below Tributary

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

Water Temperature	2019	2018	2017
Min	3.4	1.7	0
Max	15.2	17.4	14.5
Median	9.2	9.2	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.

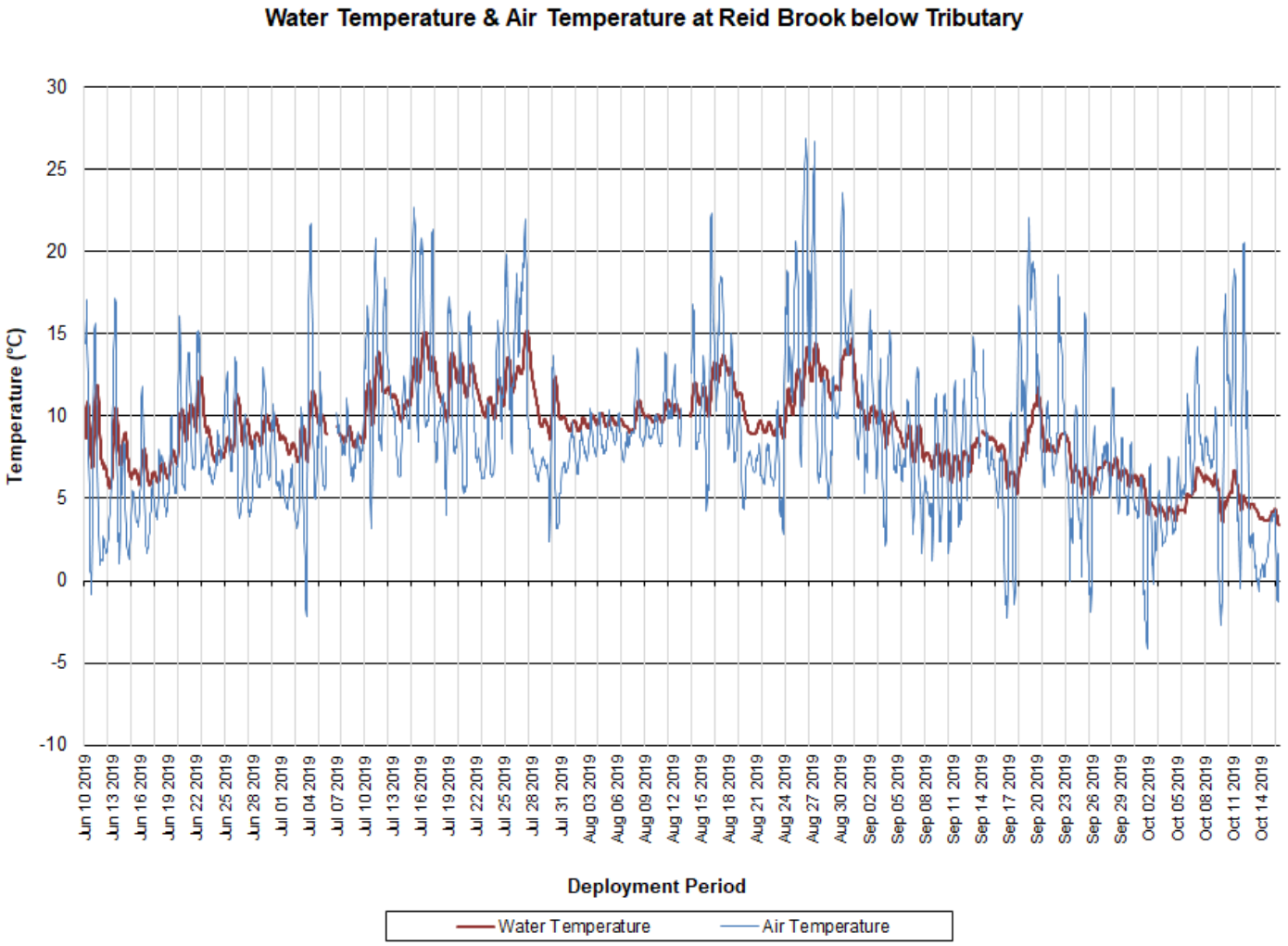

Figure 14: Water Temperature & Air Temperature at Reid Brook below Tributary

During the 2019 deployment season, pH ranged from 5.97 pH units to a maximum of 7.71 pH units, with a median value of 6.72 (Figure 15). pH data at this station has been consistent over recent years with median values of 6.83 in 2018 and 6.74 in 2017 (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 much of the deployment season. pH values were below the CCME's Minimum Guideline from early July through early August, which was associated with high stage levels.

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.

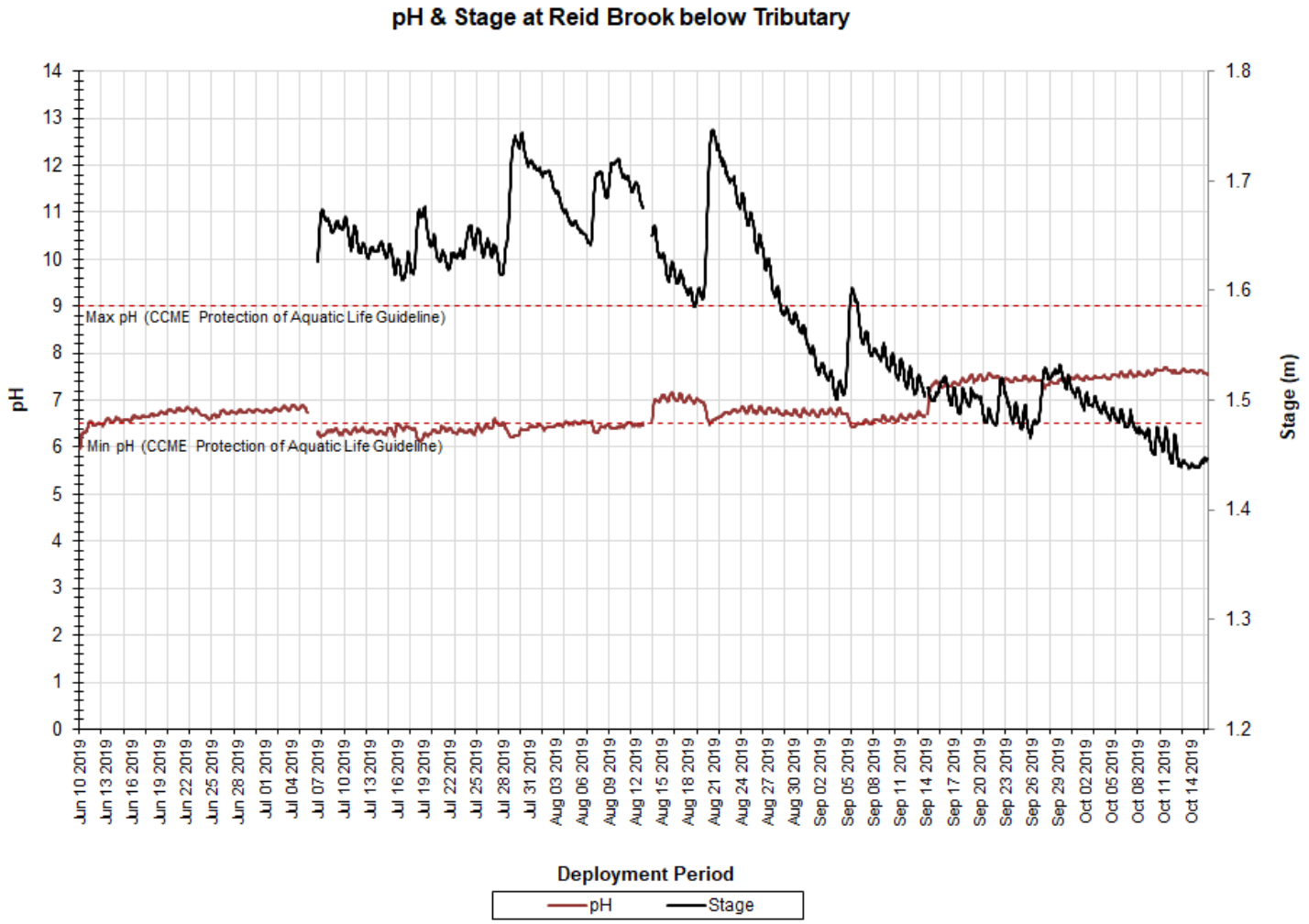

Figure 15: pH & Stage at Reid Brook below Tributary

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

pH	2019	2018	2017
Min	5.97	6.15	6.11
Max	7.71	7.28	7.09
Median	6.72	6.83	6.74

During the 2019 deployment season, specific conductivity levels ranged from 20.0µS/cm to a maximum of 42.3µS/cm, with a median value of 30.7µS/cm (Figure 16). Specific conductivity levels have been quite consistent at this site over recent years, with median values of 27.8µS/cm in 2018 and 28.6µS/cm in 2017 (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. This relationship is evident in the graph below.

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.

