Real-Time Water Quality Deployment Report

Rattling Brook and Residue Storage Area

Annual Report 2016

Government of Newfoundland & Labrador
Department of Municipal Affairs and Environment
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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 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.

Long Harbour is the site of Vale's nickel refinery in Newfoundland and Labrador. Baseline real-time water quality monitoring began in late 2007 prior to the commencement of construction. This initial station located on Rattling Brook was followed by an expansion in 2009 which saw an additional station downstream and another at the headwaters on Rattling Brook Big Pond (locally known as Coady's Pond). This expansion was completed before intensive earthworks began in 2010 and has been pivotal in the collection of a thorough record of water quality. The Rattling Brook monitoring network is pictured in Photo 1.

Photo 1: Aerial view of Rattling Brook Monitoring Network in Long Harbour

In addition to the surface water monitoring on Rattling Brook, a network of groundwater monitoring stations has been deployed around the Residue Storage Area (RSA), also known as Sandy Pond. This collection of five stations, deployed in late 2012, has been situated to detect leaching from Sandy Pond. The RSA monitoring network is pictured in Photo 2

Photo 2: Aerial view of the Residue Storage Area groundwater monitoring network in Long Harbour

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.

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

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 Rattling Brook and the RSA in 2016.

Table 1: Deployment schedule at Rattling Brook Network for 2016

Station	Installation	Removal	Duration (Days)
Big Pond	2015-12-11	2016-01-21	20
	2016-04-28	2016-06-23	56
	2016-06-24	2016-08-04	41
	2016-08-05	2016-09-22	48
	2016-09-22	2016-11-03	42
	2016-11-03	2017-01-05	58
	Percent of Year Deployed		72.6%
Below Bridge	2015-12-11	2016-01-21	20
	2016-01-22	2016-02-18	27
	2016-02-19	2016-03-23	33
	2016-03-24	2016-04-28	35
	2016-04-29	2016-06-23	55
	2016-06-24	2016-08-04	41
	2016-08-05	2016-09-22	48
	2016-09-23	2016-11-03	41
	2016-11-03	2017-01-05	58
	Percent of Year Deployed		98.1%
Below Plant Discharge	2015-12-10	2016-01-22	21
	2016-01-22	2016-02-18	27
	2016-02-19	2016-03-23	33
	2016-03-24	2016-04-28	35
	2016-04-29	2016-06-23	55
	2016-06-24	2016-08-04	41
	2016-08-05	2016-09-22	48
	2016-09-22	2016-11-03	42
	2016-11-03	2017-01-05	58
	Percent of Year Deployed		98.6%

Table 2: Deployment schedule at Residue Storage Area for 2016

Station	Installation	Removal	Duration (Days)
Well 1 Deep	2015-10-29	2016-05-10	130
	2016-05-11	2016-08-17	98
	2016-08-18	2016-12-06	110
	2016-12-07	-	24
	Percent of Year Deployed		99.2%
Well 2 Shallow	2015-10-29	2016-05-10	130
	2016-05-12	2016-08-17	97
	2016-08-18	2016-12-06	110
	2016-12-07	-	24
	Percent of Year Deployed		98.9%
Well 2 Deep	2015-10-29	2016-05-10	130
	2016-05-12	2016-08-17	97
	2016-08-18	2016-12-06	110
	2016-12-07	-	24
	Percent of Year Deployed		98.9%
Well 3 Deep	2015-11-13	2016-05-10	130
	2016-05-12	2016-08-17	97
	2016-08-18	2016-12-06	110
	2016-12-07	-	24
	Percent of Year Deployed		98.9%
Well 4 Deep	2015-10-29	2016-05-10	130
	2016-05-11	2016-08-17	98
	2016-08-18	2016-12-06	110
	2016-12-07	-	24
	Percent of Year Deployed		99.2%

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 Argentia weather station near Long harbour from 1995 to 2016 for comparative purposes.

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.

Rattling Brook 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.

Figure 1 shows that a small warming trend is present at each station from the outset of monitoring to the end of 2016. With only seven years of data at Big Pond and Plant Discharge station, it is impossible to tell if this is a long-term change or natural variation in climate.

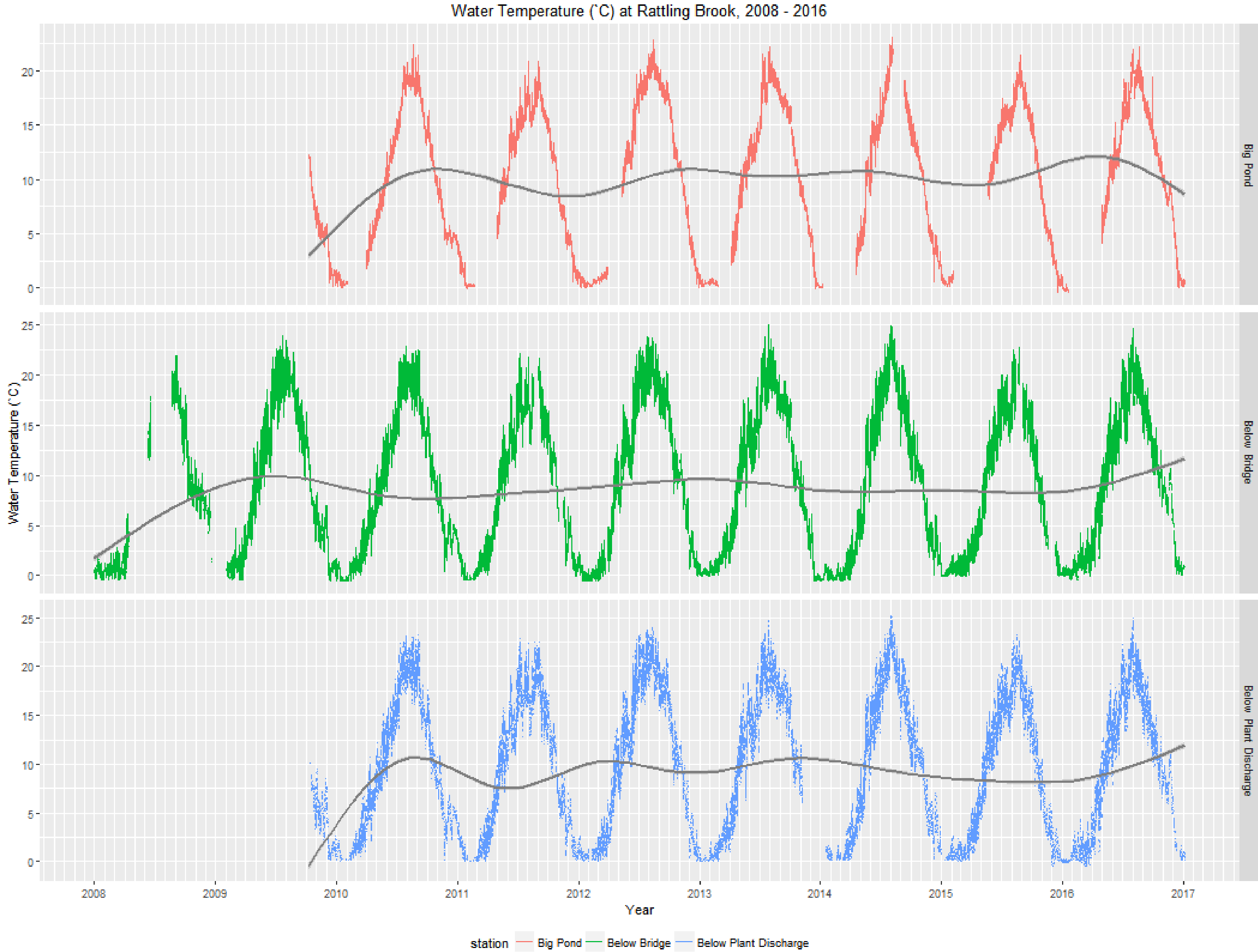

Figure 1: Water temperature at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

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

Boxplots in Figure 2 give an indication that, year over year, water temperatures at Plant Discharge station tend to be slightly warmer than those at Below Bridge station. Since monitoring equipment is removed from Big Pond station once ice forms (to avoid damage), there is a bias towards warmer temperatures in the Big Pond dataset.

Table 3: Descriptive statistics for temperature at Rattling Brook

Station	Year	Mean	Median	Min	Max
Big Pond	2010	10.08	9.65	0.04	22.40
	2011	9.58	9.88	-0.02	20.88
	2012	10.00	11.28	0.00	22.87
	2013	9.67	10.04	-0.02	22.17
	2014	10.58	11.37	0.01	23.10
	2015	10.11	11.68	-0.39	21.46
	2016	10.87	11.52	-0.44	22.24
Below Bridge	2008	6.73	6.20	-0.42	21.93
	2009	9.14	8.03	-0.50	23.97
	2010	8.65	7.73	-0.50	22.84
	2011	7.70	6.43	-0.48	22.20
	2012	9.52	9.77	-0.51	23.82
	2013	9.03	9.16	-0.49	24.98
	2014	8.65	7.46	-0.50	24.93
	2015	7.91	6.69	-0.03	22.69
	2016	9.10	9.15	-0.54	24.69
Below Plant Discharge	2010	9.04	8.12	0.02	23.67
	2011	8.43	7.49	-0.07	22.89
	2012	9.98	10.16	-0.03	24.33
	2013	10.05	10.90	-0.03	24.70
	2014	9.27	9.36	0.00	25.48
	2015	8.05	6.71	-0.51	23.25
	2016	9.10	9.23	-0.55	25.00

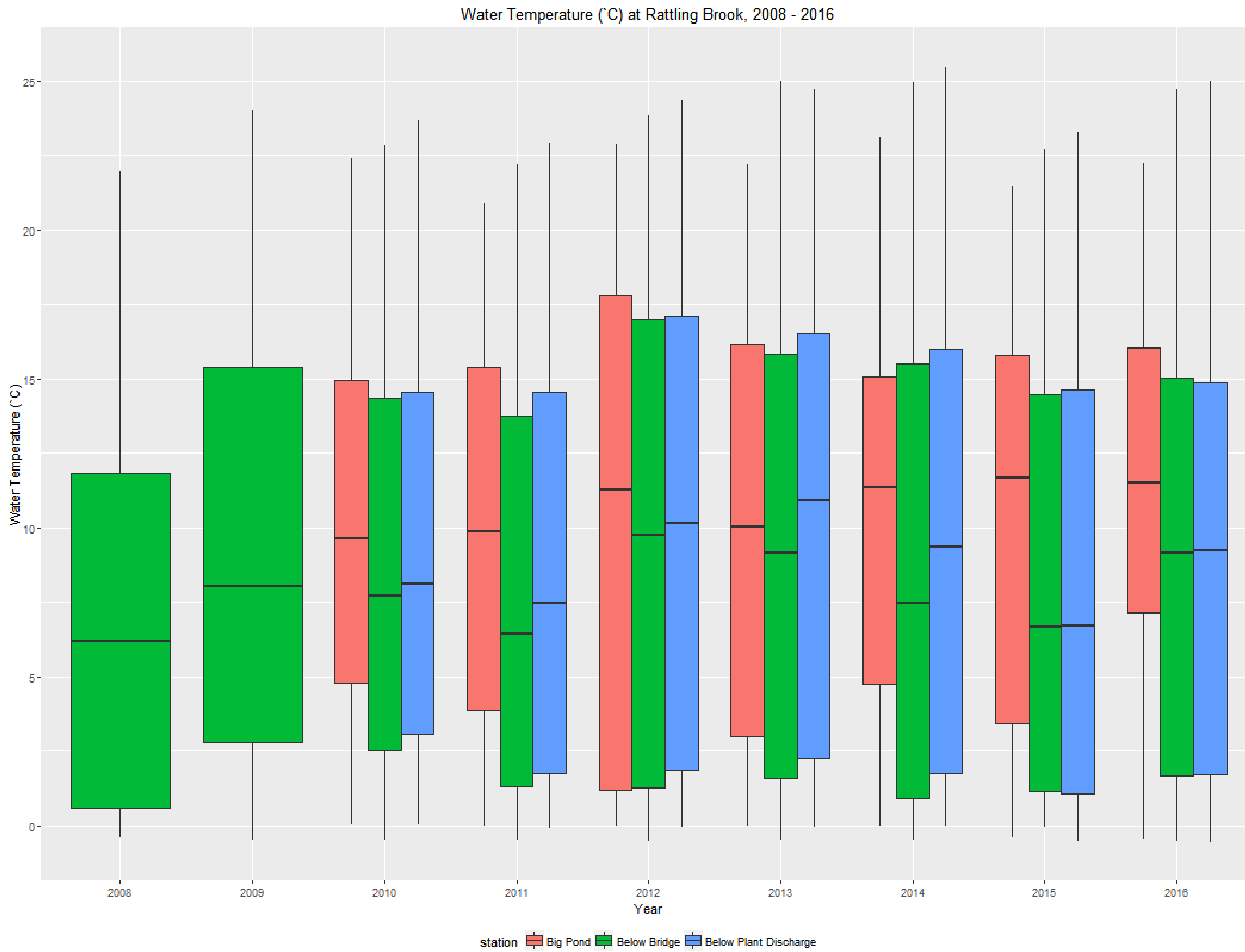

Figure 2: Boxplots of water temperature at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

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.*

Site Specific Guidelines (SSGs) were established for the Rattling Brook network prior to the initiation of major construction. The SSGs were set at the 95th (5.67 pH units) and 5th (6.56 pH units) percentiles of pH data from Big Pond, Below Bridge, and Below Plant Discharge stations from the initiation of monitoring to the start of tree clearing. These guidelines are indicated by the dashed lines in Figure 3.

