Real-Time Water Quality Deployment Report

Teck Duck Pond Operations

Annual Report 2016

Government of Newfoundland & Labrador
Department of Environment and Climate Change
Water Resources Management Division
St. John’s, NL, A1B 4J6 Canada

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Introduction

Background

Ambient surface water quality monitoring is carried out by the Water Resources Management Division (WRMD) of the Department of Environment and Climate Change (ECC). 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 and one groundwater monitoring stations 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 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.

Photo 1: Aerial view of Duck Pond Operations in Central Newfoundland

Method 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.

Table 1 and Table 2 outline the deployments at the Duck Pond Operations surface water and groundwater monitoring stations in 2016.

Table 1: Deployment Schedule at Duck Pond Operations surface water network in 2016

Station	Installation	Removal	Duration (Days)
East Pond Brook	2015-11-16	2016-05-26	146.5
	2016-05-26	2016-07-06	41
	2016-07-06	2016-08-30	55
	2016-08-30	2016-10-05	36
	2016-10-05	2016-11-17	43
	2016-11-17	-	43.5
	Percent of Year Deployed		100%
Tributary to Gills Pond Brook	2015-11-16	2016-05-26	146.5
	2016-05-26	2016-07-06	41
	2016-07-06	2016-08-30	55
	2016-08-30	2016-10-05	36
	2016-10-05	2016-11-17	43
	2016-11-17	-	43.5
	Percent of Year Deployed		100%

Table 2: Deployment Schedule at Duck Pond Operations groundwater station in 2016

Station	Installation	Removal	Duration (Days)
Well after Tailings Dam	2015-11-16	2016-05-25	145
	2016-05-25	2016-11-17	176
	2016-11-17	-	44
	Percent of Year Deployed		100%

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

Results and Discussion

The following sections present and discuss water quality trends and events seen in 2016 and provide comparisons to previous years.

The Appendix of this document presents climate data retrieved from the Badger weather station approximately 50 km NNE of the Duck Pond Operations site.

In this document, a series of boxplots depict the spread of data for variables on an annual basis. Normally, data falling outside the range of boxplot whiskers (1.5 * IQR) is plotted as an outlier[†]. Given the tendency for real-time data to produce a substantial amount of outlier data, they have been omitted from figures to avoid cluttering.

Duck Pond Surface Water Monitoring Network

Temperature

> *Water Temperature is a major factor used to describe water quality. Temperature has major implications on both the ecology and chemistry of a water body, governing processes such as the metabolic rate of aquatic plants and animals and the degree of dissolved oxygen saturation.*

Water temperature profiles tend to be similar between EPB and TGPB stations. Differences between the stations are generally seen in the annual maxima/minima and variability seen at TGPB during the winter. Discharge of effluent from settling ponds just upstream from TGPB station is likely to cause some fluctuation in water temperature as illustrated in Figure 1.

[†] Retrieved on January 24, 2017: http://docs.ggplot2.org/0.9.3.1/geom_boxplot.html#

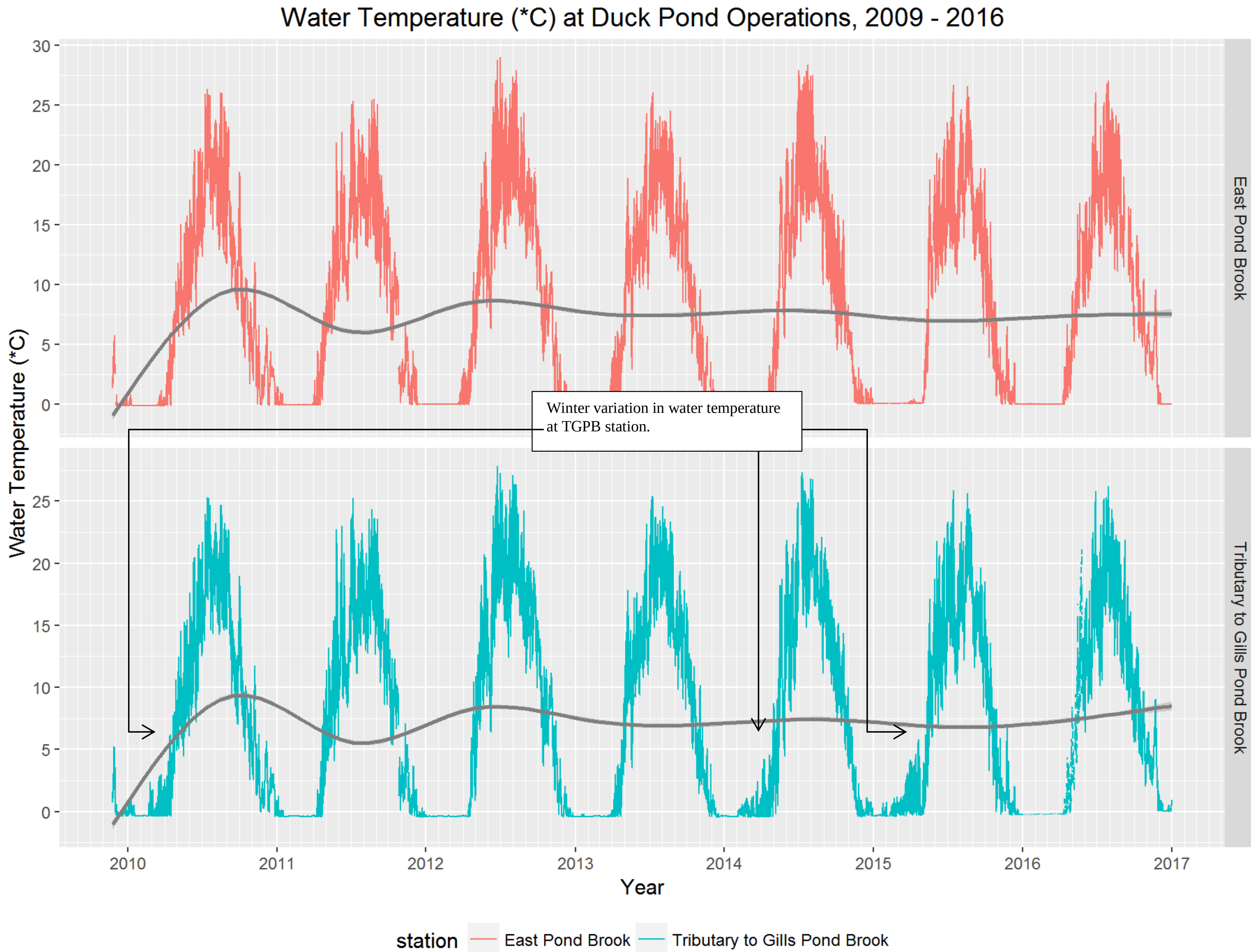

Figure 1: Water temperature at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2009 to 2016

EPB station exhibits a tendency for slightly warmer temperature maxima and minima (Figure 2). In fact, winter temperature conditions at TGPB station are routinely almost 0.5°C below zero while EPB is generally hovers at, or barely below, zero.

Table 3: Descriptive statistics for temperature at Duck Pond Operations

Station	Year	Mean	Median	Min	Max
East Pond Brook	2009	0.57	-0.07	-0.13	5.80
	2010	7.56	6.15	-0.14	26.34
	2011	7.11	4.81	-0.07	25.54
	2012	8.13	6.57	-0.04	29.05
	2013	7.70	5.60	0.03	26.05
	2014	7.61	4.97	0.01	28.39
	2015	7.14	2.93	-0.02	26.74
	2016	6.78	4.06	-0.01	27.09
Tributary to Gills Pond Brook	2009	0.35	-0.16	-0.38	5.23
	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	27.80
	2013	7.18	4.75	-0.45	25.43
	2014	7.25	4.01	-0.45	27.34
	2015	6.91	2.93	-0.39	25.84
	2016	7.09	4.98	-0.24	26.22

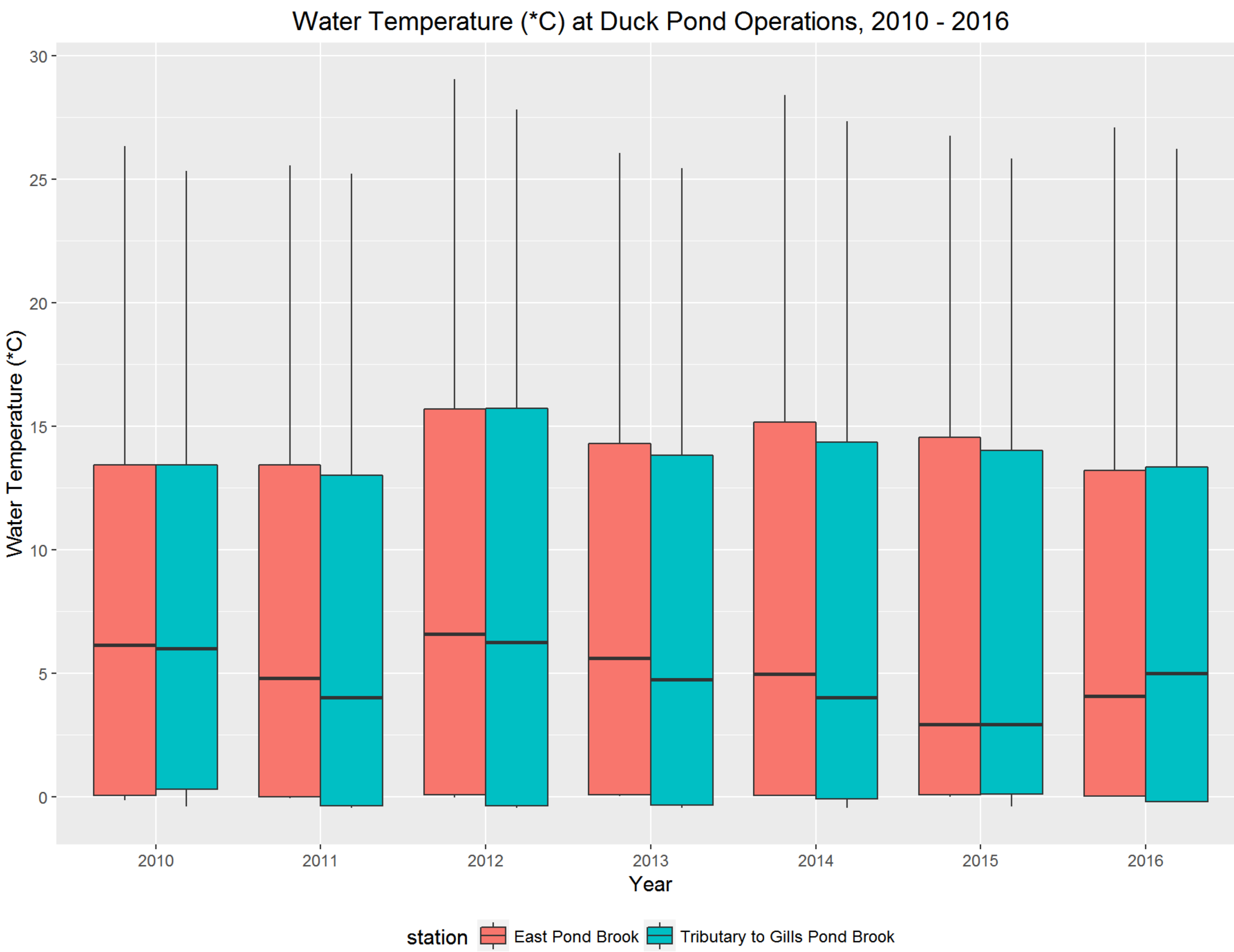

Figure 2: Boxplots of water temperature at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2010 to 2016

pH

> *pH is used to give an indication of the acidity or basicity of a solution. A pH of 7 denotes a neutral solution while lower values are acidic and higher values are basic. Technically, the pH of a solution indicates the availability of protons to react with molecules dissolved in water. Such reactions can affect how molecules function chemically and metabolically.*

The redirection of water impacted by the Duck Pond Operation away from East Pond Brook means that water passing EPB station is unimacted and exhibits ambient conditions. Part of the water flow passing TGPB station, however, is effluent from the tailings management area and polishing pond. Effluent from the polishing pond has undergone treatment to ensure that industrial discharge regulations are respected.

As a result, pH at TGPB station tends to be less variable and also closer to neutral compared to the slightly acidic and variable conditions at EPB station (Figure 3).

Dashed lines in Figure 3 illustrate CCME Guidelines for the protection of cold water organisms. Waters in this region of the province tend to be somewhat acidic due to geochemical conditions. As such, even natural waters tend to fall below CCME Guidelines, as the guidelines are derived from a national scope.