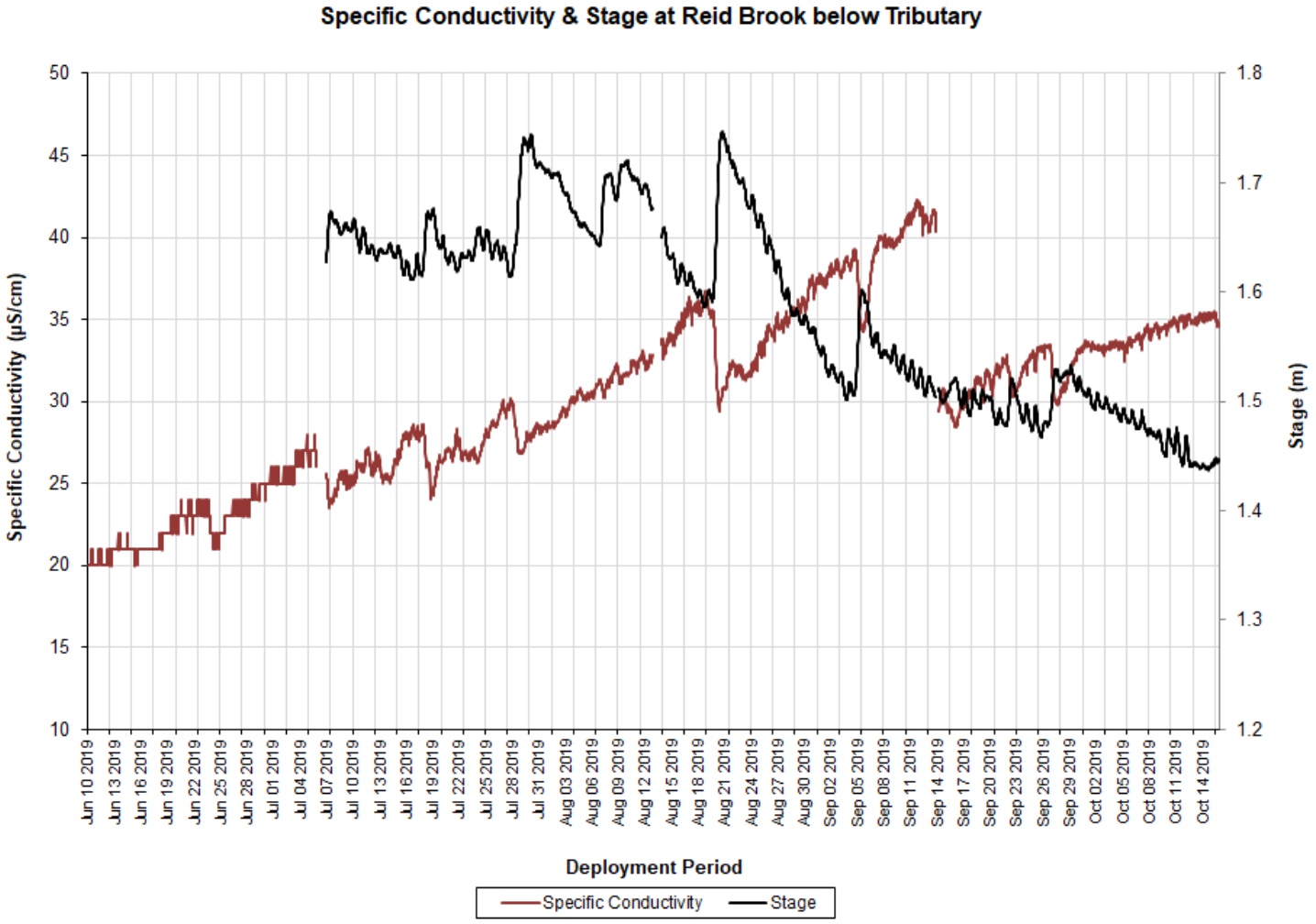

Figure 16: Specific Conductivity & Stage at Reid Brook below Tributary

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

Specific Conductivity	2019	2018	2017
Min	20.0	14	2.5
Max	42.3	40.3	40.9
Median	30.7	27.8	28.6

During the 2019 deployment season, dissolved oxygen concentrations ranged from 9.58mg/L to a maximum of 12.68mg/L, with a median value of 11.05mg/L. The saturation of dissolved oxygen ranged from 91.9% to 102.3%, with a median value of 97.0% (Figure 17). Dissolved oxygen values have been very consistent at this site over recent years (Table 17).

Dissolved oxygen concentrations were lowest through late July and late 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 beginning of September onwards, dissolved oxygen concentrations started to increase.

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

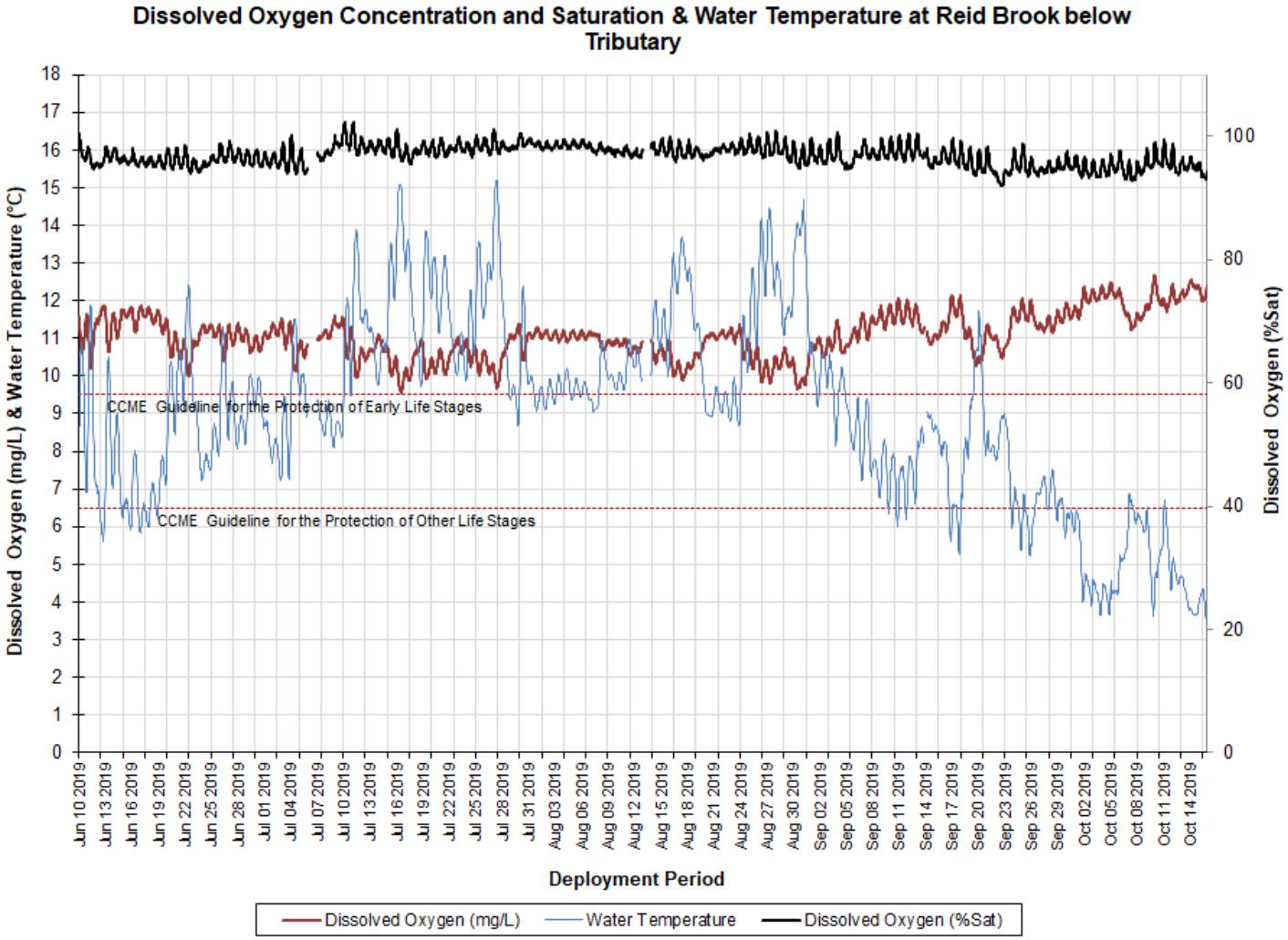

Figure 17: Dissolved Oxygen Concentration and Saturation & Water Temperature at Reid Brook below Tributary

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

Dissolved Oxygen (mg/L)	2019	2018	2017
Min	9.58	9.05	9.66
Max	12.68	13.26	14.19
Median	11.05	10.95	11.04

Percent Saturation (%)	2019	2018	2017
Min	91.7	90.9	90.5
Max	102.3	102.6	100.6
Median	97.0	94.8	95.8

During the 2019 deployment season, turbidity ranged from 0.0NTU to a maximum of 1053NTU, with a median value of 0.0NTU (Figure 18). A median value of 0.0NTU indicates that there is a very low level of natural background turbidity at this station, and is consistent with past deployment seasons (Table 18).

Turbidity is graphed to a maximum of 60NTU in the graph below in order to show the relationship between turbidity and precipitation. 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.

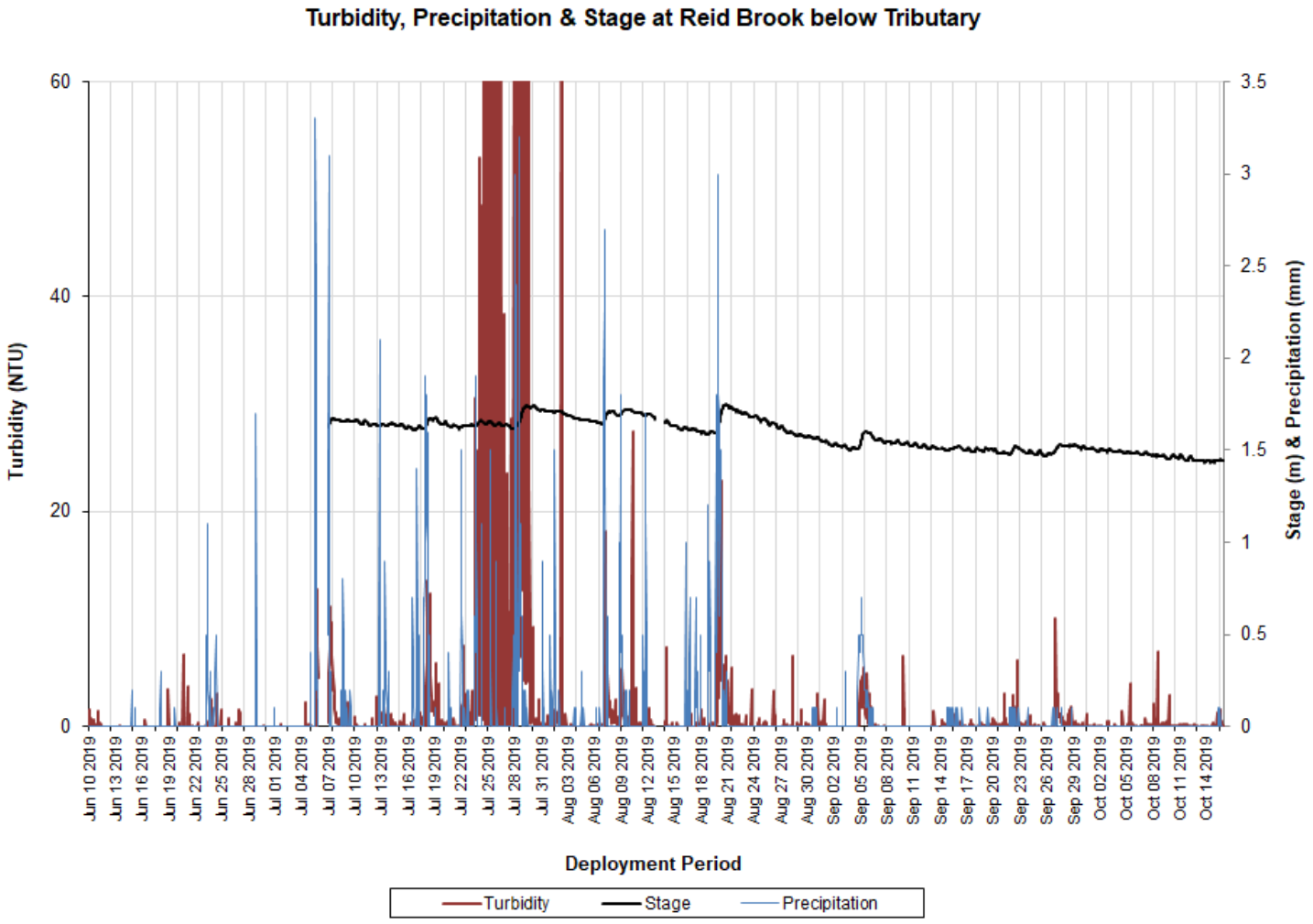

Figure 18: Turbidity, Precipitation & Stage at Reid Brook below Tributary

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

Turbidity	2019	2018	2017
Min	0.0	0.0	0.0
Max	1053	52.8	287.2
Median	0.0	16.8*	0.0