For both Big Pond and Bridge stations, pH values have historically fallen below the 95th percentile of pre-construction pH values. Meanwhile, median values at Plant Discharge station have increased over time leading to the majority of pH values sitting above the upper SSG.

As a result of different levels of variability at each station, Figure 3 presents pH in three different scales. Individual instances of high pH variability, such as late September 2016 at Big Pond, are discussed in monthly reports.

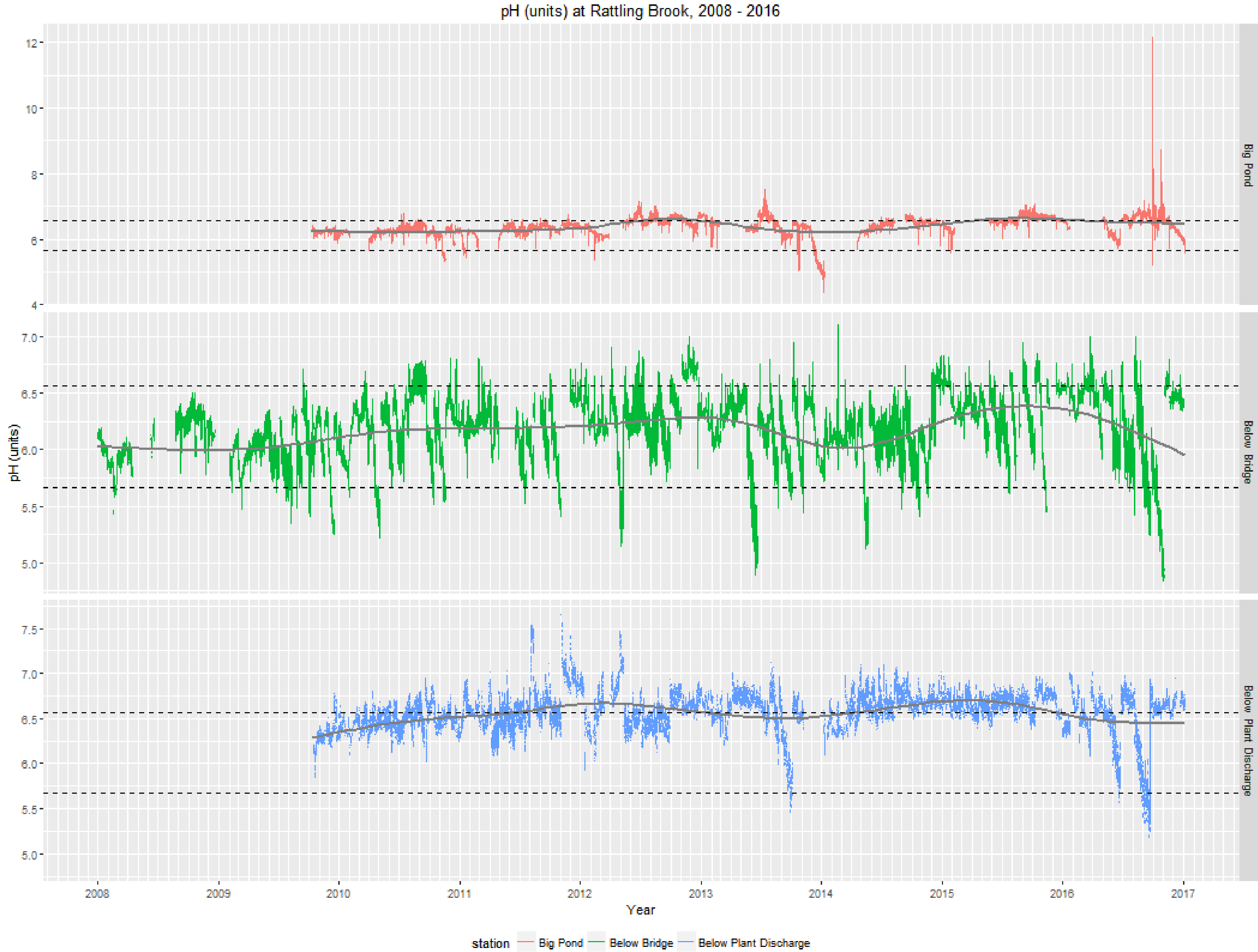

Figure 3: pH at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

Figure 4 shows that pH is consistently found to be lowest at Bridge station and highest at Plant Discharge station.

Table 4: Descriptive statistics for pH at Rattling Brook

Station	year	Mean	Median	Min	Max
Big Pond	2010	6.22	6.25	5.34	6.80
	2011	6.29	6.32	5.45	6.74
	2012	6.48	6.51	5.37	7.14
	2013	6.33	6.41	4.94	7.51
	2014	6.38	6.46	4.36	6.78
	2015	6.58	6.59	5.57	7.07
	2016	6.50	6.54	5.23	12.17
Below Bridge	2008	6.08	6.11	5.42	6.50
	2009	5.98	5.99	5.25	6.71
	2010	6.19	6.24	5.22	6.81
	2011	6.16	6.19	5.41	6.81
	2012	6.29	6.29	5.15	7.00
	2013	6.14	6.21	4.89	6.94
	2014	6.09	6.09	5.13	7.10
	2015	6.34	6.37	5.45	6.94
	2016	6.21	6.39	4.84	7.00
Below Plant Discharge	2010	6.45	6.44	5.12	6.95
	2011	6.61	6.57	6.07	7.67
	2012	6.58	6.58	5.92	7.48
	2013	6.54	6.60	5.45	7.12
	2014	6.62	6.63	4.83	7.17
	2015	6.66	6.66	6.37	6.96
	2016	6.46	6.57	5.17	7.03

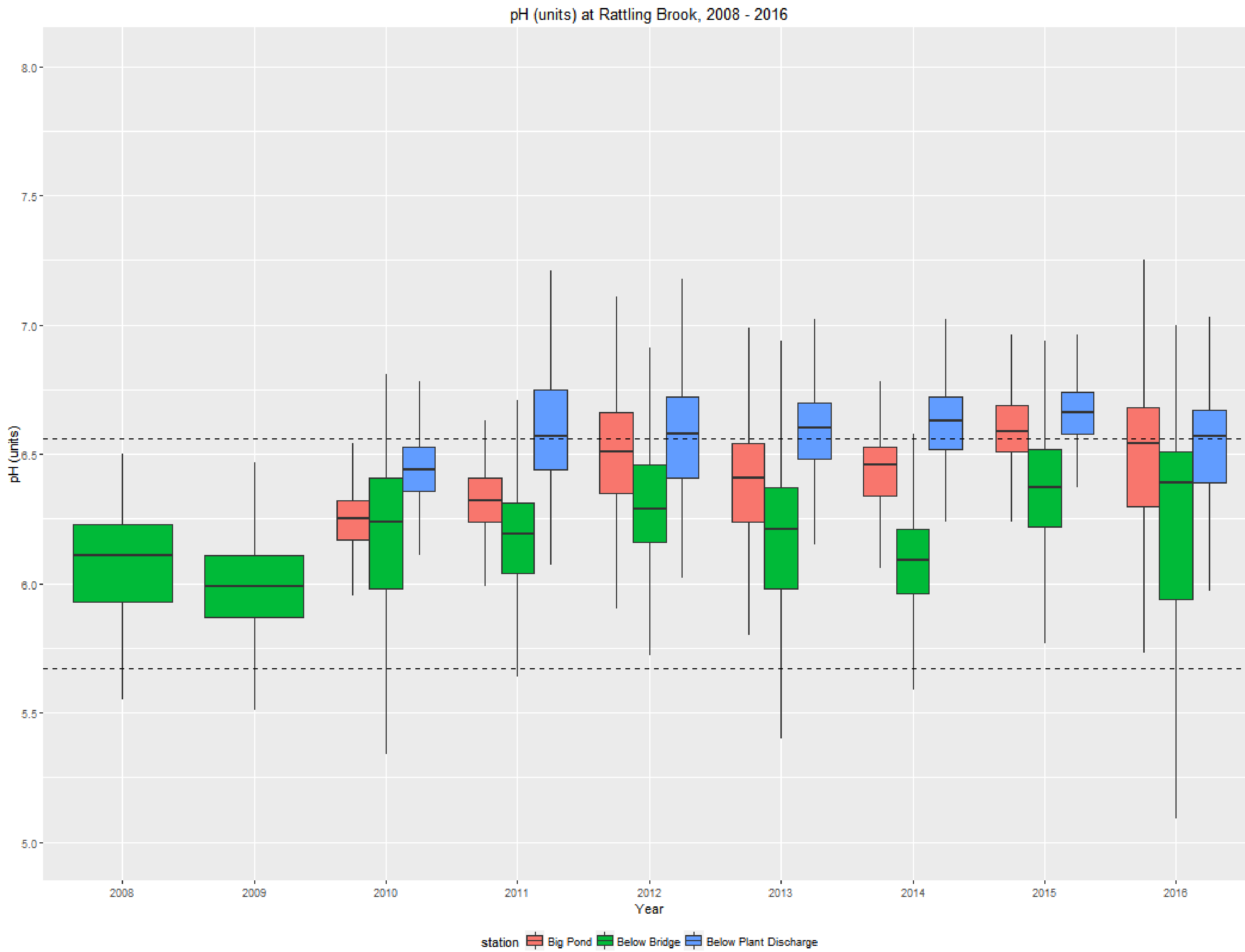

Figure 4: Boxplots of pH at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

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^{o}C to allow comparison across variable temperatures.*

In Figure 5 a steady increase in specific conductivity is clear at each Rattling Brook station as a result of dissolved solids entering the river channel from nearby roads and disturbed soils. The increasing trend was most substantial during the constructions phase beginning in 2010 and appears to have peaked in 2013, slowing thereafter. As construction winds down and onsite work becomes more routine, runoff into the river channel and sedimentation pond effluent will likely run clearer, reducing conductivity.

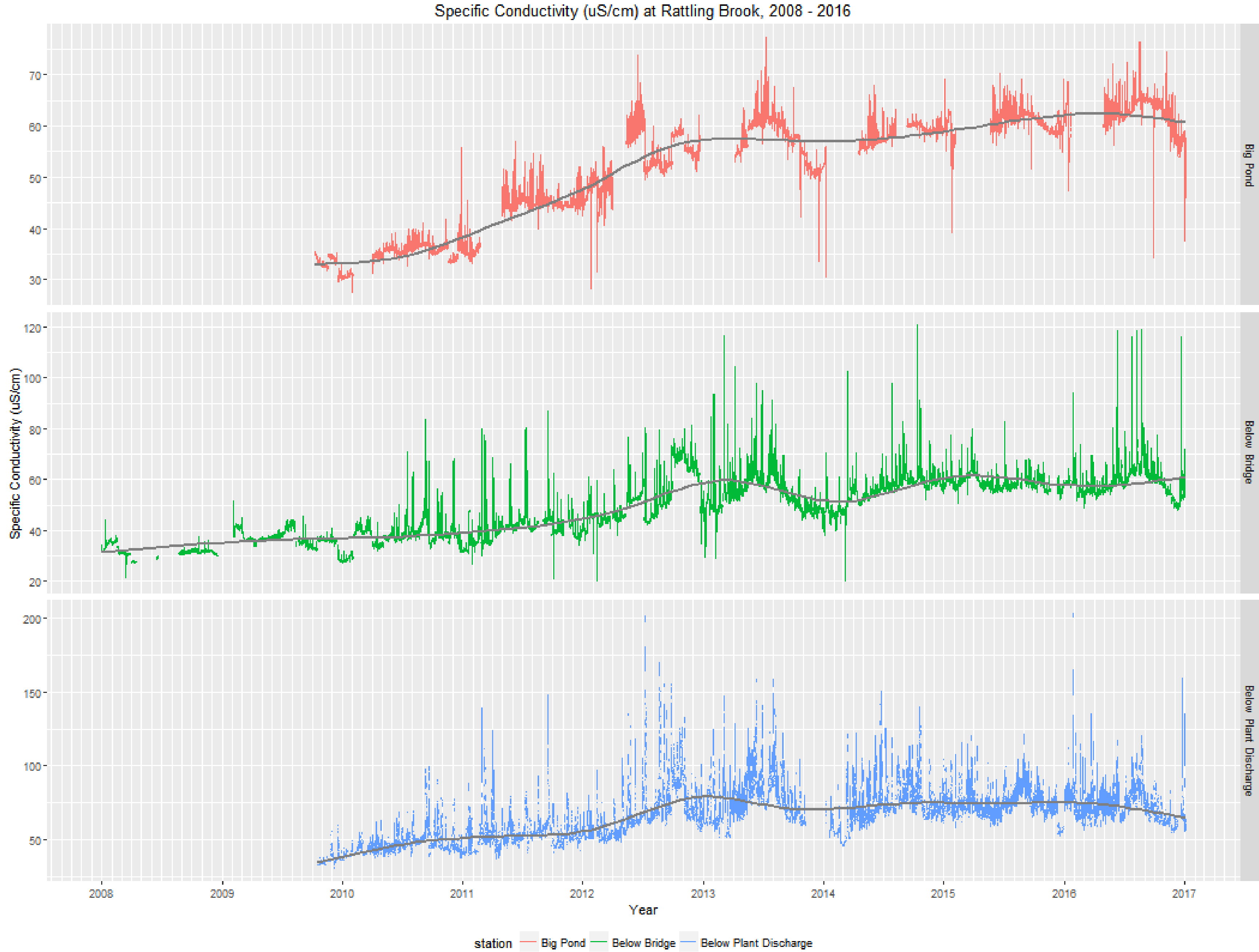

Figure 5: Specific conductivity at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

The rapid rise in conductivity following the commencement of construction is seen in Figure 6. Also apparent is the relative level of specific conductivity at each station: Bridge station tends to be lower than both Big Pond and Plant Discharge station, while Plant Discharge station is highest.