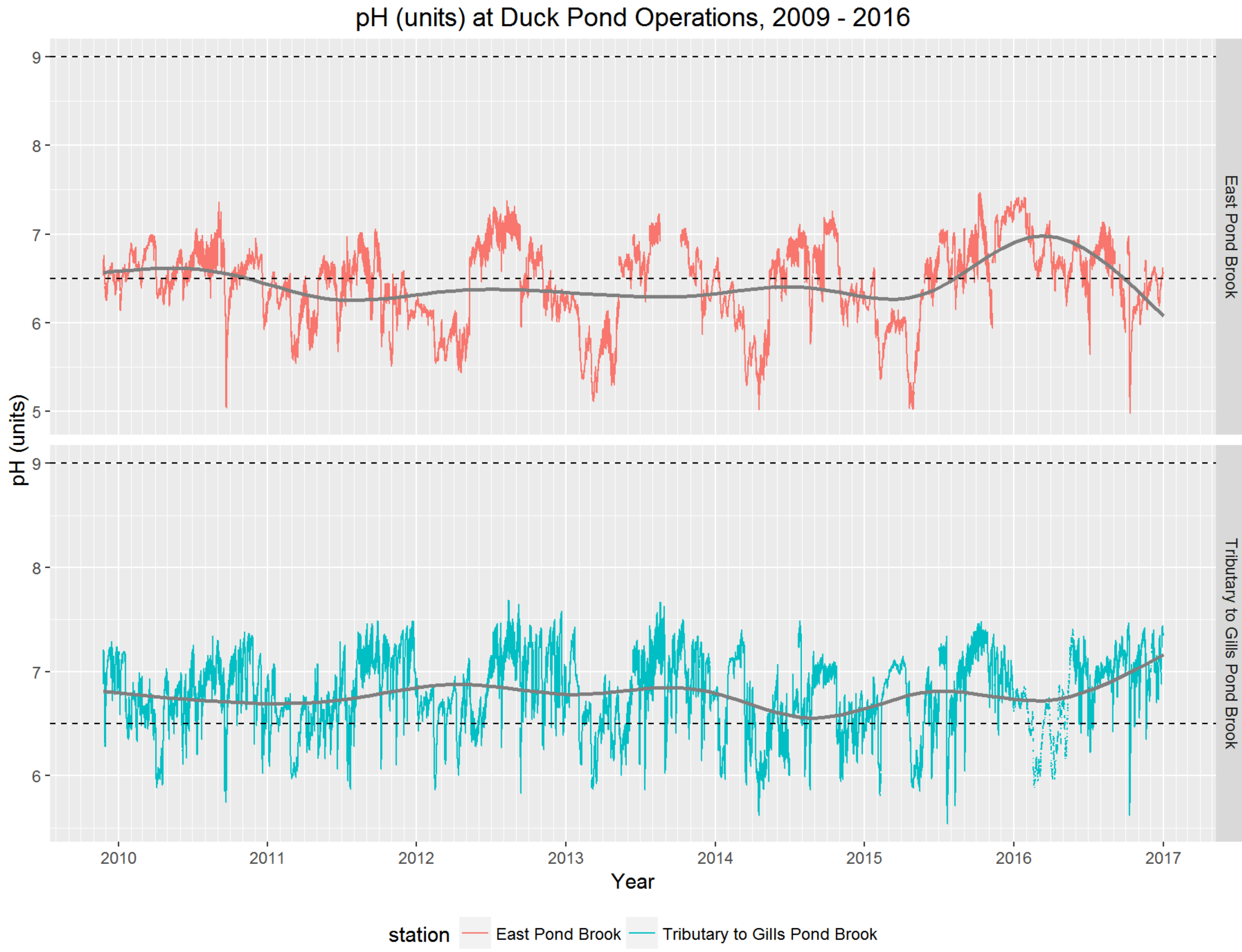

Figure 3: pH at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2009 to 2016

Figure 4 clearly shows the difference in pH at EPB and TGPB stations. Also observed in this figure is an increase in median pH year over year at EPB station since 2012. Whether this is short-term variability or a long-term trend remains to be seen.

Table 4: Descriptive statistics for pH at Duck Pond Operations

Station	Year	Mean	Median	Min	Max
East Pond Brook	2009	6.51	6.52	6.25	6.76
	2010	6.60	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	6.40	5.02	7.26
	2015	6.46	6.55	4.94	7.47
	2016	6.67	6.66	4.98	7.42
Tributary to Gills Pond Brook	2009	7.02	7.07	6.28	7.29
	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	6.80	6.81	5.86	7.67
	2014	6.61	6.60	5.62	7.49
	2015	6.80	6.90	5.54	7.48
	2016	6.81	6.88	5.62	7.47

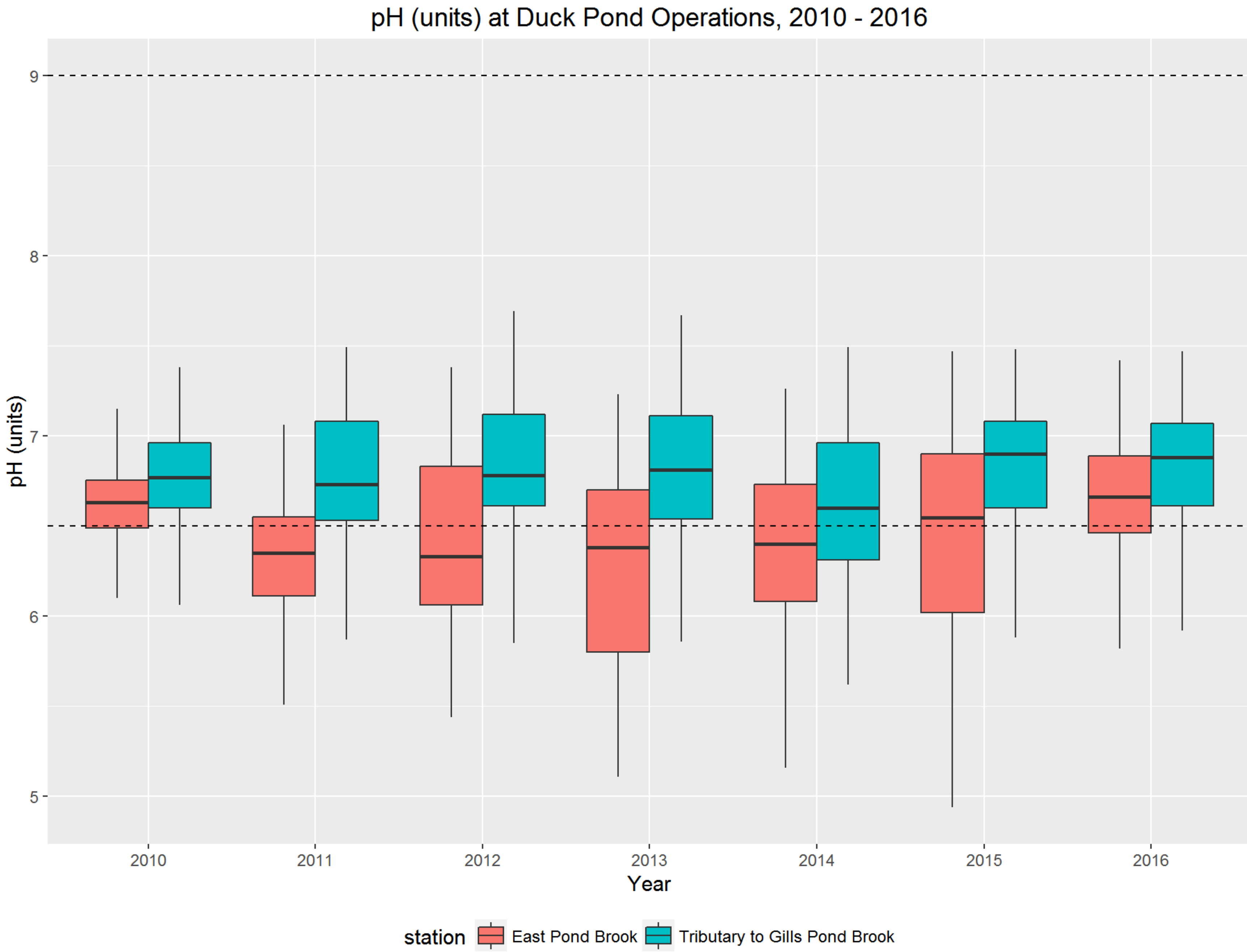

Figure 4: Boxplots of pH at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2010 to 2016

Specific Conductivity

> *Conductivity relates to the ease of passing an electric charge – or resistance – through a solution. Conductivity is highly influenced by the concentration of dissolved ions in solution: distilled water has zero conductivity (infinite resistance) while salty solutions have high conductivity (low resistance). Specific Conductivity is corrected to 25°C to allow comparison across variable temperatures.*

Tailings residue from mining operations typically contains a high level of dissolved solids compared to natural waters. As such, conditions at EPB station are generally governed by natural processes such as weather and climate variation, as opposed to the conditions at TGPB station which are dominated by effluent discharge upstream of the station.

The relative stability and low-level specific conductivity at EPB station is seen in Figure 5 compared to TGPB.

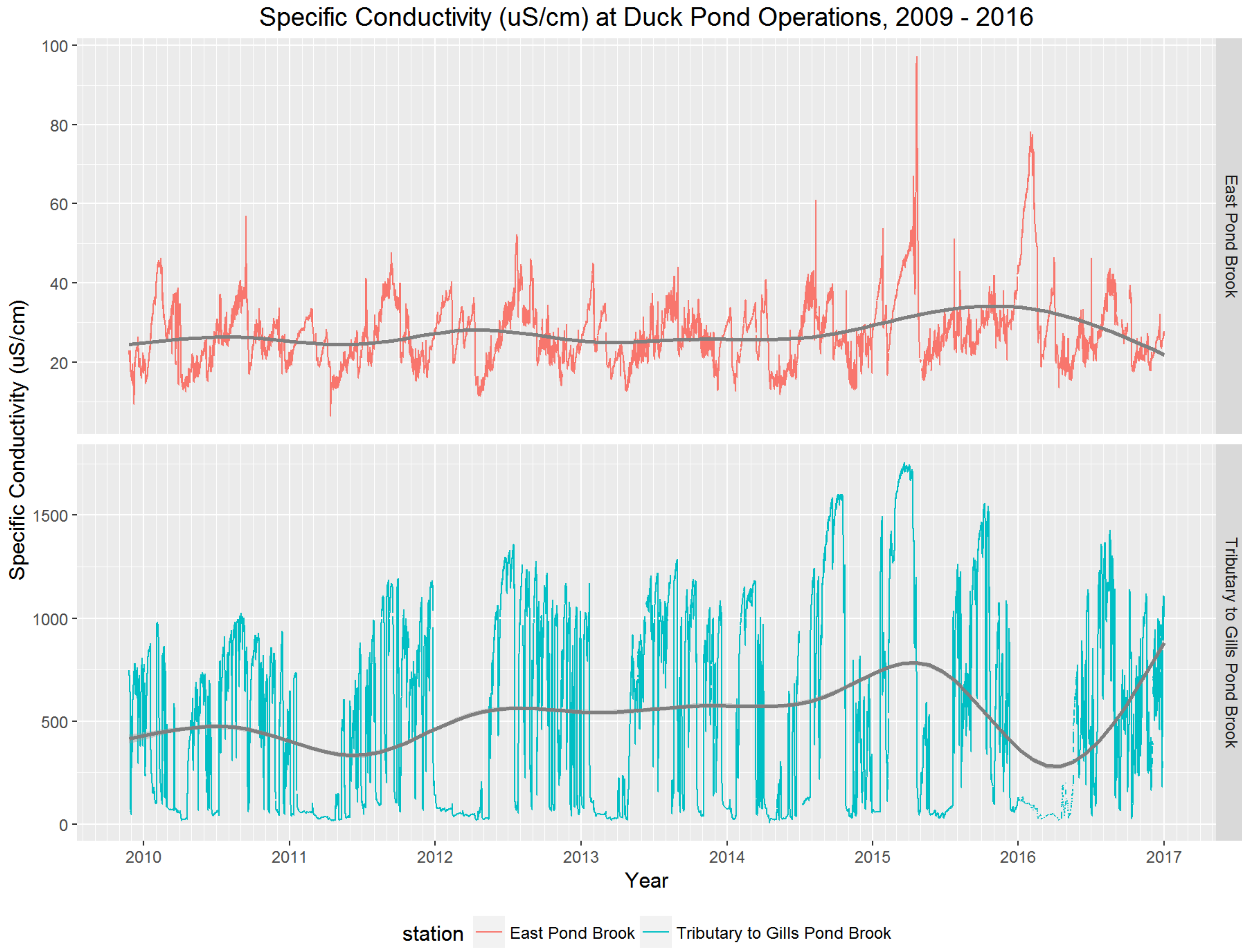

Figure 5: Specific conductivity at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2009 to 2016

Upper hinges of boxplots for TGPB station shows that, year over year, specific conductivity tended to show higher levels as Duck Pond Operations continued to generate tailings residue (Figure 6). 2016 showed a decrease in median and mean specific conductivity (Table 5). This is to be expected as operations ceased in 2015 and Duck Pond Operations are currently involved in remediation efforts.

