# Real-Time Water Quality Deployment Report

## Teck: Duck Pond Operations Annual Report

**2017**

**Government of Newfoundland & Labrador**
**Department of Municipal Affairs and Environment**
**Water Resources Management Division**
**St. John's, NL, A1B 4J6 Canada**

## Introduction

Ambient surface water quality monitoring is carried out by the Water Resources Management Division (WRMD) of the Department of Municipal Affairs and Environment (MAE). Much of this work is carried out under the Real-Time Water Quality (RTWQ) monitoring program, especially in instances where industrial development could potentially impact ambient water bodies. The RTWQ program consists of more than 30 stations across the province from Voisey's Bay to St. Lawrence and Corner Brook to St. John's.

Real-time water quality monitoring began at the Duck Pond Operation with two surface water stations and one groundwater monitoring station in 2006 when it was run by Aur Resources Inc. As the site was developed, the outflow of Duck Pond was diverted from flowing into East Pond Brook via East Pond and instead directed in an opposite direction towards a series of settling and polishing ponds before being released into a tributary to Gills Pond Brook. As a result of this flow alteration, East Pond Brook below East Pond station (EPB) has retained background conditions while Tributary to Gills Pond Brook station (TGPB) monitors effluent from the mine site. The well, located immediately down-gradient from the dam diverting Duck Pond's outflow, is intended to monitor seepage from the tailings pond.

## Methods and Procedures

Work under the RTWQ program is conducted according to the Protocols Manual for Real-Time Water Quality Monitoring in NL[*]. This document outlines the procedures, methods, and QAQC regimen used by all staff involved in the RTWQ program at all stations, province wide. For surface water monitoring, water quality instrumentation – in this case the Hydrolab DS5X multi-parameter sonde – is deployed on six-week intervals with in situ data validation at the beginning and end of deployment using an equivalent and freshly calibrated multi-parameter sonde. Additionally, a grab sample is collected at the start of a deployment as an independent indicator of data quality.

Due to the complicated nature of groundwater monitoring, data validation is restricted to the use of grab samples at the time of deployment. During groundwater sampling a volume equivalent to three well casings is purged from the well prior to sampling. This process flushes stagnant water from the well and ensures that the water being observed is aquifer water.

## Results and Discussion

In the next sections, data from both surface and groundwater networks are presented as a series of line and box plots for water quality visualization over time and between stations. Summary statistics are presented in the appendix by year and station.

[*] http://www.mae.gov.nl.ca/waterres/rti/rtwq/NL_RTWQ_Manual.pdf

## Surface Water Stations

### Water Temperature

Water temperatures at both EPB and TGPB stations tend to be similar and vary from year to year with no obvious trend one way or another. Winter water temperatures are somewhat dissimilar between both stations with winter temperatures at EPB station remaining low whereas TGPB is often punctuated by variation and a shorter period of flat-line temperatures (see indicator arrow in Figure 1). This is likely due to the steady flow and relatively deep water at EPB vs the turbulent flow and shallow water at TGPB station that is more prone to influence by air temperatures.

**Table 1: Summary statistics of water temperature at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

| Station | Year | Mean | Median | Min | Max |
|---|---|---|---|---|---|
| East Pond Brook below East Pond | 2010 | 7.56 | 6.15 | -0.14 | 26.34 |
| | 2011 | 7.11 | 4.81 | -0.07 | 25.54 |
| | 2012 | 8.12 | 6.55 | -0.04 | 29.05 |
| | 2013 | 7.7 | 5.6 | 0.03 | 26.05 |
| | 2014 | 7.61 | 4.97 | 0.01 | 28.39 |
| | 2015 | 7.14 | 2.93 | -0.02 | 26.74 |
| | 2016 | 6.77 | 4.04 | -0.01 | 27.09 |
| | 2017 | 7.2 | 4.39 | -0.15 | 28.28 |
| Tributary to Gills Pond Brook | 2010 | 7.43 | 5.99 | -0.41 | 25.31 |
| | 2011 | 6.67 | 4.02 | -0.45 | 25.22 |
| | 2012 | 7.86 | 6.24 | -0.45 | 27.8 |
| | 2013 | 7.17 | 4.72 | -0.45 | 25.43 |
| | 2014 | 7.25 | 4.01 | -0.45 | 27.34 |
| | 2015 | 6.91 | 2.93 | -0.39 | 25.84 |
| | 2016 | 7.08 | 4.98 | -0.24 | 26.22 |
| | 2017 | 7.34 | 4.79 | -0.33 | 27.18 |

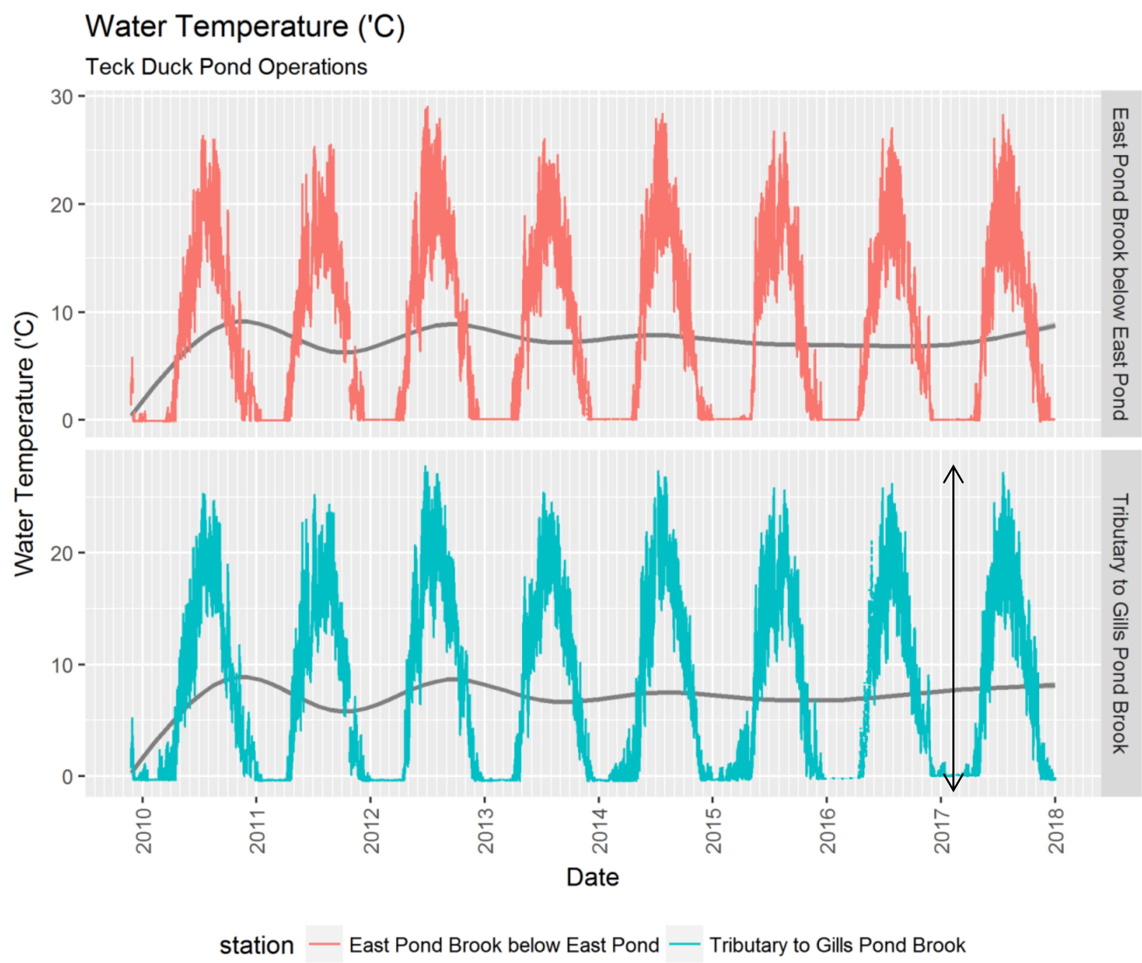


**Figure 1: Water temperature at East Pond Brook and Tributary to Gills Pond Brook stations from 2009 to 2017**

Boxplots of water temperature in Figure 2 further reinforce that there is no substantial trend in water temperature at both surface water stations near Teck Duck Pond Operations.

From 2010 to 2014, median water temperature was found to be lower at TGPB compared to EPB station until 2015, when they were equivalent. From 2016 onwards, TGPB station has been slightly higher. This may be due to stabilisation efforts within the tailings storage area and resultant flow reduction.

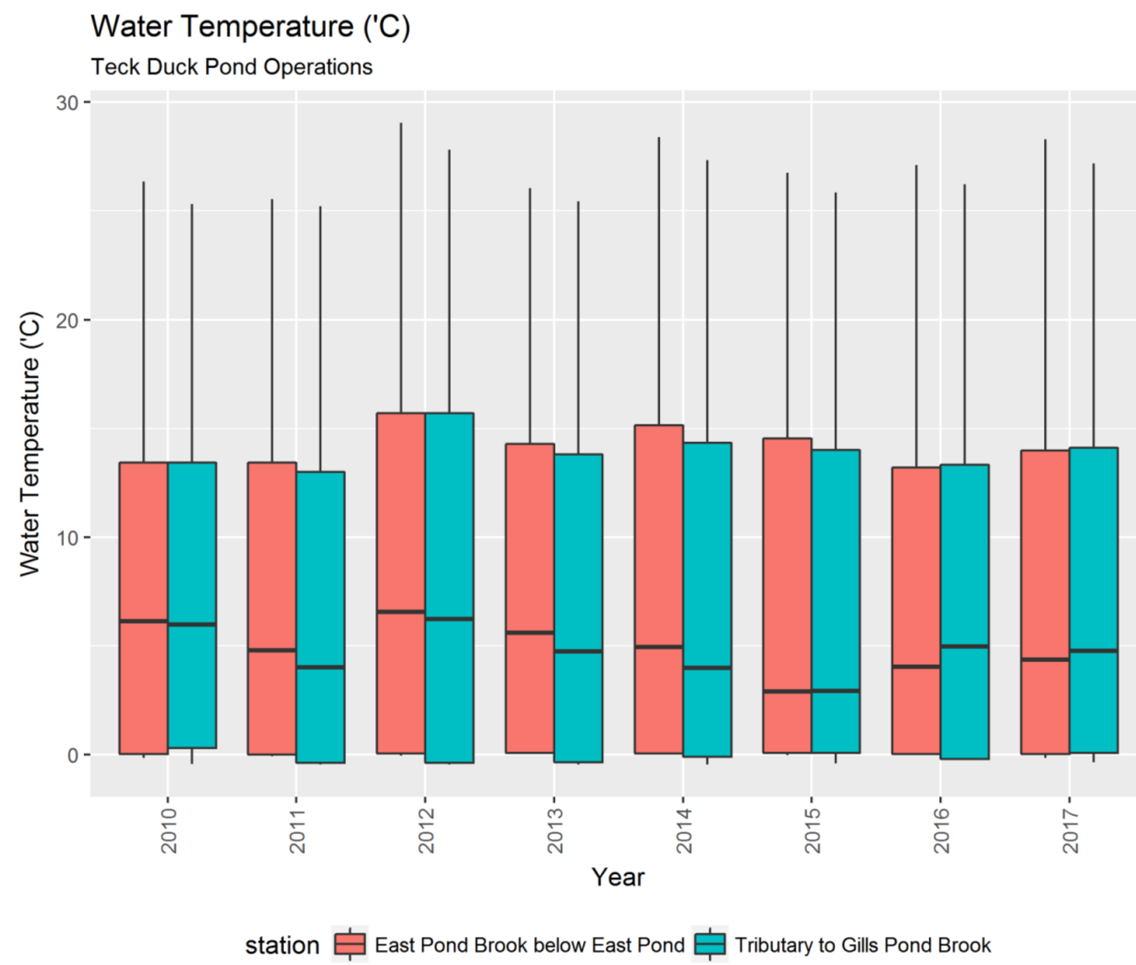


**Figure 2: Boxplots of water temperature at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

## pH

Observation of the solid gray trend line in Figure 3 shows that pH levels at EPB station tend to be slightly more acidic and more variable than those at TGPB station. This is likely the result of efforts to control pH level within the tailings management pond at the Teck facility.