Table 5: Descriptive statistics for specific conductivity at Rattling Brook

Station	year	Mean	Median	Min	Max
Big Pond	2010	35.2	35.6	27.4	55.7
	2011	43.4	44.6	33.1	57.0
	2012	53.3	52.9	28.2	73.8
	2013	57.3	58.0	33.6	77.4
	2014	58.4	58.8	30.6	68.1
	2015	60.6	60.8	39.1	70.3
	2016	62.1	62.4	34.4	76.3
Below Bridge	2008	32.2	31.8	21.6	44.4
	2009	36.9	36.5	27.5	51.6
	2010	38.1	38.0	27.4	83.6
	2011	40.8	40.6	21.2	87.1
	2012	52.9	50.1	20.2	81.1
	2013	55.1	53.9	29.3	116.6
	2014	56.1	57.0	20.3	120.7
	2015	59.0	58.3	50.6	82.6
	2016	59.1	58.7	47.3	119.1
Below Plant Discharge	2010	46.5	44.9	35.5	99.8
	2011	53.4	51.9	36.5	147.9
	2012	69.1	64.7	45.5	202.0
	2013	75.8	72.5	51.0	158.7
	2014	72.4	70.4	43.9	161.4
	2015	74.0	73.0	52.3	121.0
	2016	72.4	71.0	54.3	203.0

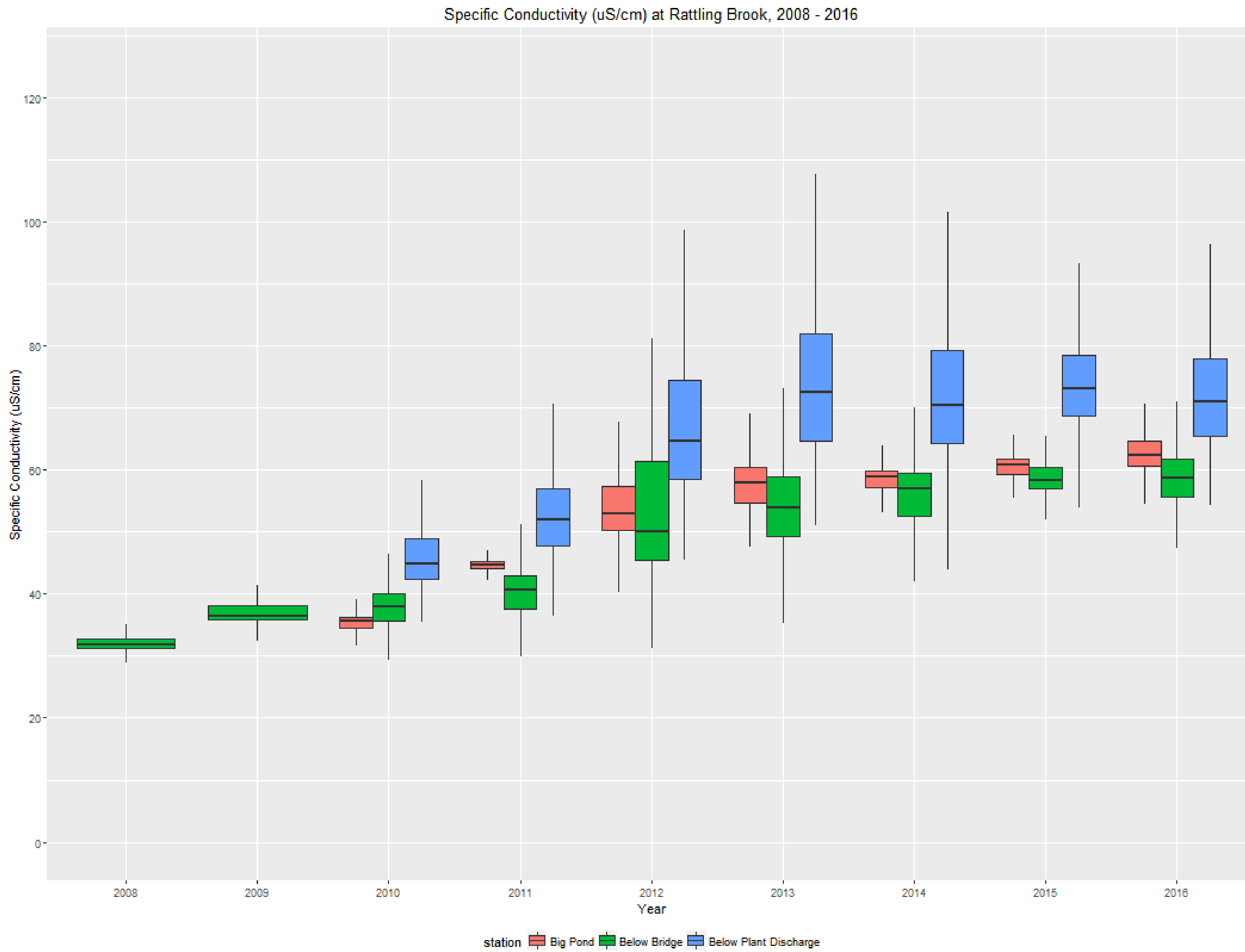

Figure 6: Boxplots of specific conductivity at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

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 levels are generally well-within expected levels throughout the year and do not show any obvious trend up or downwards.

CCME guidelines are illustrated in Figure 7 as dashed lines at 9.5 and 6.5 mg/l. These guidelines are for the protection of "early" and "other" life stage cold water organisms, respectively. DO concentrations rarely fall below the 6.5 mg/l guideline and are usually well within specified guidelines.

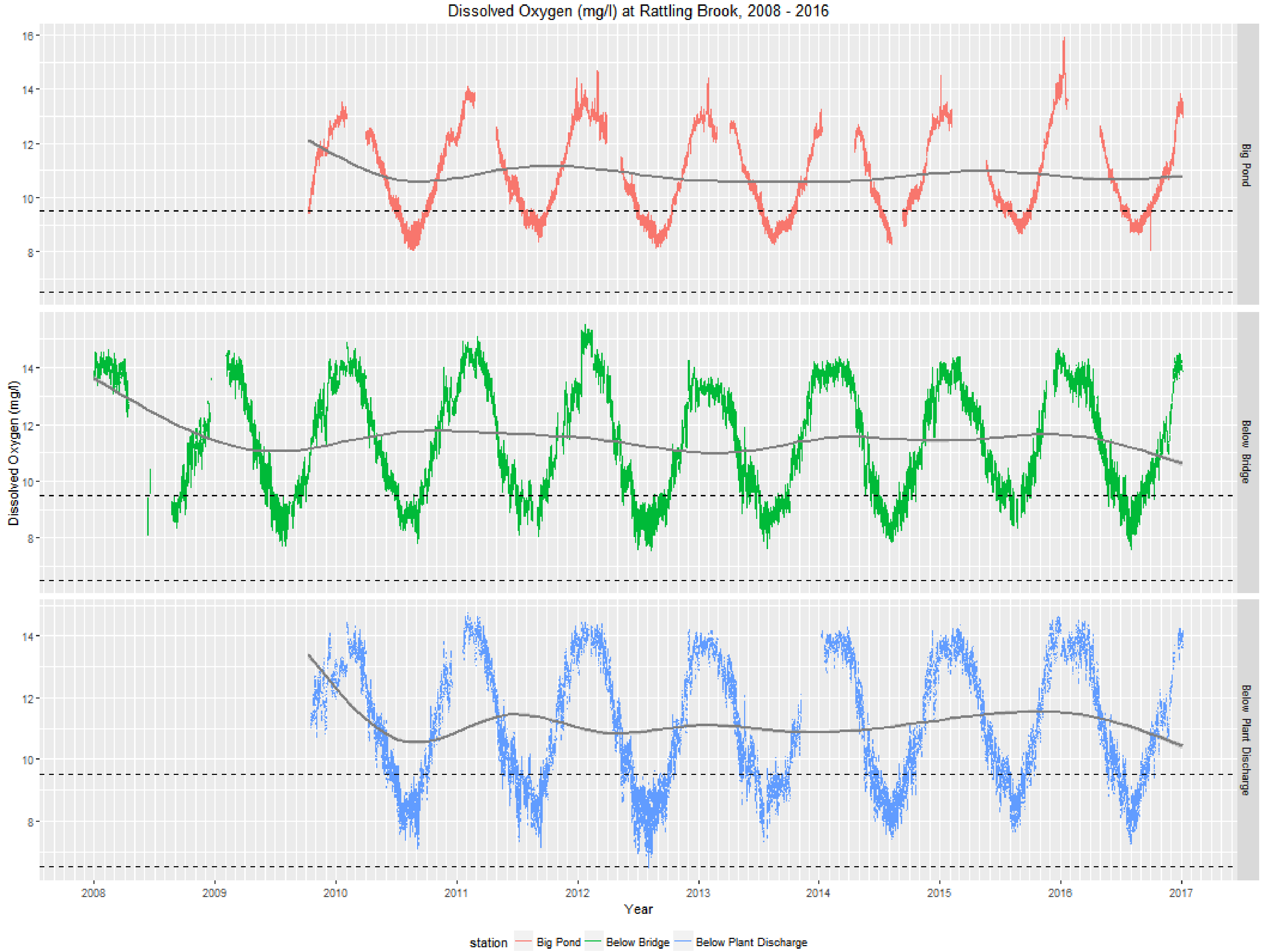

Figure 7: Dissolved oxygen at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

Dissolved oxygen values at Big Pond station tend to show less variability and are generally lower compared to the stations downstream. Lower DO levels are likely related to the removal of monitoring equipment from Big Pond station during freeze-up as this is also when DO levels are highest. This process imposes a certain bias.

Bridge and Plant Discharge stations are located in riverine conditions with strong flow ensuring high saturation of DO compared to Big Pond.

Table 6: Descriptive statistics for dissolved oxygen at Rattling Brook

Station	year	Mean	Median	Min	Max
Big Pond	2010	10.68	10.69	8.06	13.53
	2011	10.99	10.71	8.39	14.42
	2012	10.86	10.47	8.17	14.69
	2013	10.74	10.55	8.29	14.43
	2014	10.80	10.36	8.27	13.27
	2015	10.90	10.26	8.68	14.54
	2016	10.74	10.42	8.07	15.93
Below Bridge	2008	12.04	12.13	8.06	14.63
	2009	11.30	11.26	7.72	14.61
	2010	11.43	11.36	7.81	14.90
	2011	11.74	11.70	8.08	15.11
	2012	11.32	10.95	7.54	15.51
	2013	11.17	11.04	7.65	14.21
	2014	11.41	11.53	7.86	14.40
	2015	11.70	11.82	8.34	14.68
	2016	11.38	11.15	7.61	14.53
Below Plant Discharge	2010	10.94	10.95	7.02	14.48
	2011	11.24	10.99	7.12	14.76
	2012	10.91	10.66	6.46	14.45
	2013	10.96	10.52	7.28	14.20
	2014	11.09	10.95	7.39	14.30
	2015	11.55	11.79	7.59	14.68
	2016	11.23	11.10	7.18	14.57

Figure 8: Boxplots of dissolved oxygen at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 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 levels increased with the rise in industrial activity near the Rattling Brook system before peaking in 2012. A slow decline followed as earth movement was completed and siltation-control became more established.

In 2016, however, median turbidity rose from 0.0 NTU to 0.6 NTU at Plant Discharge station, as seen in Table 7. To a lesser degree, this was also observed at Below Bridge station and can be seen in Figure 10. This could be the result of natural variation due to weather, but will be observed closely in the future.

