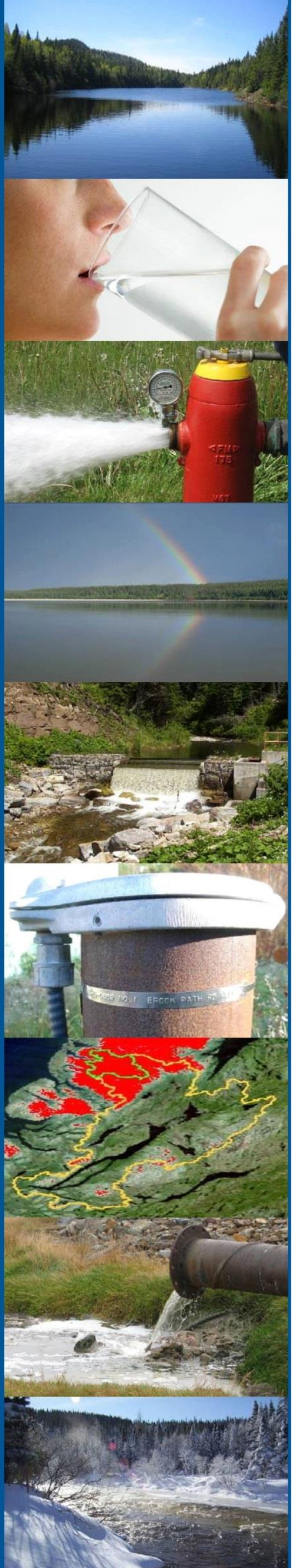

Real-Time Water Quality Deployment Report

Rattling Brook and Sandy Pond (Residue Storage Area) Real-Time Water Quality Networks

Annual Report 2014

Government of Newfoundland and Labrador
Department of Environment and Conservation
Water Resources Management Division
St. John’s, NL, Canada

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Introduction

Background

Prior to the initial construction of Vale's nickel processing plant in Long Harbour, Newfoundland and Labrador the Department of Environment and Conservation has been involved in long-term real-time water quality monitoring of Rattling Brook – a moderately sized river traversing the construction site.

Photo 1: Rattling Brook Real-Time Water Quality Monitoring Network

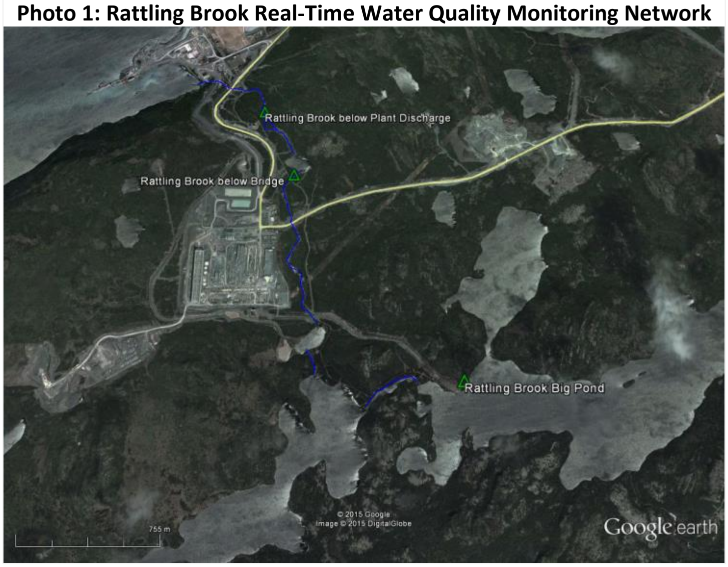
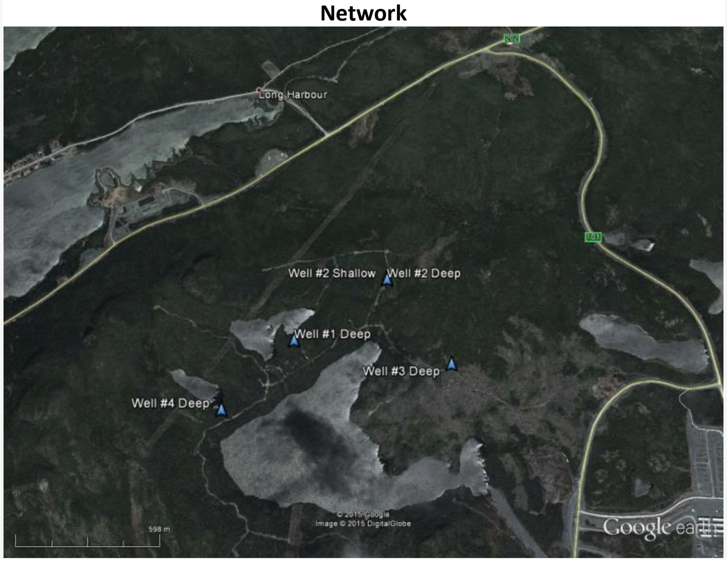


Photo 2: Residue Storage Area Real-Time Water Quality Monitoring Network



The original station, Rattling Brook below Bridge, was deployed in late 2006 with an additional two stations deployed in 2009 – Rattling Brook Big Pond and Rattling Brook below Plant Discharge. These stations are illustrated in Photo 1.

In 2012, five real-time groundwater monitoring stations were deployed around Sandy Pond (Residue Storage Area) to observe for potential residue leakage into local aquifers. The stations, outlined in Photo 2, are strategically located to intercept the predominant groundwater flow in the area (note that Well 2 Shallow and Well 2 Deep are collocated, but bound within the shallow and deep aquifers, respectively).

All monitoring stations record hourly data and report in near-real time to rolling thirty day graphs on the Water Resources Management Website[1]. Surface water stations report temperature, pH, specific conductivity, dissolved oxygen (concentration and saturation), total dissolved solids, and turbidity. Groundwater stations report temperature, pH, specific conductivity, oxidation-reduction potential, and water level elevation.

[1] http://www.env.gov.nl.ca/wrmd/ADRS/v6/Graphs_List.asp

Maintenance and Calibration

Deployment periods and maintenance intervals balance the frequency of travel to remote field locations and data quality objectives. Generally this places a 30 day limit on surface water deployment periods and 3 or 4 month limits on groundwater deployment periods; this avoids excessive drift and fouling of water quality instrumentation.

Table 1: Deployment Statistics for Rattling Brook and Residue Storage Area Stations

Station	Number of Days Deployed	Percent of Year Deployed
Rattling Brook Monitoring Network		
Big Pond	228	62.5
Below Bridge	353	96.7
Below Plant Discharge	341	93.4
Residue Storage Area Network		
Well 1 Deep	358	98.2
Well 2 Shallow	360	98.8
Well 2 Deep	361	98.9
Well 3 Deep	358	98.3
Well 4 Deep	356	97.5

Results and Discussion

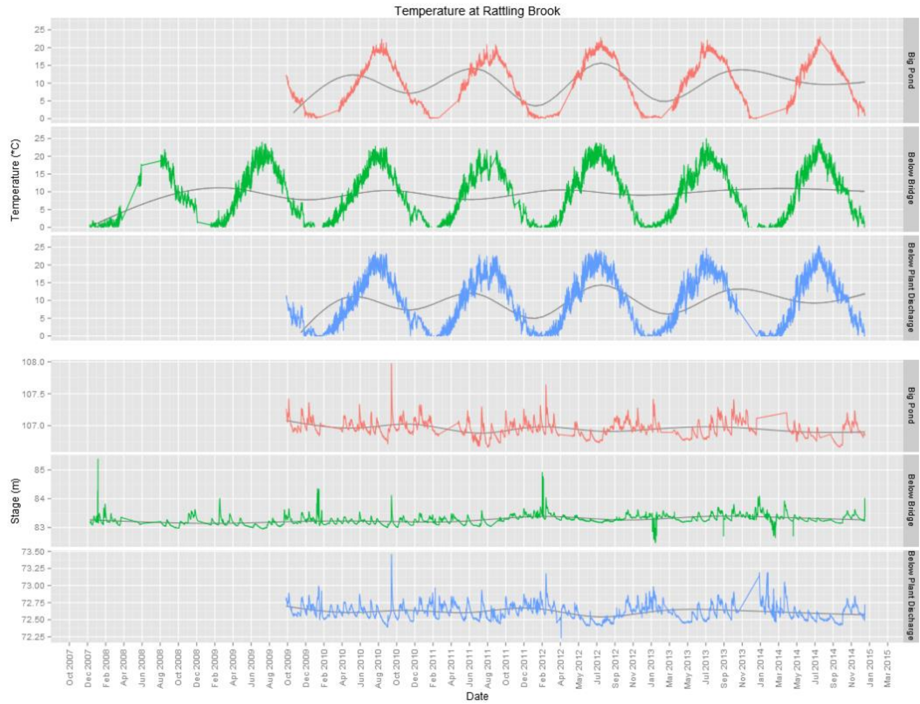
The following graphs and figures illustrate trends in water quality parameters since deployment. Boxplots for each station and parameter, however, are calculated based on concurrent timeframes within the respective surface water and groundwater networks.