Dashed lines in Figure 3 indicate upper and lower CCME Guidelines for the Protection of aquatic life. As is commonly found on the island of Newfoundland, pH levels tend to fall on or just below the lower limit.

**Table 2: Summary statistics of pH at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

| Station | Year | Mean | Median | Min | Max |
|---|---|---|---|---|---|
| East Pond Brook below East Pond | 2010 | 6.6 | 6.63 | 5.04 | 7.36 |
| | 2011 | 6.32 | 6.35 | 5.51 | 7.06 |
| | 2012 | 6.41 | 6.33 | 5.44 | 7.38 |
| | 2013 | 6.29 | 6.38 | 5.11 | 7.23 |
| | 2014 | 6.36 | 6.4 | 5.02 | 7.26 |
| | 2015 | 6.46 | 6.54 | 4.94 | 7.47 |
| | 2016 | 6.67 | 6.66 | 4.98 | 7.42 |
| | 2017 | 6.64 | 6.7 | 5.44 | 7.29 |
| Tributary to Gills Pond Brook | 2010 | 6.76 | 6.77 | 5.74 | 7.38 |
| | 2011 | 6.77 | 6.73 | 5.87 | 7.49 |
| | 2012 | 6.83 | 6.78 | 5.83 | 7.69 |
| | 2013 | 6.8 | 6.81 | 5.86 | 7.67 |
| | 2014 | 6.61 | 6.6 | 5.62 | 7.49 |
| | 2015 | 6.8 | 6.9 | 5.54 | 7.48 |
| | 2016 | 6.81 | 6.88 | 5.62 | 7.47 |
| | 2017 | 7 | 7.07 | 6.27 | 7.5 |

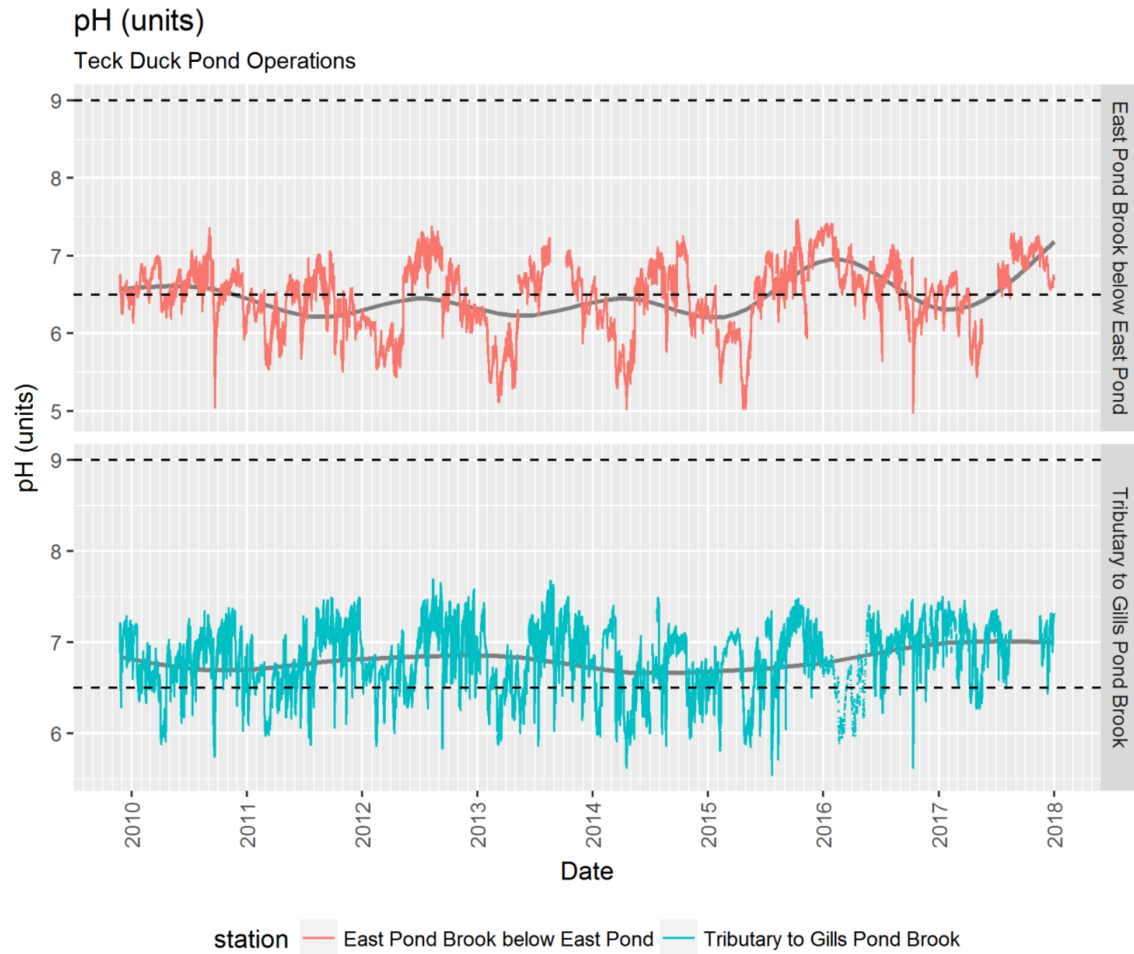


**Figure 3: pH at East Pond Brook and Tributary to Gills Pond Brook stations from 2009 to 2017**

Figure 4 illustrates the difference in pH between EPB and TGPB stations. Median pH values are consistently lower at EPB compared to TGPB.

While there is no rapid trend in pH at either monitoring station, there does appear to be an increase at the 1st, median, and 3rd quartiles at TGPB station. This could be the result of upstream work at the tailings management area.

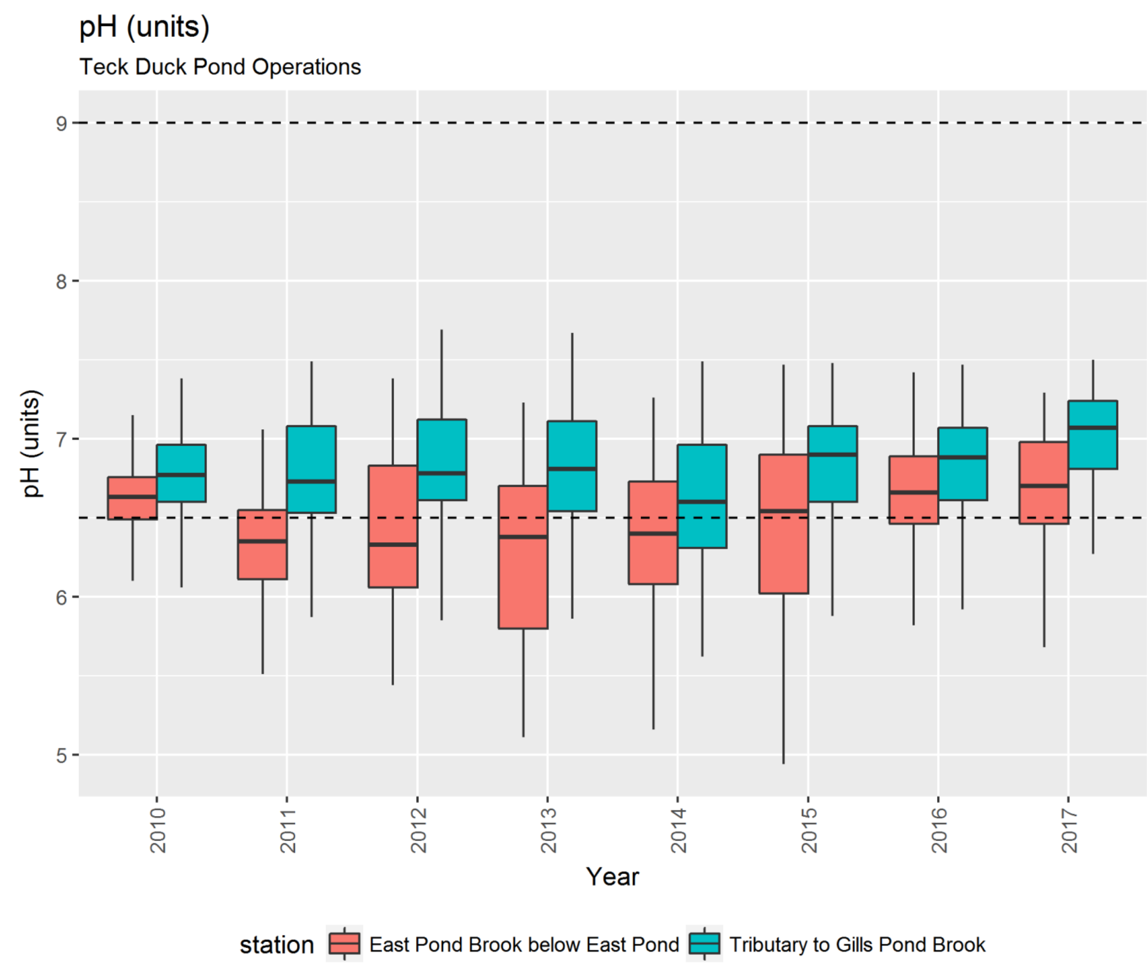


**Figure 4: Boxplots of pH at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

## Specific Conductivity

Whereas EPB station receives water from a relatively unimpacted area near the Duck Pond Operations site, TGPB station receives variable flow from the tailings management and clarifying ponds. This flow tends to be of high ionic strength compared to the natural flow of the tributary. As such, conductivity levels at TGPB station are substantially affected by the volume of flow and are almost always an order of magnitude greater than conductivity values found at EPB station.