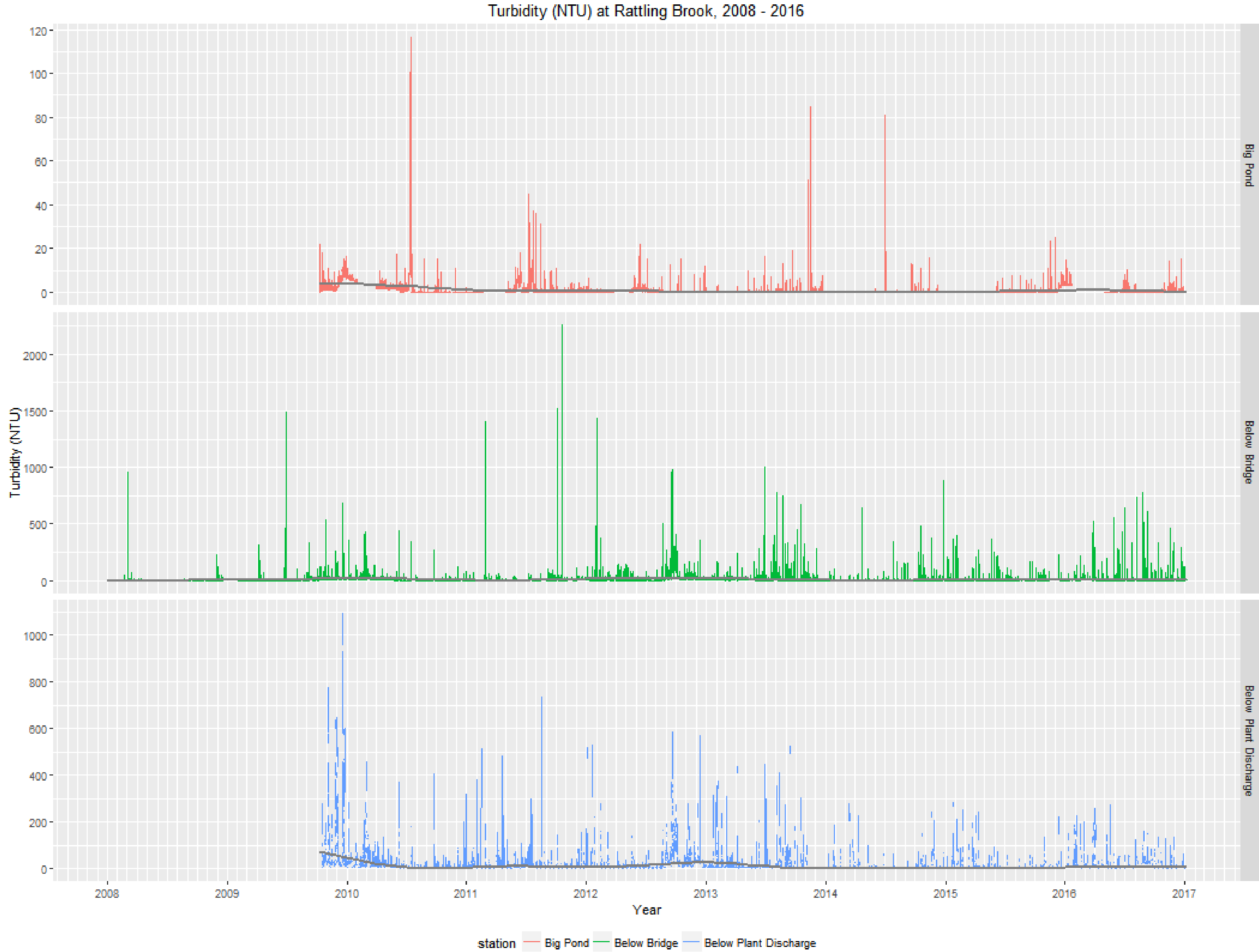

Figure 9: Turbidity at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

Table 7: Descriptive statistics for turbidity at Rattling Brook

Station	year	Mean	Median	Min	Max
Big Pond	2010	2.4	0.0	0.0	116.6
	2011	0.6	0.0	0.0	44.9
	2012	0.2	0.0	0.0	22.0
	2013	0.1	0.0	0.0	84.8
	2014	0.0	0.0	0.0	81.1
	2015	0.3	0.0	0.0	25.3
	2016	0.5	0.0	0.0	15.0
Below Bridge	2008	0.6	0.0	0.0	963.0
	2009	10.4	0.0	0.0	1486.0
	2010	10.2	2.5	0.0	445.0
	2011	6.0	0.4	0.0	2259.0
	2012	22.6	3.4	0.0	1437.0
	2013	6.4	2.4	0.0	998.0
	2014	2.3	0.0	0.0	886.0
	2015	2.9	0.0	0.0	396.9
	2016	5.4	0.0	0.0	781.0
Below Plant Discharge	2010	11.5	3.3	0.0	460.0
	2011	6.7	1.7	0.0	734.0
	2012	19.4	4.8	0.0	586.0
	2013	11.1	4.5	0.0	580.0
	2014	2.6	0.0	0.0	277.2
	2015	2.5	0.0	0.0	282.5
	2016	7.7	0.6	0.0	314.6

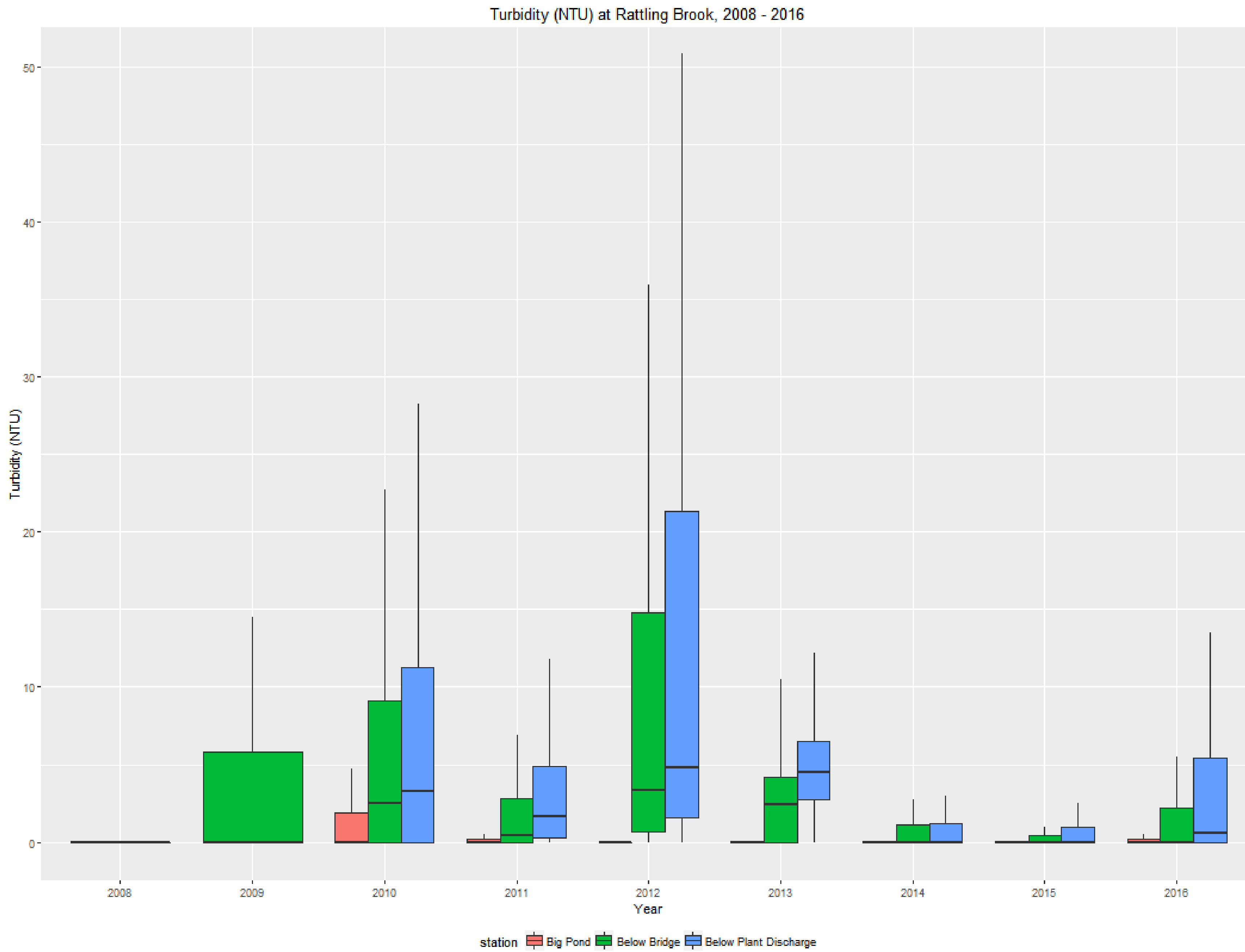

Figure 10: Boxplots of Turbidity at the Rattling Brook Real-Time Water Quality Monitoring Network Stations from 2008 to 2016

Residue Storage Area Monitoring Network

The RSA is the discharge point for waste materials following recovery of valuable metals. While solid materials are left submerged within the RSA, the liquid fraction is decanted and treated to meet industrial discharge regulations prior to ultimate dispersal via the marine outfall.

Discharge into the RSA has been ongoing since late 2014 with a slow ramp-up as the plant is commissioned.

Temperature

Seasonal variation in water temperature is observed at all wells except Well 1 Deep (Figure 11). This indicates there is a certain degree of interaction between surface and aquifer water at the wells surrounding the RSA

When maximum well temperature and surface temperatures occur together, a great degree of surface water interaction is implied. Greater time lag between maximum well and surface temperatures implies a greater disconnect. Assuming that surface temperatures are greatest from mid-July to August, the degree of surface water interaction at each well can be assessed by observing the timing of maximum well temperatures (see Table 8 and Table 1).

Table 8: Approximate timing of warm well seasons

Well	Approximate Warm Season	Connection to Surface
Well 1 Deep	NA	NA
Well 2 Shallow	September – October	Strong
Well 2 Deep	January – February	Weak
Well 3 Deep	March – April	Very Weak
Well 4 Deep	April - May	Very Weak

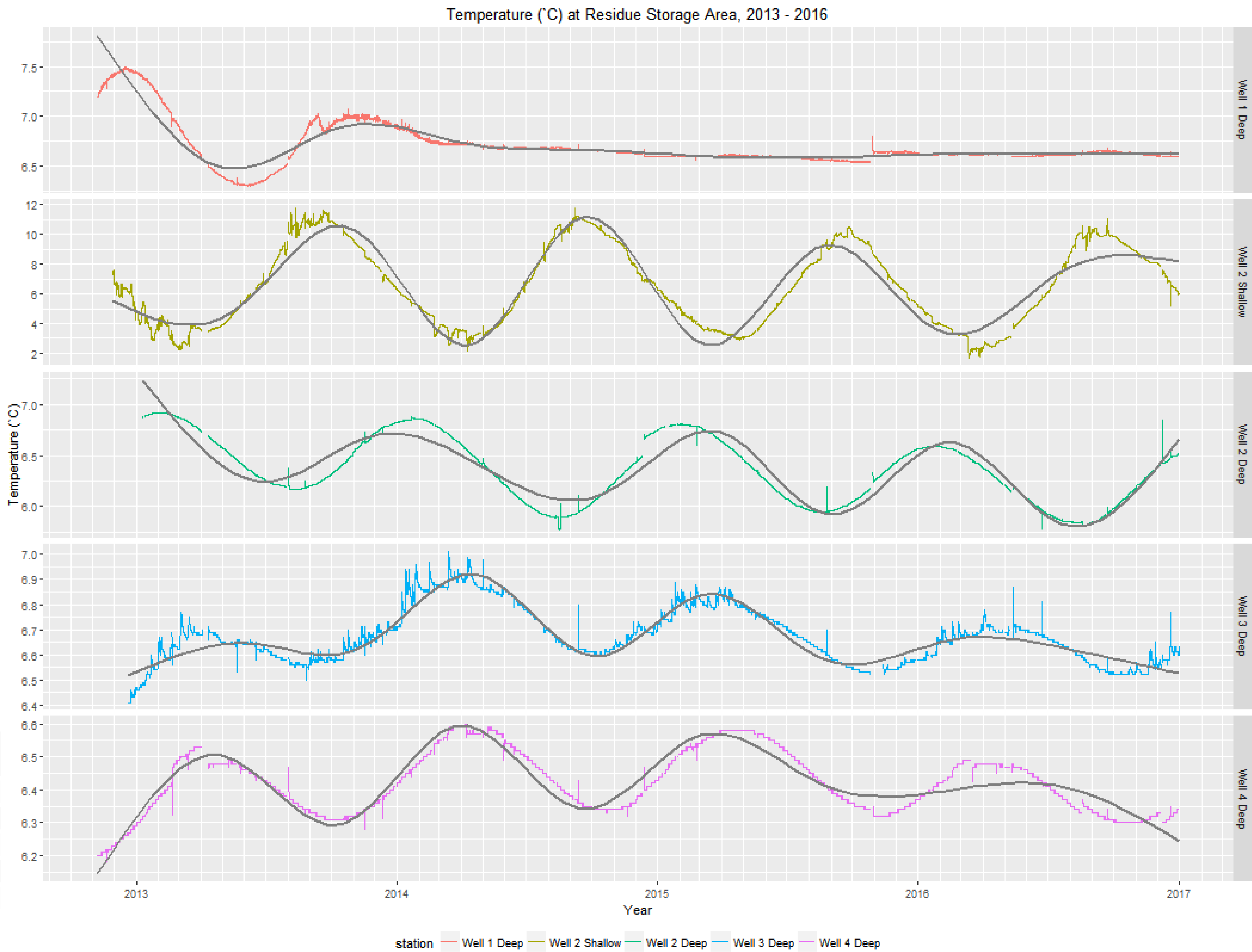

Figure 11: Temperature at Residue Storage Area monitoring network from 2013 to 2016

Figure 12 provides an immediate indication of connectedness between surface water and aquifer of Well 2 Shallow. Whereas other wells show a smaller spread of data (established by the height of boxplots), Well 2 Shallow shows a much larger range in temperatures.

Well 1 Deep, Well 3 Deep, and Well 4 Deep show relatively little connection to surface water.