Stage and flow data used throughout this report is preliminary and has not been through Water Survey of Canada's QAQC process. It is presented strictly as a means to explain variation in water quality variables. Stage and Flow data vetted by Water Survey of Canada can be retrieved via their website at http://www.ec.gc.ca/rhc-wsc/

Rattling Brook Network

Temperature

Figure 1: Temperature at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2007 to 2014



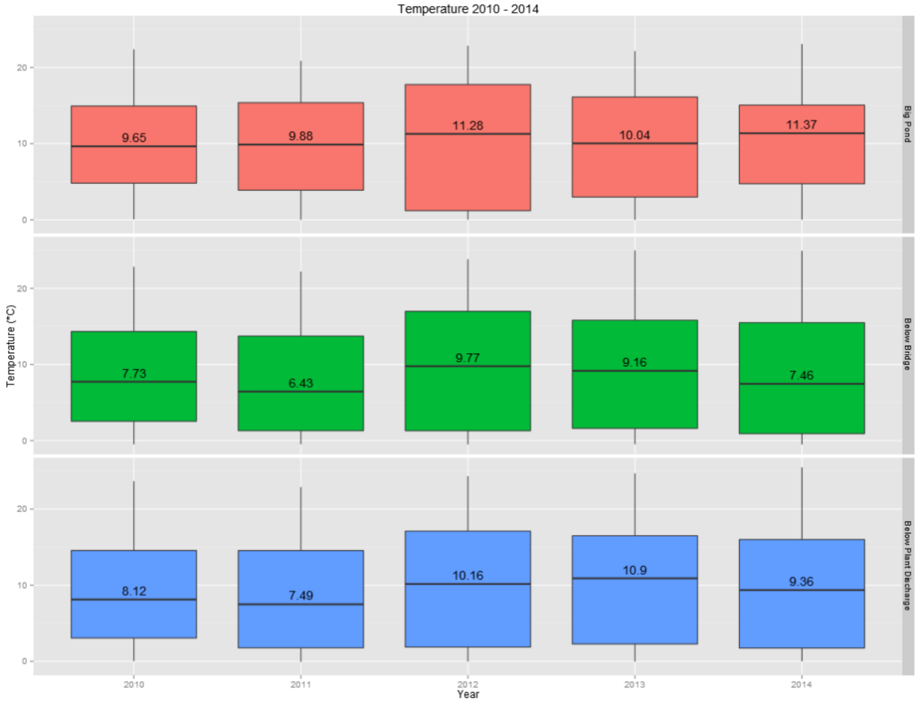
Water Temperature is a major factor used to describe water quality. Temperature has major implications on both the ecology and chemistry of a water body, governing processes such as the metabolic rate of aquatic plants and animals and the degree of dissolved oxygen saturation.

2014 was not the warmest or coldest year on record at Long Harbour since monitoring began (Figure 1). System wide, water temperatures ranged from 25.48^{o}C at Below Plant Discharge station to a low of -0.50^{o}C at Below Bridge station (Table 2). While this was the highest recorded temperature at any of the stations on Rattling Brook since monitoring began, it was not indicative of a particularly warm year since mean and median temperatures fell within the range of previous years.

Table 2: Summary Statistics of Temperature for Big Pond, Below Bridge, and Below Plant Discharge stations from 2008 to 2014

Station	Year	Mean	Median	Min	Max
Big Pond	2010	10.08	9.65	0.04	22.4
	2011	9.58	9.88	-0.02	20.88
	2012	10	11.28	0	22.87
	2013	9.67	10.04	-0.02	22.17
	2014	10.58	11.37	0.01	23.1
Below Bridge	2008	6.73	6.2	-0.42	21.93
	2009	9.14	8.03	-0.5	23.97
	2010	8.65	7.73	-0.5	22.84
	2011	7.7	6.43	-0.48	22.2
	2012	9.52	9.77	-0.51	23.82
	2013	9.03	9.16	-0.49	24.98
	2014	8.65	7.46	-0.5	24.93
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	10.9	-0.03	24.7
	2014	9.27	9.36	0	25.4

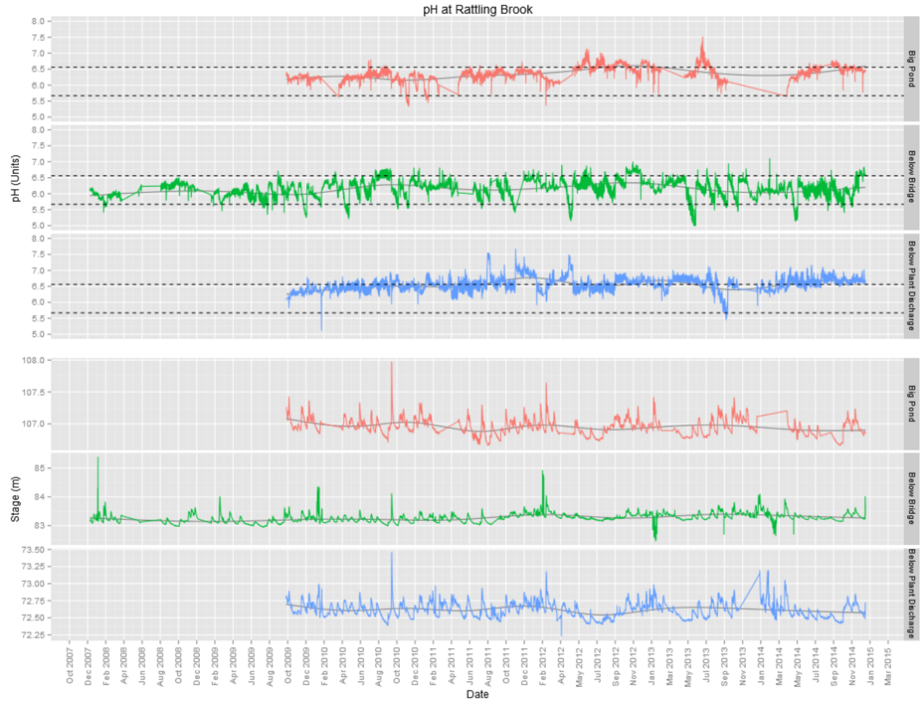
Figure 2: Boxplots of Temperature at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2010 to 2014



No trend in water temperatures is observed at any station from 2010 to 2014 (Figure 2). Big Pond station continues to exhibit higher median temperatures than both stations downstream but this effect is considered to be due to a combination of the heat sink effect of a large, still water body capable of retaining heat better than flowing water and also sampling bias. Since instrumentation is often removed from Big Pond station during frozen conditions, the lowest expected annual water temperatures are omitted from the sampling, artificially inflating mean and median water temperatures.

pH

Figure 3: pH at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2007 to 2014



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 range of extreme pH values is similar in 2014 to 2013 (**Error! Not a valid bookmark self-reference.**); however, for all three stations 2014 median values are similar to those observed in 2013.

Table 3: Summary Statistics of pH for Big Pond, Below Bridge, and Below Plant Discharge stations from 2008 to 2014

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	6.46	6.46	5.72	7.51
	2014	6.43	6.46	5.65	6.78
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
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	5.89	7.17

A slightly upward trend is observed from 2010 to 2014 at Big Pond and Plant Discharge stations, but this is not apparent at Bridge station (Figure 3). The upward trend at Big Pond and Plant Discharge station is slight and variable year over year. This will be observed into the future.

Figure 4: Boxplots of pH at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2010 to 2014