*median higher than expected due to suspected calibration error

Tributary to Reid Brook

During the 2019 deployment season, water temperature ranged from 3.30°C to a maximum of 15.10°C, with a median value of 9.20°C (Figure 19). Water temperature at this site has been quite consistent over recent years, with median values of 9.39°C in 2018 and 9.21°C in 2017 (Table 19).

Water temperatures were highest through late July and late August as air temperatures increased with the summer season (Figure 19 & 20). From the beginning of September 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.

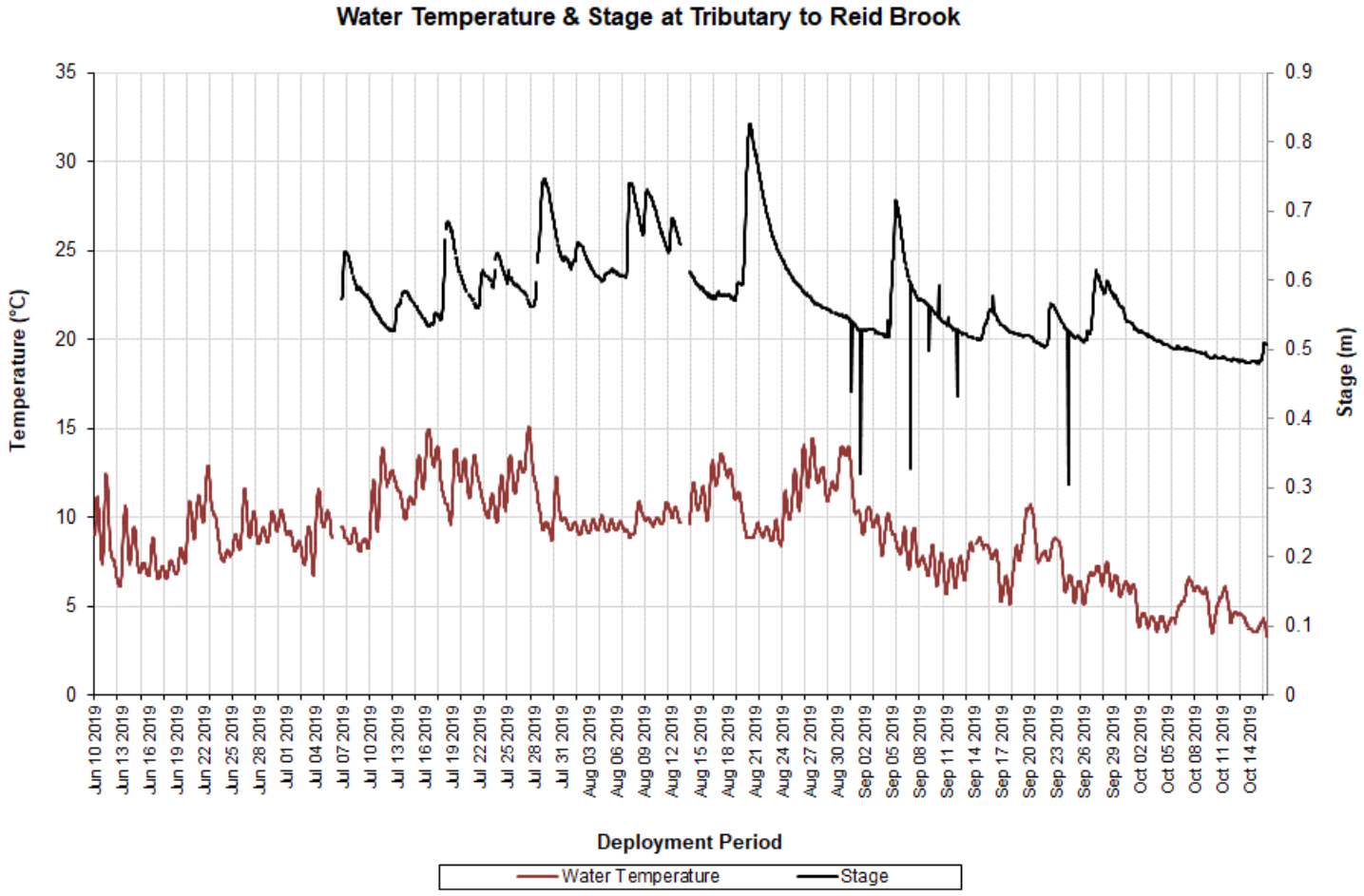

Figure 19: Water Temperature & Stage at Tributary to Reid Brook

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

Water Temperature	2019	2018	2017
Min	3.30	1.86	0.17
Max	15.10	18.02	16.81
Median	9.20	9.39	9.21

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.

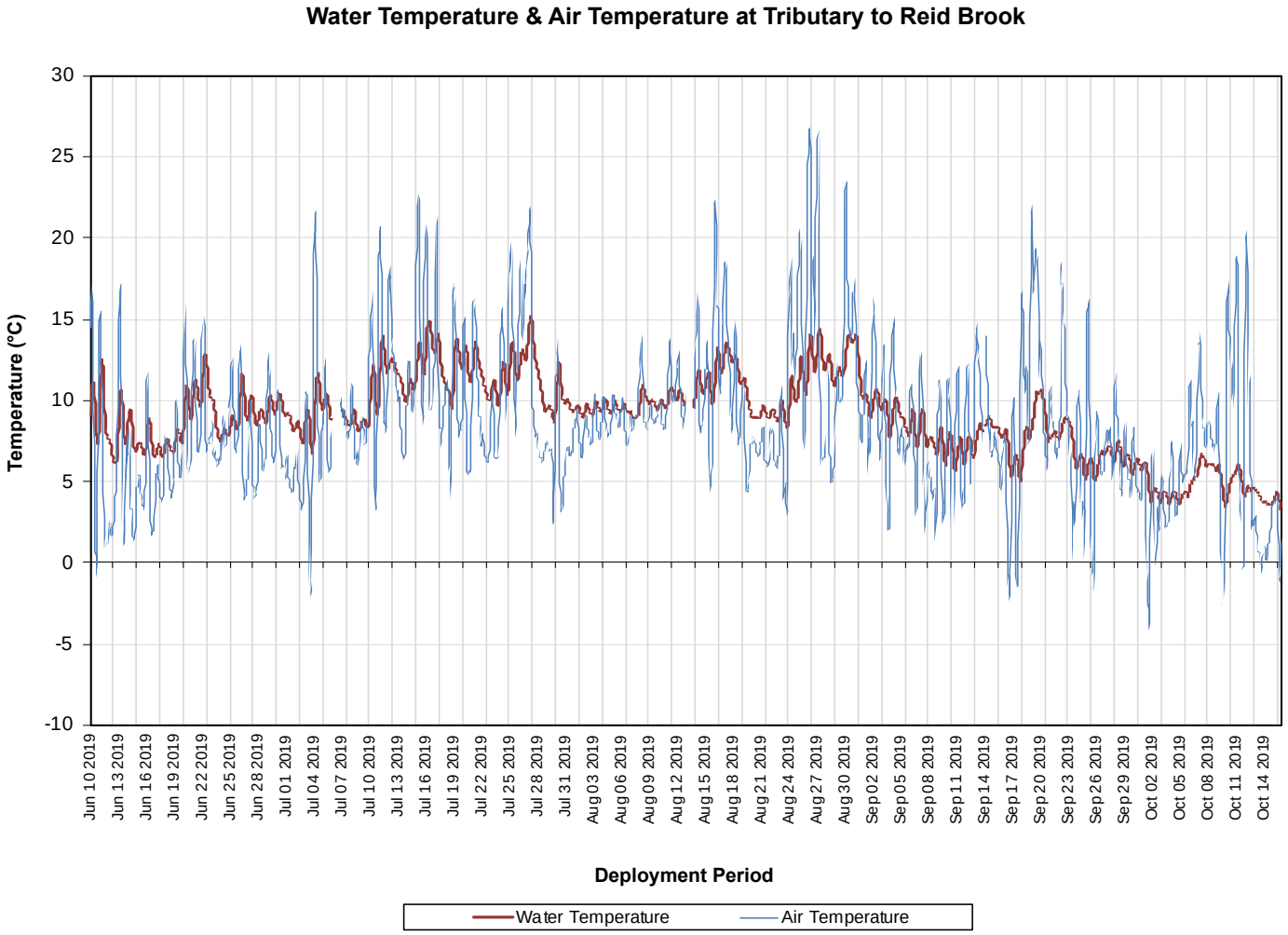

Figure 20: Water Temperature & Air Temperature at Tributary to Reid Brook

During the 2019 deployment season, pH data ranged from 6.05 to a maximum of 7.11 pH units, with a median value of 6.74 pH units (Table 20).

Stage data is included in Figure 21 to show how stage influences pH over time. In general, as stage decreases pH increases, and vice versa. Sharp increases in stage correlate closely with sharp decreases in pH.

pH values remained within the CCME's Guidelines for the Protection of Aquatic Life for the majority of the deployment season. Instances where pH values temporarily fell below the CCME's Minimum Guideline correlate closely with sharp increases in stage (Figure 21).