Table 5: Descriptive statistics for specific conductivity at Duck Pond Operations

Station	Year	Mean	Median	Min	Max
East Pond Brook	2009	19.3	19.4	9.3	26.4
	2010	26.5	25.9	12.4	57.0
	2011	24.9	23.8	6.3	47.6
	2012	27.0	25.8	11.3	52.3
	2013	26.0	25.7	12.6	45.0
	2014	25.5	25.4	11.8	61.0
	2015	32.0	30.2	15.3	97.3
	2016	30.9	26.0	13.4	78.2
Tributary to Gills Pond Brook	2009	584.2	639.0	45.0	808.0
	2010	482.6	529.0	17.0	1023.9
	2011	411.6	250.0	17.3	1193.0
	2012	503.3	319.0	20.1	1356.0
	2013	545.9	601.0	18.6	1288.0
	2014	564.1	338.5	7.4	1603.0
	2015	704.3	590.0	29.3	1755.0
	2016	425.3	327.0	18.3	1428.0

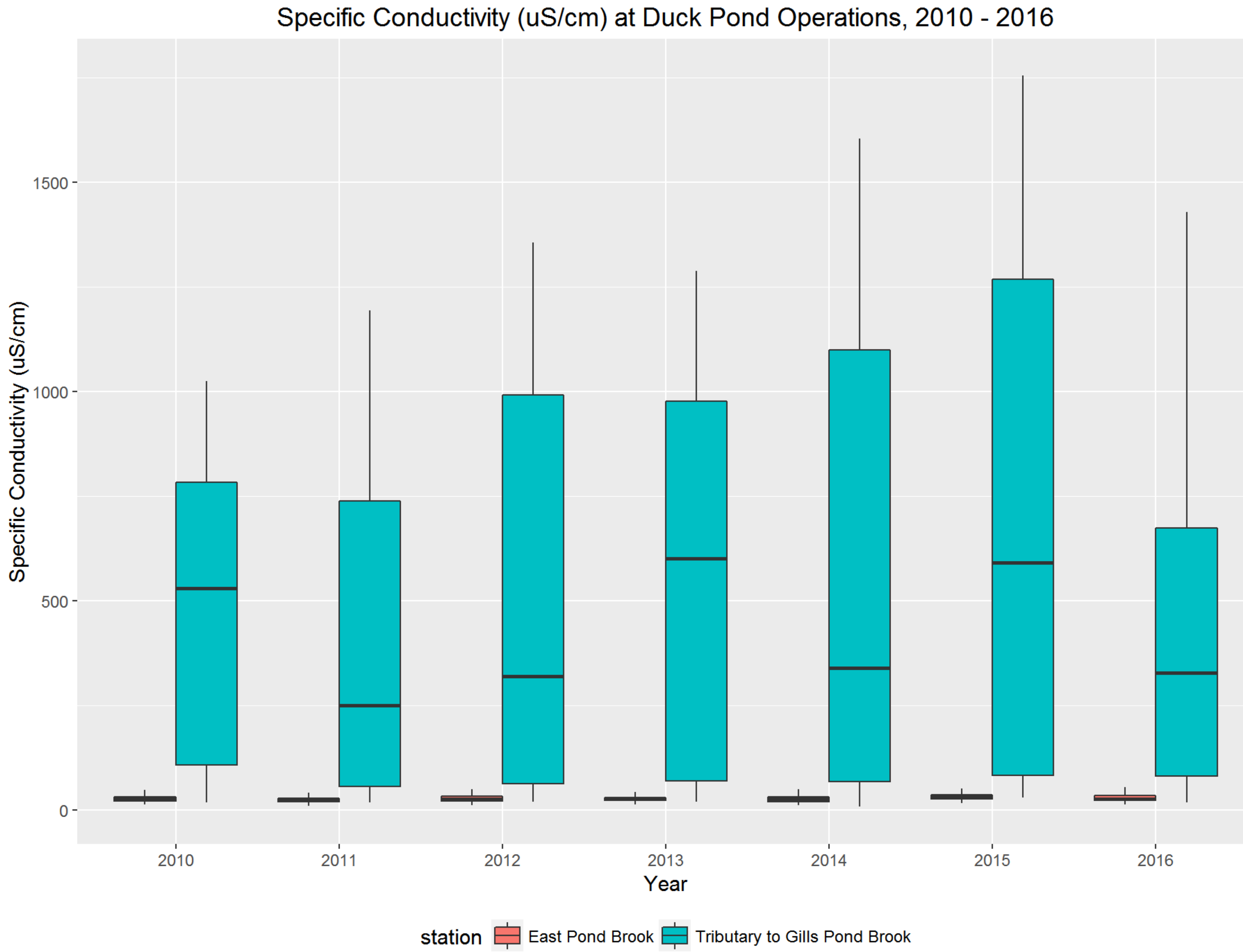

Figure 6: Boxplots of specific conductivity at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2010 to 2016

Dissolved Oxygen

> *Dissolved oxygen is a metabolic requirement of aquatic plants and animals. The concentration of oxygen in water depends on many factors, especially temperature – the saturation of oxygen in water is inversely proportional to water temperature. Oxygen concentrations also tend to be higher in flowing water compared to still, lake environments. Low oxygen concentrations can give an indication of excessive decomposition of organic matter or the presence of oxidizing materials.*

Dissolved oxygen concentration is depicted in Figure 7. As expected, DO concentrations peak in the winter and drop in the warmer summer waters.

Dashed lines in Figure 7 indicate the CCME guidelines for the protection of early life stage and other cold water biota (9.5 mg/l and 6.5 mg/l, respectively).

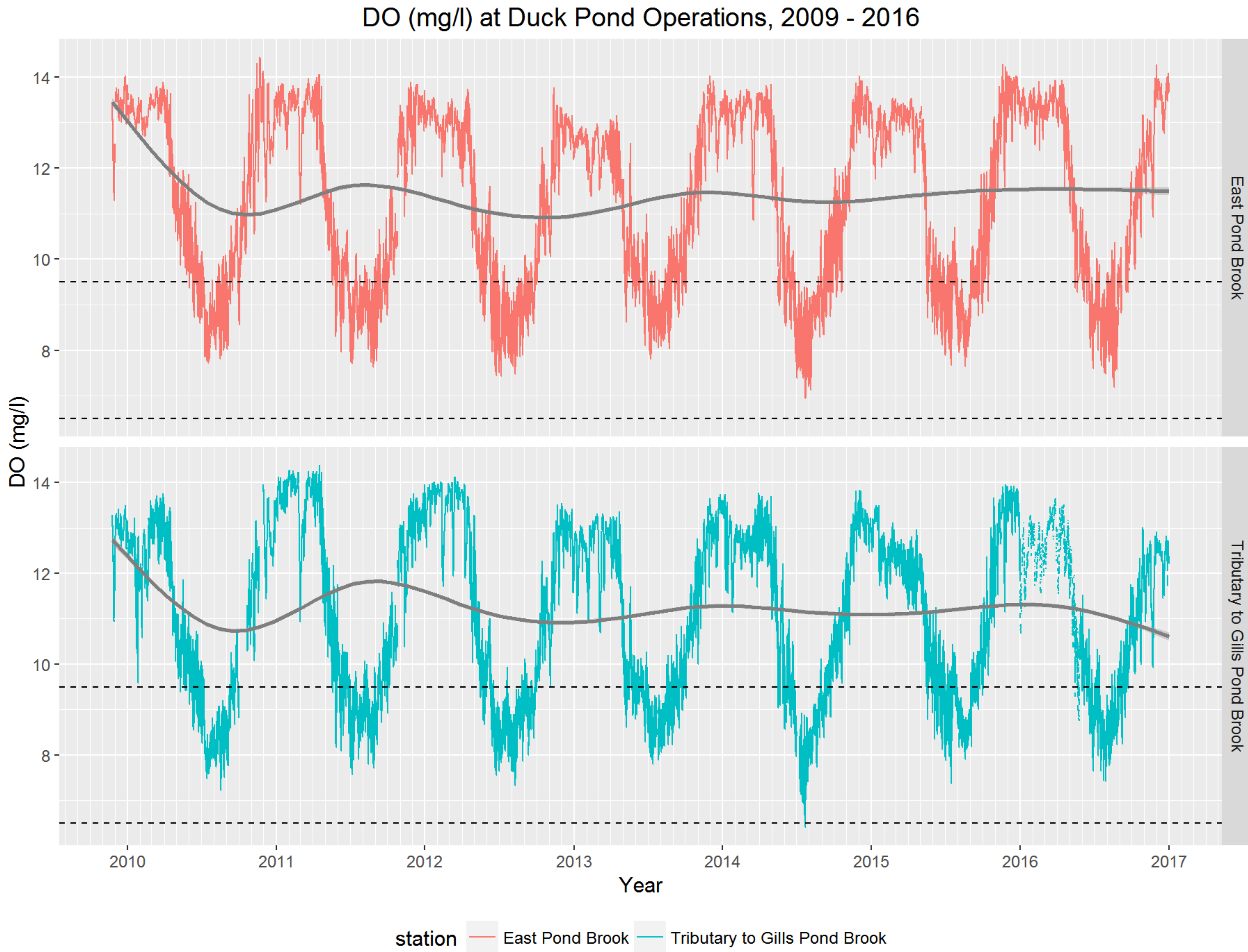

Figure 7: Dissolved oxygen at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2009 to 2016

Dashed lines in Figure 8 indicate the CCME guidelines for the protection of early life stage and other cold water biota (9.5 mg/l and 6.5 mg/l, respectively). Almost all dissolved oxygen values are above the conservative CCME value of 6.5 mg/l.

Table 6: Descriptive statistics for dissolved oxygen at Duck Pond Operations

Station	Year	Mean	Median	Min	Max
East Pond Brook	2009	13.27	13.41	11.29	14.02
	2010	11.44	11.62	7.72	14.44
	2011	11.44	11.75	7.63	14.06
	2012	11.16	11.45	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
Tributary to Gills Pond Brook	2009	12.86	12.98	10.95	13.50
	2010	10.95	11.00	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	11.33	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	11.54	7.42	13.67

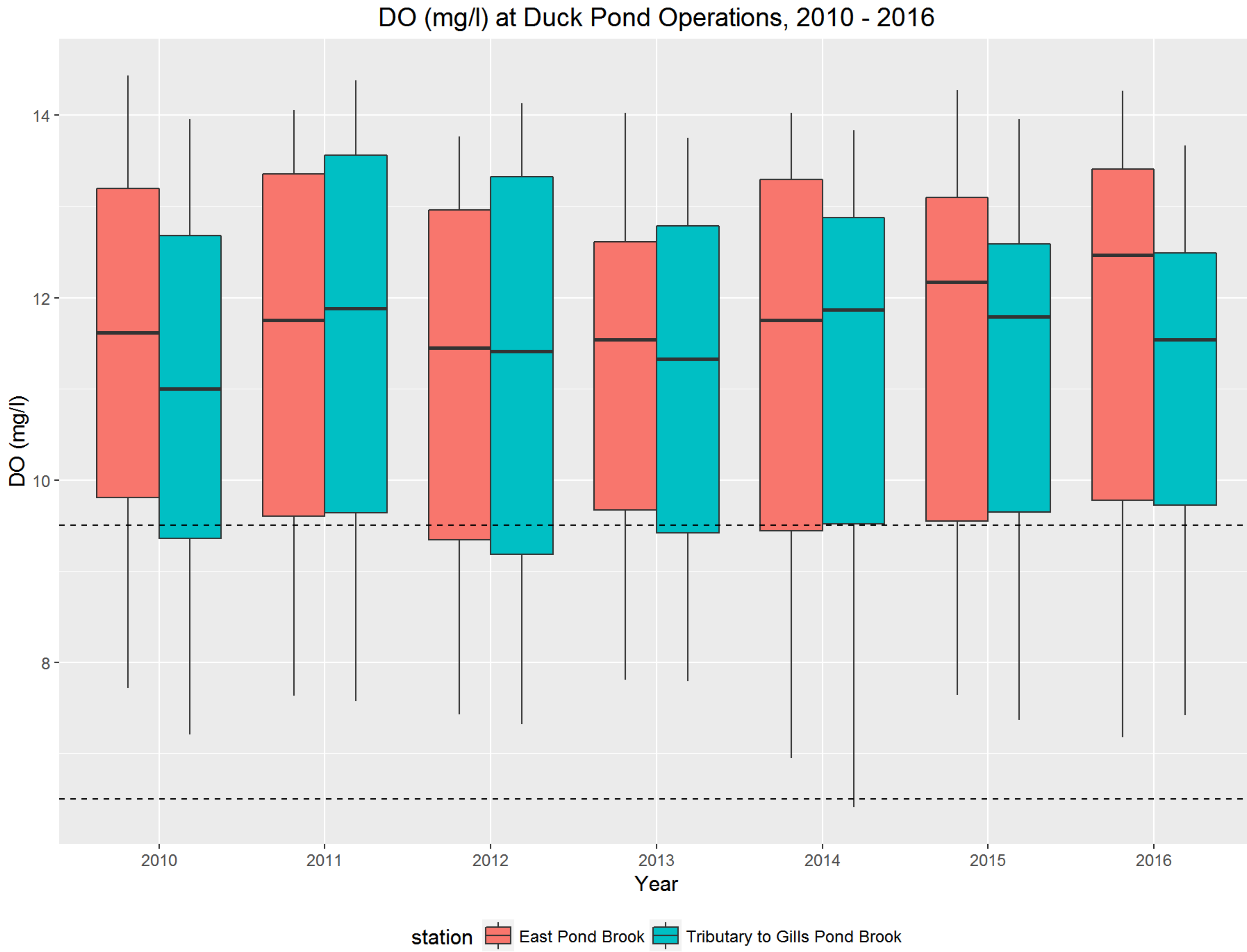

Figure 8: Boxplots of dissolved oxygen at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2010 to 2016

Turbidity

> *Turbidity is typically caused by fine suspended solids such as silt, clay, or organic material. Consistently high levels of turbidity tend to block sunlight penetration into a waterbody, discouraging plant growth. High turbidity can also damage the delicate respiratory organs of aquatic animals and cover spawning areas.*

Turbidity at both EPB and TGPB stations tends to be low with occasional perturbations. These perturbations occur with more frequency at TGPB (Figure 9), however, this could be related to turbulent flow conditions as opposed to effluent discharge.