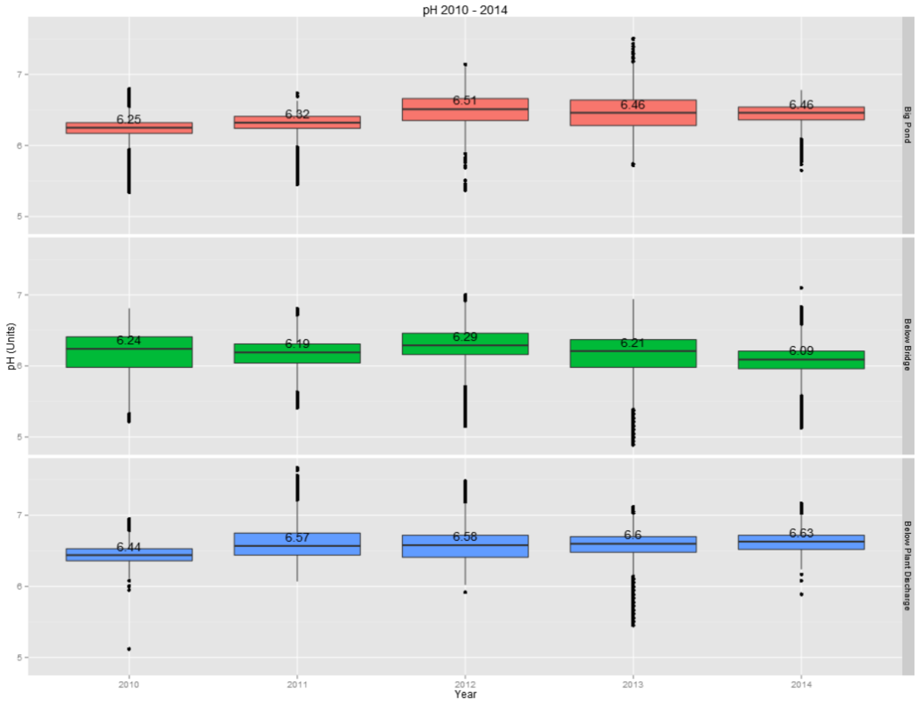
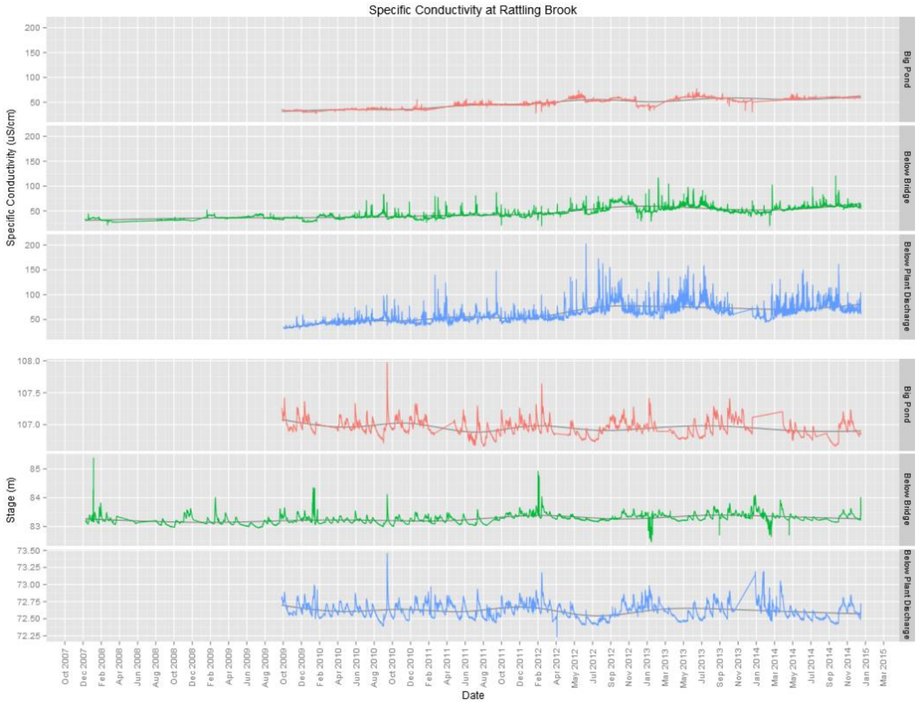


Figure 4 indicates that pH variability was lower in 2014 at all stations compared to 2012 and 2013. This is shown by the size of the box for each station and year: smaller boxes show that data tends to center closer to the median (the horizontal line crossing each box) while larger boxes indicate that data is spread farther from the median. This reduction in variability in 2014 may be due to weather or improving water quality conditions.

Specific Conductivity

Figure 5: Specific Conductivity at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2007 to 2014



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.

Specific conductivity has been steadily on the rise at Big Pond and Bridge stations since the initiation of monitoring, as shown in Figure 5. This is likely the result of inflow and airborne deposition of dust into the Rattling Brook system. This effect was expected, given the scope of the Long Harbour Production Plant project. As the ground stabilizes and construction winds down, the trend in specific conductivity should level off and possibly decline.

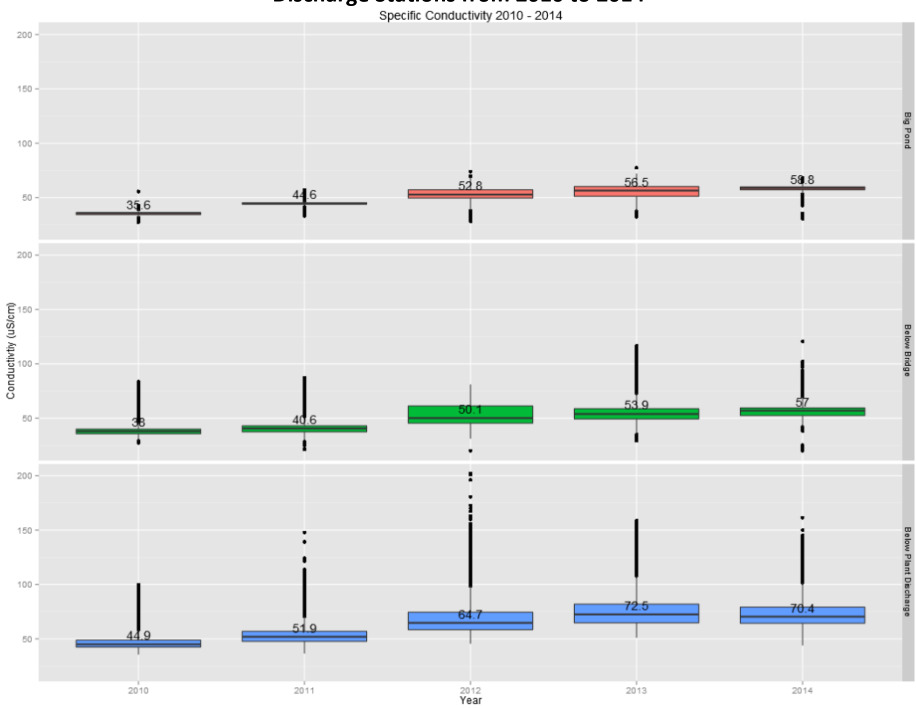
A promising indication of a potential decrease is the reduction in mean and median conductivity values in 2014 at Plant Discharge station shown in Table 4. Additionally, a decrease in conductivity at Plant Discharge can be seen in the latter parts of Figure 5. This will be monitored going forward.

Table 4: Summary Statistics of Specific Conductivity for Big Pond, Below Bridge, and Below Plant Discharge stations from 2008 to 2014

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	53.0	52.8	28.2	73.8
	2013	54.8	56.5	32.5	77.4
	2014	58.4	58.8	30.6	68.1
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
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

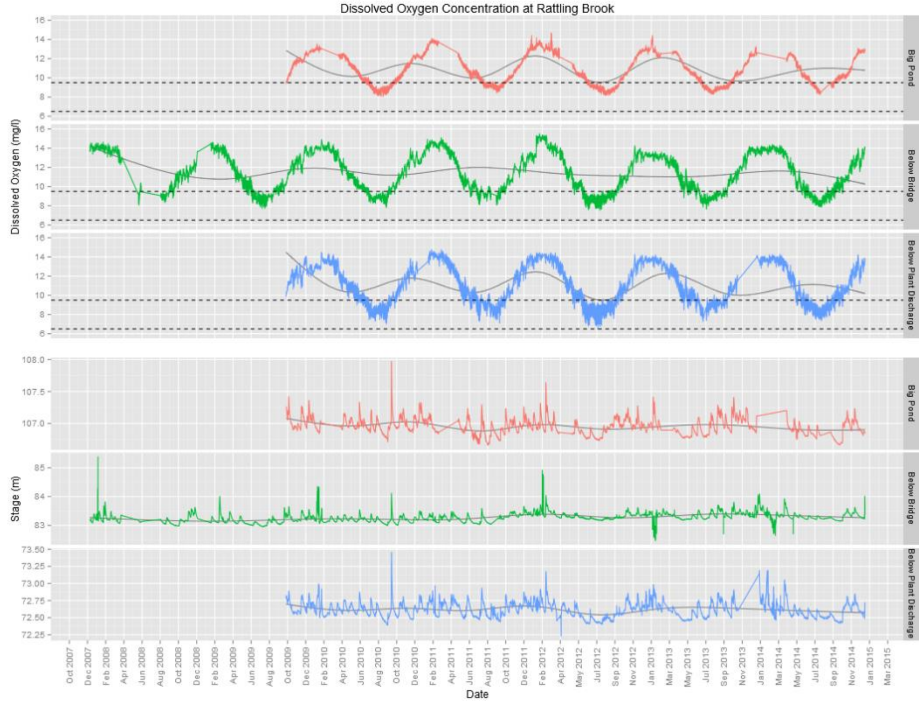
A slight decrease in conductivity variation was seen at Big Pond and Bridge stations despite an overall increase in conductivity there (Figure 6). Specific Conductivity remained variable at Plant Discharge station, but the magnitude appears to have decreased. This could be related to cleaner water entering and/or leaving the settling pond which discharges upstream of Plant Discharge station.