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.

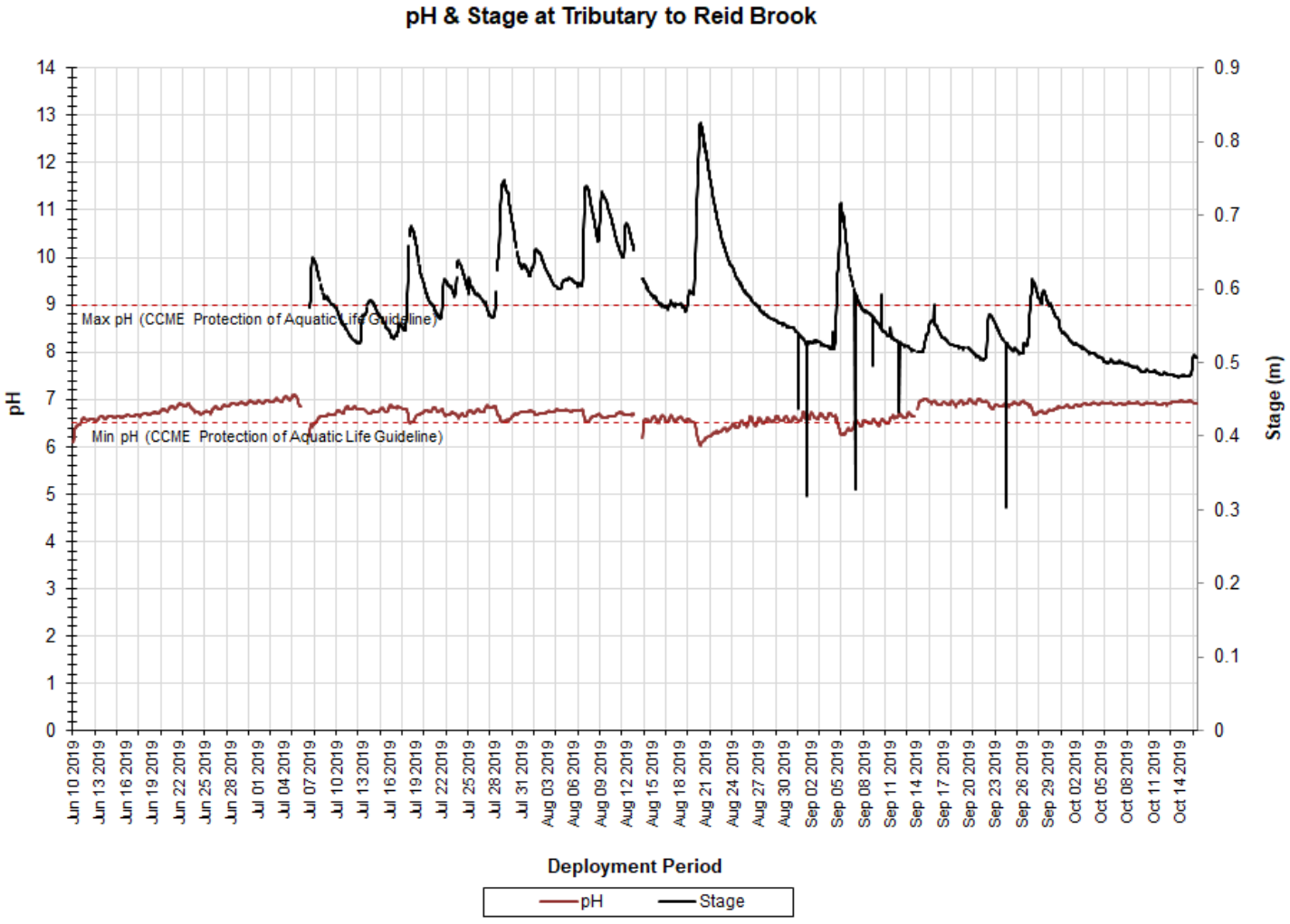

Figure 21: pH & Stage at Tributary to Reid Brook

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

pH	2019	2018	2017
Min	6.05	5.31	6.06
Max	7.11	7.84	7.48
Median	6.74	7.33	6.85

During the 2019 deployment season, specific conductivity ranged from 8.8µS/cm to a maximum of 41.1µS/cm, with a median value of 27.5µS/cm (Table 21).

Specific conductivity generally increased over the course of deployment, exhibiting an inverse relationship with stage. 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.

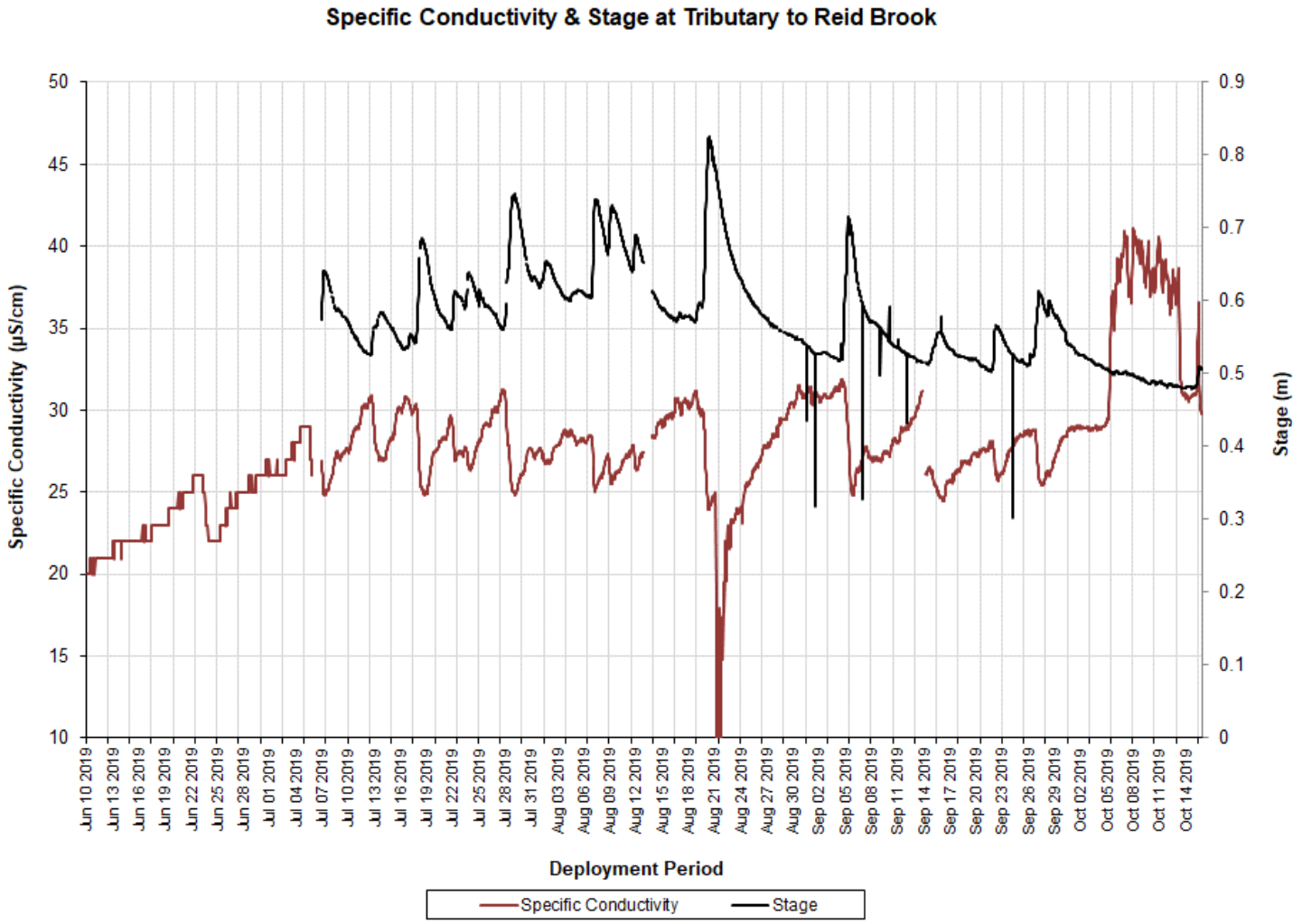

Figure 22: Specific Conductivity & Stage at Tributary to Reid Brook

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

Specific Conductivity	2019	2018	2017
Min	8.8	14.3	16.1
Max	41.1	38.1	43
Median	27.5	29.2	28.7

During the 2019 deployment season, dissolved oxygen concentration ranged from 9.50mg/L to a maximum of 12.73mg/L, with a median value of 10.99mg/L. Saturation of dissolved oxygen ranged from 92.2% to 100.7%, with a median value of 96.5% (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 concentrations were lowest through July and late August when water temperatures were warmest. Dissolved oxygen concentrations began to increase through September and October as water temperatures decreased (Figure 23).