**Table 3: Summary statistics of specific conductivity at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

| Station | Year | Mean | Median | Min | Max |
|---|---|---|---|---|---|
| East Pond Brook below East Pond | 2010 | 26.5 | 25.9 | 12.4 | 57 |
| | 2011 | 24.9 | 23.8 | 6.3 | 47.6 |
| | 2012 | 27 | 25.8 | 11.3 | 52.3 |
| | 2013 | 26 | 25.7 | 12.6 | 45 |
| | 2014 | 25.5 | 25.4 | 11.8 | 61 |
| | 2015 | 32 | 30.2 | 15.3 | 97.3 |
| | 2016 | 30.9 | 26 | 13.4 | 78.2 |
| | 2017 | 31.1 | 32.2 | 12.4 | 51.5 |
| Tributary to Gills Pond Brook | 2010 | 482.7 | 529 | 17 | 1023.9 |
| | 2011 | 411.7 | 251 | 17.3 | 1193 |
| | 2012 | 503.2 | 318 | 20.1 | 1356 |
| | 2013 | 545.2 | 600 | 18.6 | 1288 |
| | 2014 | 564.1 | 338.5 | 7.4 | 1603 |
| | 2015 | 704.3 | 590 | 29.3 | 1755 |
| | 2016 | 425.2 | 327 | 18.3 | 1428 |
| | 2017 | 493.3 | 373 | 28.6 | 1234 |

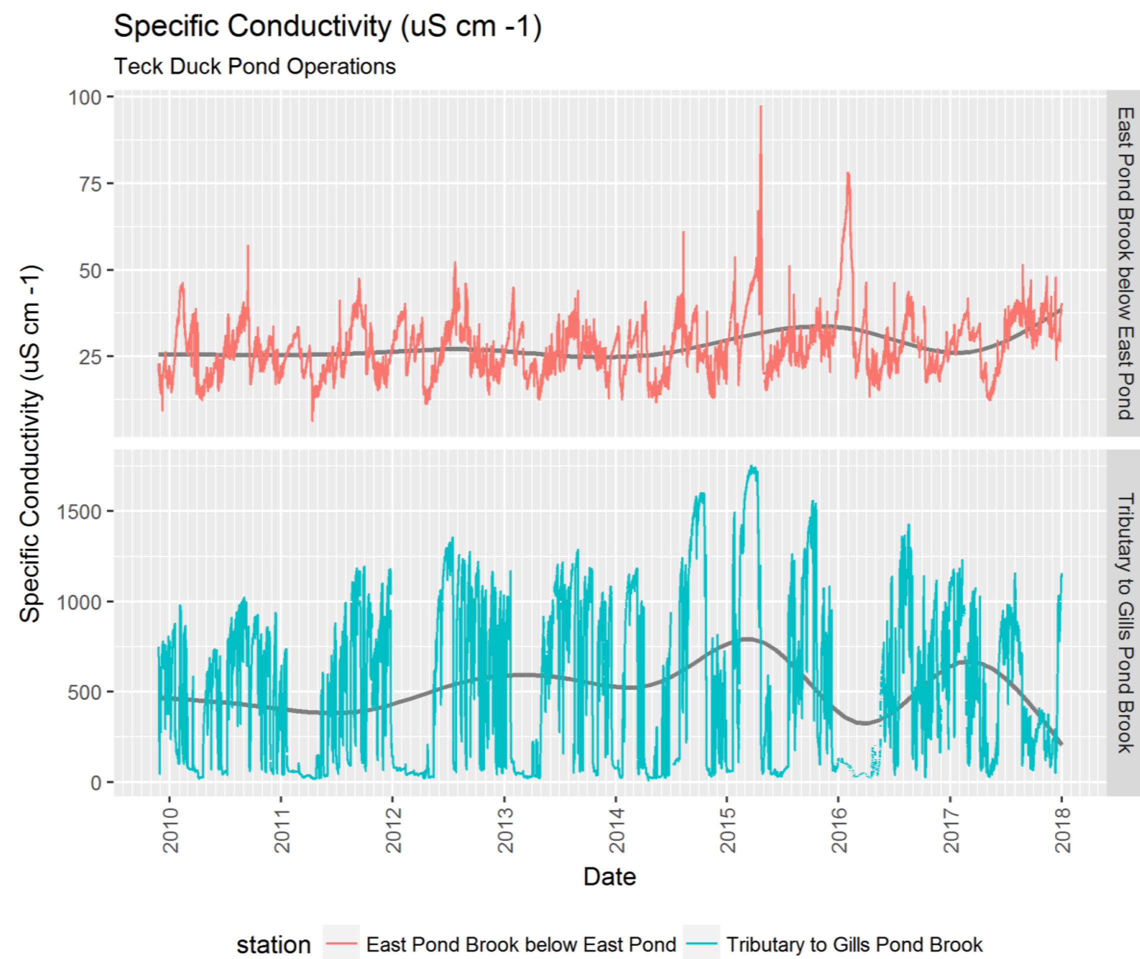


**Figure 5: Specific conductivity at East Pond Brook and Tributary to Gills Pond Brook stations from 2009 to 2017**

Specific conductivity has been stable at EPB station since 2010, although there could be some indication of an increasing trend from 2016 into 2017 as seen in Figure 6. Meanwhile, median conductivity and range was lower at TGPB station in 2016 and 2017 compared to previous years.

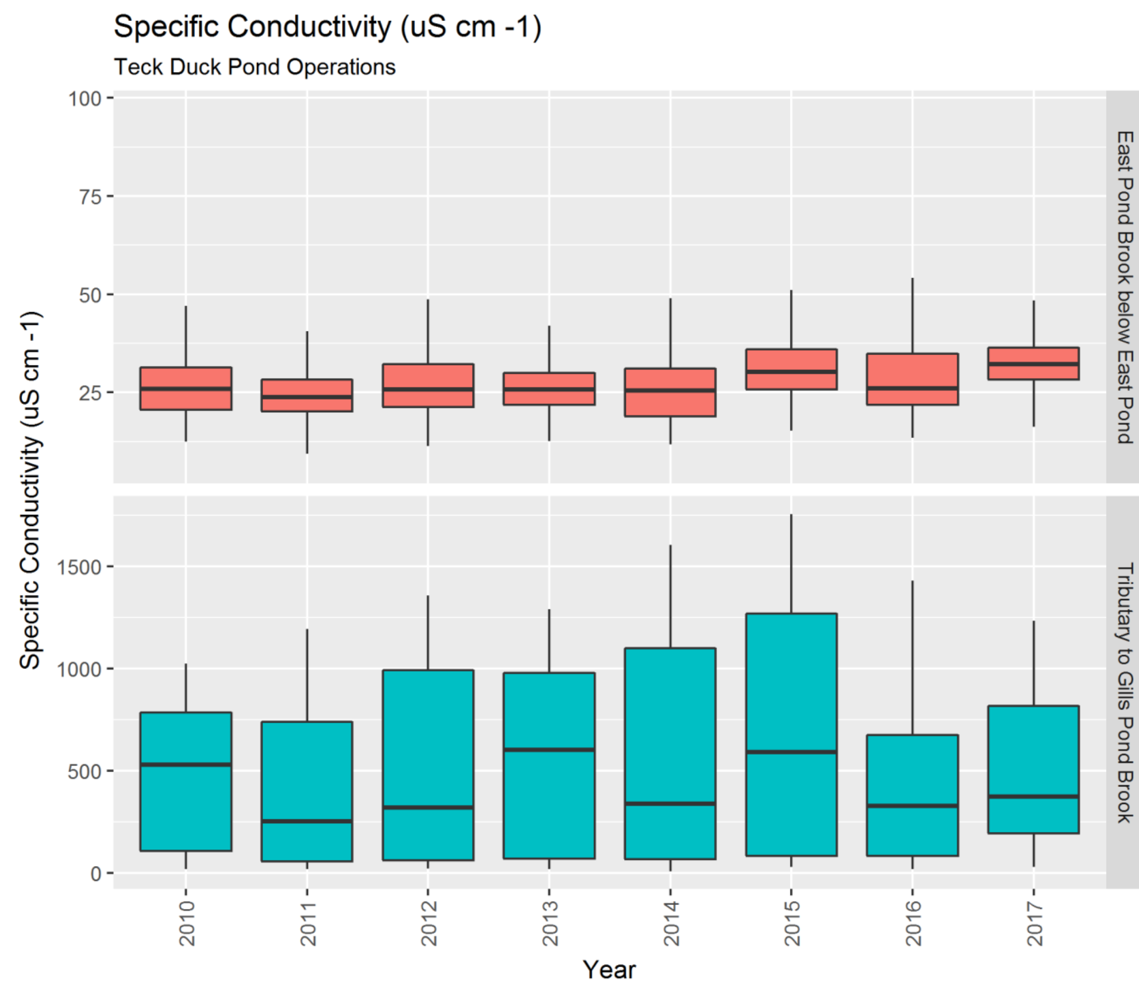


**Figure 6: Boxplots of specific conductivity at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

## Dissolved Oxygen

Dissolved oxygen concentration is usually limited by water temperature and flow. Gas solubility decreases with rising temperature and increases as temperature decreases. Meanwhile, agitation can encourage gas to dissolve beyond what would be saturation in calm conditions (called supersaturation). Calm water will allow gas to disperse, if the concentration is beyond saturation. Microbial or chemical constituents can also impact oxygen concentrations as microbes consume oxygen through respiration or chemicals are oxidized.

Oxygen concentrations are often slightly lower at TGPB station compared to EPB station. This could be the result of the relative size of the rivers, the flow characteristics, or even the chemical constituents within each river.

CCME guidelines for the protection of cold water biota are shown as dashed lines in Figure 7. Almost all values were found to reside over the guideline of 6.5 mg/l for early life stages and most were greater than the guideline of 9.5 mg/l for other life stages. A few instances of low dissolved oxygen values were observed at TGPB station in July 2014

**Table 4: Summary statistics of dissolved oxygen at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

| Station | Year | Mean | Median | Min | Max |
|---|---|---|---|---|---|
| East Pond Brook below East Pond | 2010 | 11.44 | 11.62 | 7.72 | 14.44 |
| | 2011 | 11.44 | 11.75 | 7.63 | 14.06 |
| | 2012 | 11.16 | 11.46 | 7.43 | 13.77 |
| | 2013 | 11.17 | 11.54 | 7.81 | 14.03 |
| | 2014 | 11.38 | 11.75 | 6.95 | 14.03 |
| | 2015 | 11.42 | 12.17 | 7.64 | 14.28 |
| | 2016 | 11.67 | 12.47 | 7.18 | 14.27 |
| | 2017 | 11.65 | 12.08 | 7.25 | 14.39 |
| Tributary to Gills Pond Brook | 2010 | 10.95 | 11 | 7.21 | 13.96 |
| | 2011 | 11.56 | 11.88 | 7.57 | 14.38 |
| | 2012 | 11.26 | 11.41 | 7.32 | 14.13 |
| | 2013 | 11.09 | 11.34 | 7.79 | 13.75 |
| | 2014 | 11.22 | 11.87 | 6.41 | 13.84 |
| | 2015 | 11.24 | 11.79 | 7.37 | 13.96 |
| | 2016 | 11.12 | 11.55 | 7.42 | 13.67 |
| | 2017 | 10.93 | 11.6 | 7.33 | 13.72 |