Figure 6: Boxplots of Specific Conductivity at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2010 to 2014



Dissolved Oxygen

Figure 7: Dissolved Oxygen at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2007 to 2014



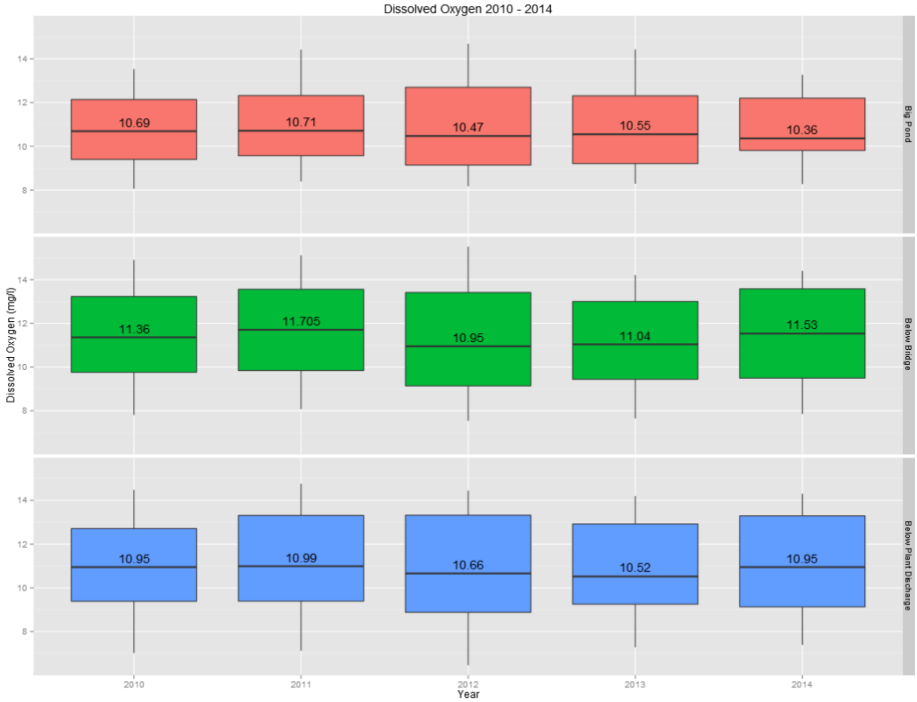
Dissolved oxygen is a metabolic requirement of aquatic plants and animals. The concentration of oxygen in water depends on many factors, especially temperature – the saturation of oxygen in water is inversely proportional to water temperature. Oxygen concentrations also tend to be higher in flowing water 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 concentrations in Figure 7 and Figure 8 show no defined trend from 2010 to 2014 at any Rattling Brook station. In 2014, concentrations were found to be somewhat higher than those in 2013 (Table 5), mostly due to cooler water temperatures (water temperature and dissolved oxygen have a strong negative correlation. Tau = -0.88, p < 2.2e-16).

Table 5: Summary Statistics of Dissolved Oxygen Concentration for Big Pond, Below Bridge, and Below Plant Discharge stations from 2008 to 2014

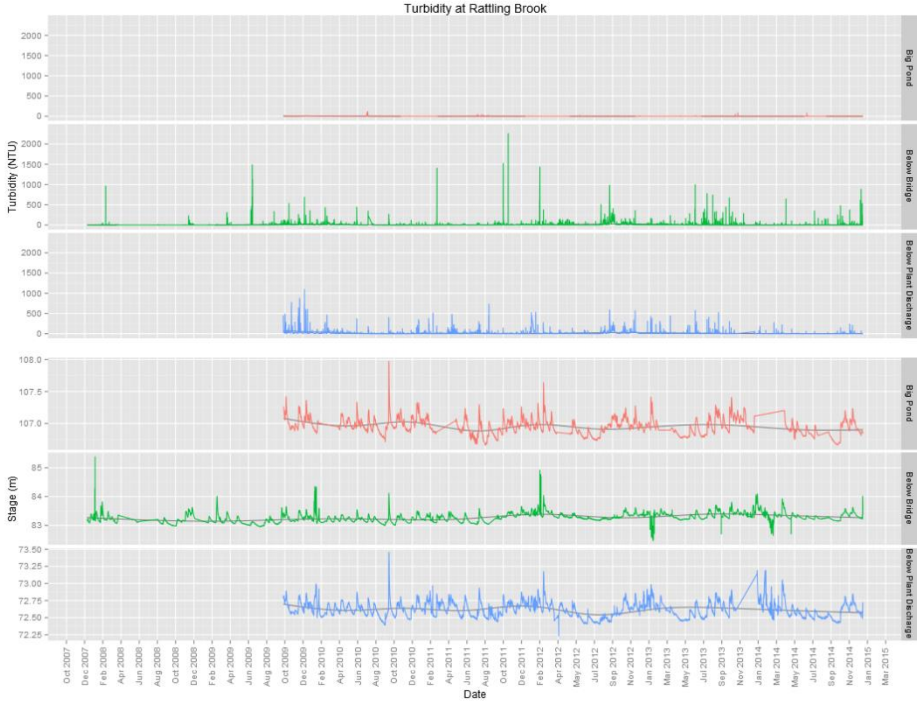
Station	Year	Mean	Median	Min	Max
Big Pond	2010	10.68	10.69	8.06	13.53
	2011	10.99	10.71	8.39	14.42
	2012	10.86	10.47	8.17	14.69
	2013	10.74	10.55	8.29	14.43
	2014	10.80	10.36	8.27	13.27
Below Bridge	2008	12.04	12.13	8.06	14.63
	2009	11.30	11.26	7.72	14.61
	2010	11.43	11.36	7.81	14.90
	2011	11.74	11.71	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
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

Figure 8: Boxplots of Dissolved Oxygen Concentration at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2010 to 2014



Turbidity

Figure 9: Turbidity at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2007 to 2014



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 water body, discouraging plant growth. High turbidity can also damage the delicate respiratory organs of aquatic animals and cover spawning areas.

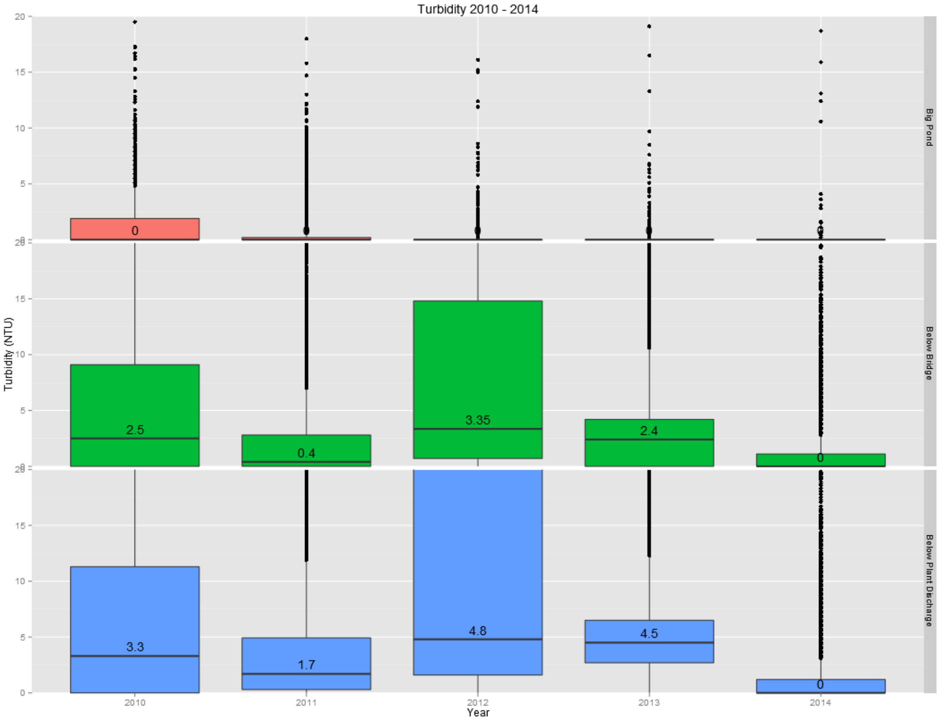
During initial major construction at the Vale plant Site in 2010, turbidity showed high variability and above-background levels at Bridge and Plant Discharge stations. These levels reached their highest point in 2012 and began to decline into 2013 (Figure 9). For the first time since construction began, median turbidity levels were 0 NTU for all three stations in 2014, marking an important milestone (Table 6).

Table 6: Summary Statistics of Turbidity for Big Pond, Below Bridge, and Below Plant Discharge stations from 2008 to 2014

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
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	2.5	0.0	0.0	886.0
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

Turbidity values at Bridge and Plant Discharge stations have greatly reduced variability and magnitude in 2014 compared to 2012 and 2013. Further declines could be seen in coming years depending on ground rehabilitation strategy and construction completion.