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

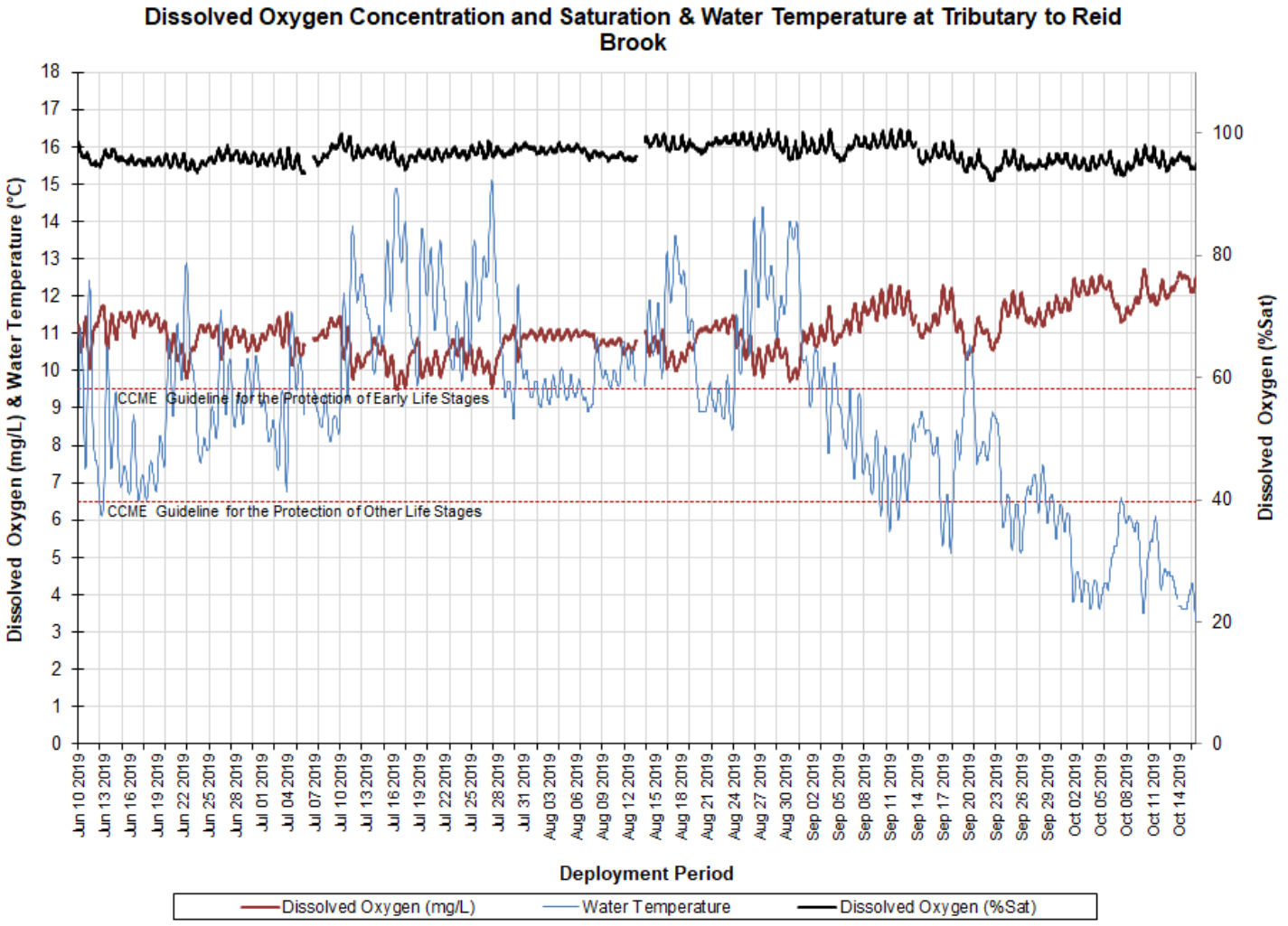

Figure 23: Dissolved Oxygen Concentration and Saturation & Water Temperature at Tributary to Reid Brook

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

Dissolved Oxygen (mg/L)	2019	2018	2017
Min	9.50	9.03	9.78
Max	12.73	13.22	13.56
Median	10.99	10.89	11.22

Percent Saturation (%)	2019	2018	2017
Min	92.2	91.4	89.4
Max	100.7	103.9	108.9
Median	96.5	95.6	96.8

During the 2019 deployment season, turbidity ranged from 0.0NTU to a maximum of 1131.0NTU, with a median value of 1.2NTU (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 30NTU 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.

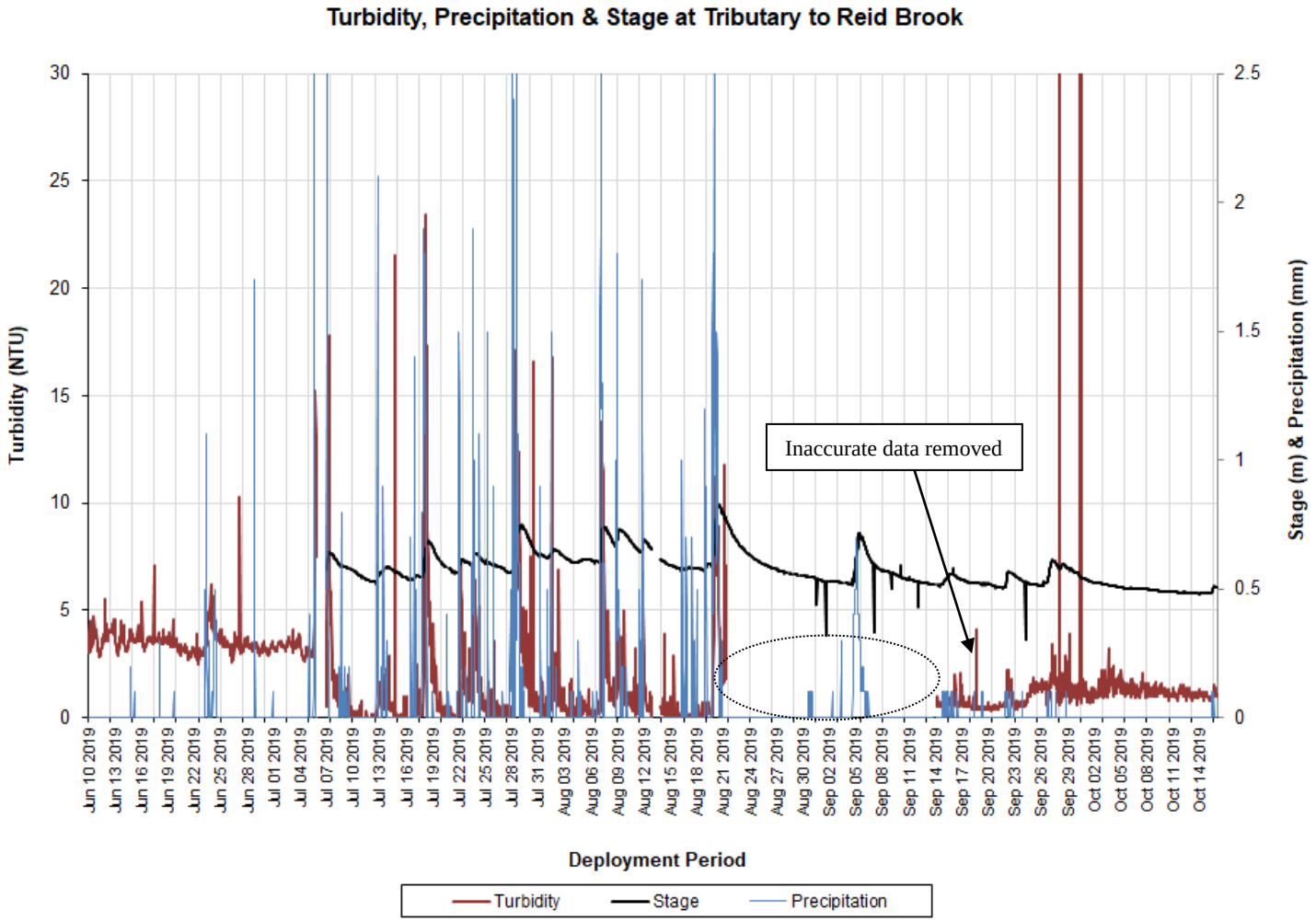

Figure 24: Turbidity, Precipitation & Stage at Tributary to Reid Brook

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

Turbidity	2019	2018	2017
Min	0.0	0.0	0
Max	1131.0	366.1	54.6
Median	1.2	0.0	0.8

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 2019 deployment season, water temperatures at all four real-time stations ranged from 2.49°C at Reid Brook at Outlet of Reid Pond to a maximum of 18.76°C 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. 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 early July 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 18.76°C, as well as the highest median temperature of 11.22°C (Table 24).

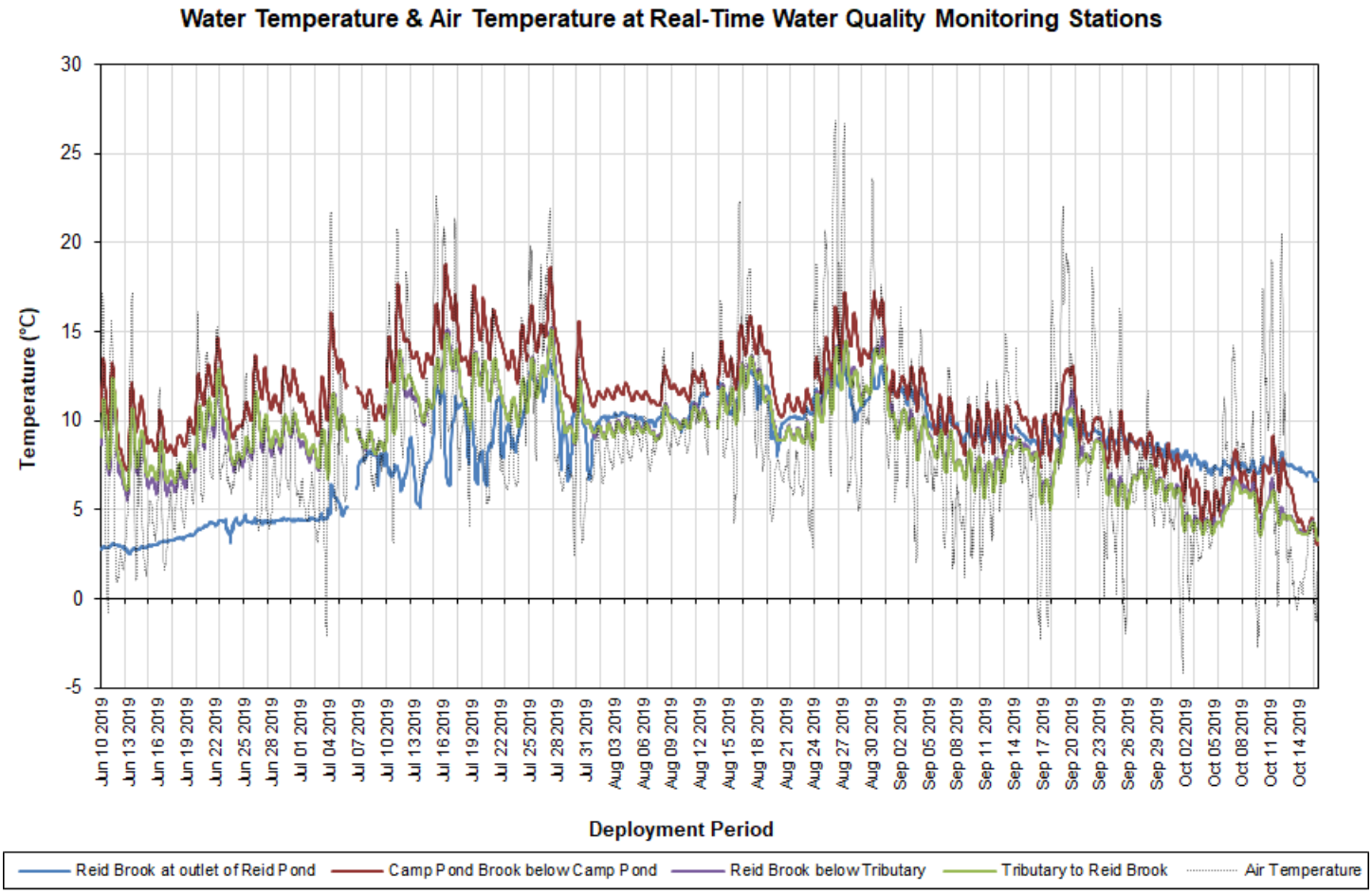

Figure 25: Water Temperature & Air Temperature at all RTWQ Stations

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	2.49	2.99	3.40	3.30
Max	13.99	18.76	15.20	15.10
Median	8.90	11.22	9.21	9.20

pH

During the 2019 deployment season, median pH values at all four real-time stations ranged from 6.58 pH units at Camp Pond Brook below Camp Pond to 6.86 pH units at Reid Brook at Outlet of Reid Pond (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 CCME's Minimum 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.