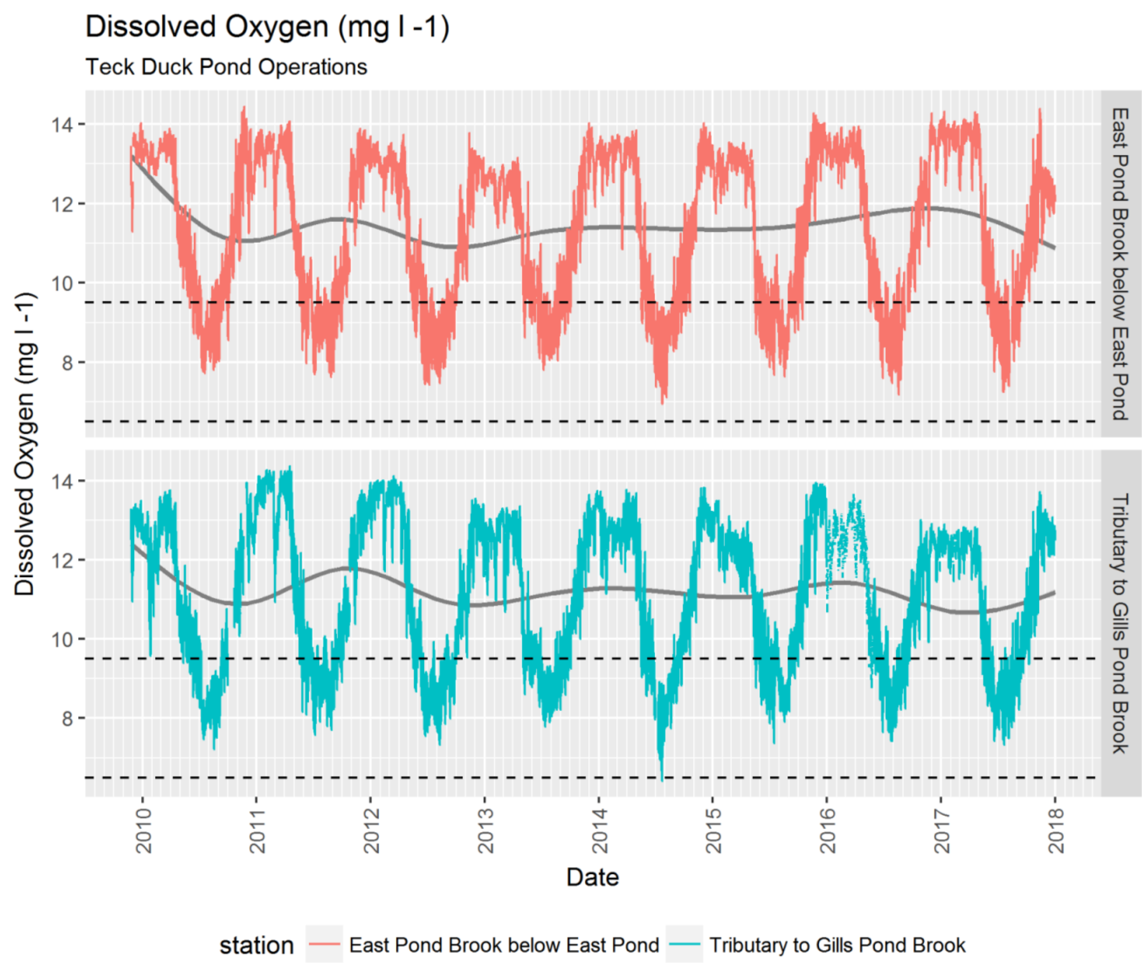


**Figure 7: Dissolved Oxygen at East Pond Brook and Tributary to Gills Pond Brook stations from 2009 to 2017**

As seen in Figure 8, most dissolved oxygen values were found to be above the CCME Guidelines for the protection of cold water biota (dashed lines in Figure 8).

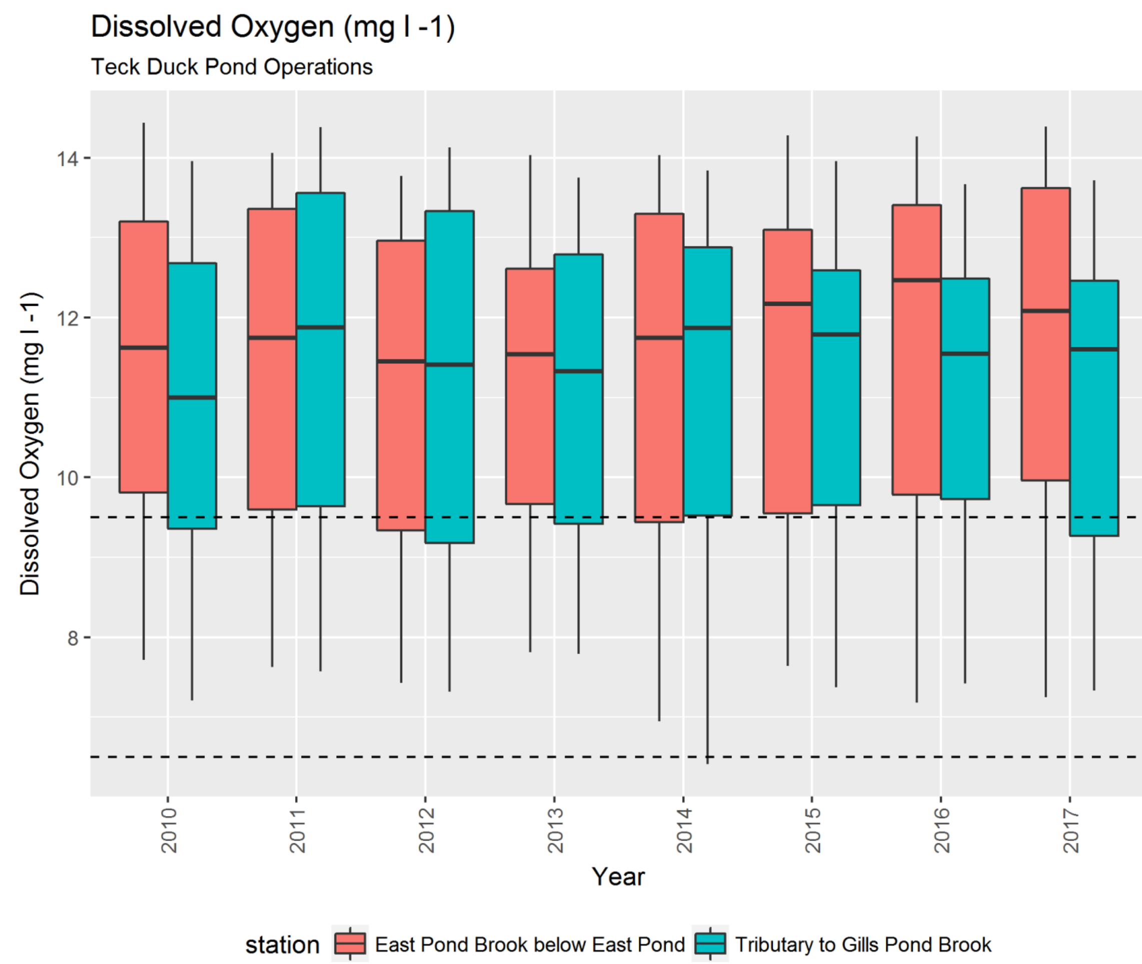


**Figure 8: Boxplots of dissolved oxygen at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

## Turbidity

Variability in turbidity is considerable between EPB and TGPB stations: the former is a steady and smooth flowing river while the latter is a babbling brook. TGPB tends to flow more vigorously and picks up fine sediment and small air bubbles. This results in a greater degree of variability as seen in Figure 9. This variability, however, is often short term and Table 9 points out that annual median values have been 0.0 NTU at TGPB since monitoring began at Teck.

**Table 5: Summary statistics of turbidity at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

| Station | Year | Mean | Median | Min | Max |
|---|---|---|---|---|---|
| East Pond Brook below East Pond | 2010 | 0.2 | 0 | 0 | 331.1 |
| | 2011 | 19 | 0 | 0 | 1753 |
| | 2012 | 0.8 | 0 | 0 | 229.9 |
| | 2013 | 0.6 | 0 | 0 | 152.3 |
| | 2014 | 0.6 | 0 | 0 | 123.6 |
| | 2015 | 1.7 | 0 | 0 | 1660 |
| | 2016 | 1.5 | 0.2 | 0 | 1789 |
| | 2017 | 1 | 0.5 | 0 | 61.3 |
| Tributary to Gills Pond Brook | 2010 | 5.4 | 0 | 0 | 1635 |
| | 2011 | 2.8 | 0 | 0 | 746 |
| | 2012 | 1.7 | 0 | 0 | 434 |
| | 2013 | 2.2 | 0 | 0 | 1295 |
| | 2014 | 1.1 | 0 | 0 | 382.4 |
| | 2015 | 0.2 | 0 | 0 | 42.3 |
| | 2016 | 5.6 | 0 | 0 | 678 |
| | 2017 | 1.2 | 0 | 0 | 72.1 |

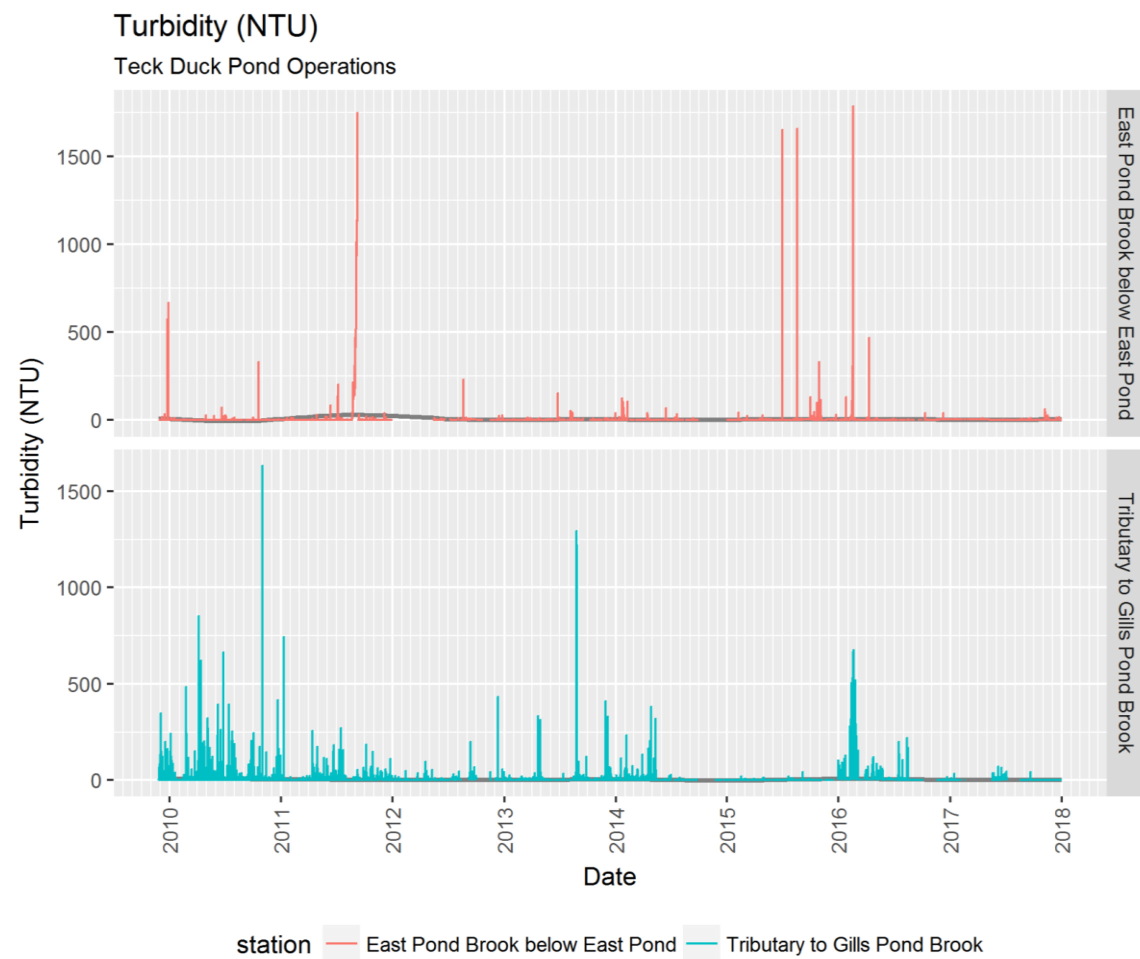


**Figure 9: Turbidity at East Pond Brook and Tributary to Gills Pond Brook stations from 2009 to 2017**

Turbidity variability has been greater at EPB compared to TGPB since 2015, given by the difference in height of boxplots in Figure 10. 2016 and 2017 are the first two years in which the median turbidity values at EPB station were found to be greater than 0.0 NTU. This may be natural variation, or related to changing conditions in the area.