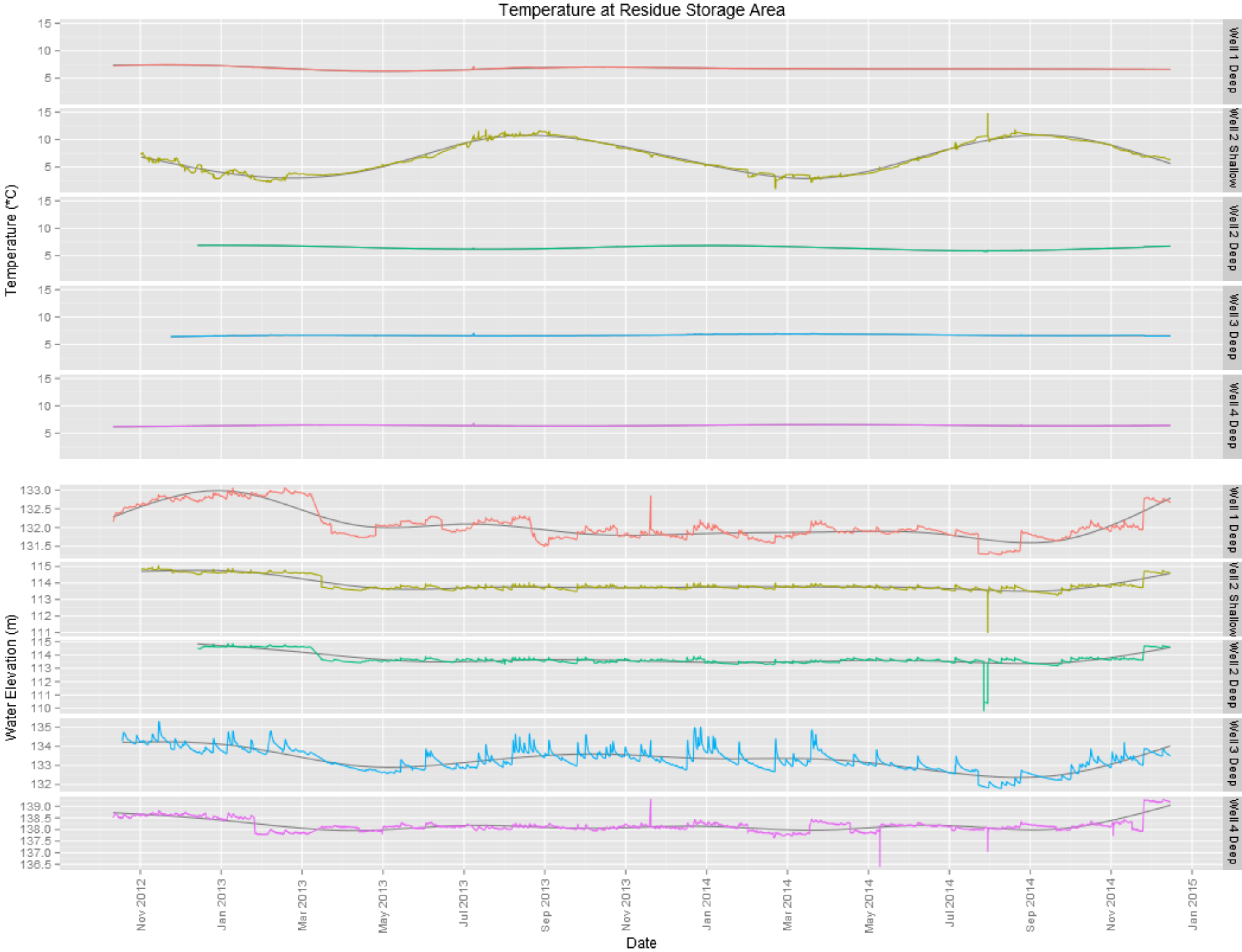
Figure 10: Boxplots of Turbidity at Big Pond, Below Bridge, and Below Plant Discharge Stations from 2010 to 2014



Sandy Pond (Residue Storage Area) Network

Temperature

Figure 11: Temperature at Residue Storage Area Stations from 2012 to 2014



In deep aquifers, water temperature is normally very stable due to the insulating effect of the surrounding bedrock (Figure 11). Long-term cyclical variation is typically small and is generally associated with seasonal recharge from melting snow. Short-term fluctuations often hint at a connection to shallow aquifers or the influence of surface water.

Water temperatures are very consistent at all wells except Well 2 Shallow. The observed range varied within as little as 0.59°C at Well 3 Deep in two years. Well 2 Shallow, however, shows a great degree of variability and seasonal cycling due to the surface aquifer supplying the well. Here, water temperature varied by 13.73°C over two years (Table 7). In all of the wells monitored, water temperatures appear to reach their maximum by September.

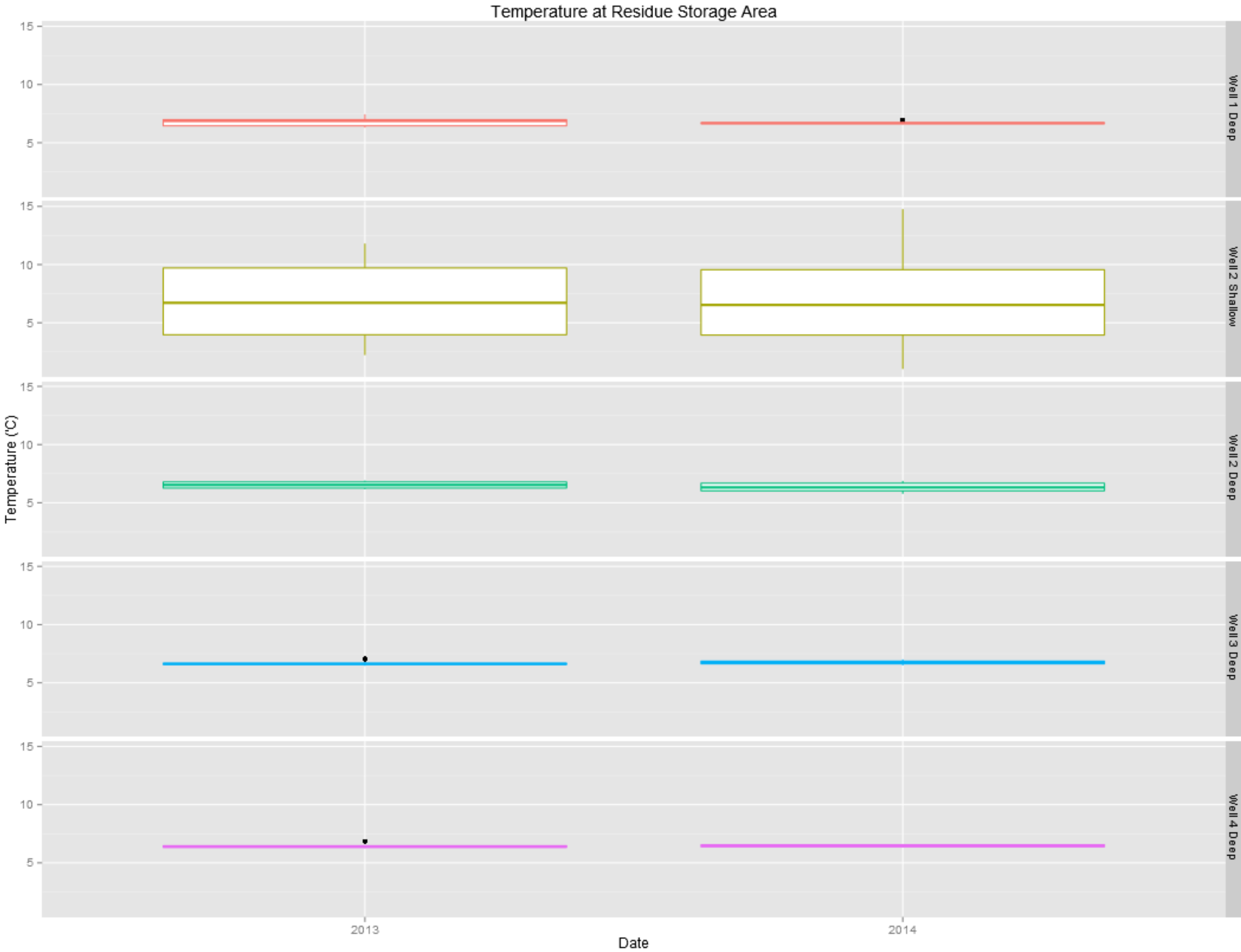
Table 7: Summary Statistics of Temperature for Residue Storage Area stations from 2013 to 2014

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
Well 2 Deep	2013	6.53	6.53	6.17	6.91

Station	Year	Mean	Median	Min	Max
	2014	6.35	6.32	5.77	6.88
Well 2 Shallow	2013	6.83	6.71	2.22	11.81
	2014	6.77	6.53	1.03	14.76
Well 3 Deep	2013	6.62	6.63	6.46	7.05
	2014	6.75	6.76	6.50	7.01
Well 4 Deep	2013	6.40	6.39	6.25	6.85
	2014	6.46	6.46	6.32	6.61