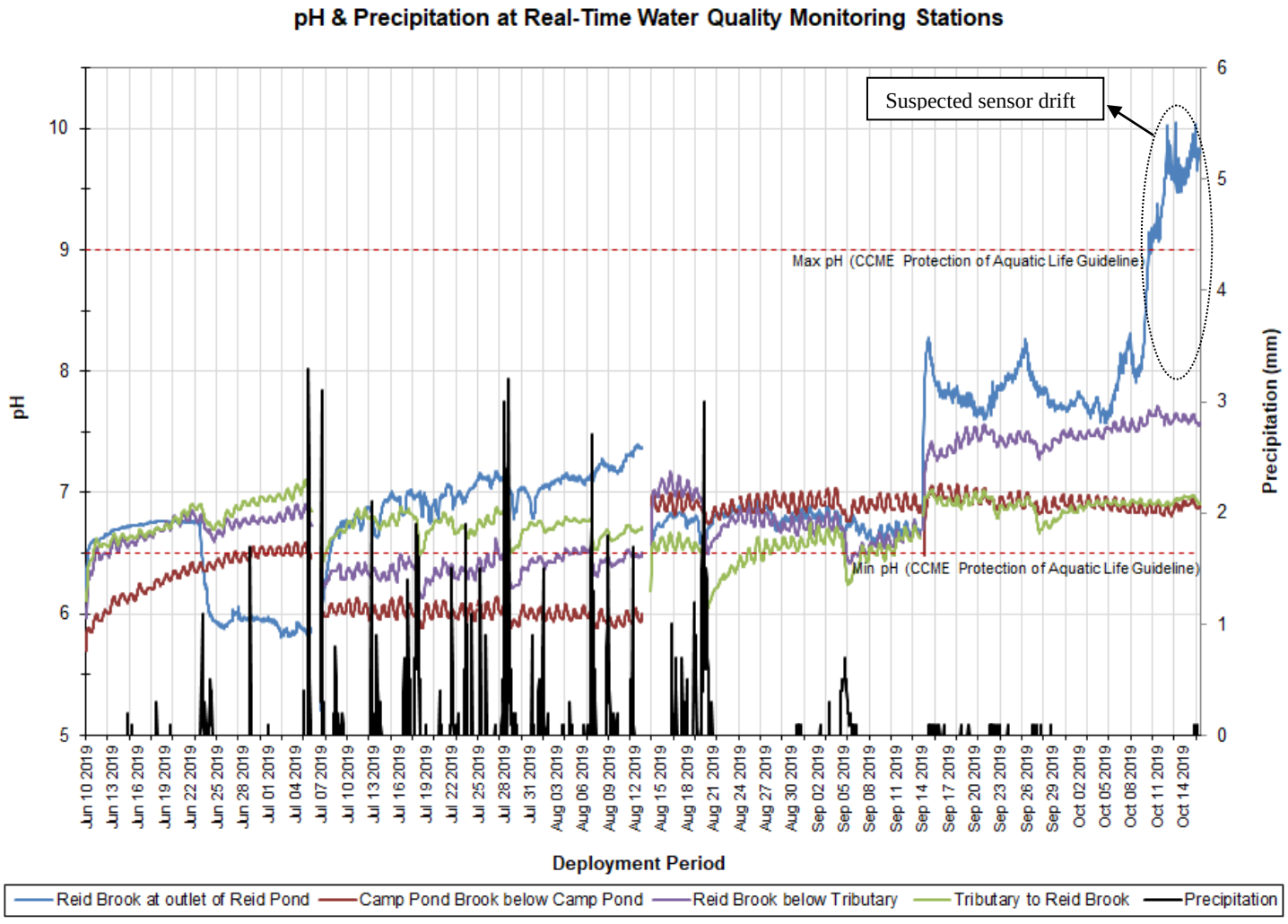

Figure 26: pH & Precipitation at all RTWQ Stations

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	5.21	5.70	5.97	6.05
Max	10.05	7.07	7.71	7.11
Median	6.86	6.58	6.72	6.74

Specific Conductivity

During the 2019 deployment season, specific conductivity medians ranged from 11.6µS/cm at Reid Brook at Outlet of Reid Pond to a maximum of 34.8µS/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. 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 and is therefore more susceptible to anthropogenic influences (Figure 27).

Reid Brook below Tributary, Tributary to Reid Brook and Camp Pond Brook below Camp Pond 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 quite consistent across the deployment season.

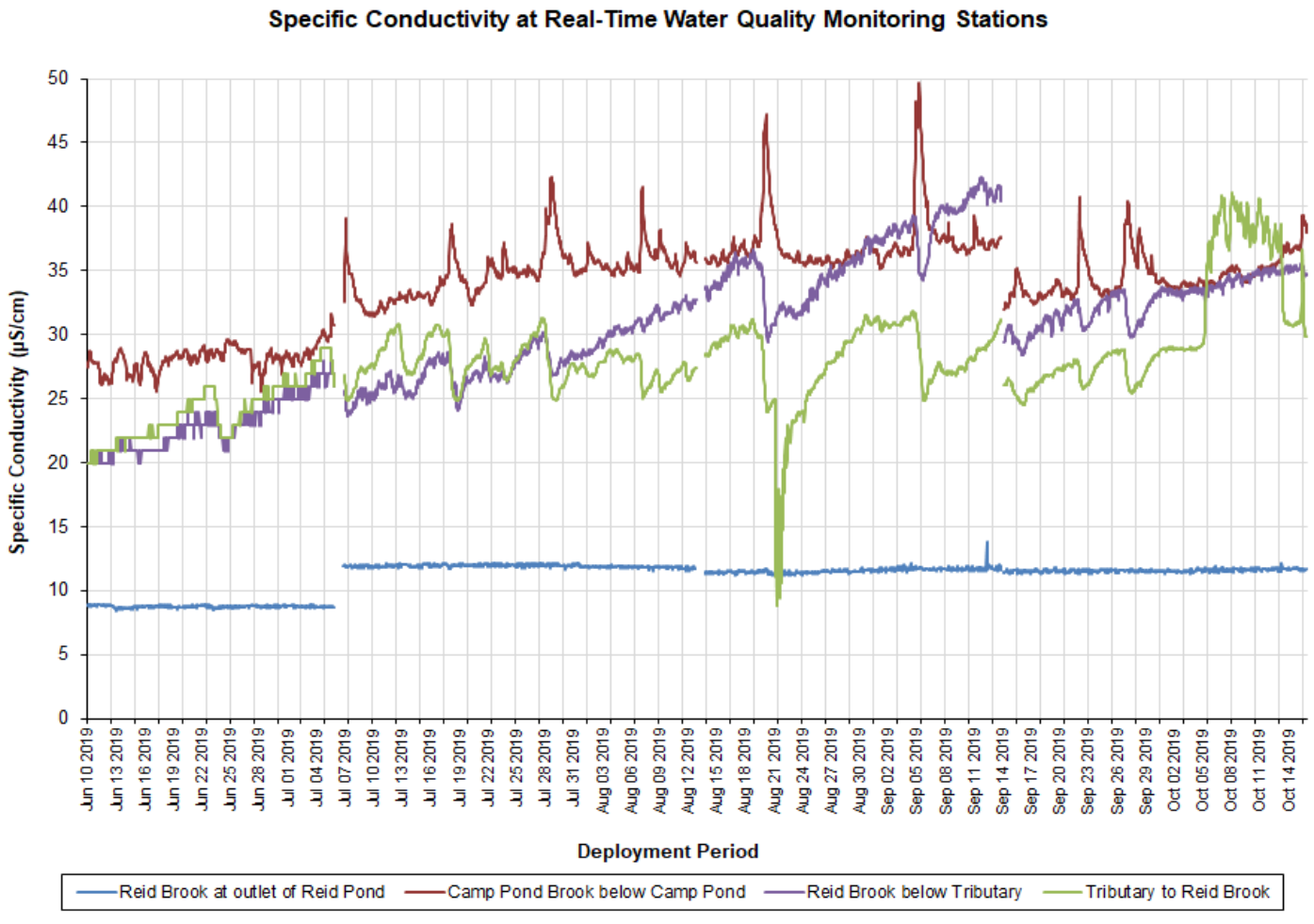

Figure 27: Specific Conductivity at all RTWQ Stations

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	8.5	25.6	20.0	8.8
Max	13.8	49.7	42.3	41.1
Median	11.6	34.8	30.7	27.5

Dissolved Oxygen Concentration and Saturation of Dissolved Oxygen

During the 2019 deployment season, dissolved oxygen concentration medians ranged from 10.46mg/L at Camp Pond Brook below Camp Pond to a maximum of 11.05mg/L at Reid Brook below Tributary (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 at Outlet of Reid Pond, whereas there was greater fluctuation at the other three stations.

During the warmer periods in late July and late August, dissolved oxygen levels at Camp Pond Brook below Camp Pond occasionally fell below the CCME's Guideline for the Protection of Early Life Stages (9.5mg/L). Other than these brief occurrences, dissolved oxygen concentrations remained above the CCME's Guidelines for the Protection of Early and Other Life Stages for the duration of deployment at all stations (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.