As a result of reduced vehicle traffic in the area (due to the cessation of mine and mill operations) it is possible that atmospheric deposition of road and construction dust will be curtailed. Resultant overland runoff may carry less silt in the future, reducing peak turbidity events.

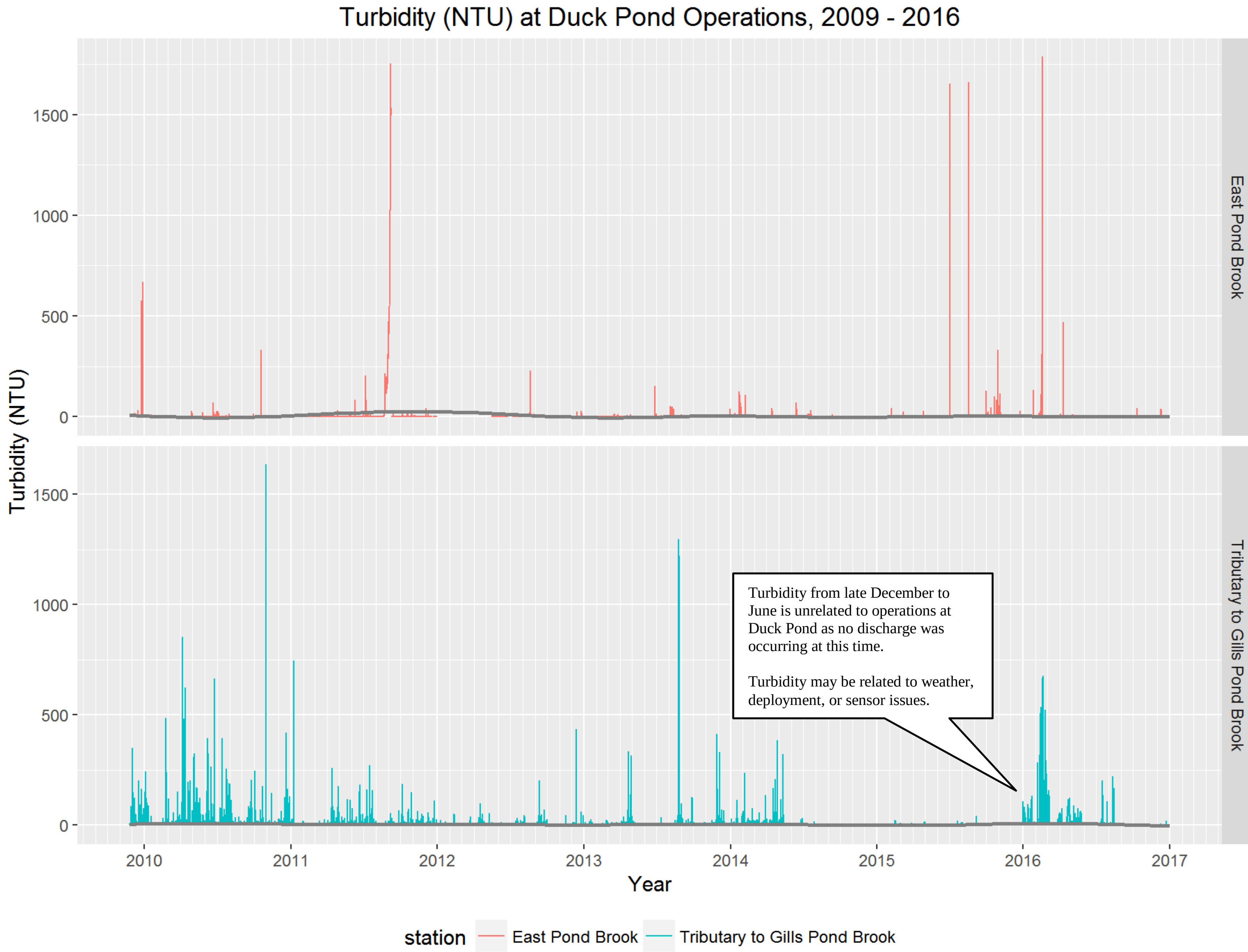

Figure 9: Turbidity at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2009 to 2016

Median turbidity values have generally been 0 NTU at both stations since 2010 (Table 7), except for 2016 when median turbidity was found to be 0.2 NTU. This increase may simply be natural variability.

Table 7: Descriptive statistics for turbidity at Duck Pond Operations

Station	Year	Mean	Median	Min	Max
East Pond Brook	2009	2.5	0.0	0.0	668.0
	2010	0.2	0.0	0.0	331.1
	2011	19.0	0.0	0.0	1753.0
	2012	0.8	0.0	0.0	229.9
	2013	0.6	0.0	0.0	152.3
	2014	0.6	0.0	0.0	123.6
	2015	1.7	0.0	0.0	1660.0
	2016	1.5	0.2	0.0	1789.0
Tributary to Gills Pond Brook	2009	6.2	0.2	0.0	347.7
	2010	5.4	0.0	0.0	1635.0
	2011	2.8	0.0	0.0	746.0
	2012	1.7	0.0	0.0	434.0
	2013	2.2	0.0	0.0	1295.0
	2014	1.1	0.0	0.0	382.4
	2015	0.3	0.0	0.0	107.3
	2016	5.6	0.0	0.0	678.0

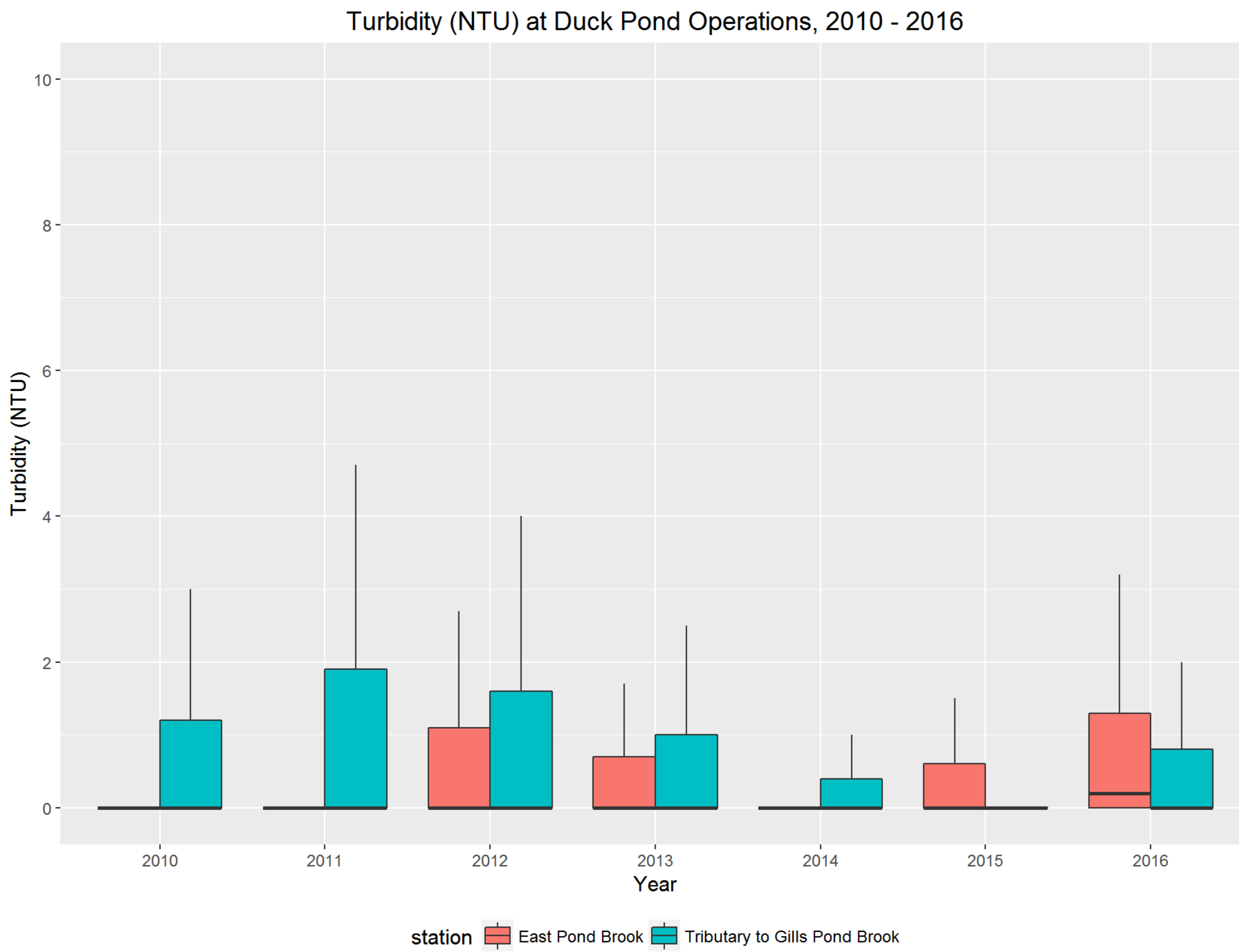

Figure 10: Boxplots of Turbidity at the Duck Pond Operations Real-Time Water Quality Monitoring Network Stations from 2010 to 2016

Duck Pond Groundwater Monitoring Station – Well after Tailings Dam

Temperature

Water temperature reaches an annual maximum in mid-December to mid-January (Figure 11). The degree of lag between surface and well temperatures suggests very little surface water influence.

Max water temperatures increased from 2007 to 2015 and declined thereafter. This occurs, however, as median and minimum water temperatures decline from 2012 to 2016.

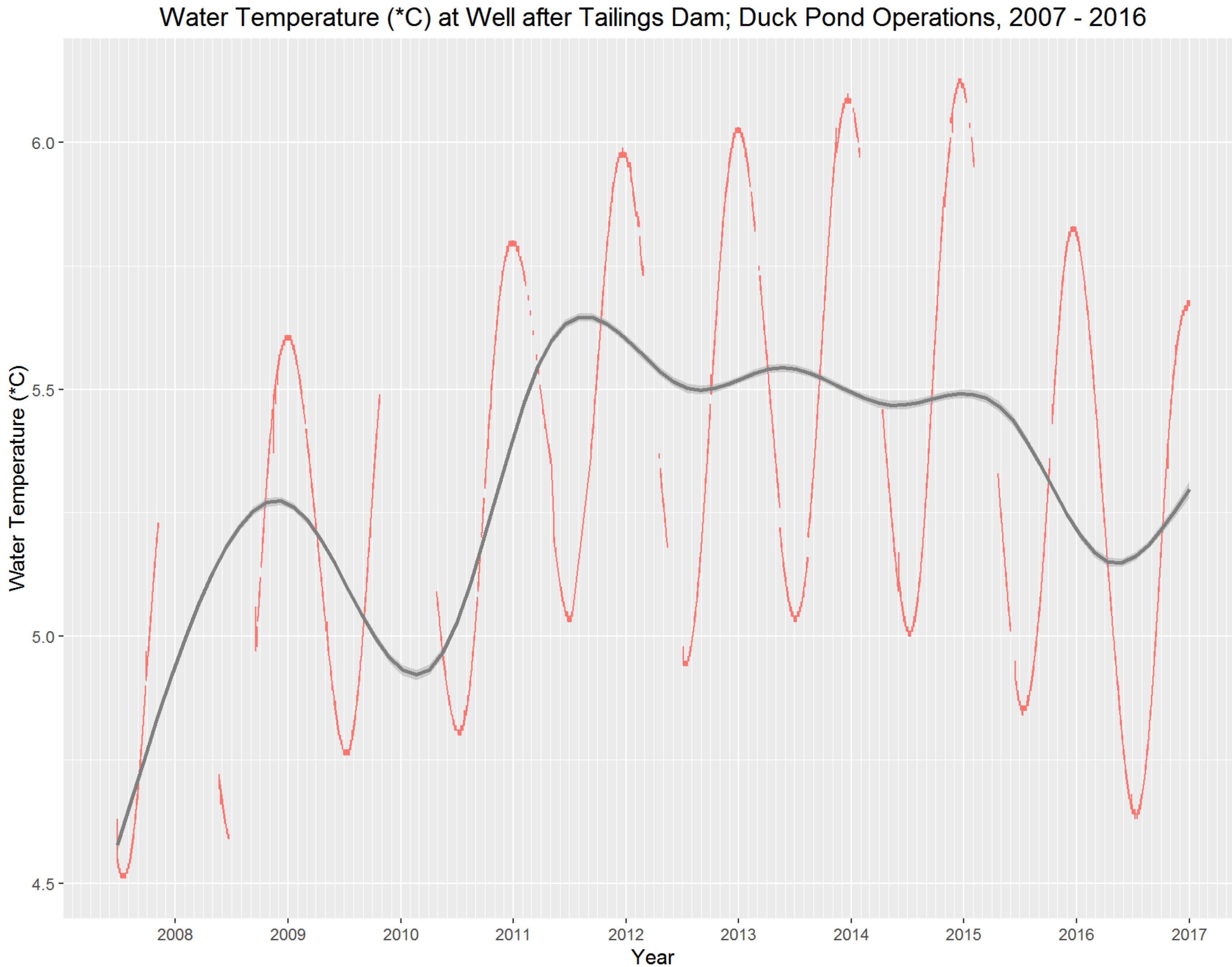

Figure 11: Temperature at Well after Tailings Dam station from 2013 to 2016

A falling trend from 2012 to 2016 is evident in Figure 12. However, since this falling trend follows a period of warming from 2007 to 2011, this may simply be natural variation.