Table 9: Descriptive statistics for temperature at the Residue Storage Area monitoring network

Station	Year	Mean	Median	Min	Max
Well 1 Deep	2013	6.78	6.87	6.30	7.45
	2014	6.69	6.68	6.59	6.97
	2015	6.59	6.60	6.54	6.80
	2016	6.62	6.62	6.59	6.68
Well 2 Shallow	2013	6.83	6.71	2.22	11.81
	2014	6.78	6.54	2.18	11.81
	2015	6.15	5.80	2.91	10.50
	2016	6.21	6.10	1.68	11.07
Well 2 Deep	2013	6.53	6.53	6.17	6.91
	2014	6.35	6.32	5.77	6.88
	2015	6.35	6.35	5.95	6.81
	2016	6.20	6.19	5.78	6.84
Well 3 Deep	2013	6.62	6.63	6.46	6.77
	2014	6.76	6.76	6.60	7.01
	2015	6.69	6.72	6.52	6.89
	2016	6.62	6.63	6.52	6.87
Well 4 Deep	2013	6.40	6.39	6.28	6.53
	2014	6.46	6.46	6.32	6.60
	2015	6.45	6.44	6.32	6.58
	2016	6.39	6.39	6.30	6.49

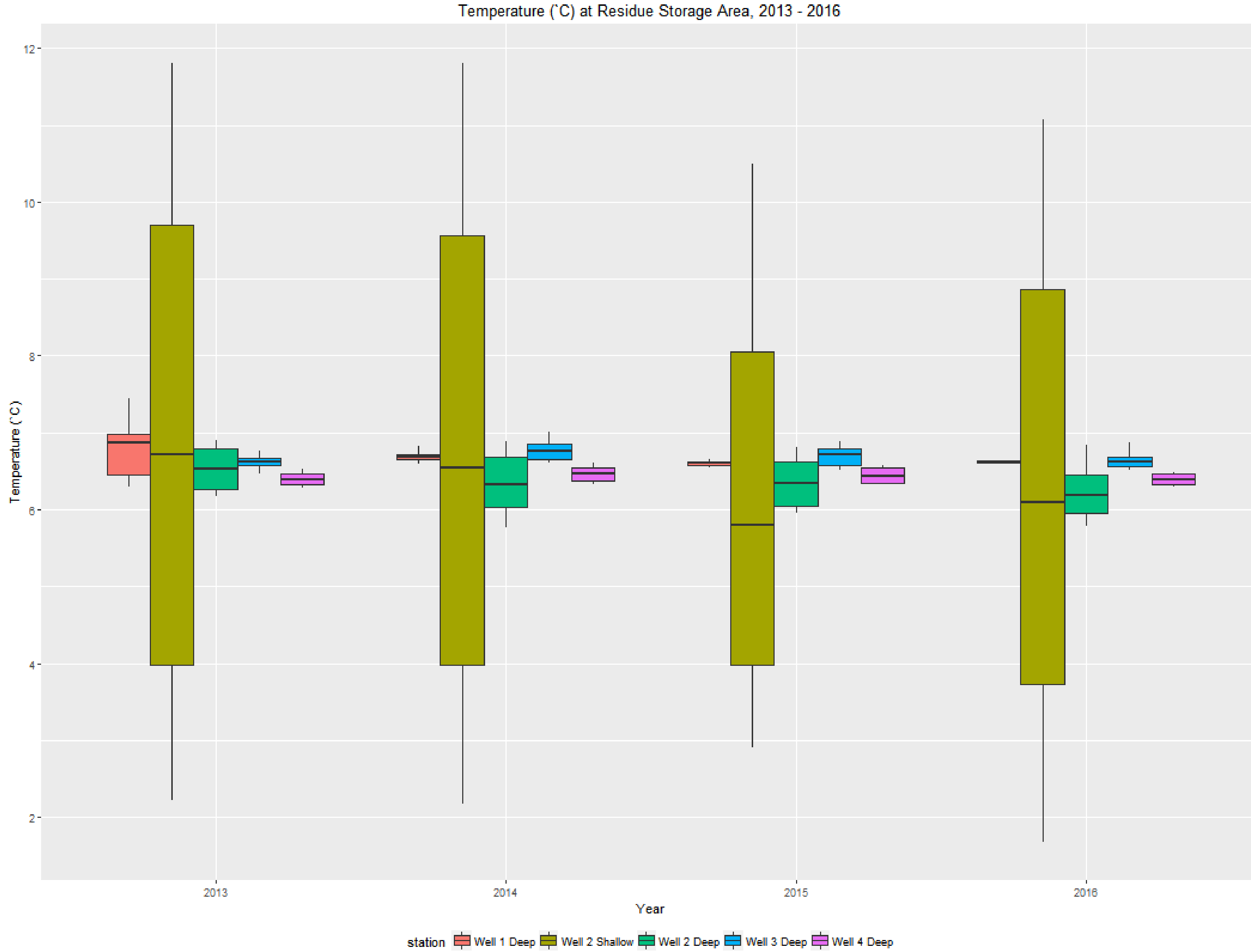

Figure 12: Boxplots of temperature at the Residue Storage Area monitoring network from 2013 to 2016

pH

Figure 13 gives an indication of pH increase at Well 1 Deep, Well 2 Shallow, and Well 3 Deep since 2015.

At this time it is difficult to determine the mechanism behind a pH change. Given the nature of materials stored within the RSA, leakage would likely manifest as lower pH, not higher. These trends will be followed into the future.

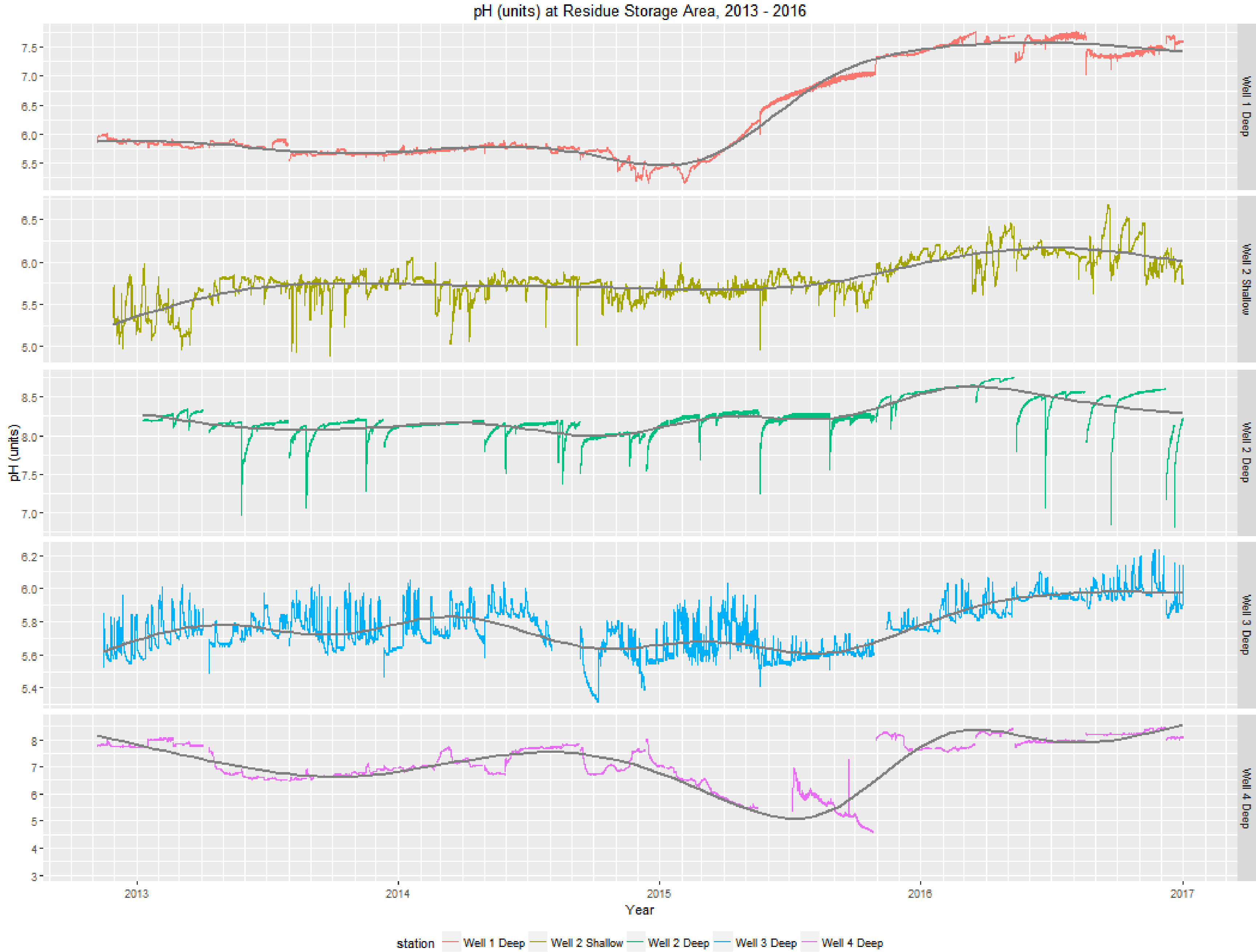

Figure 13: pH at Residue Storage Area monitoring network from 2013 to 2016

According to Figure 14 pH may be rising at Well 2 Deep. Median pH values have risen year after year since 2014, although it is challenging to see this in Figure 13.

Table 10: Descriptive statistics for pH at the Residue Storage Area monitoring network

Station	Year	Mean	Median	Min	Max
Well 1 Deep	2013	5.75	5.76	5.51	5.92
	2014	5.68	5.72	5.15	5.88
	2015	6.46	6.67	5.15	7.43
	2016	7.55	7.57	7.02	7.77
Well 2 Shallow	2013	5.64	5.72	4.89	5.98
	2014	5.70	5.74	5.01	6.05
	2015	5.75	5.73	4.95	6.12
	2016	6.11	6.11	5.61	6.68
Well 2 Deep	2013	8.13	8.16	6.98	8.35
	2014	8.08	8.12	7.38	8.20
	2015	8.27	8.25	7.24	8.57
	2016	8.49	8.55	6.80	8.75
Well 3 Deep	2013	5.75	5.73	5.47	6.03
	2014	5.73	5.74	5.32	6.05
	2015	5.67	5.63	5.40	6.03
	2016	5.93	5.95	5.73	6.23
Well 4 Deep	2013	7.03	6.77	6.43	8.08
	2014	7.25	7.15	6.71	8.04
	2015	6.06	5.90	3.03	8.27
	2016	8.04	8.06	7.54	8.45

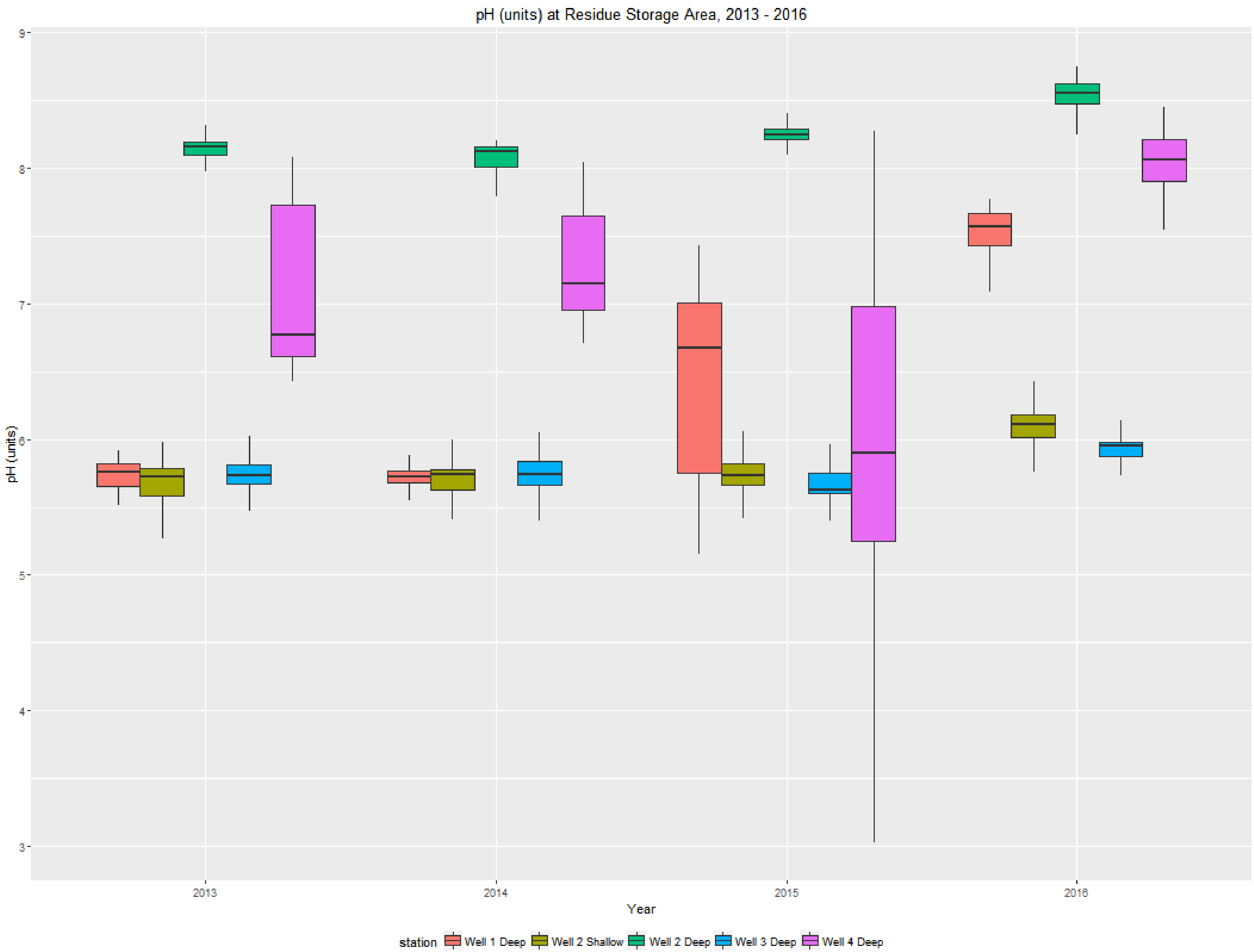

Figure 14: Boxplots of pH at the Residue Storage Area monitoring network from 2013 to 2016

Specific Conductivity

Specific conductivity is seen to be increasing over time at all monitoring stations except Well 2 Deep where it is decreasing (Figure 15). From 2013 to 2016, a 51% increase in specific conductivity has been observed at Well 1 Deep (Table 11).

The reasoning for a decline at Well 2 Deep while others increase is unclear, but will be monitored closely into the future.