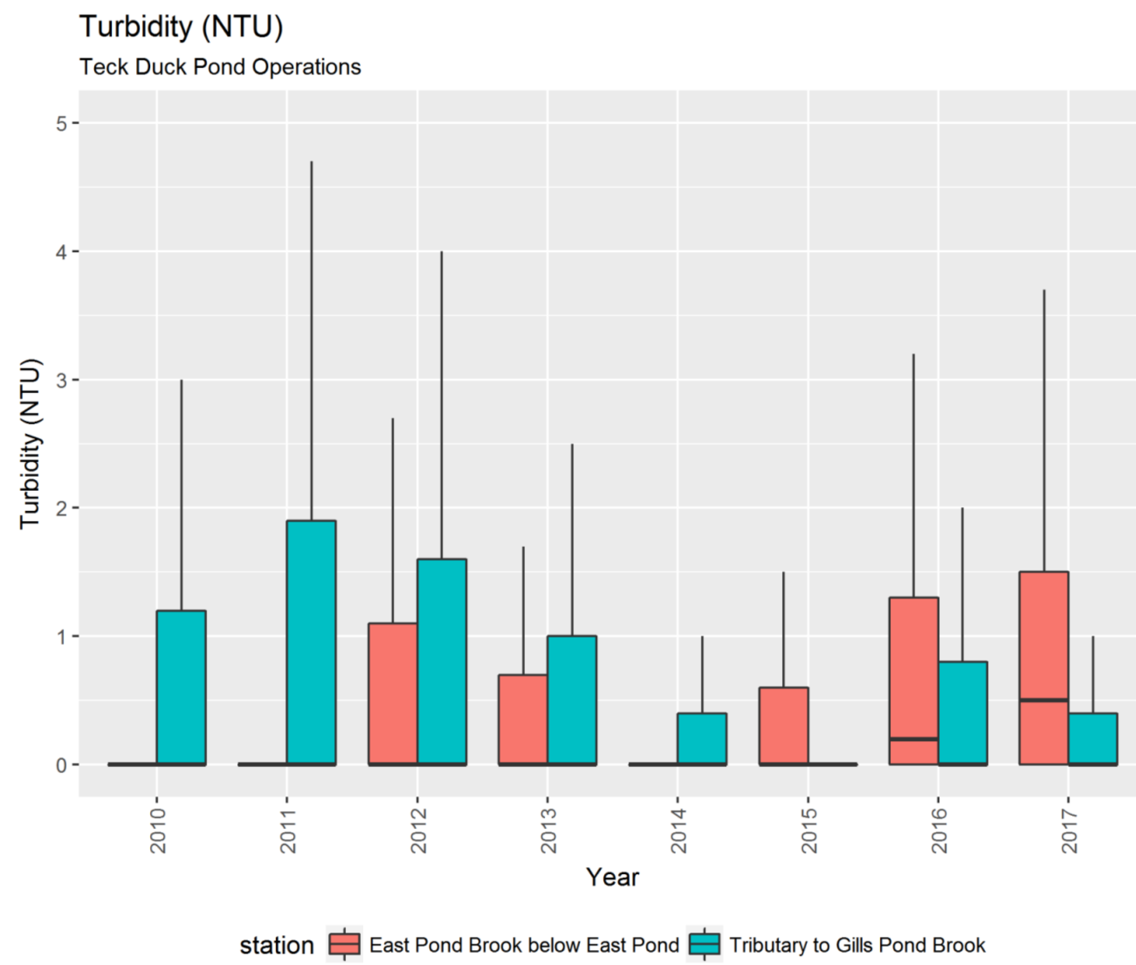


**Figure 10: Boxplots of turbidity at East Pond Brook and Tributary to Gills Pond Brook stations from 2010 to 2017**

## Groundwater Station

### Water Temperature

A rising trend in annual maximum temperatures was observed from 2007 to 2014. A subsequent decline in annual maximum temperatures occurred until 2017 when water temperatures once again moved into a warming phase (Figure 11). This may be long-term variation rather than any particular external factor.

Water within the monitoring well has only varied by 1.54°C since the initial deployment.

**Table 6: Summary statistics of water temperature at Well after Tailings Dam from 2007 to 2017**

| Year | Mean | Median | Min | Max |
|---|---|---|---|---|
| 2008 | 5.2 | 5.31 | 4.59 | 5.61 |
| 2009 | 5.14 | 5.12 | 4.76 | 5.61 |
| 2010 | 5.2 | 5.04 | 4.8 | 5.8 |
| 2011 | 5.54 | 5.58 | 5.03 | 5.99 |
| 2012 | 5.53 | 5.6 | 4.94 | 6.03 |
| 2013 | 5.56 | 5.54 | 5.03 | 6.1 |
| 2014 | 5.49 | 5.36 | 5 | 6.13 |
| 2015 | 5.3 | 5.2 | 4.84 | 6.11 |
| 2016 | 5.19 | 5.19 | 4.63 | 5.82 |
| 2017 | 5.43 | 5.42 | 4.97 | 5.99 |

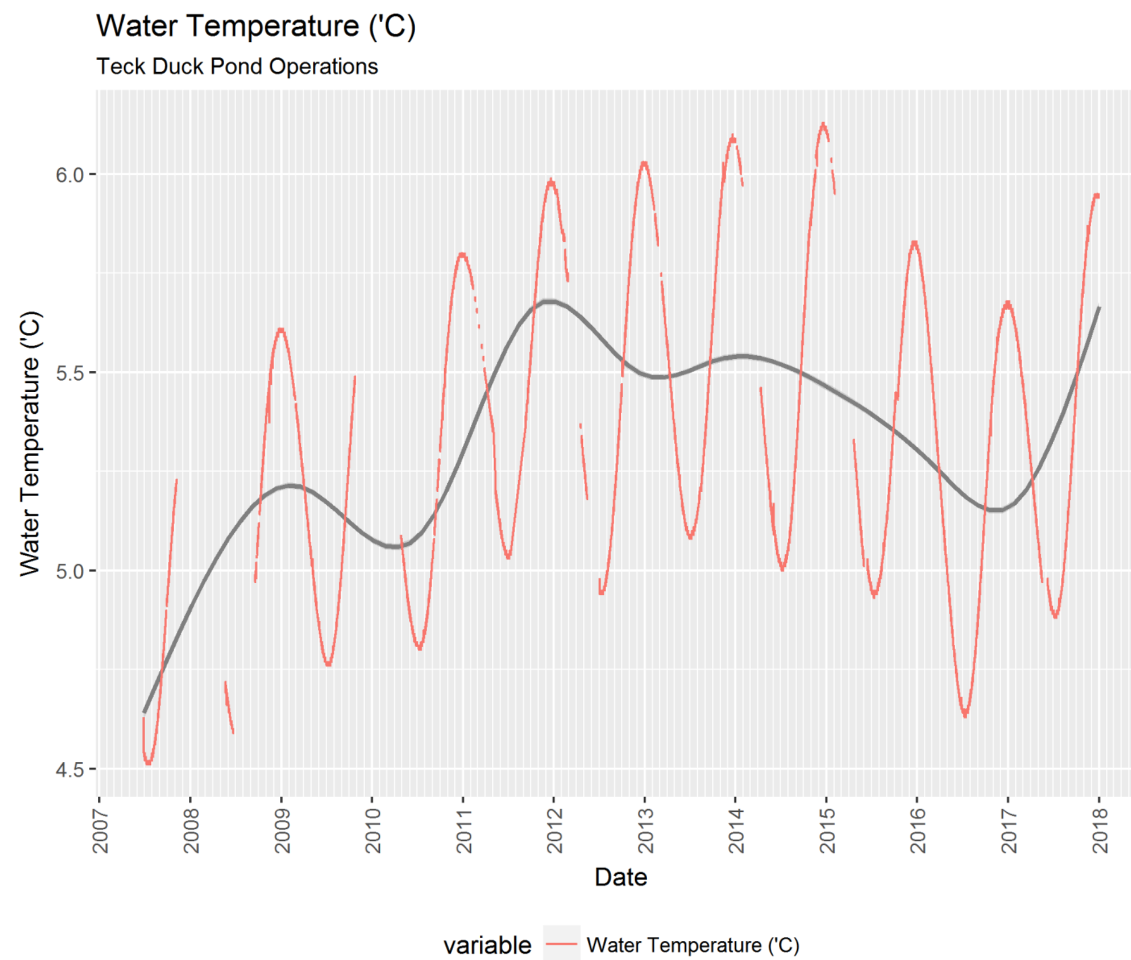


**Figure 11: Water temperature at Well after Tailings Dam from 2007 to 2017**

Data gaps observed in Figure 11 can influence the boxplots in Figure 12 by introducing bias, especially if a gap primarily occurs in the warm or cold groundwater period such as 2008 and 2010. In such cases, a skewed boxplot will be produced where the median value falls closer to the top or bottom of the boxplots as opposed to the middle.

No particular long-term trend is apparent in the figure to the right.

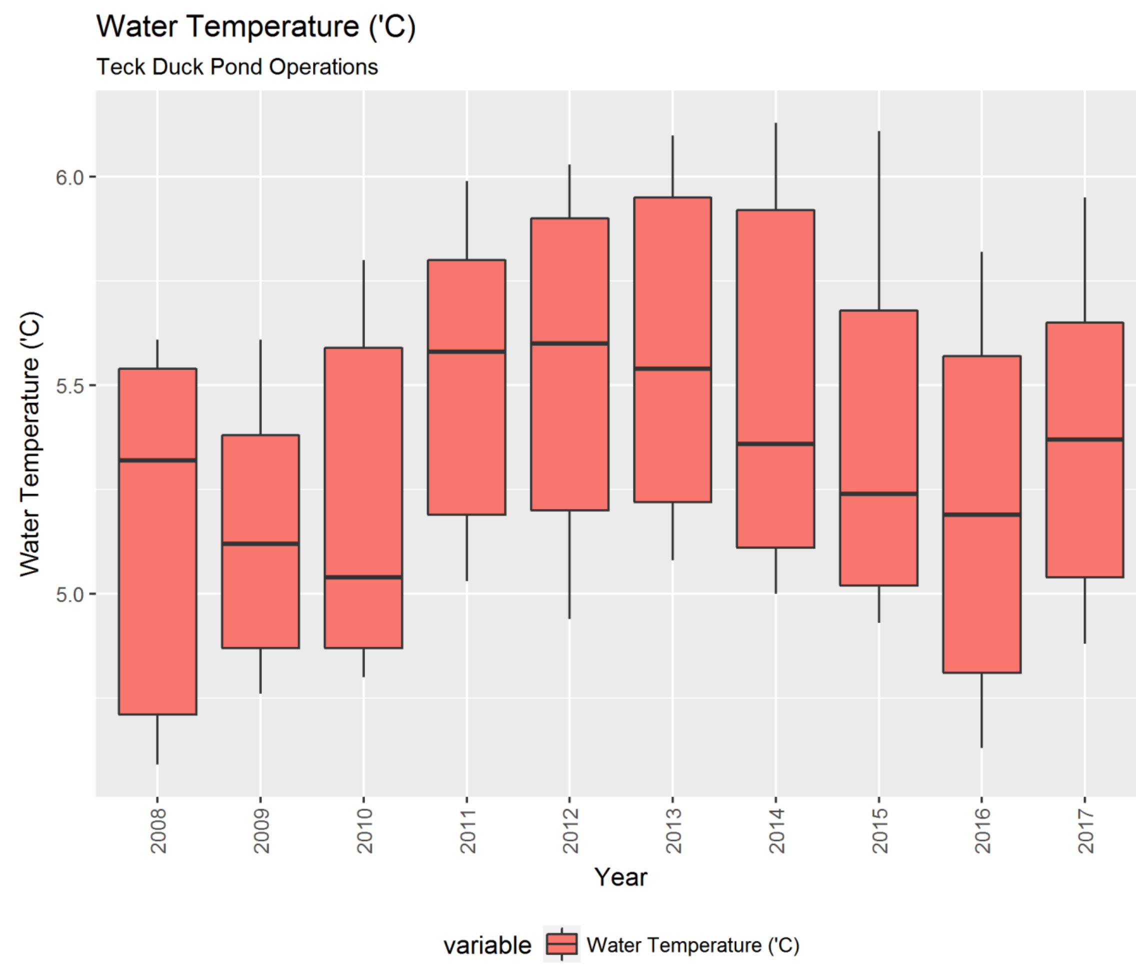


**Figure 12: Boxplots of water temperature at Well after Tailings Pond from 2008 to 2017**

## pH

The stagnant nature of groundwater makes achieving a stable pH a challenging endeavour. Following deployment, a long-duration increase in pH is normally observed, followed by a plateau phase. This is caused by a combination of grab sampling-induced disturbance of the water and sensor equilibration time. In Figure 13, the gray trend line provides a better indication of pH rather than the red hourly data.