Descriptive statistics are presented in Table 8.

Table 8: Descriptive statistics for temperature at Well after Tailings Dam

Year	Mean	Median	Min	Max
2007	4.76	4.69	4.51	5.23
2008	5.20	5.32	4.59	5.61
2009	5.14	5.12	4.76	5.61
2010	5.20	5.04	4.80	5.80
2011	5.54	5.58	5.03	5.99
2012	5.53	5.60	4.94	6.03
2013	5.56	5.54	5.03	6.10
2014	5.49	5.36	5.00	6.13
2015	5.30	5.20	4.84	6.11
2016	5.19	5.19	4.63	5.82

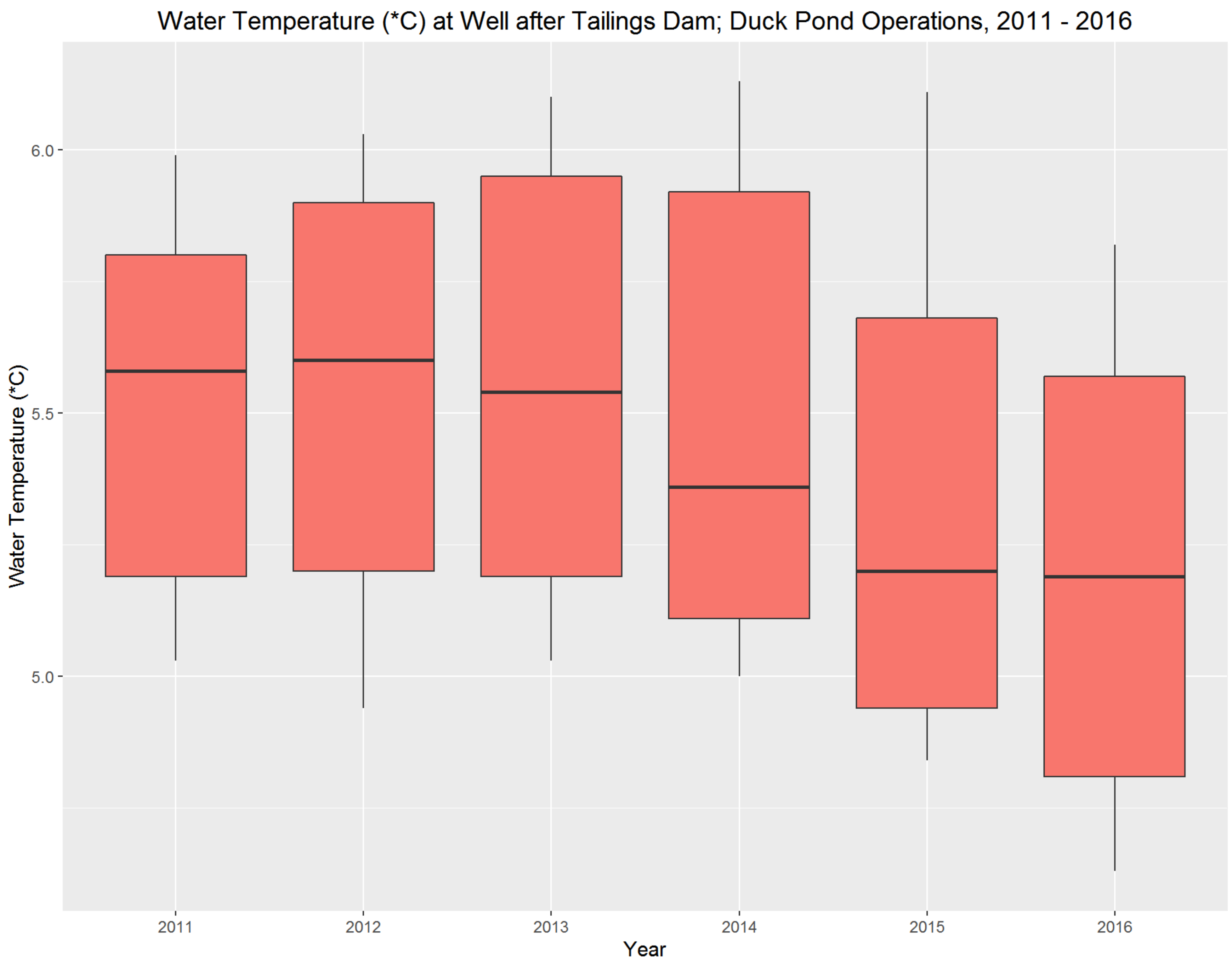

Figure 12: Boxplots of temperature at Well after Tailings Dam station from 2011 to 2016

pH

It is common for pH to require a long duration to reach equilibrium following maintenance and calibration work. The equilibration time is clearly seen in Figure 13 where pH values begin low and climb over the course of a month before reaching stability.

A period of decline in pH is observed from 2008 to 2013 before an increasing trend is observed. As decommissioning of the Duck Pond Operations site continues, pH will be monitored closely as residue stored within the tailings pond is potentially acid generating

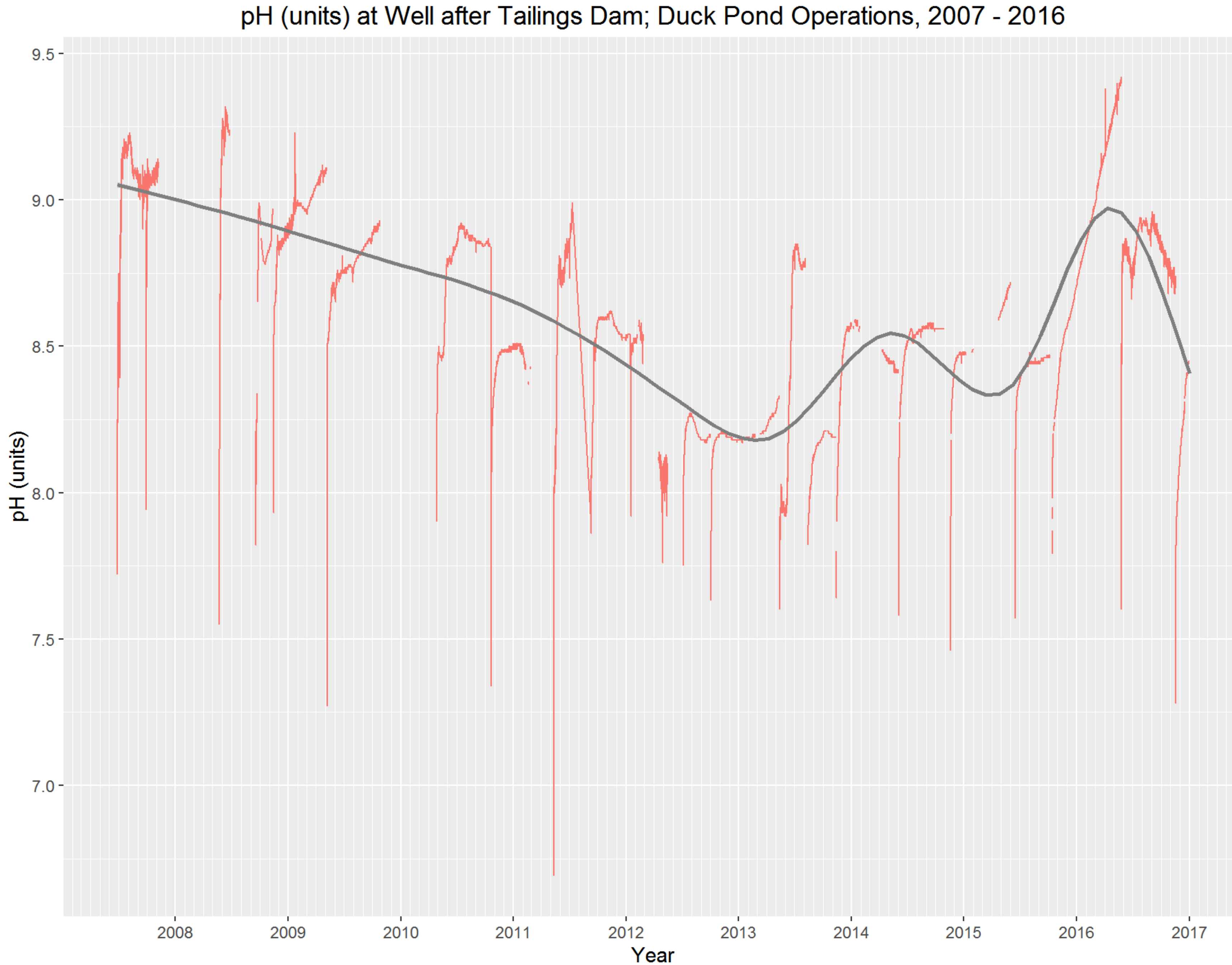

Figure 13: pH at Well after Tailings Dam station from 2007 to 2016

Steady-state pH conditions are challenging to observe in Figure 13 due to extreme values recorded following a disturbance in aquifer conditions (i.e. maintenance and calibration work). Figure 14 gives a better indication of the central 75% of data. A rising trend is seen from 2013 to 2016, however this is following a prolonged falling trend from 2008 to 2012 seen in Figure 13.

Table 9: Descriptive statistics for pH at Well after Tailings Dam

Year	Mean	Median	Min	Max
2007	9.04	9.09	7.72	9.23
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

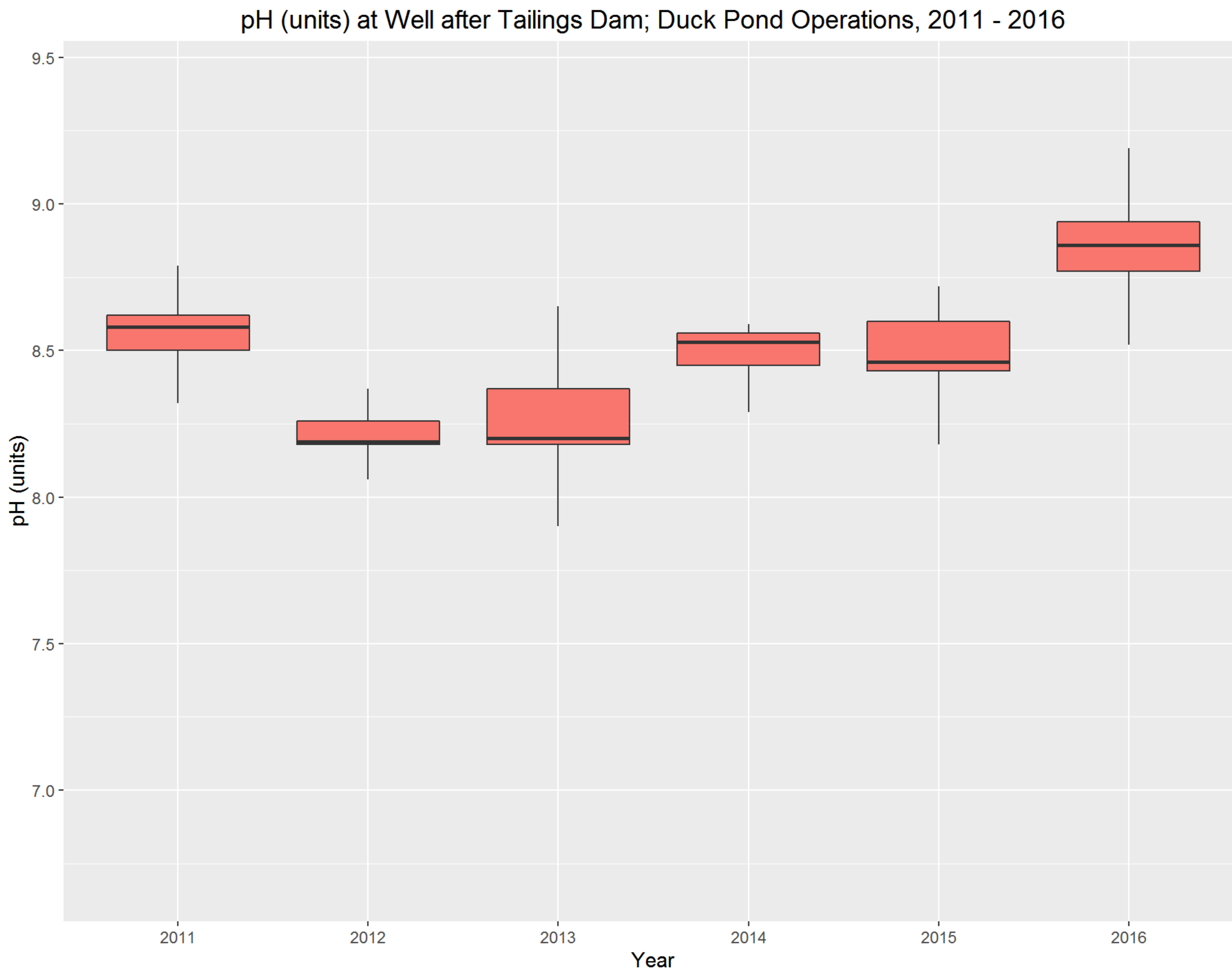

Figure 14: Boxplots of pH at Well after Tailings Dam station from 2011 to 2016

Specific Conductivity

A clear trend in specific conductivity can be observed in specific conductivity as values increased from approximately 200 uS/cm to more than 900 uS/cm since 2008. As more dissolved solids enter the aquifer, specific conductivity increases.