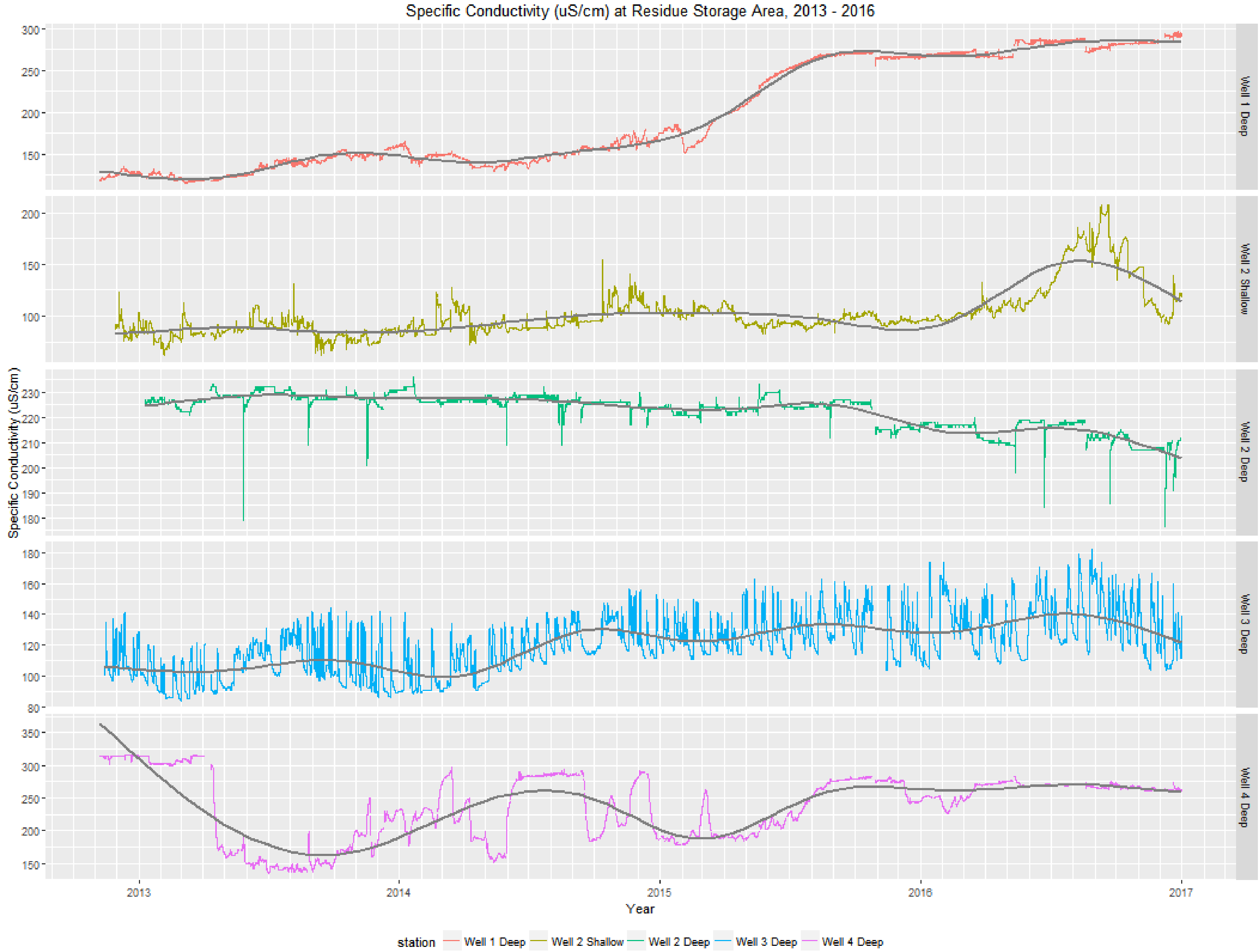

Figure 15: Specific conductivity at Residue Storage Area from 2013 to 2016

Well 2 Shallow is typically found to have the lowest conductivity amongst the monitoring stations around the RSA, as seen in Figure 16 and Table 11. Other wells with higher conductivity levels appear to reside mainly in deeper aquifers containing a greater amount of dissolved solids from native bedrock.

Table 11: Descriptive statistics for specific conductivity at the Residue Storage Area monitoring network

Station	Year	Mean	Median	Min	Max
Well 1 Deep	2013	135	136	116	161
	2014	150	149	129	179
	2015	233	253	151	273
	2016	278	282	264	296
Well 2 Shallow	2013	85	85	62	131
	2014	96	94	72	154
	2015	97	96	83	120
	2016	128	115	92	208
Well 2 Deep	2013	228	228	179	233
	2014	226	226	209	236
	2015	223	224	212	233
	2016	213	213	176	220
Well 3 Deep	2013	105	102	84	144
	2014	115	116	88	157
	2015	129	127	104	163
	2016	134	132	104	182
Well 4 Deep	2013	206	173	135	315
	2014	237	234	152	297
	2015	240	244	178	283
	2016	264	268	226	283

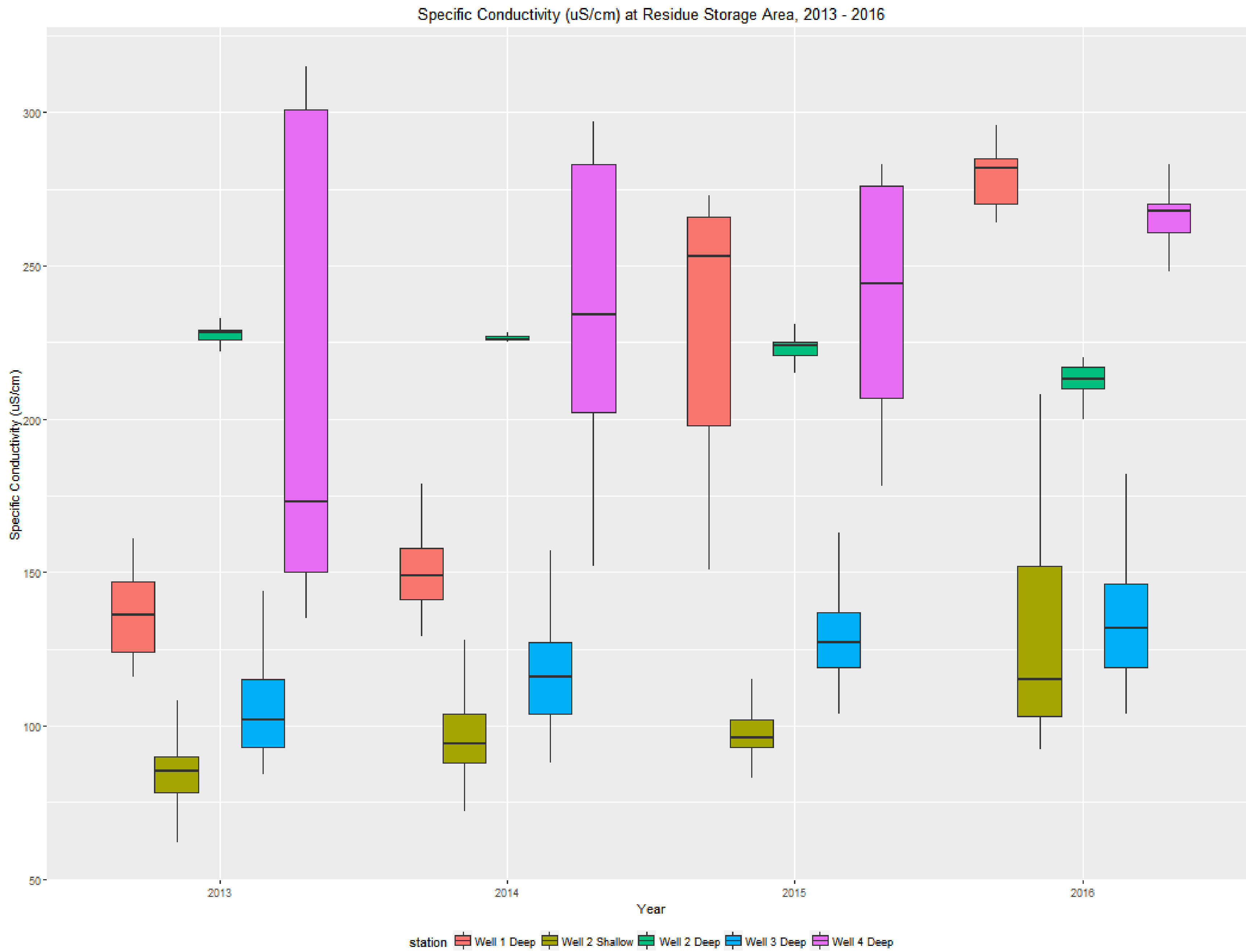

Figure 16: Boxplots of specific conductivity at the Residue Storage Area monitoring network from 2013 to 2016

Oxidation-Reduction Potential

Oxidation-reduction potential (ORP) is used to define an environment as oxidative or reductive. ORP values greater than 0 mV define oxidative environments whereas values less than 0 mV define reductive environments. Values further from 0 mV indicate a greater potential for oxidative or reductive processes.

Interpretation of ORP at the RSA monitoring network has been challenging due to the intense fluctuation over time – especially around maintenance and calibration activities. In Figure 17 , maintenance activities at Well 3 Deep are immediately obvious due to the tendency for ORP values to start as weakly oxidative before stabilizing as strongly oxidative by the end of the deployment.

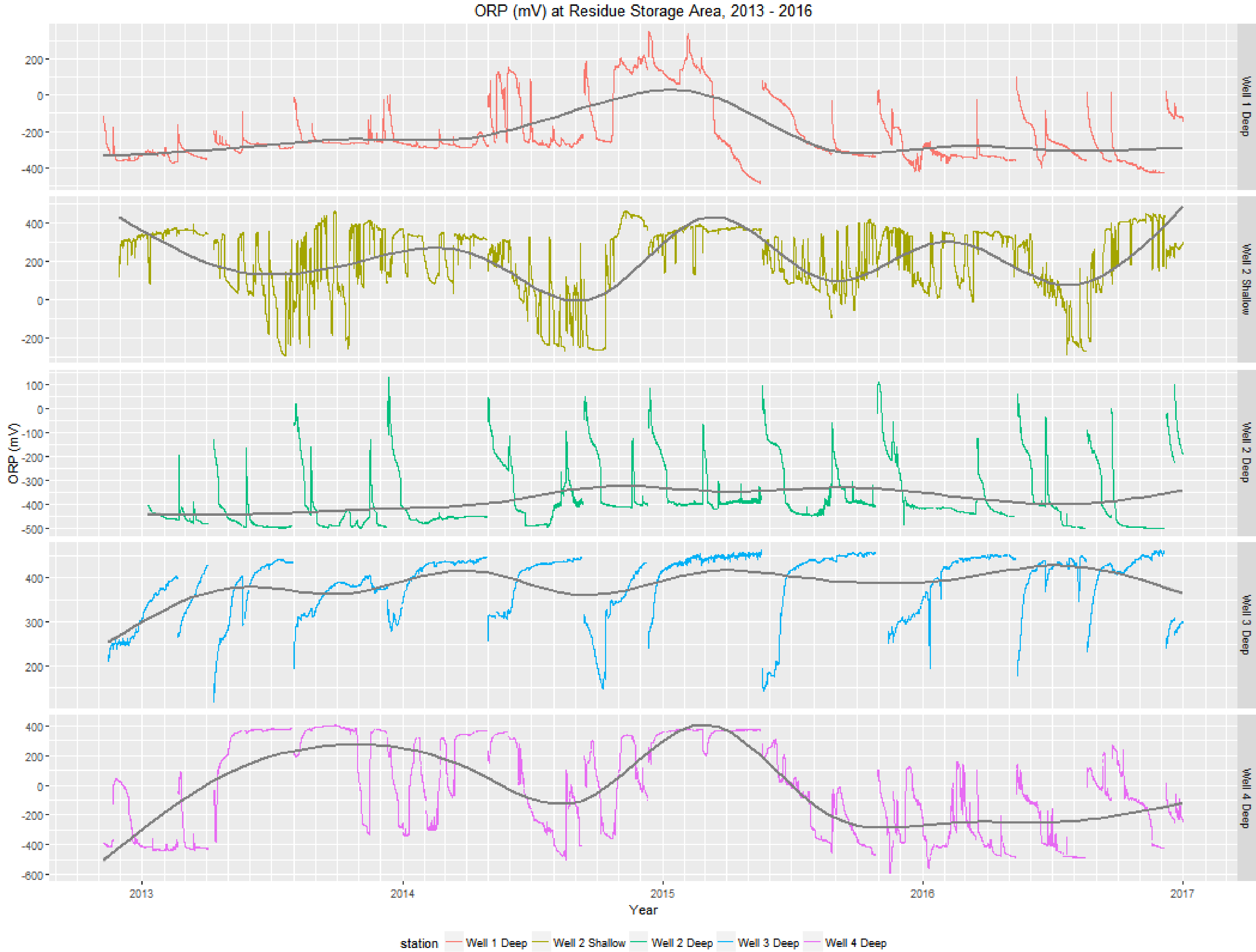

Figure 17: Oxidation-reduction Potential at Residue Storage Area from 2013 to 2016

Examination of median ORP values (shown in Figure 18 and Table 12) may give a better indication of change over time compared to line plots in Figure 17. For example, boxplots appear to show a change from oxidative to reductive conditions at Well 4 Deep whereas the same trend is difficult to discern from the line plot.

Aside from changes over time, interquartile range (IQR, or the difference between 75th and 25th percentiles) is notably smaller at Well 3 Deep and Well 2 Deep compared to other wells. It is unclear why ORP at other stations shows such disparate variability.