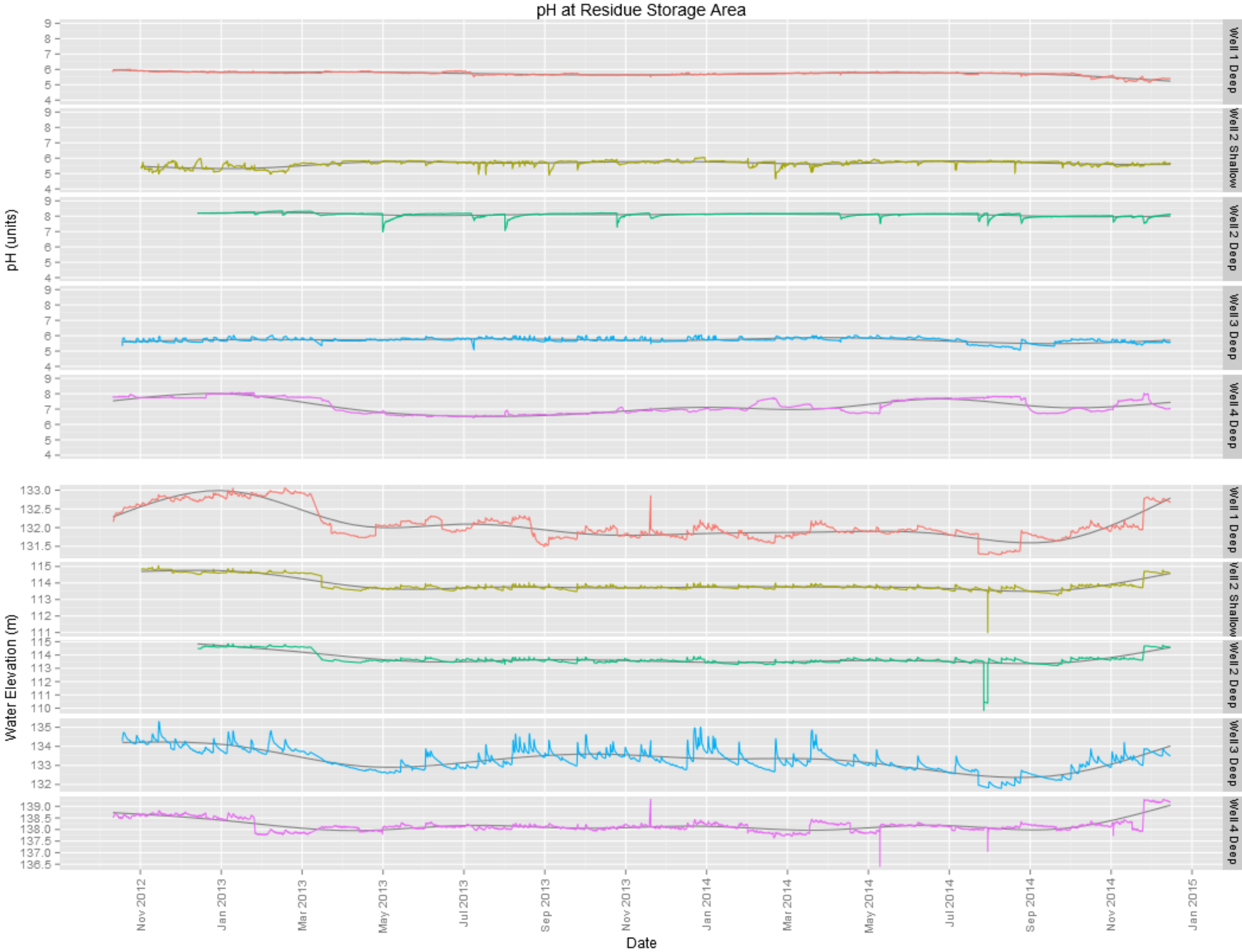
Water temperatures at each station are very stable and median temperatures fell within 0.27^{o}C of each other. As shown in Figure 12, water temperatures at Well 2 Shallow, however, were very broad indicating interaction with water under the influence of surface conditions.

Figure 12: Boxplots of Temperature at Residue Storage Area Stations from 2013 to 2014



pH

Figure 13: pH at Residue Storage Area Stations from 2012 to 2014



pH is a logarithmic scale referring to the concentration of H+ ions in solution, where low pH represents a high concentration of H+ ions (acid) while high pH represents a low concentration of H+ ions (base). Acidic and basic conditions have wide ranging effects on such things as metal solubility and microbiological growth.

Figure 13 presents very little variation in pH at Well 1 Deep, Well 2 Shallow, Well 2 Deep, and Well 3 Deep. Well 4 Deep, however, showed a greater degree of variability compared to other wells. It is unclear at this time why such variation is present here since water temperatures don't necessarily indicate surface water interaction. A potential source could be a particularly high hydraulic conductivity in the area (groundwater flow).

Well 2 Deep tends to be a great deal more alkaline than other wells; potentially due to local geological conditions.

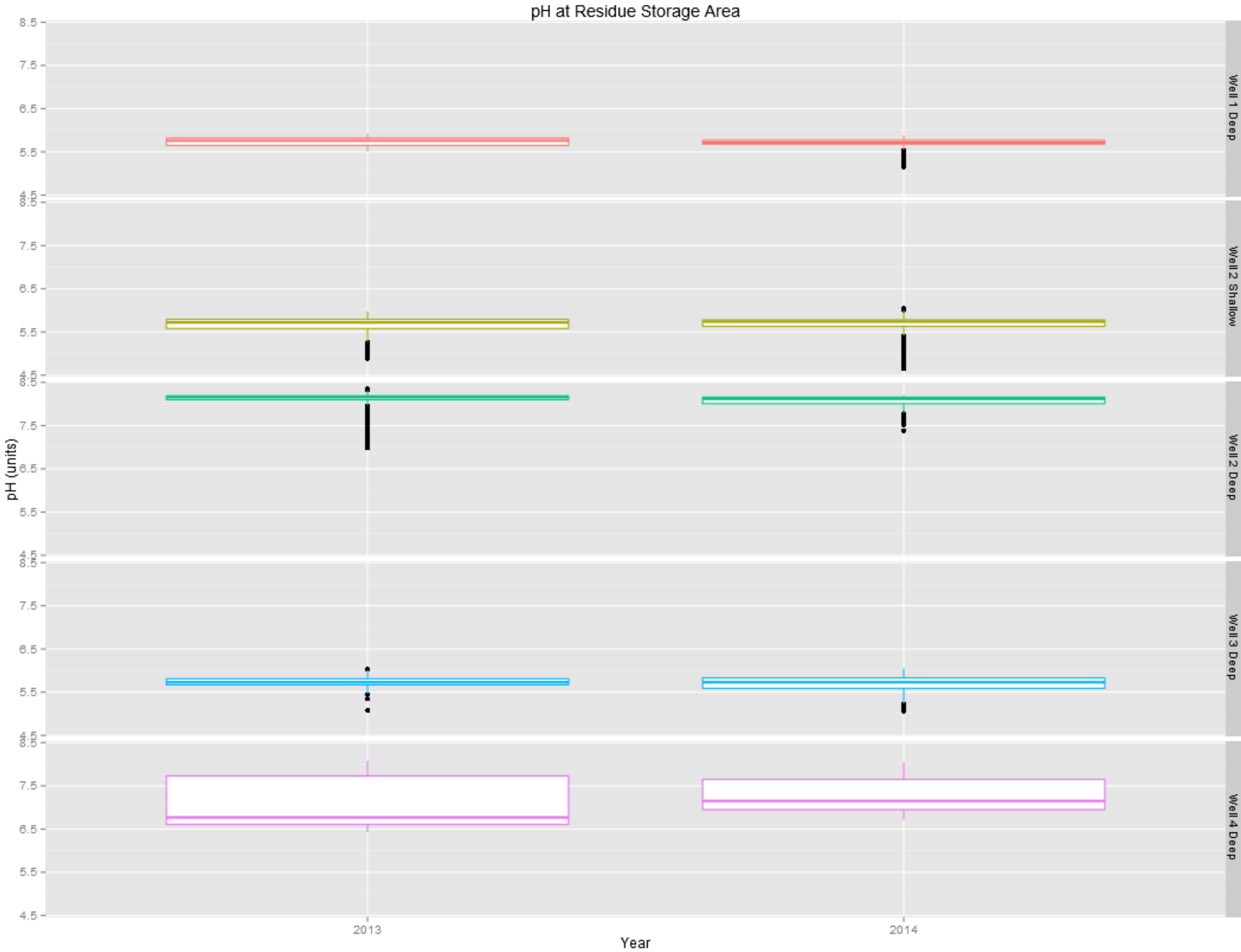
Table 8: Summary Statistics of pH for Residue Storage Area stations from 2013 to 2014

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
Well 2 Deep	2013	8.13	8.16	6.98	8.35
	2014	8.08	8.12	7.38	8.20
Well 2 Shallow	2013	5.64	5.72	4.89	5.98

Station	Year	Mean	Median	Min	Max
	2014	5.70	5.74	4.65	6.05
Well 3 Deep	2013	5.75	5.73	5.08	6.03
	2014	5.69	5.73	5.06	6.05
Well 4 Deep	2013	7.03	6.77	6.43	8.08
	2014	7.25	7.15	6.71	8.04