As decommissioning continues, specific conductivity will be monitored to observe for especially abrupt changes. Over the long term, it is expected that specific conductivity could gradually decrease.

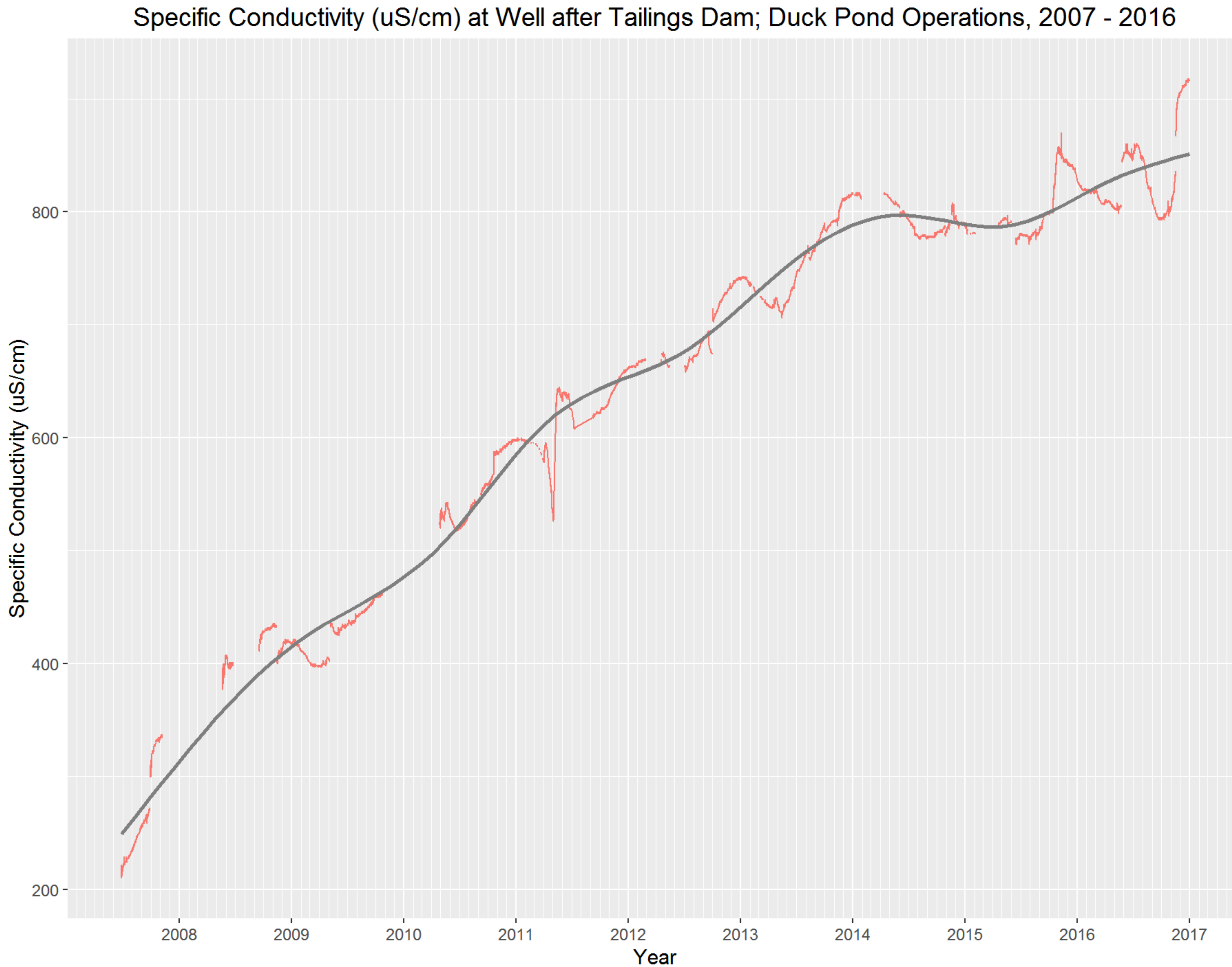

Figure 15: Specific conductivity at Well after Tailings Dam station from 2007 to 2016

Figure 16 gives another view of the increasing specific conductivity within the aquifer. It appears that the rate of increase has slowed since 2013.

Table 10: Descriptive statistics for specific conductivity at Well after Tailings Dam

Year	Mean	Median	Min	Max
2007	269	256	210	337
2008	416	419	377	436
2009	427	430	397	463
2010	554	543	517	599
2011	621	626	526	662
2012	691	678	658	742
2013	756	751	706	817
2014	792	789	776	817
2015	804	792	771	870
2016	831	819	793	918

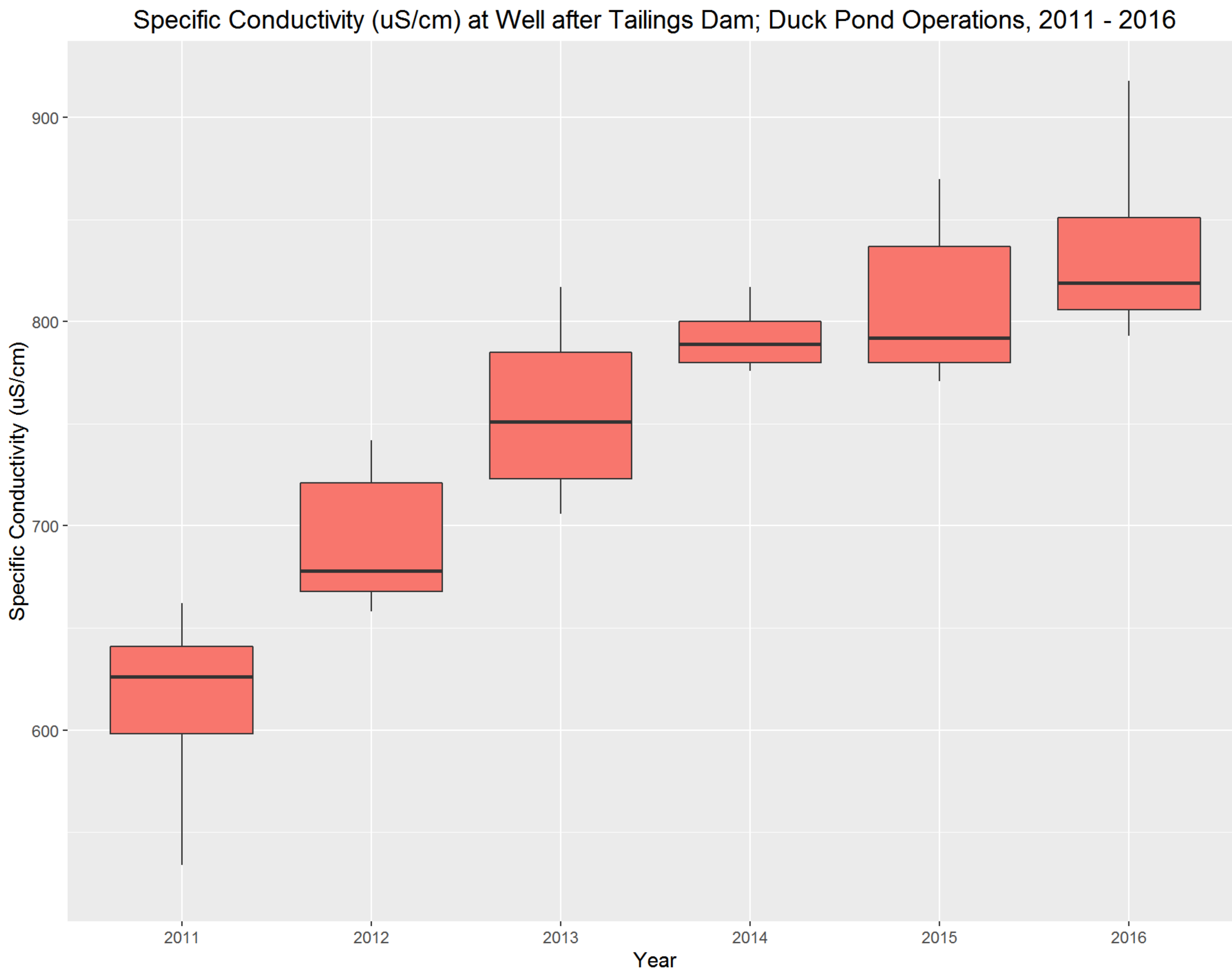

Figure 16: Boxplots of specific conductivity at Well after Tailings Dam station from 2011 to 2016

Oxidation-Reduction Potential

Extreme values in ORP tend to obscure long-term ORP trends in Figure 17. It is clear, however that ORP values tend to reside below 0 mV, indicating a predominantly reductive environment.

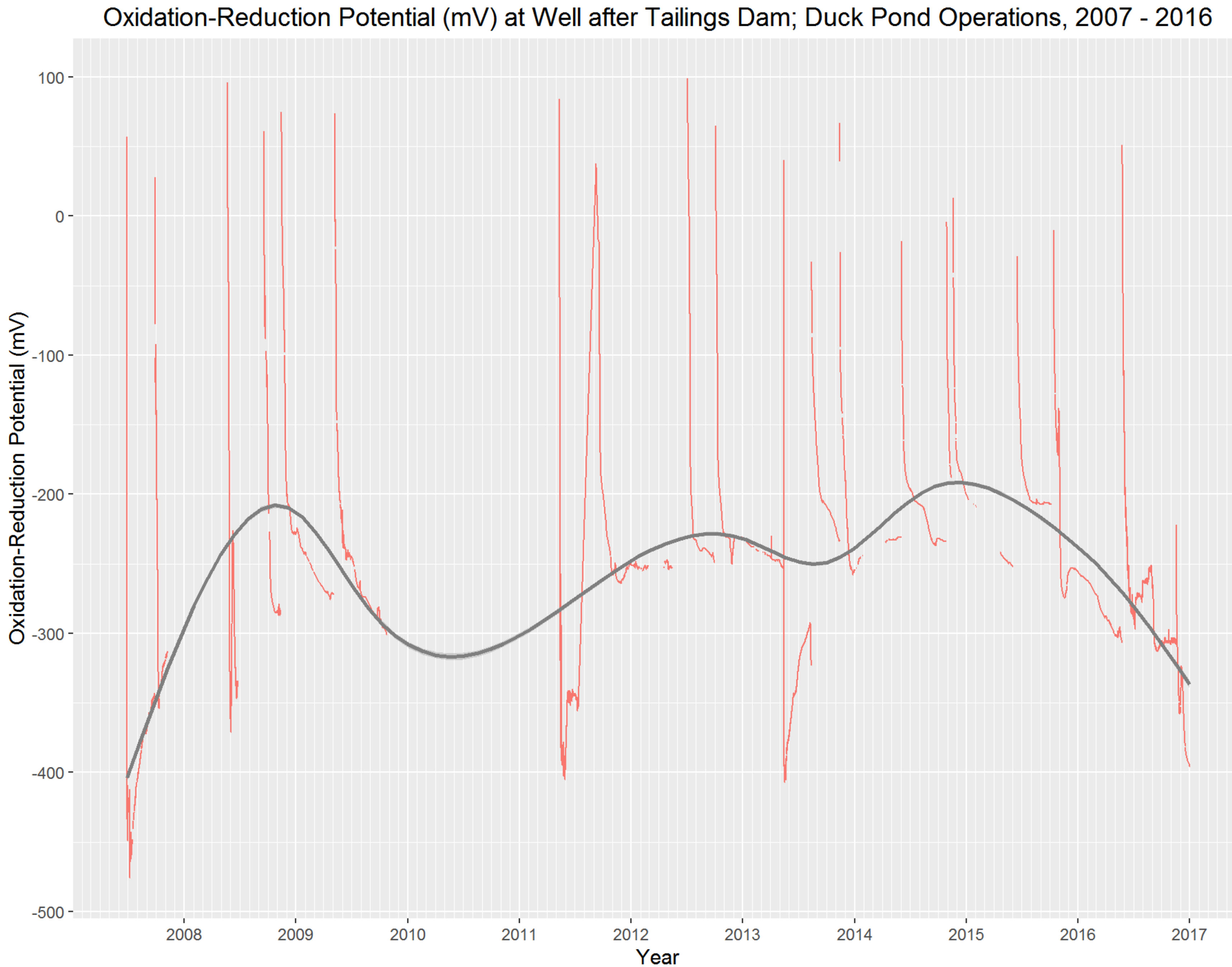

Figure 17: Oxidation-reduction potential at Well after Tailings Dam station from 2007 to 2016

According to Figure 18 and Table 11, ORP tends to reside between -200 and -300 mV. A slight rising trend was observed from 2011 to 2014, but began to drop off in 2015 – potentially due to natural variation.