From 2007 to late 2012, an overall decline in pH is observed before an increase from 2013 to 2016 when pH once again began to decrease until late 2017. This may be the result of natural variation or effects of transition from active deposition into the tailings management area to remediation work.

**Table 7: Summary statistics of pH at Well after Tailings Dam from 2007 to 2017**

| Year | Mean | Median | Min | Max |
|---|---|---|---|---|
| 2008 | 8.86 | 8.85 | 7.55 | 9.32 |
| 2009 | 8.87 | 8.88 | 7.27 | 9.23 |
| 2010 | 8.68 | 8.80 | 7.34 | 8.92 |
| 2011 | 8.57 | 8.58 | 6.69 | 8.99 |
| 2012 | 8.24 | 8.19 | 7.63 | 8.59 |
| 2013 | 8.29 | 8.20 | 7.60 | 8.85 |
| 2014 | 8.49 | 8.53 | 7.46 | 8.59 |
| 2015 | 8.48 | 8.46 | 7.57 | 8.72 |
| 2016 | 8.84 | 8.86 | 7.28 | 9.42 |
| 2017 | 8.46 | 8.56 | 6.87 | 8.80 |

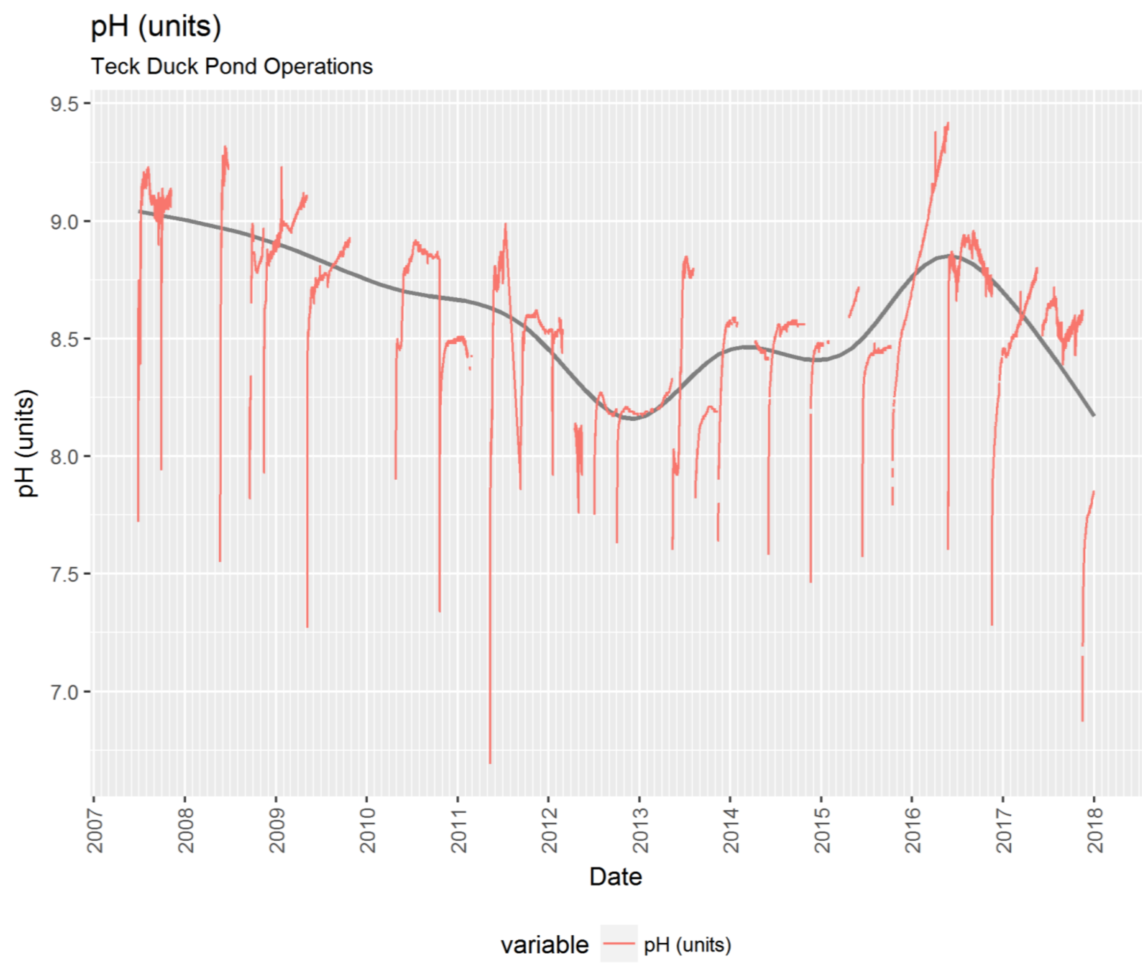


**Figure 13: pH at Well after Tailings Dam from 2007 to 2017**

Figure 14 reflects the general trend as above, clearly illustrating that 2012 and 2013 represented the lowest median pH values observed since 2008. All pH values are found to be alkaline in nature.

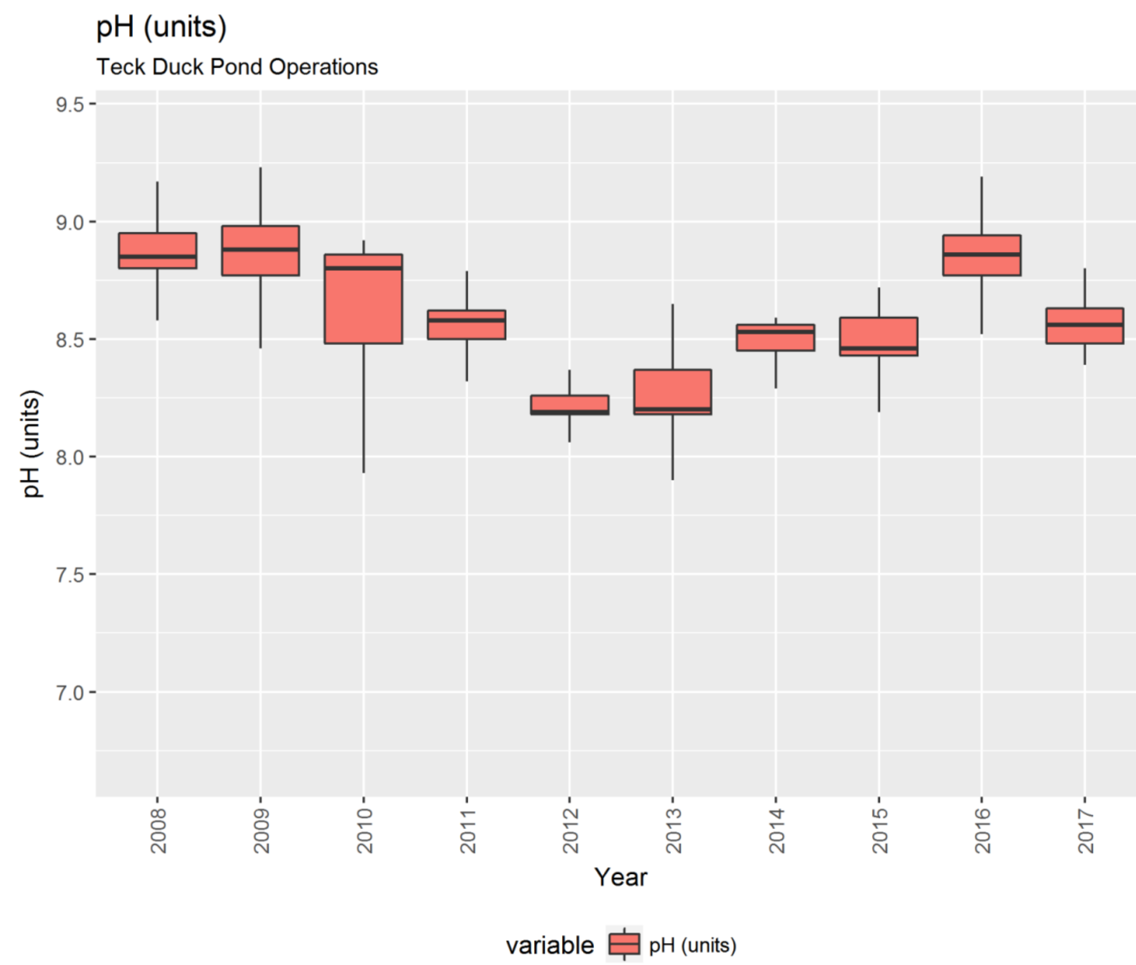


**Figure 14: Boxplots of pH at Well after Tailings Pond from 2008 to 2017**

## Specific Conductivity

From 2007 to 2014, specific conductivity within the monitoring well increased from nearly ~200 uS/cm to a high of 817 uS/cm in 2013, according to Figure 15. From 2014 to the third quarter of 2015, a plateau was observed before a subsequent increase through to the end of 2017 was observed once again. On average, specific conductivity has increased about 60 uS/cm per year since 2008.

This behaviour is likely related to development in the area, operation of the mine, and subsequent remediation of the area. As remediation concludes and conditions settle, conductivity within the monitoring well should begin to decline over time.

**Table 8: Summary statistics of specific conductivity at Well after Tailings Dam from 2007 to 2017**

| Year | Mean | Median | Min | Max |
|---|---|---|---|---|
| 2008 | 416.3 | 419 | 377 | 436 |
| 2009 | 427.3 | 430 | 397 | 463 |
| 2010 | 553.6 | 543 | 517 | 599 |
| 2011 | 621.1 | 626 | 526 | 662 |
| 2012 | 691.1 | 678 | 658 | 742 |
| 2013 | 756 | 751 | 706 | 817 |
| 2014 | 791.8 | 789 | 776 | 817 |
| 2015 | 803.6 | 792 | 771 | 870 |
| 2016 | 831 | 819 | 793 | 918 |
| 2017 | 949 | 942 | 917 | 976 |