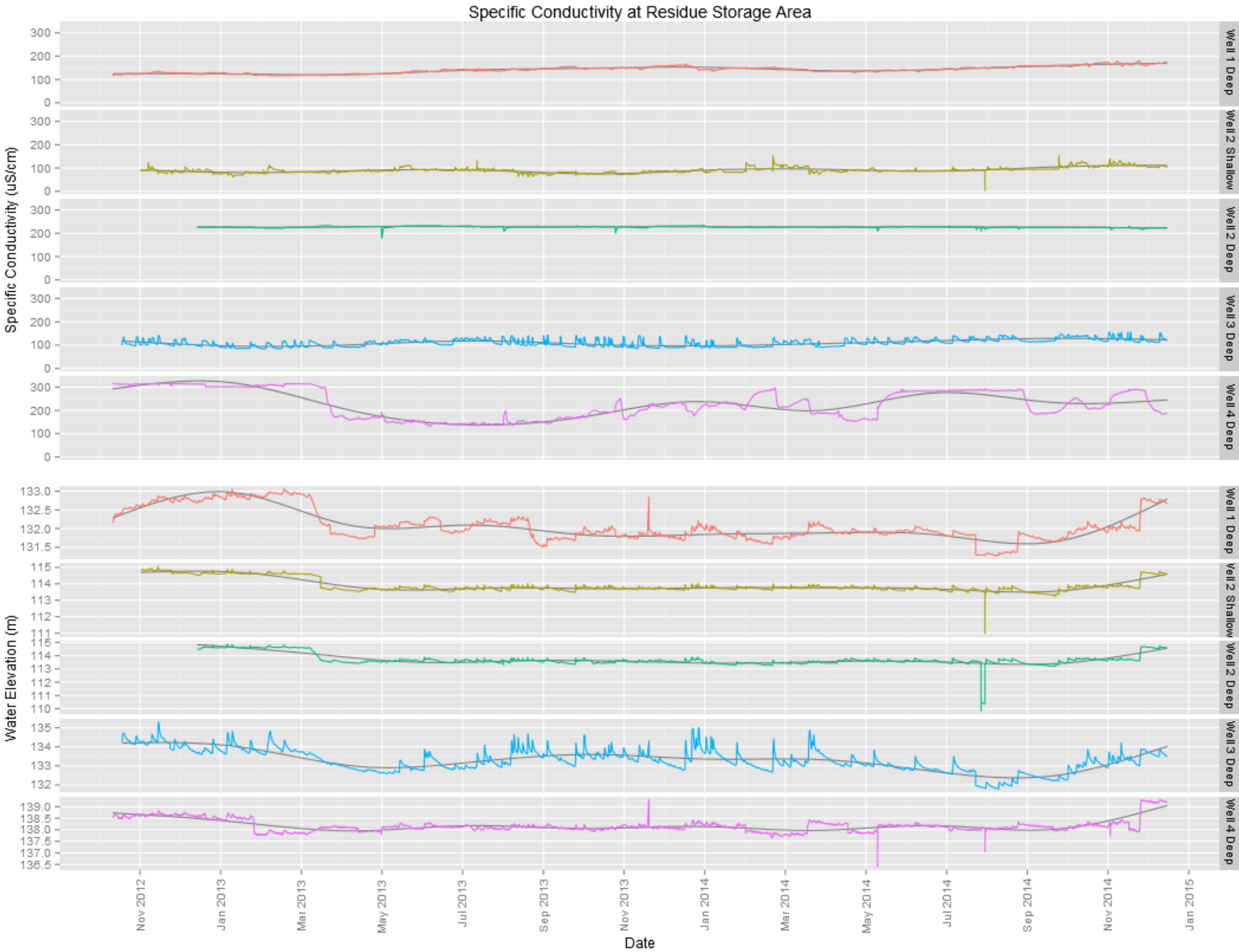
Most of the wells showed narrow ranges of pH except for Well 4 Deep (Table 8) which shows a typically neutral pH interspersed with occasional basic pH conditions. This is also seen in Figure 14 with a relatively wide-set median-third quartile range.

Figure 14: Boxplots of pH at Residue Storage Area Stations from 2013 to 2014



Specific Conductivity

Figure 15: Specific Conductivity at Residue Storage Area Stations from 2012 to 2014



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.

Specific conductivity in each monitoring well is generally fairly stable with the exception of Well 4 Deep which shares a similar conductivity and pH trace (Figure 15). The mechanism of this variability has not been determined, but it could be the result of particularly high hydraulic conductivity in the area due to bedrock fracturing.

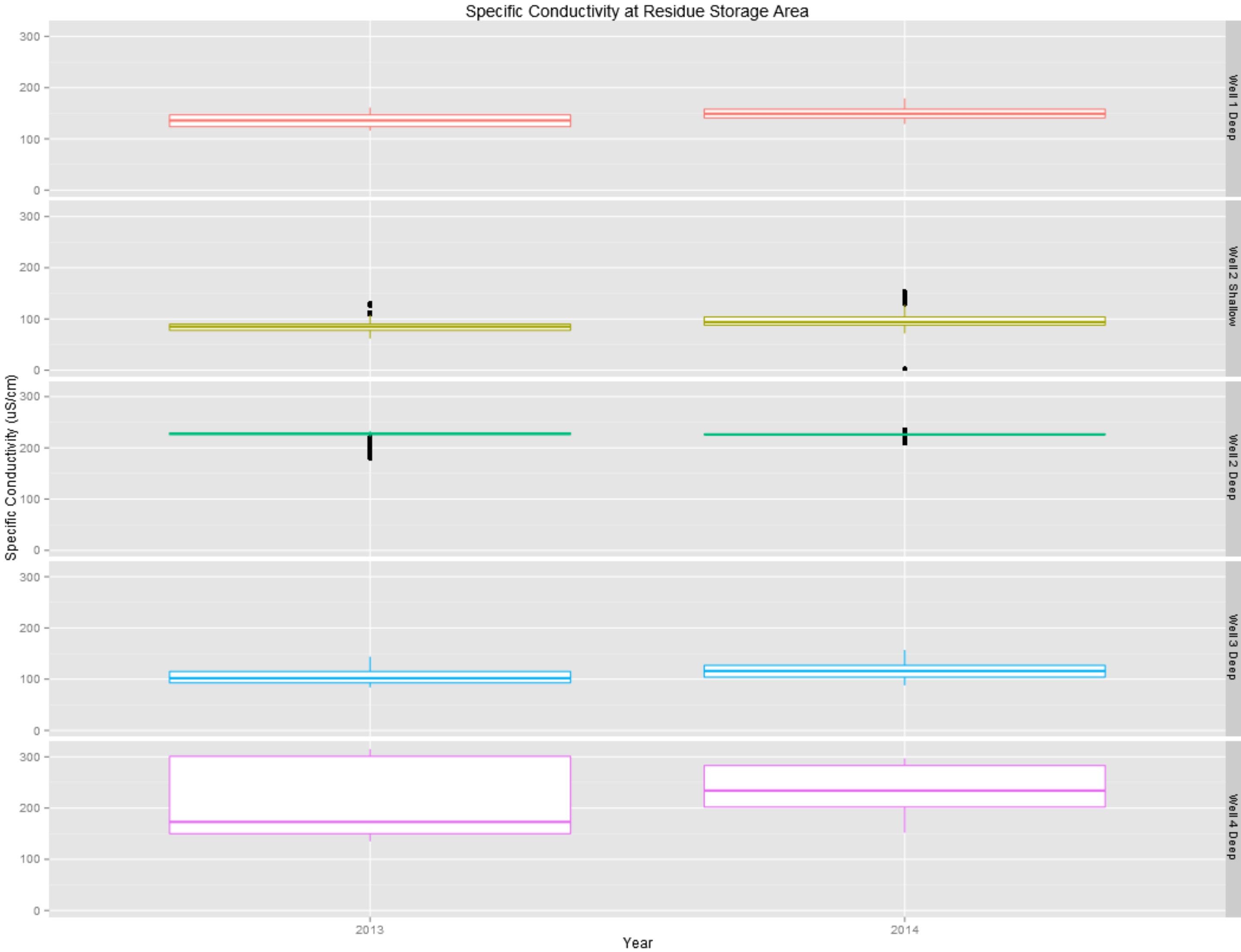
Table 9: Summary Statistics of Specific Conductivity for Residue Storage Area stations from 2013 to 2014

Station	Year	Mean	Median	Min	Max
Well 1 Deep	2013	135	136	116	161
	2014	150	149	129	179
Well 2 Deep	2013	228	228	179	233
	2014	226	226	209	236
Well 2 Shallow	2013	85	85	62	131
	2014	96	94	3	154
Well 3 Deep	2013	105	102	84	144

Station	Year	Mean	Median	Min	Max
	2014	115	116	88	157
Well 4 Deep	2013	206	173	135	315
	2014	237	234	152	297