Table 11: Descriptive statistics for ORP at Well after Tailings Dam

Year	Mean	Median	Min	Max
2007	-360	-364	-476	57
2008	-215	-228	-371	96
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

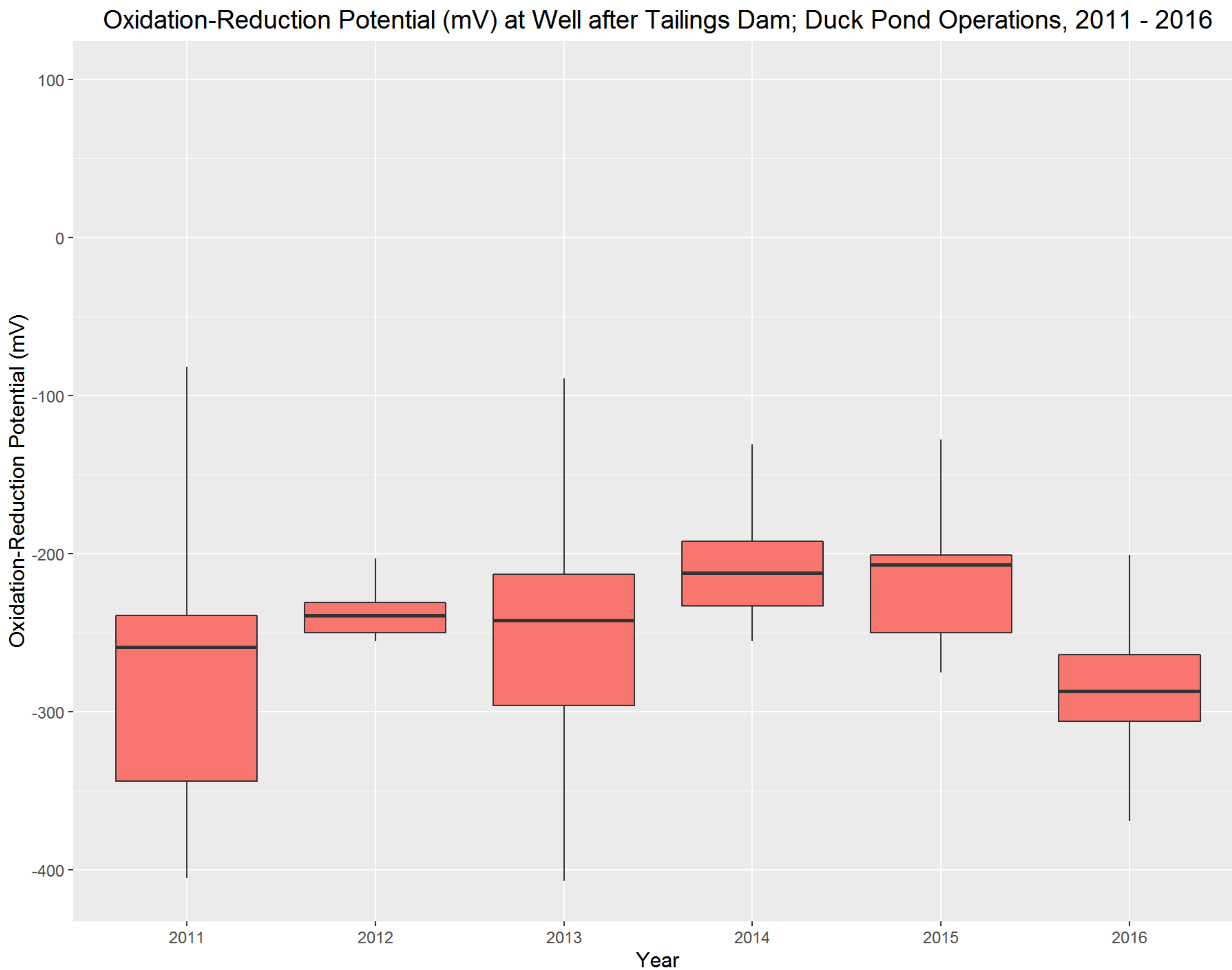

Figure 18: Boxplots of oxidation-reduction potential at Well after Tailings Dam station from 2011 to 2016

Water Elevation

From 2008 to 2010, water elevation increased by almost 40 cm before beginning a long decline through 2016. Water level changes could be related to aquifer recharge due to precipitation or operational water level changes in the nearby tailings pond.

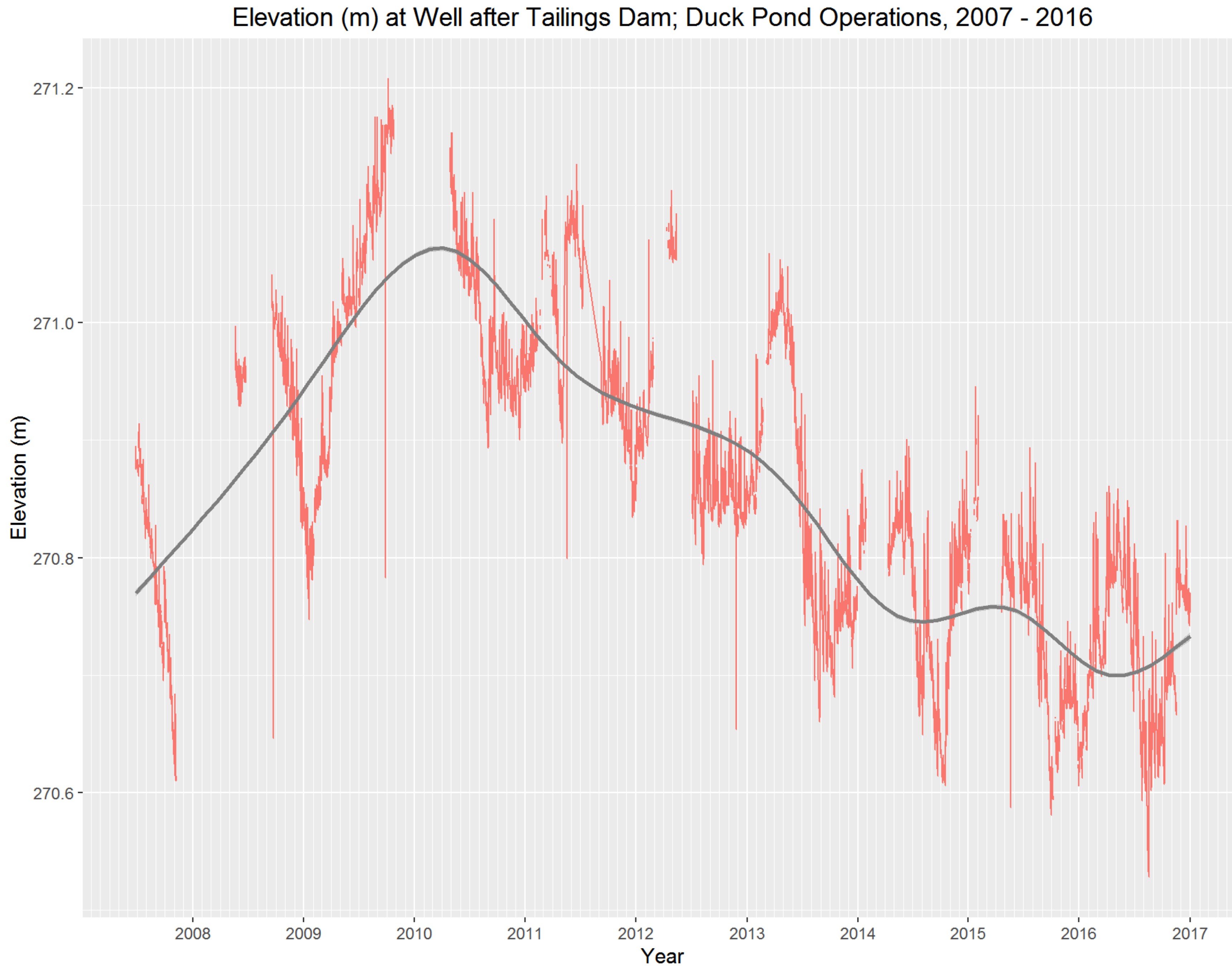

Figure 19: Water elevation at Well after Tailings Dam station from 2007 to 2016

Figure 20 shows a downward trend in water elevation, however, this is only part of a decline following a rise in water elevation from 2008 to 2010, as discussed above.

Table 12: Descriptive statistics for water elevation at Well after Tailings Dam

Year	Mean	Median	Min	Max
2007	270.776	270.779	270.610	270.914
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	270.960	270.799	271.135
2012	270.890	270.866	270.654	271.113
2013	270.842	270.812	270.660	271.059
2014	270.760	270.779	270.606	270.901
2015	270.730	270.734	270.581	270.946
2016	270.718	270.717	270.528	270.861

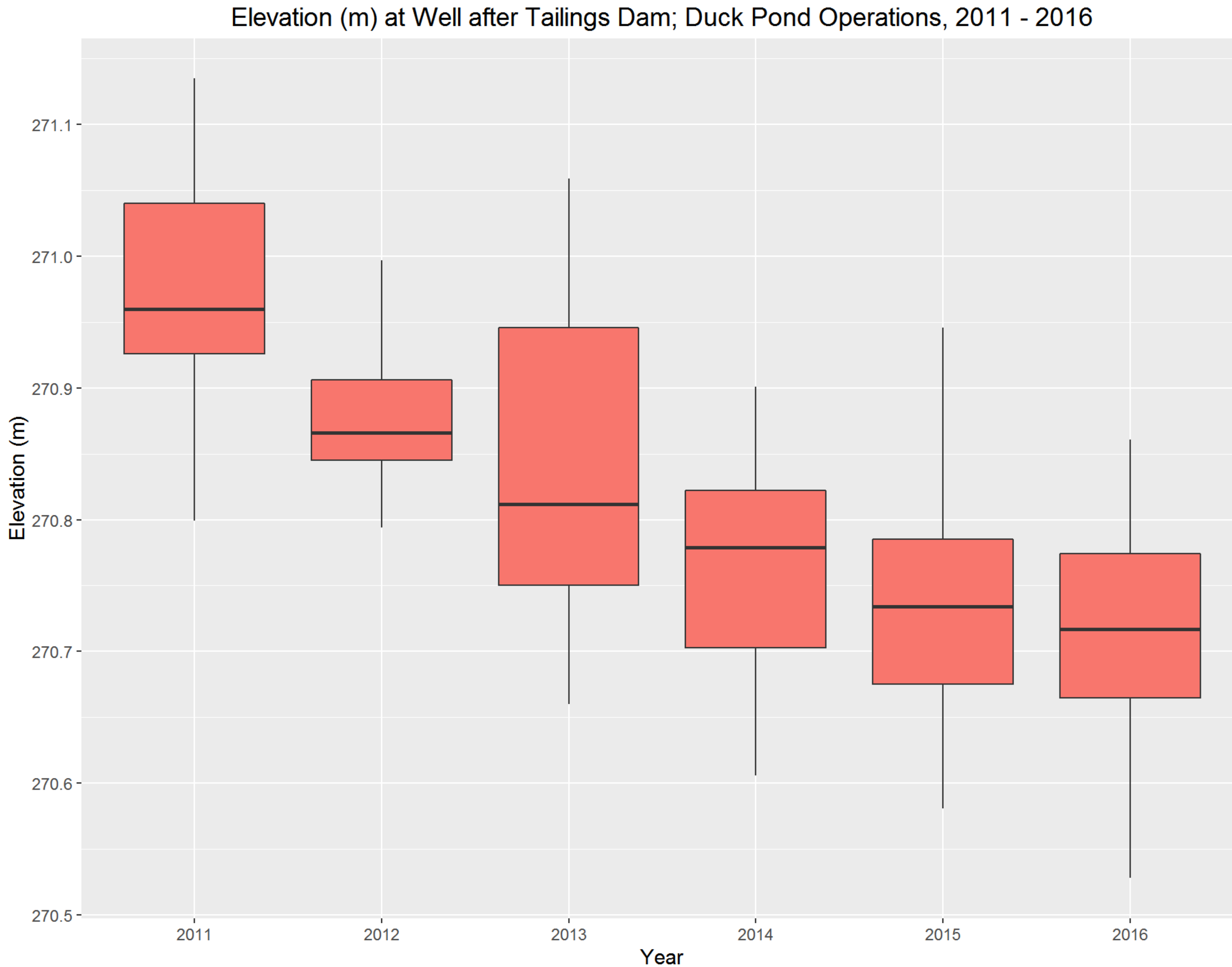

Figure 20: Boxplots of water elevation at Well after Tailings Dam station from 2011 to 2016

Conclusions

- Effluent discharge through the TGPB station has resulted in higher pH and specific conductivity compared to EPB station. No particular trend is obvious at either station for any parameter, although this will be monitored closely during rehabilitation and long-term monitoring.
- Specific conductivity within the Well after Tailings Dam has increased year over year since monitoring efforts began in 2007. It appears that the rate of increase has slowed since 2015 (potentially related to mine and mill closure). Specific conductivity will be observed closely into the future.
- With mine closure, inputs into the aquatic environment have ceased and rehabilitation efforts are underway at Duck Pond Operations. Successful rehabilitation efforts should see a gradual improvement to key water quality parameters such as pH and specific conductivity over time. Continued collaboration between ECC and Teck DPO staff will ensure rehabilitation is as successful as possible and discharge meets regulatory guidelines.