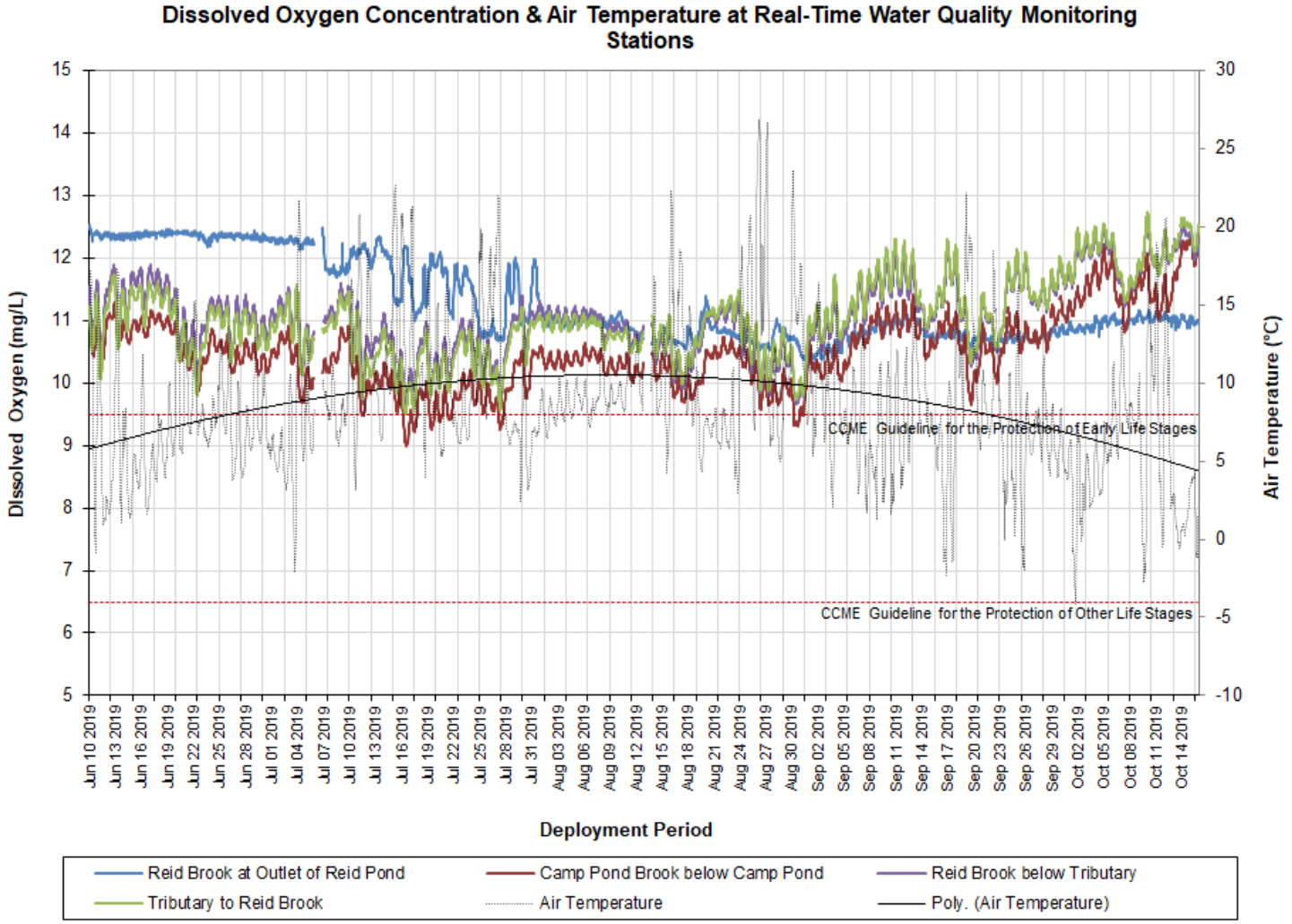

Figure 28a: Dissolved Oxygen Concentration & Air Temperature at all RTWQ Stations

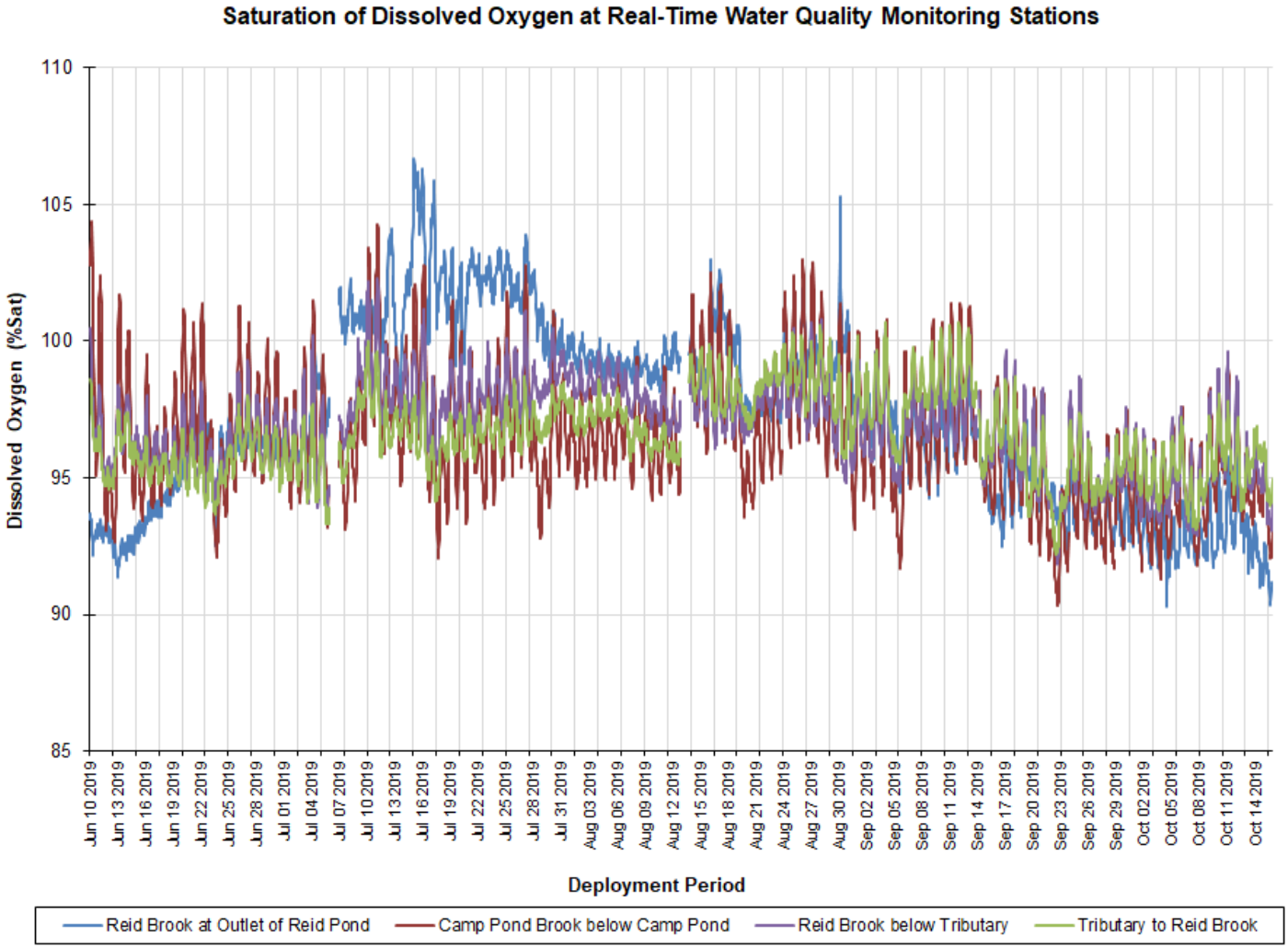

Figure 28b: Saturation of Dissolved Oxygen at all RTWQ Stations

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	10.37	9.00	9.58	9.50	90.3	90.3	91.9	92.2
Max	12.52	12.42	12.68	12.73	106.7	104.4	102.3	100.7
Median	11.00	10.46	11.05	10.99	97.0	96.2	97.0	96.5

Turbidity

During the 2019 deployment season, turbidity ranged from 0.0NTU at all stations to a maximum of 1131NTU at Tributary to Reid Brook (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 all stations indicate that there is very little background turbidity at these stations, which is to be expected. Turbidity data was removed for a portion of the deployment season at Tributary to Reid Brook due to sediment build-up interfering with the turbidity sensor (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.