Table 12: Descriptive statistics for ORP at the Residue Storage Area monitoring network

Station	year	Mean	Median	Min	Max
Well 1 Deep	2013	-271.9	-266.4	-375.2	1.7
	2014	-134.6	-250.6	-291.0	347.3
	2015	-180.8	-251.0	-481.6	336.2
	2016	-299.5	-333.0	-426.9	99.8
Well 2 Shallow	2013	208.0	309.0	-293.7	461.7
	2014	155.3	223.9	-269.0	466.5
	2015	252.6	325.4	-94.9	419.2
	2016	207.3	270.9	-284.9	453.5
Well 2 Deep	2013	-428.7	-467.7	-499.5	131.9
	2014	-370.1	-411.1	-495.4	84.4
	2015	-339.7	-392.1	-486.3	114.0
	2016	-384.7	-424.8	-502.1	100.3
Well 3 Deep	2013	364.2	375.9	119.7	442.0
	2014	388.2	422.1	147.2	448.4
	2015	401.8	440.2	143.2	462.9
	2016	411.1	430.4	179.2	462.7
Well 4 Deep	2013	98.5	349.5	-439.7	404.7
	2014	44.7	64.0	-501.0	370.1
	2015	-30.4	-58.0	-597.8	378.1
	2016	-243.0	-288.0	-556.5	270.8

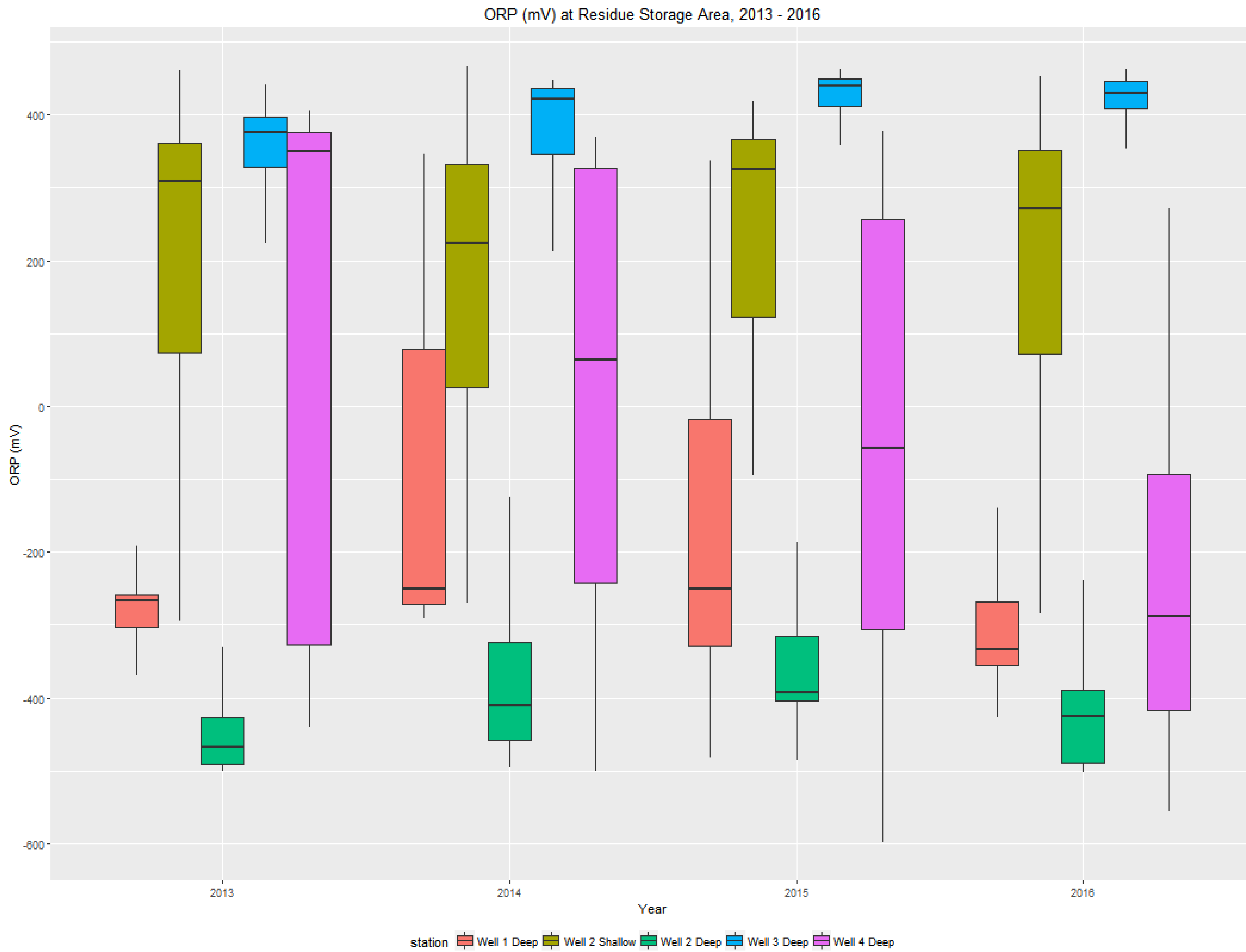

Figure 18: Boxplots of oxidation-reduction potential at the Residue Storage Area monitoring network from 2013 to 2016

Water Elevation

Figure 19 presents the surface elevation of water within each monitoring well around the RSA. Between each monitoring well, water elevation will vary according to topology of the area. Variation within each well, however, could be indicative of some event or change over time.

In June-July 2016, a downward trend in water level was observed at all monitoring wells. Following the decline, water level began to increase in early August.

A discussion with environmental staff at Vale revealed that water level is managed within the RSA to ensure sufficient freeboard along the dykes. Late in the summer and into the winter, water level is allowed to rise in order to avoid potential damage to equipment due to ice scour. Following winter, effluent is discharged from the RSA in order to inspect and repair any damage. This procedure, which began in 2016, may be the driving force behind simultaneous variation within each monitoring well.

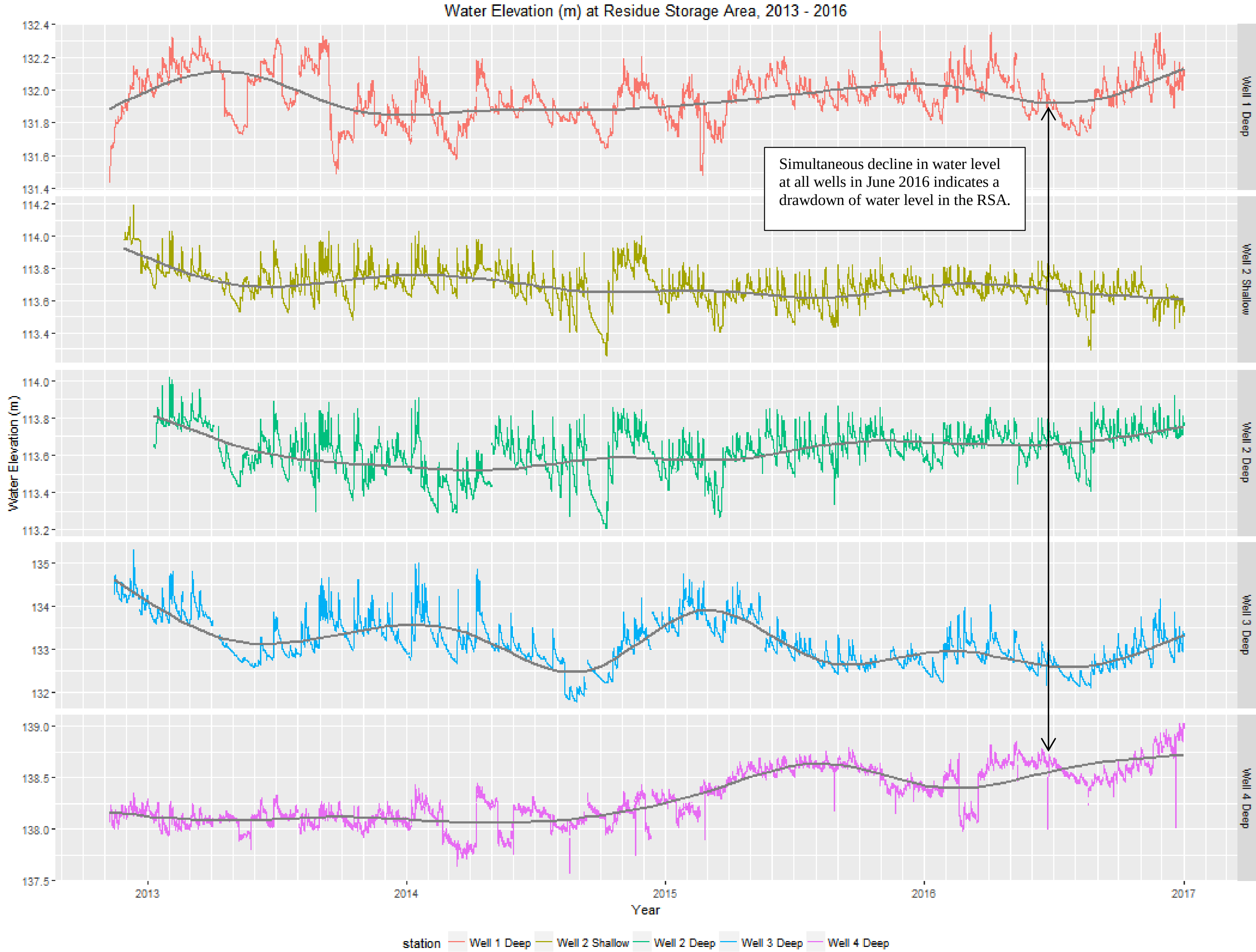

Figure 19: Water elevation at Residue Storage Area from 2013 to 2016

Boxplots in Figure 20 indicate that, within each well, on an annual basis, variability in water elevation is small. Well 3 Deep in particular shows the greatest degree of variation with a range of 3.2038 m (Table 13).

Table 13: Descriptive statistics for water elevation at the Residue Storage Area monitoring network

Station	year	Mean	Median	Min	Max
Well 1 Deep	2013	131.9967	132.0437	131.4862	132.3322
	2014	131.8821	131.8842	131.5790	132.2039
	2015	131.9620	131.9737	131.4806	132.3551
	2016	131.9903	131.9961	131.7217	132.3484
Well 2 Shallow	2013	113.7266	113.7411	113.4821	114.0309
	2014	113.7069	113.7273	113.2566	114.0288
	2015	113.6402	113.6504	113.4026	113.8651
	2016	113.6568	113.6602	113.2958	113.8466
Well 2 Deep	2013	113.6321	113.6258	113.2945	114.0186
	2014	113.5482	113.5542	113.2056	113.9122
	2015	113.6205	113.6272	113.2681	113.8631
	2016	113.6787	113.6915	113.4072	113.9247
Well 3 Deep	2013	133.4164	133.4348	132.5933	134.8164
	2014	133.0308	133.0324	131.7996	135.0034
	2015	133.2103	133.0839	132.4325	134.7668
	2016	132.8376	132.8195	132.1306	134.1729
Well 4 Deep	2013	138.0943	138.0985	137.7978	138.3314
	2014	138.1104	138.1464	137.5590	138.4492
	2015	138.5209	138.5698	137.8910	138.7961
	2016	138.5656	138.5840	137.9755	139.0317

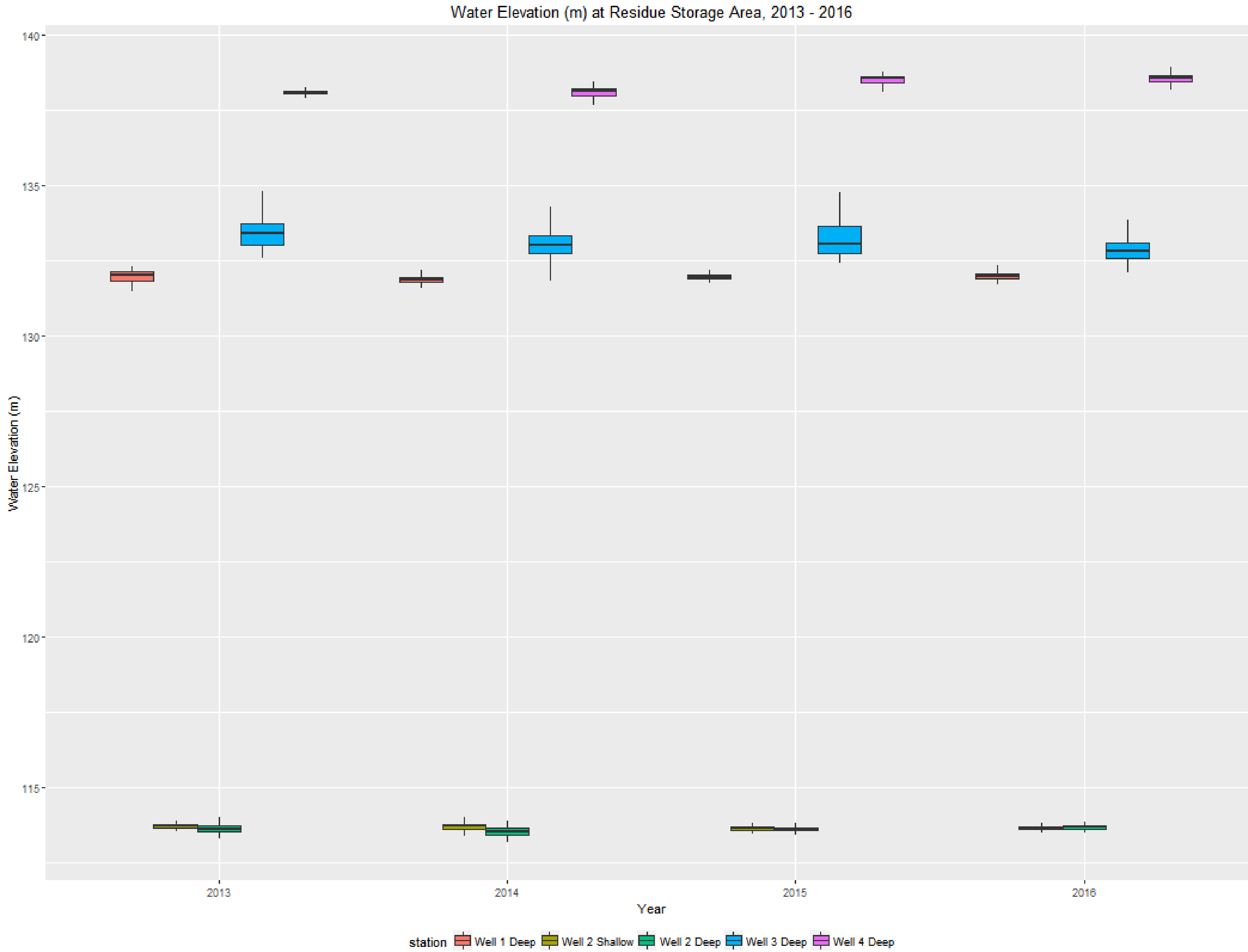

Figure 20: Boxplots of water elevation at the Residue Storage Area monitoring network from 2013 to 2016

Conclusions

- In the 2015 annual report, specific conductivity and pH within the Rattling Brook network were identified as being parameters to monitor closely. In 2016, both parameters were very close to 2015 levels – to the extent where any change would be difficult to identify. In fact, median values for both parameters declined slightly at Plant Discharge station. While no substantial upward trend was observed, likewise, there was no substantial decrease, either.
- In 2015, turbidity was stated as having stabilized at a median value of 0 NTU at all three Rattling Brook stations. In 2016, turbidity was seen to increase slightly at both stations and median turbidity values rose above 0 NTU at Plant Discharge station. This, also, will be watched closely in 2017.
- Discharge of effluent into the Residue Storage Area continued throughout 2016 (having begun in late 2014). Specific conductivity and pH at some wells (especially Well 1 Deep) may be showing some impact at this time. This will be monitored closely in 2017.