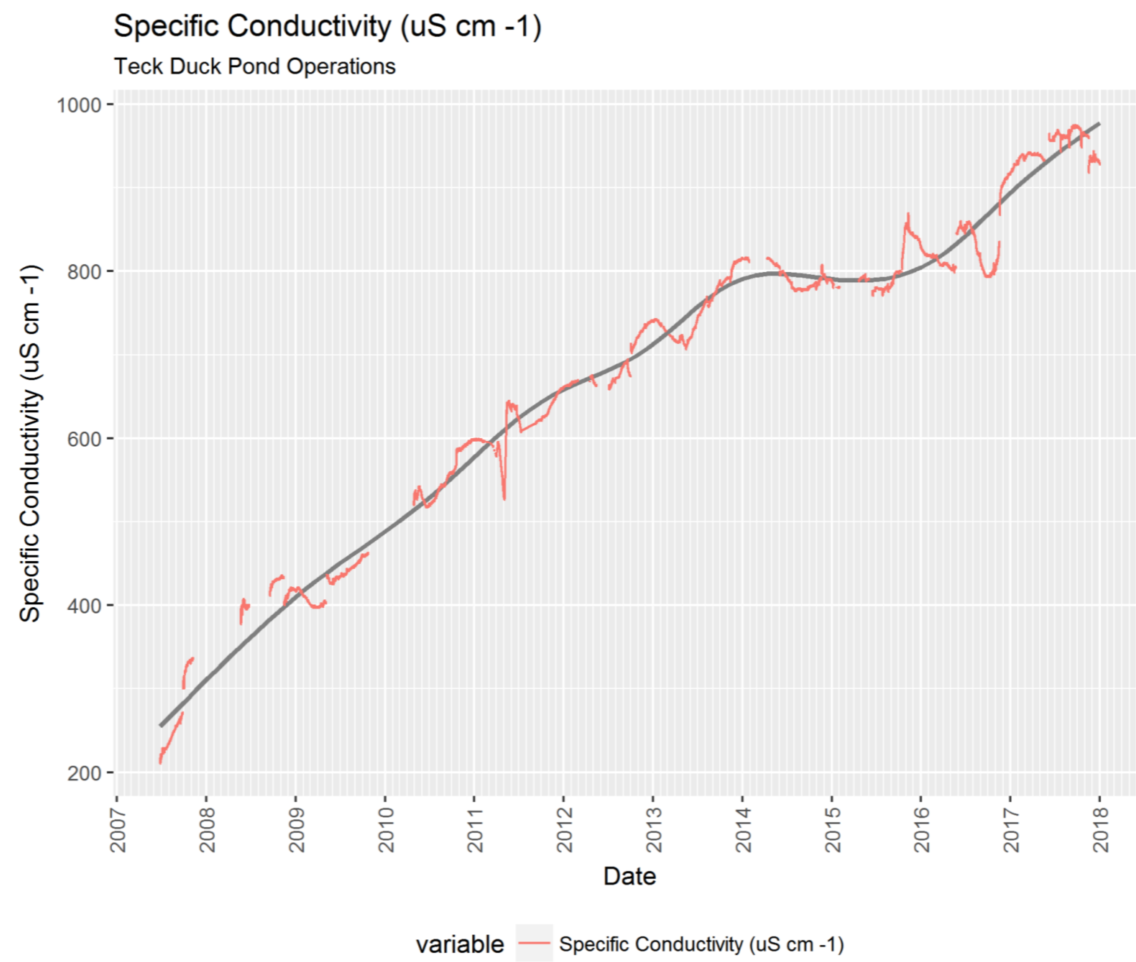


**Figure 15: Specific conductivity at Well after Tailings Dam from 2007 to 2017**

The steady increase in conductivity is clearly shown in Figure 16, especially from 2010 to 2017, which was the active phase of work at the Teck Duck Pond Operations site. This will be monitored going forward.

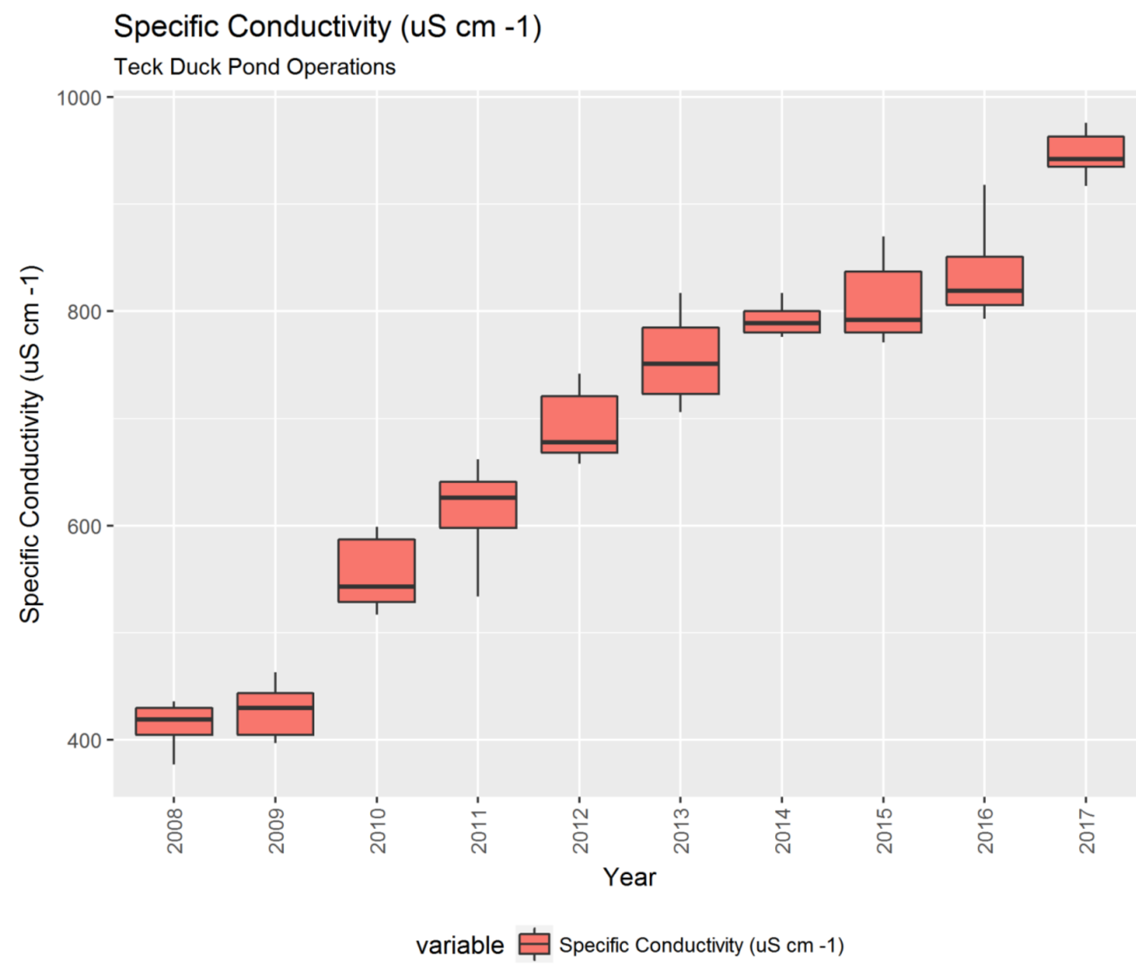


**Figure 16: Boxplots of specific conductivity at Well after Tailings Pond from 2008 to 2017**

## Oxidation-Reduction Potential

Figure 17 exhibits similar tendencies as Figure 13 whereby, following the deployment of instrumentation in the monitoring well, it takes some time to stabilize. An overall increase in ORP appears to have occurred from 2007 to 2016, followed by a decline thereafter.

**Table 9: Summary statistics of oxidation-reduction potential at Well after Tailings Dam from 2007 to 2017**

| Year | Mean | Median | Min | Max |
|---|---|---|---|---|
| 2009 | -254 | -264 | -301 | 74 |
| 2011 | -269 | -259 | -405 | 84 |
| 2012 | -223 | -239 | -255 | 99 |
| 2013 | -248 | -242 | -407 | 67 |
| 2014 | -205 | -212 | -255 | 13 |
| 2015 | -214 | -207 | -275 | -10 |
| 2016 | -286 | -287 | -396 | 51 |
| 2017 | -426 | -424 | -477 | -175 |

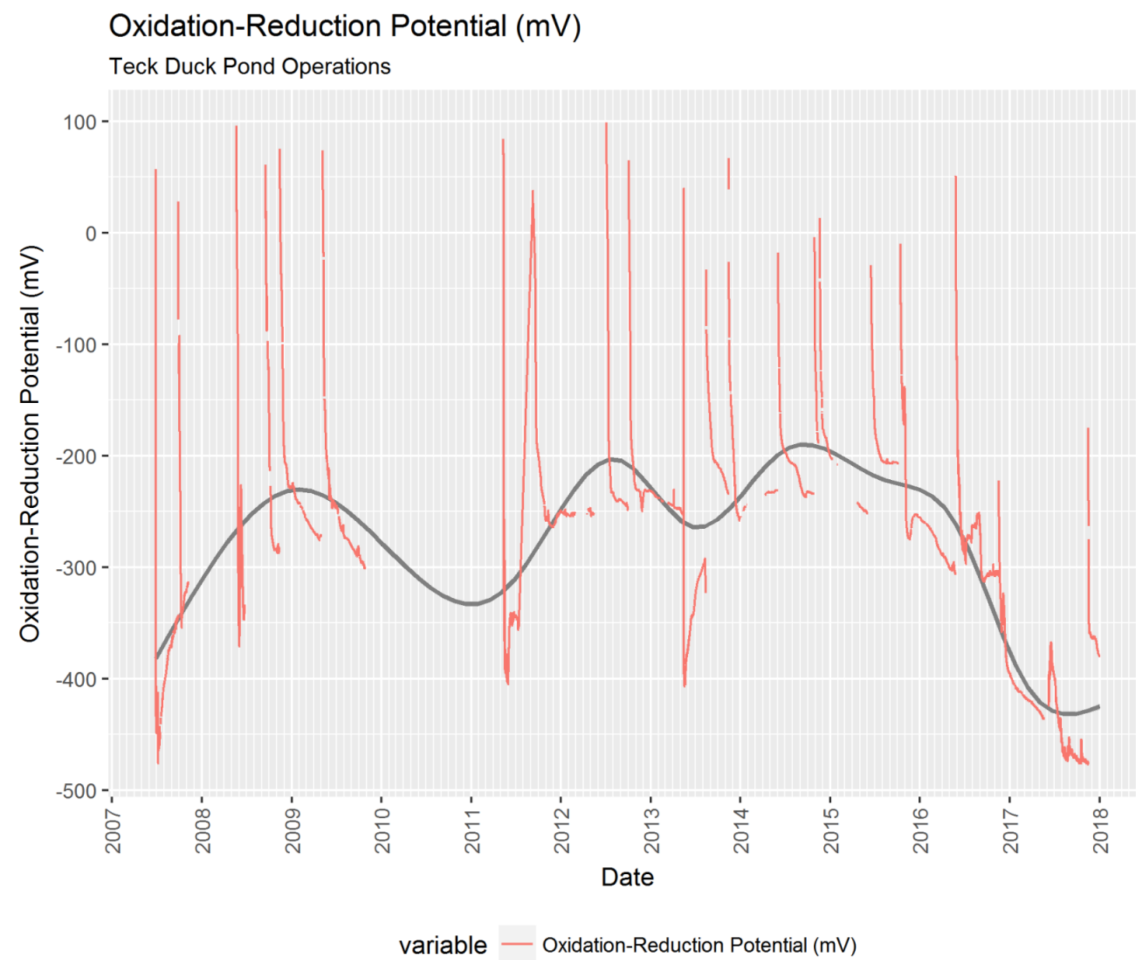


**Figure 17: Oxidation-Reduction Potential at Well after Tailings Dam from 2007 to 2017**

Figure 18 illustrates a similar trend as the previous figure with the slow rise of median ORP value from 2009 to 2015, followed by a decline in 2016 and 2017. This will be monitored into the coming seasons.