Path Forward

- Four HACH DS5X Hydrolab surface water monitors and two HACH Quanta G groundwater monitors are owned by Teck Duck Pond Operations and are maintained on a routine basis by the Department of Environment and Climate Change.
- In addition to routine maintenance and calibration work, equipment also goes through an annual performance, testing, and evaluation (PTE) process. During annual PTEs, each Hydrolab is disassembled and cleaned, and worn parts are replaced as needed. Firmware updates are applied as required and a full functional check is made; including a week-long bath test.
- Staffing changes in 2016 required a knowledge shift as new ECC staff take on the duties related to Duck Pond Operations. Each site has its own particular nuances and some time is required to become familiar with new locations.
- Mining activity ceased in 2015 and the site is currently in rehabilitation. As a result of reduced worker presence, effective communication between MAE and Teck DPO staff is more critical than ever to ensure site access is available when needed.
- Current plans are to continue water quality monitoring until at least 2020. Prior to the wrap up of environmental monitoring, trend analyses should be completed once again to ascertain the remediation work undertaken at the Duck Pond Operations site.
- Routine visits to monitoring stations will continue to be made, ensuring accurate readings. Enhancements to the monitoring program will be made as necessary.

Appendix

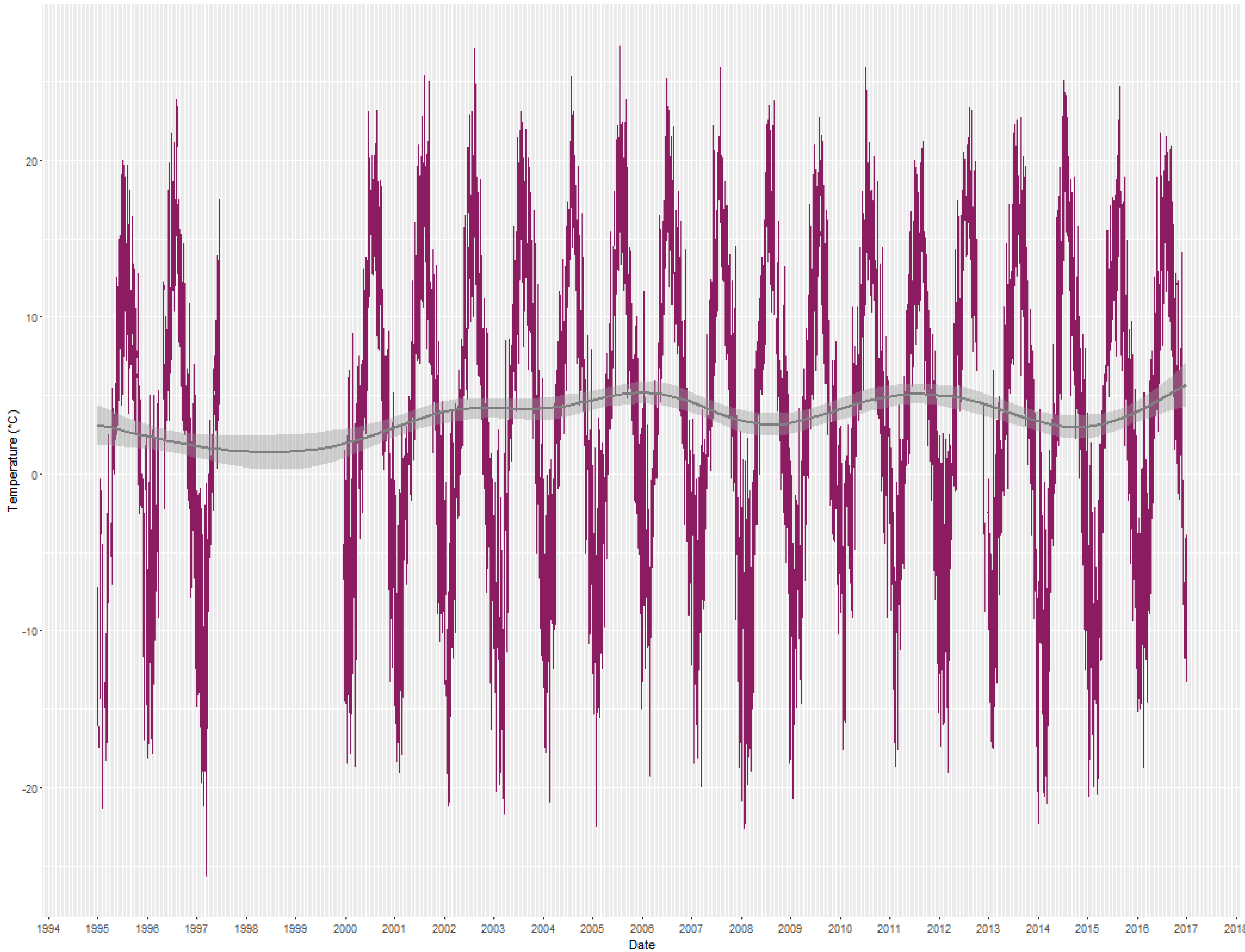

Figure 21: Temperature at Badger weather station from 1995 to 2016

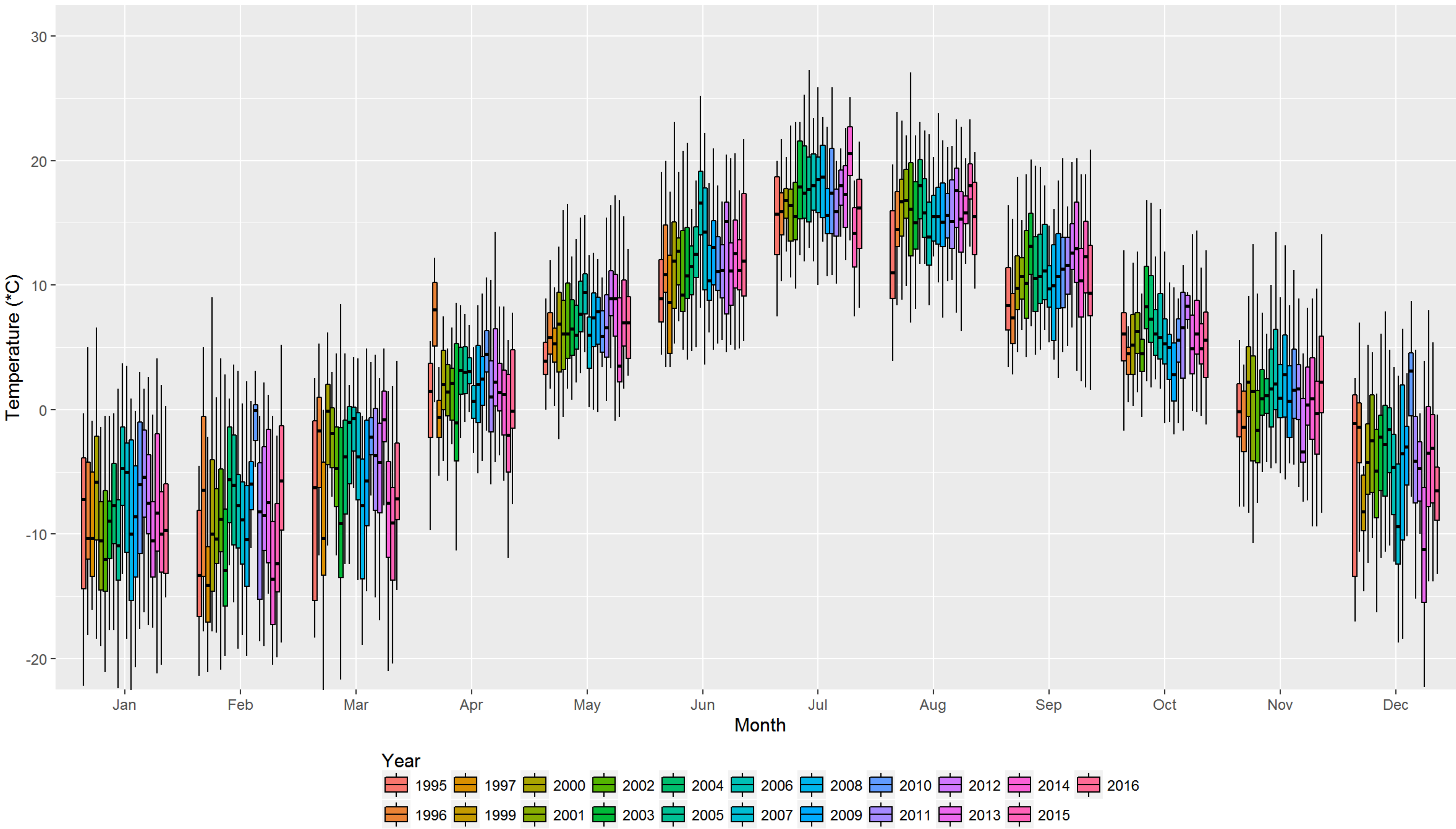

Figure 22: Monthly temperature at Badger weather station from 1995 to 2016

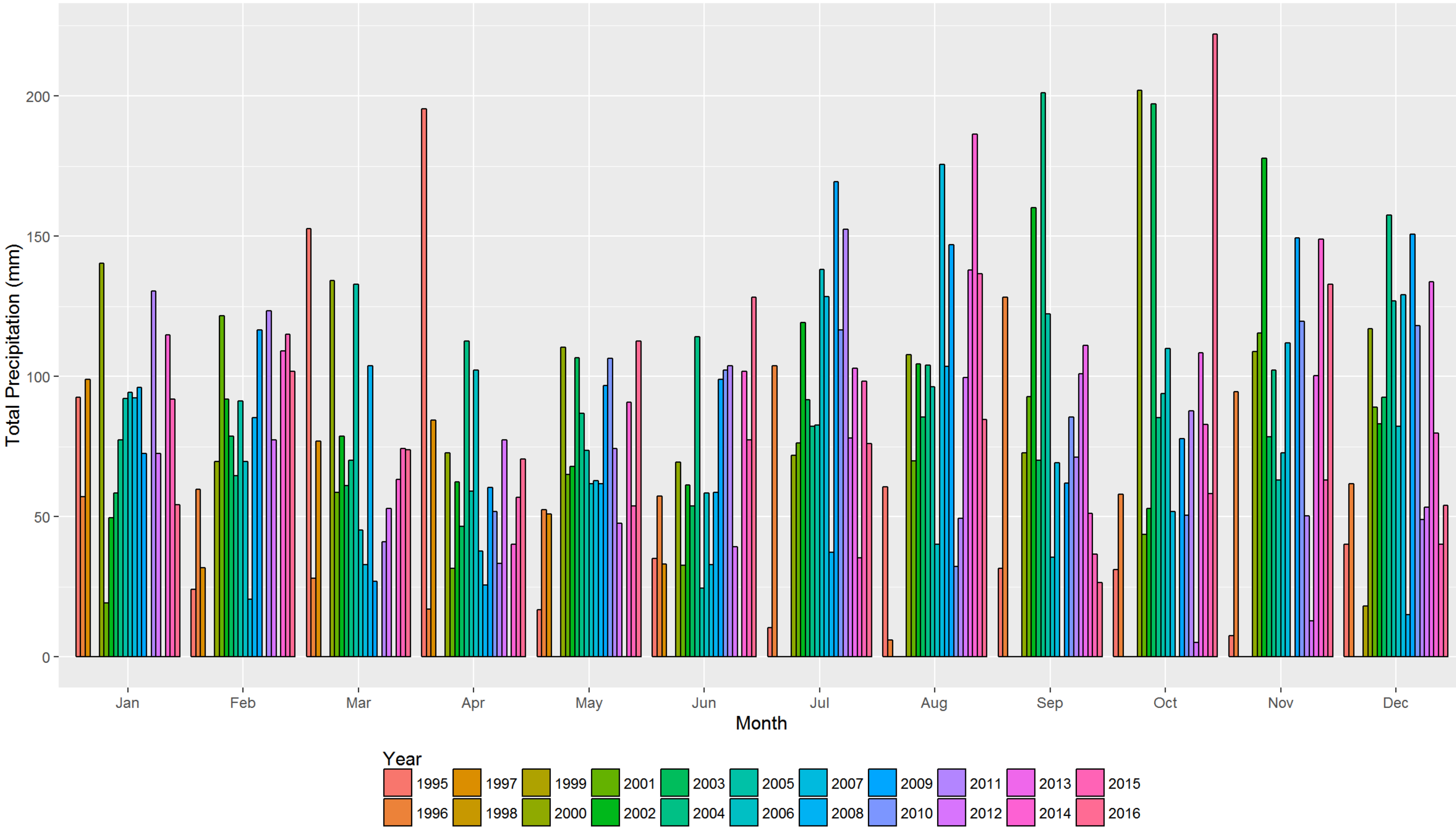

Figure 23: Total Precipitation at Badger weather station from 1995 to 2016