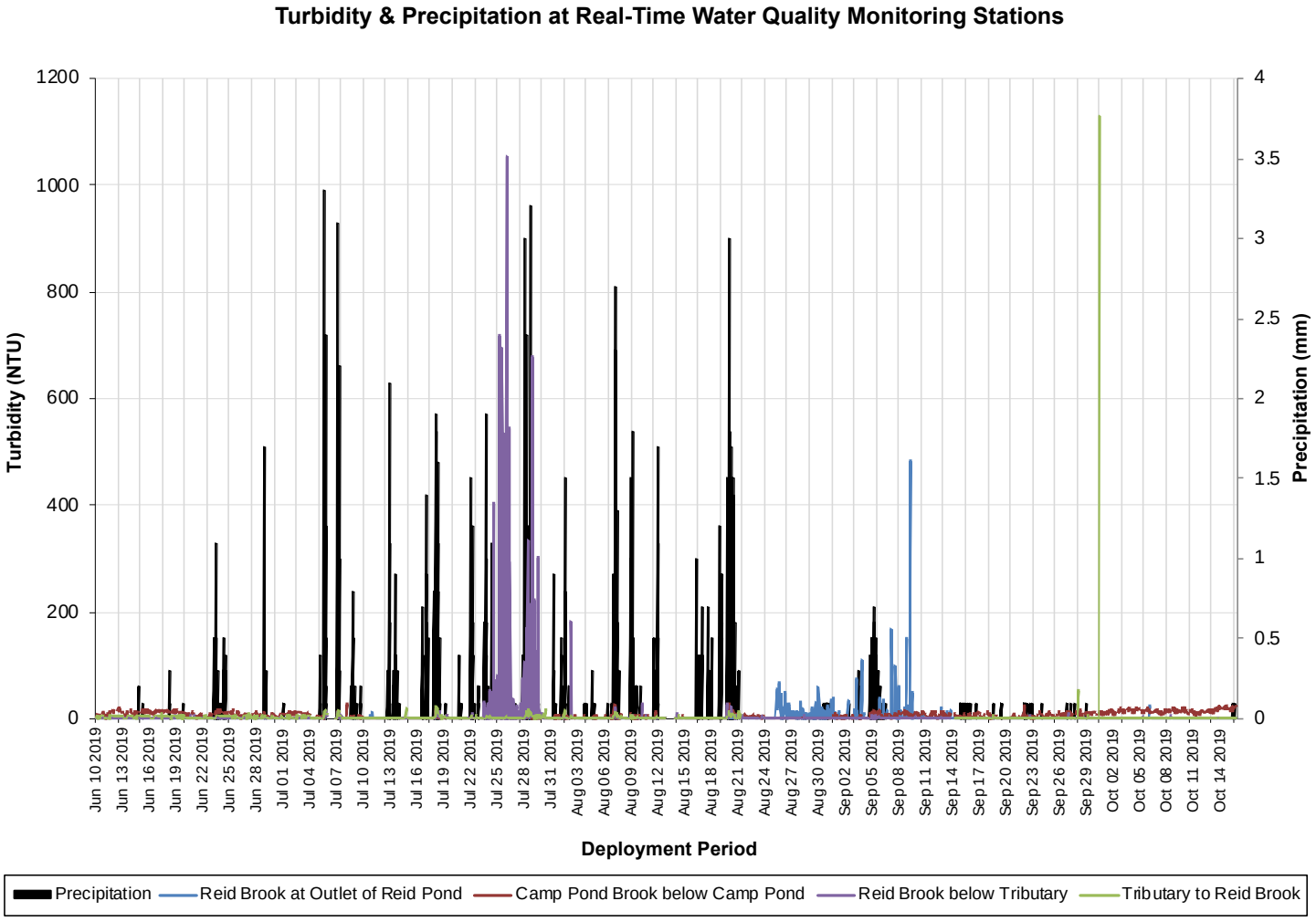

Figure 29a: Turbidity & Precipitation at all RTWQ Stations

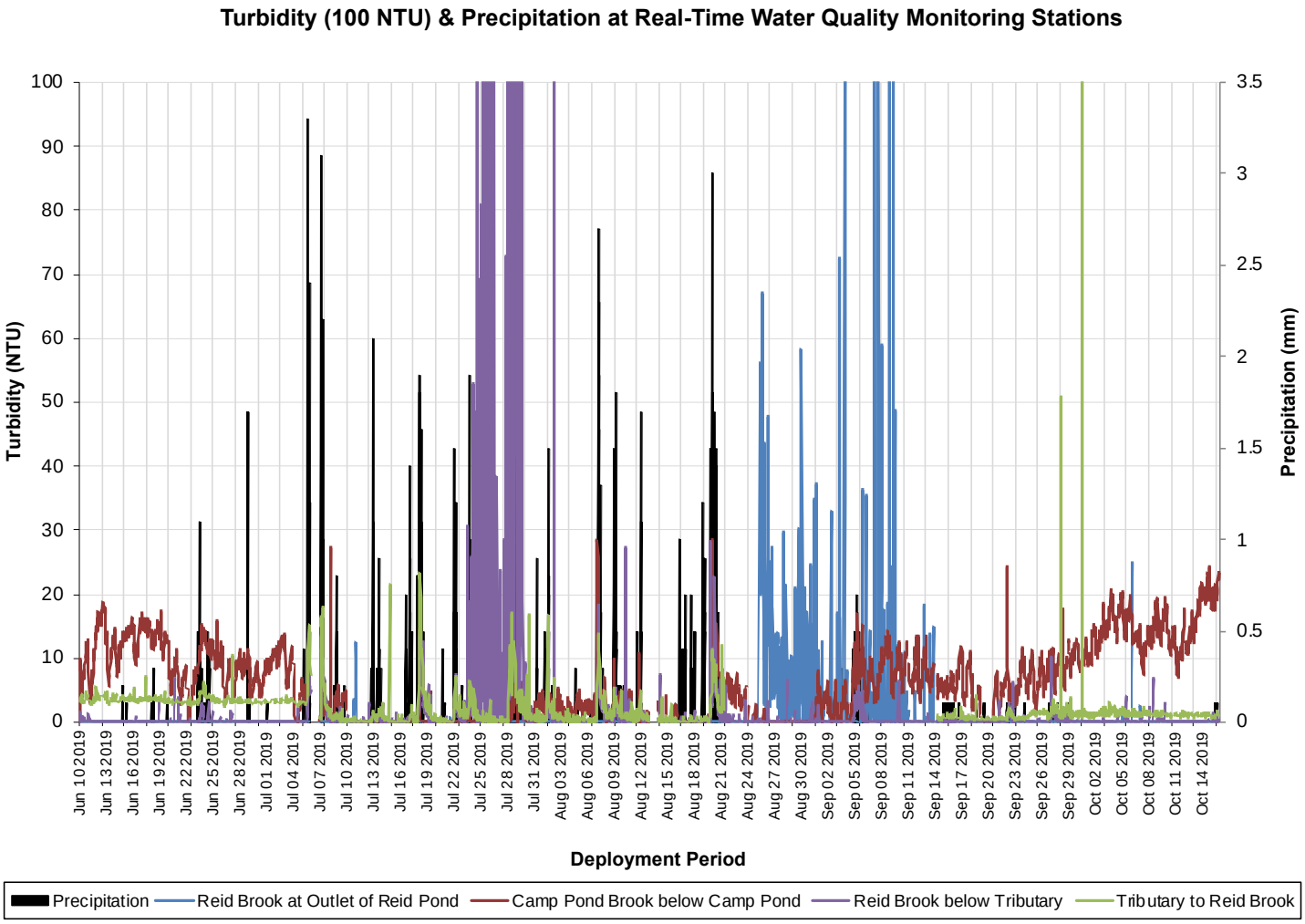

Figure 29b: Turbidity & Precipitation at all RTWQ Stations (graphed to 100 NTU)

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	0.0	0.0	0.0	0.0
Max	484.0	46.5	1053.0	1131.0
Median	0.0	4.7	0.0	1.2

Stage

During the 2019 deployment season, stage levels generally 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). Stage data is missing until early July for both Reid Brook below Tributary and Tributary to Reid Brook due to transmission failure from the station.

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.

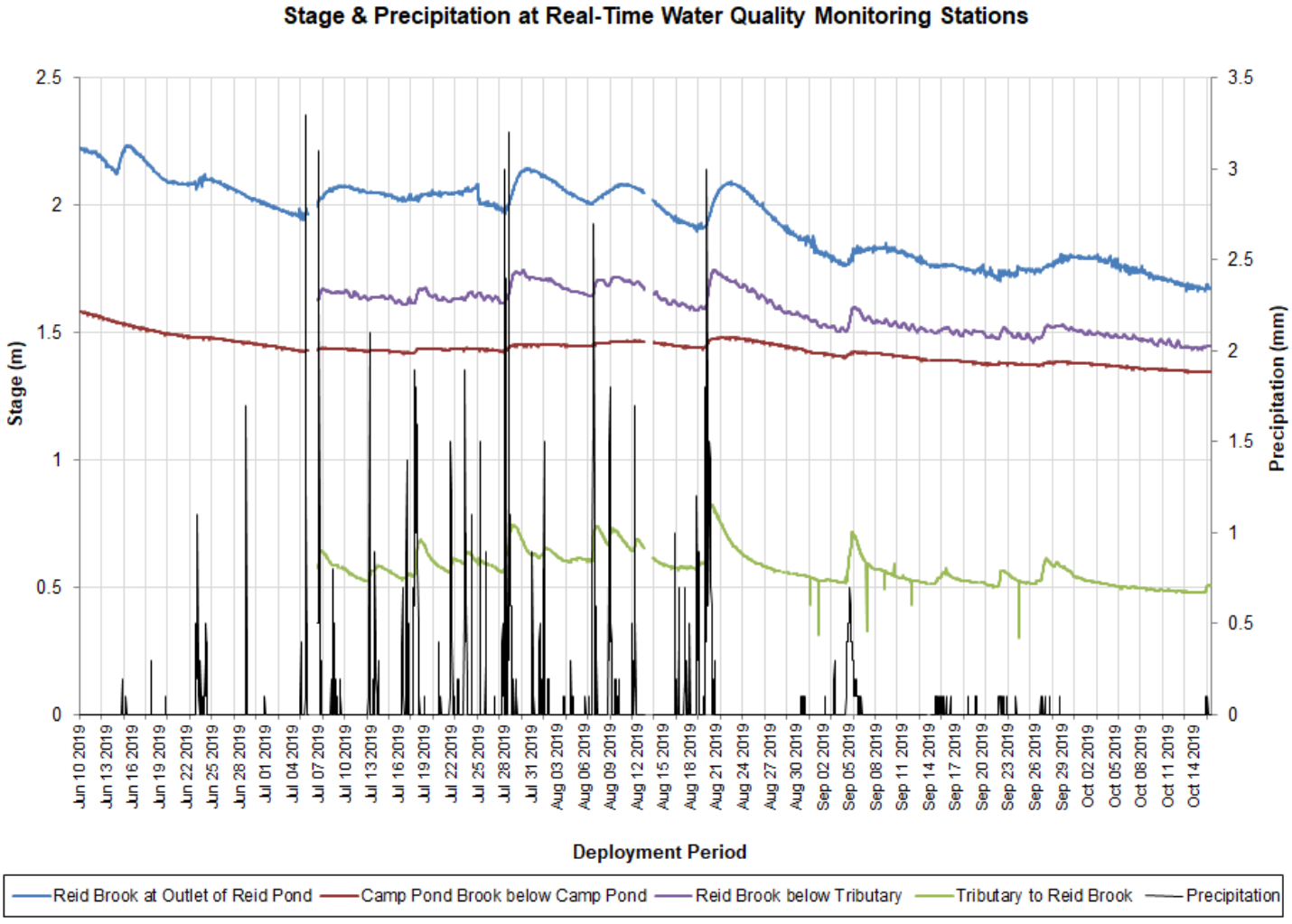

Figure 30: Stage & Precipitation at all RTWQ Stations

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	1.667	1.346	1.438	0.304
Max	2.237	1.583	1.747	0.826
Median	2.000	1.435	1.599	0.568
Difference (Max-Min)	0.570	0.237	0.309	0.522

Conclusions

The 2019 deployment season ran from June 10 until October 16, and consisted of four 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 2020 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 2020 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 2020 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*.).
- 2020 deployments will recommence in the Spring.

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