Path Forward

- Monthly calibration and reporting on surface water quality for the Rattling Brook Network will continues into 2017. Due to the nature of groundwater quality and its tendency to exhibit small changes over time, calibration will be completed quarterly and reporting will be done on an annual basis.
- ECC will continue to enhance features of the Automatic Data Retrieval System as needed to incorporate new functionality.
- Examination of the TSS-Turbidity model used in the automated turbidity alert system will take place on an annual basis.
- Continued communication and open dialogue will be maintained between Vale and ECC staff going forward, as it has in the past.

Appendix

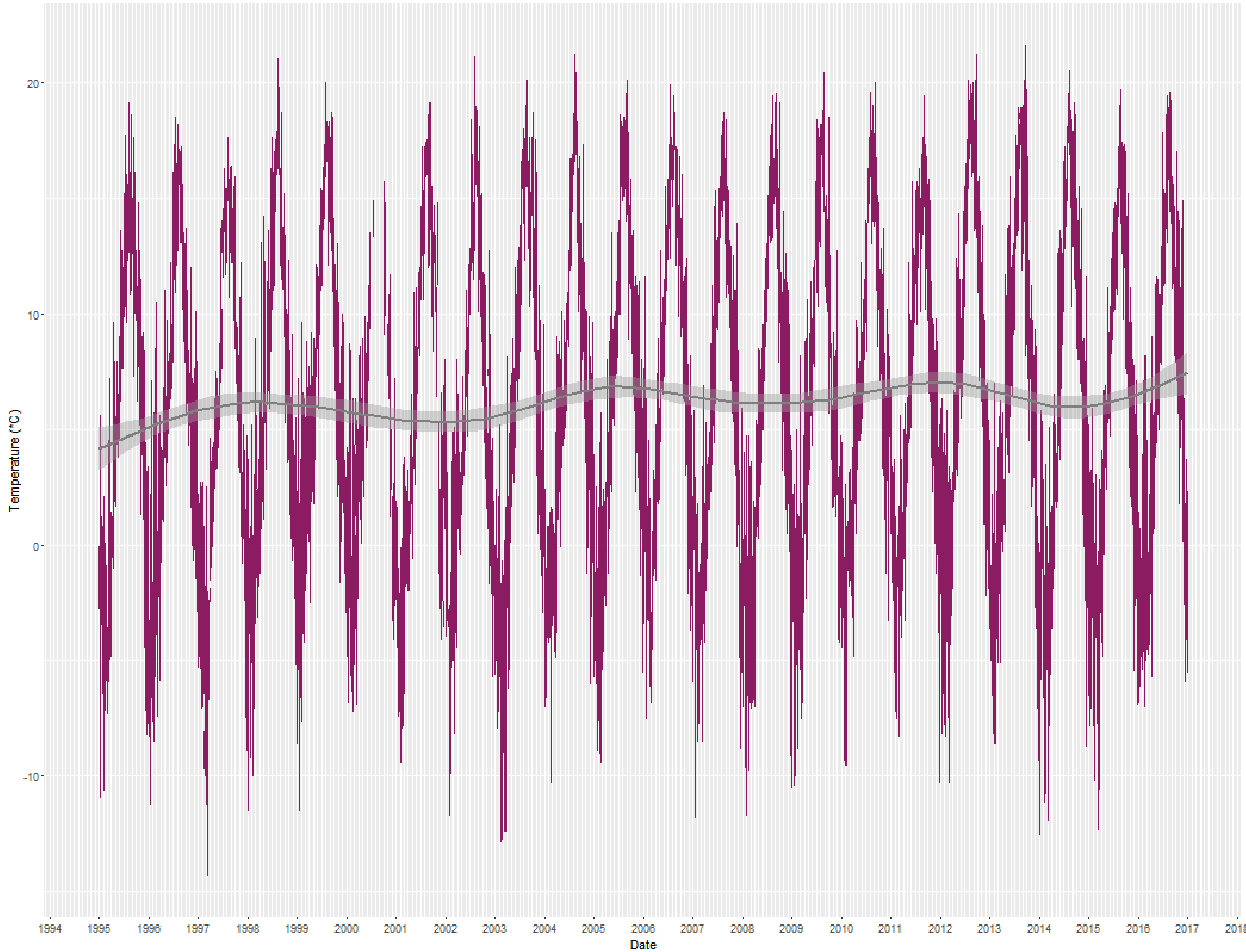

Figure 21: Temperature at Argentia weather station from 1995 to 2016

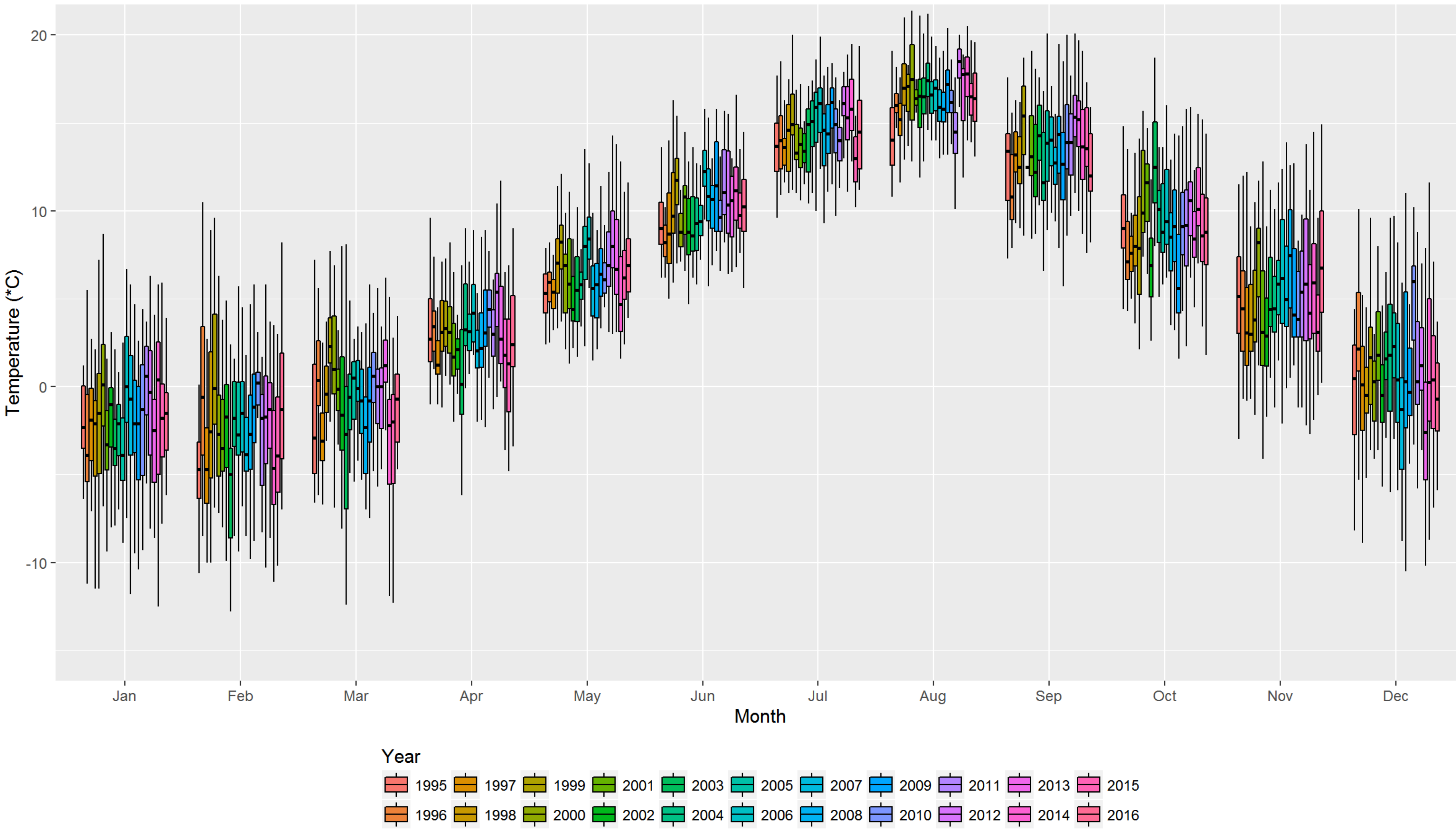

Figure 22: Monthly temperature at Argentia weather station from 1995 to 2016

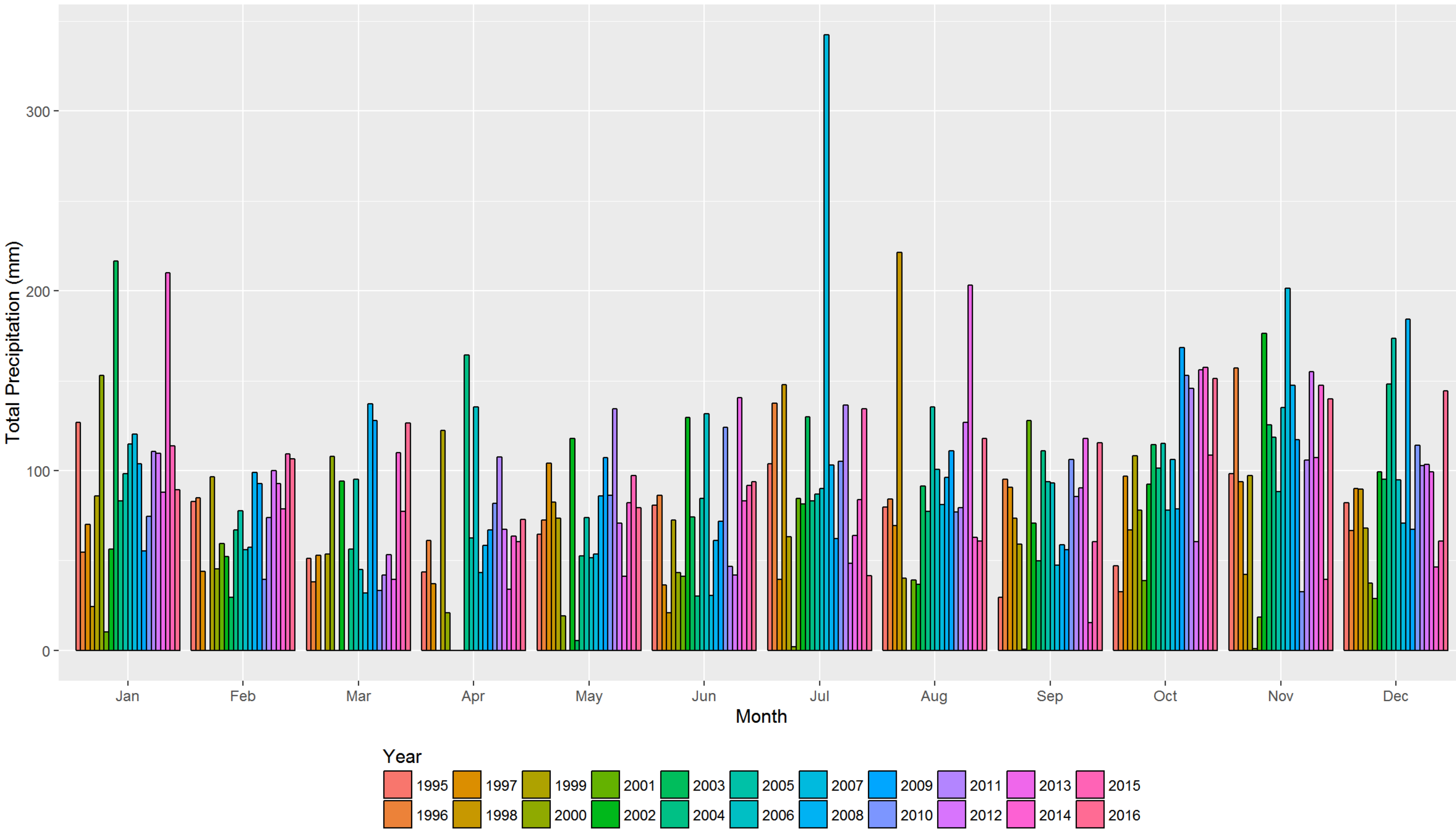

Figure 23: Total Precipitation at Argentia weather station from 1995 to 2016