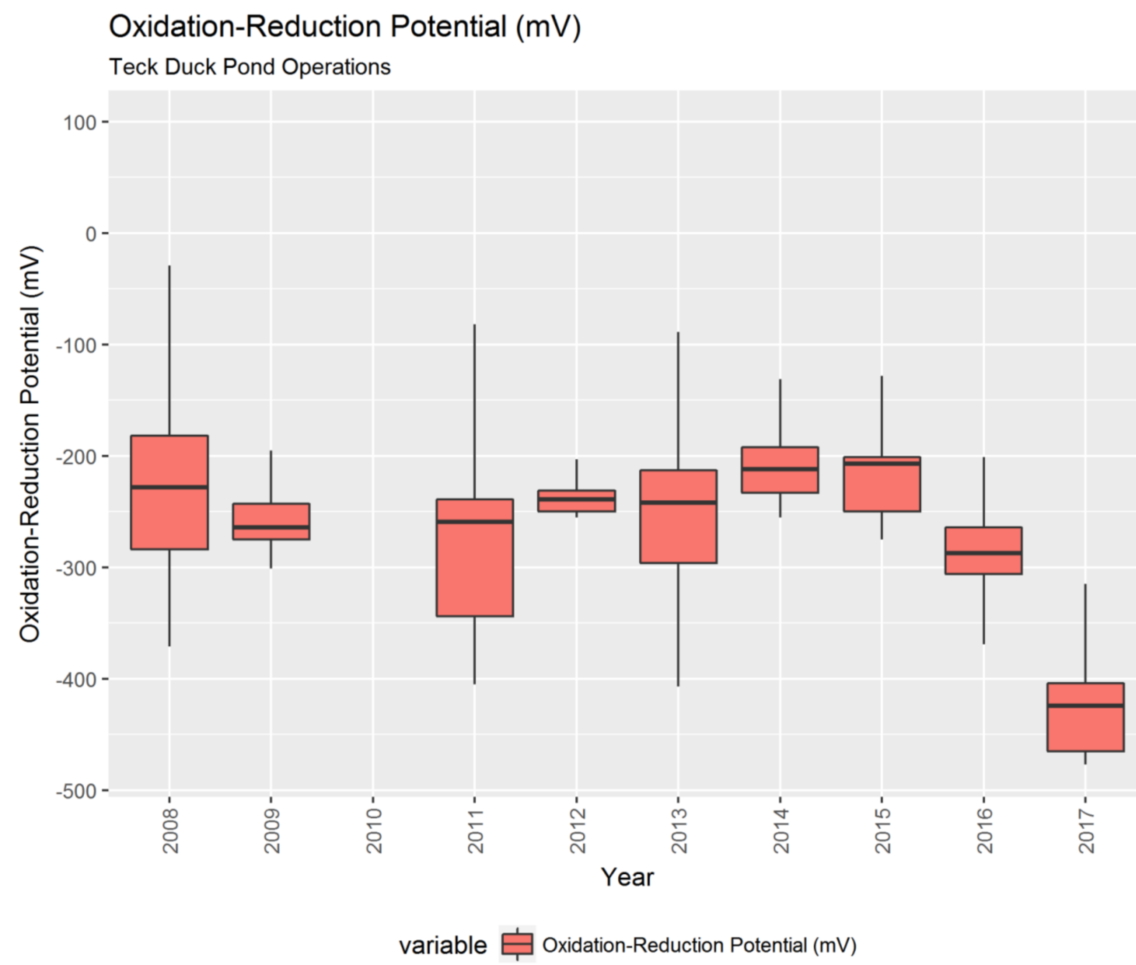


**Figure 18: Boxplots of Oxidation-Reduction Potential at Well after Tailings Pond from 2008 to 2017**

## Water Elevation

Water elevation within the monitoring well has declined consistently since 2009, according to Figure 19. This is likely due to the management of water level in the nearby tailings management area. No particular concern is warranted due to this particular parameter.

**Table 10: Summary statistics of water elevation at Well after Tailings Dam from 2007 to 2017**

| Year | Mean | Median | Min | Max |
|---|---|---|---|---|
| 2008 | 270.946 | 270.951 | 270.646 | 271.041 |
| 2009 | 271.001 | 271.016 | 270.747 | 271.208 |
| 2010 | 270.999 | 270.983 | 270.893 | 271.162 |
| 2011 | 270.977 | 270.96 | 270.799 | 271.135 |
| 2012 | 270.89 | 270.866 | 270.654 | 271.113 |
| 2013 | 270.842 | 270.812 | 270.66 | 271.059 |
| 2014 | 270.76 | 270.779 | 270.606 | 270.901 |
| 2015 | 270.73 | 270.735 | 270.581 | 270.946 |
| 2016 | 270.718 | 270.717 | 270.528 | 270.861 |
| 2017 | 270.657 | 270.674 | 270.442 | 270.786 |

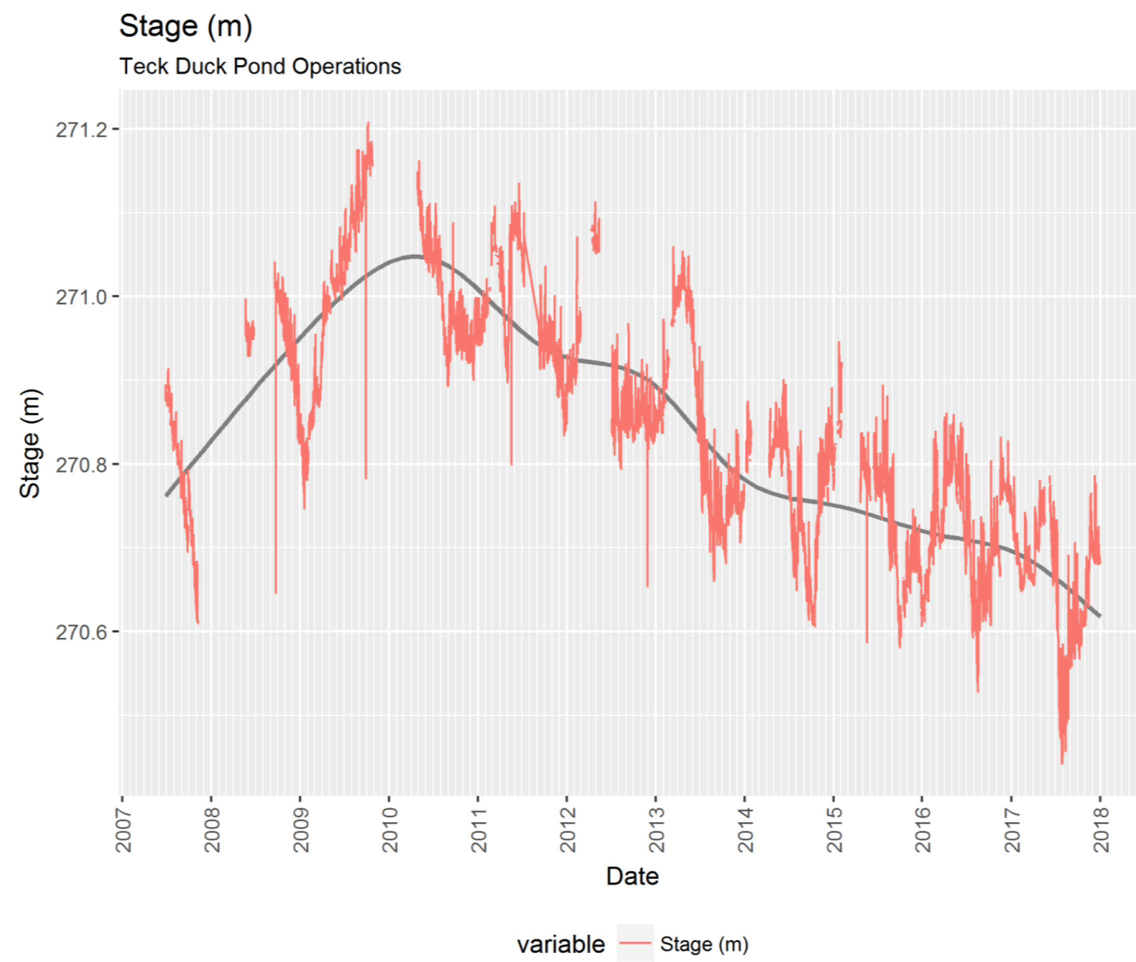


**Figure 19: Water elevation at Well after Tailings Dam from 2007 to 2017**

Figure 20 illustrates the steady decline in water elevation within the monitoring well. There may be some indication that median values are slowing their rate of change as time goes on, especially from 2015 onwards. This suggests that a new baseline is approaching.

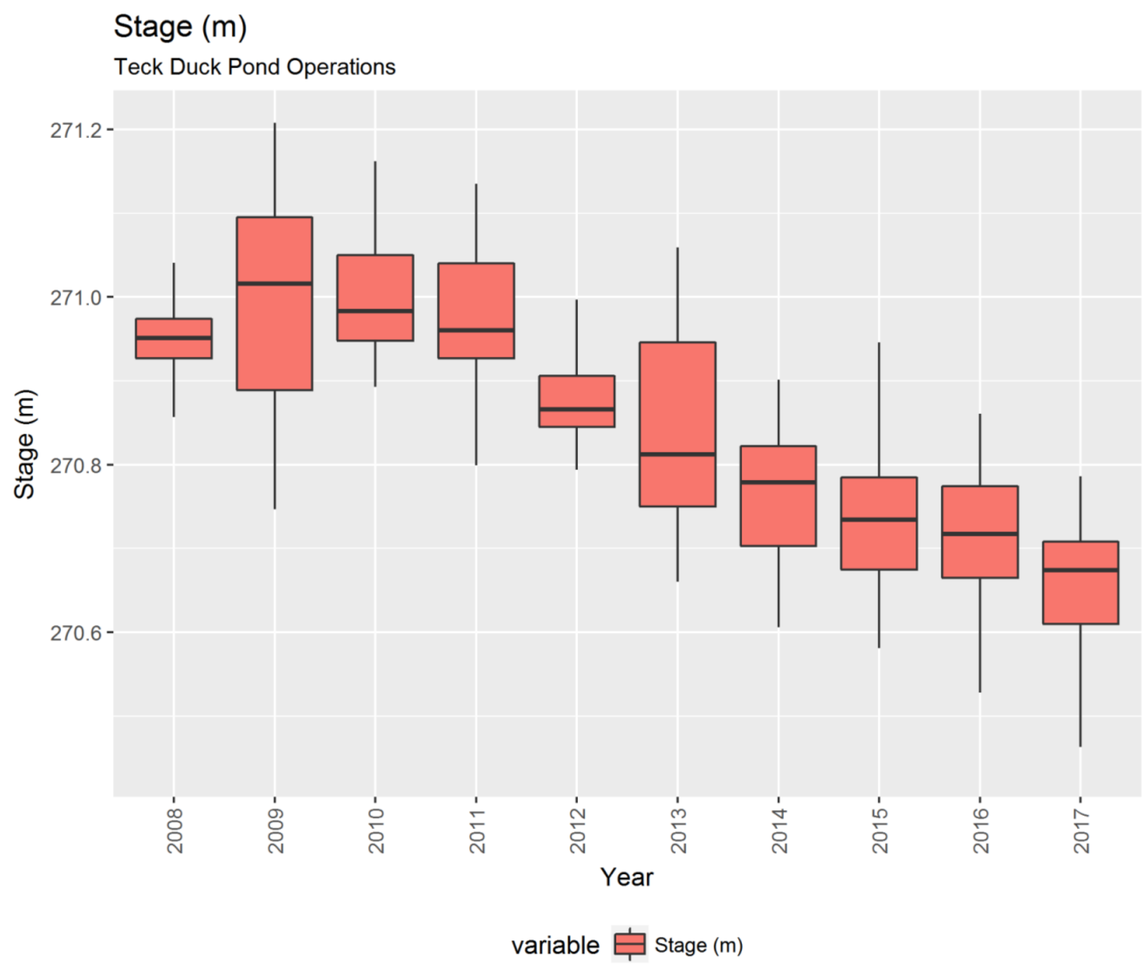


**Figure 20: Boxplots of water elevation at Well after Tailings Pond from 2008 to 2017**

## Path Forward

- Mining operations wrapped up in 2015 and the site is currently in rehabilitation. In 2017 work was done on the tailings management area to ensure long-term stability. These efforts appear to have had some impact on parameters such as conductivity and pH, especially at Tributary to Gills Pond Brook station. In the future, water quality parameters should begin to approach long-term stable conditions.
- Routine visits to monitoring stations will continue to occur on an eight week timeframe within deployment reports produced shortly thereafter. Enhancements will be made to the program as necessary.
- Performance tests and evaluations (PTEs) on each of the four Hach Hydrolabs owned by Teck DPO will continue to be performed by MAE staff on an annual basis.