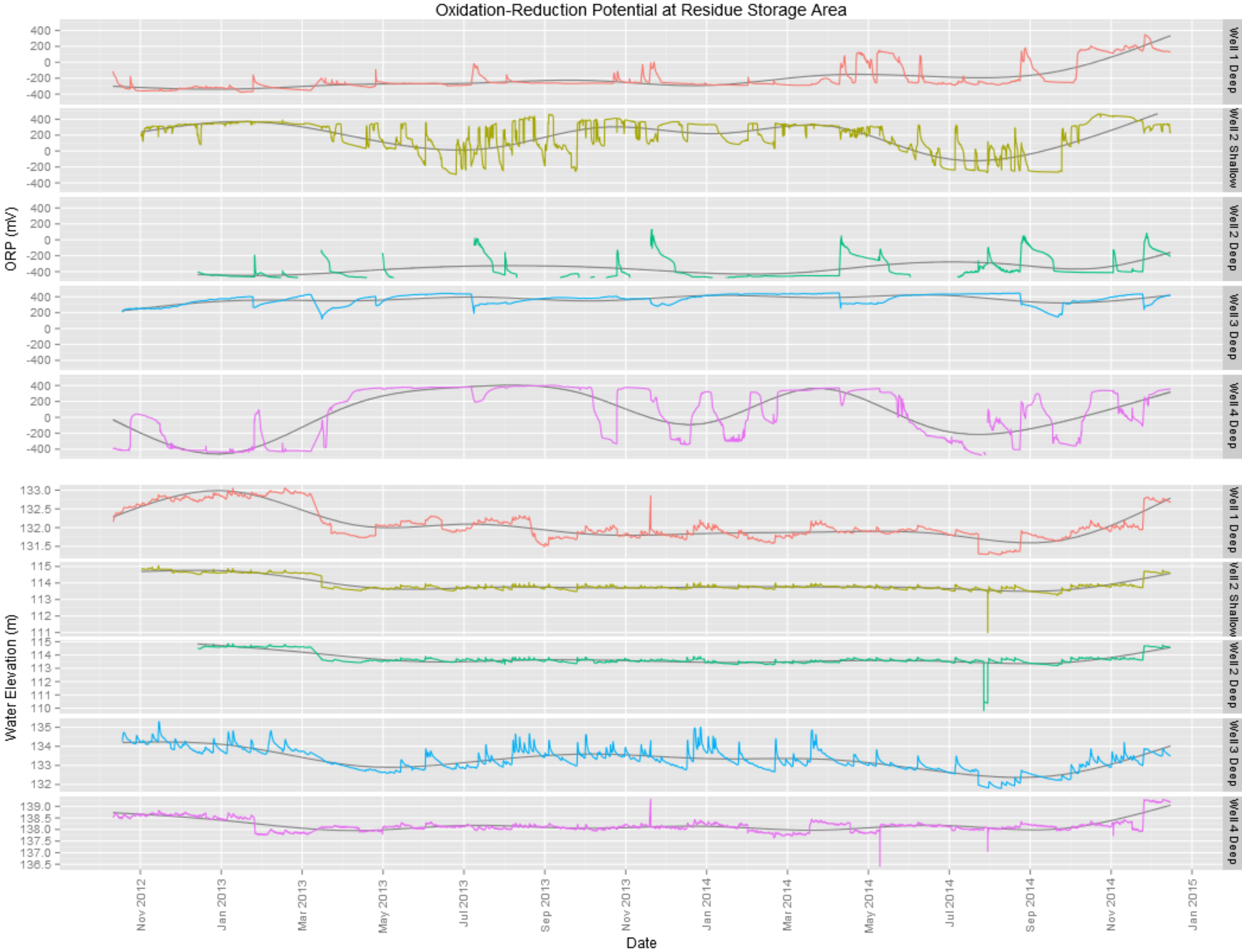
There is also a notable degree of variation in the magnitude of conductivity values in each well (Table 9; Figure 16). For example, Well 2 Shallow has a median conductivity value of 89 uS/cm compared to Well 2 Deep with a conductivity of 227 uS/cm. Such variation in conductivity between wells may be related to local geological conditions. Increased dissolved solid content is present in deep aquifer waters.

Figure 16: Boxplots of Specific Conductivity at Residue Storage Area Stations from 2013 to 2014



Oxidation-Reduction Potential

Figure 17: Oxidation-Reduction Potential at Residue Storage Area Stations from 2012 to 2014



Oxidation-Reduction Potential (ORP) gives an indication of whether oxidative or reductive processes will be prevalent in a given water sample. Positive ORP values indicate that oxidative conditions are present while negative values indicate a reducing environment. Oxidative vs reductive conditions give an indication of what types of dissolved ions are present in a water sample.

Figure 17 shows that ORP values are typically unstable at the Residue Storage Area monitoring wells. Periods of major change are observed during maintenance and purging of the wells by Vale and Environment and Conservation staff. This hints at the introduction of oxygen into the hypoxic groundwater.

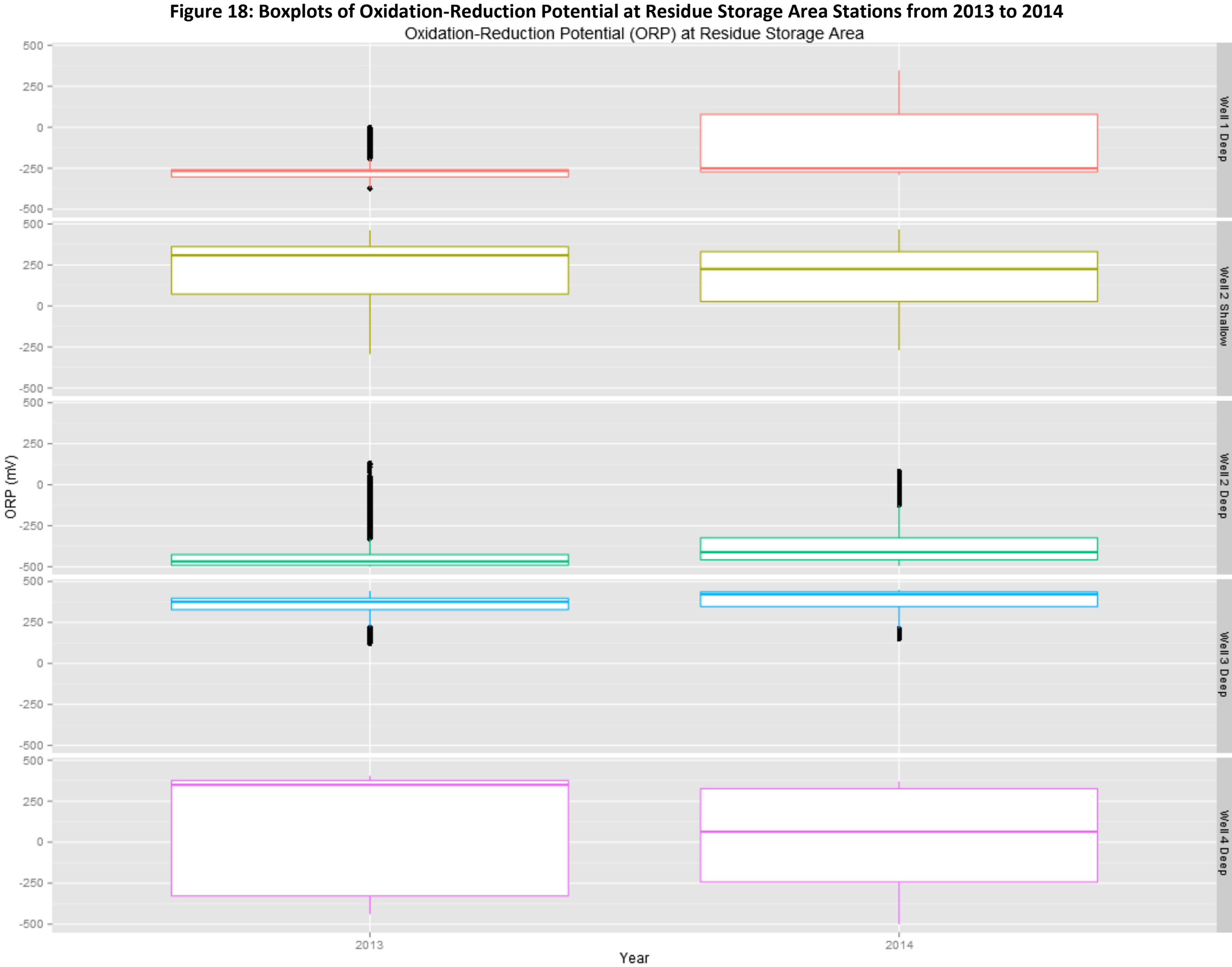
Table 10: Summary Statistics of Oxidation-Reduction Potential for Residue Storage Area stations from 2013 to 2014

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
Well 2 Deep	2013	-428.7	-467.7	-499.5	131.9
	2014	-370.1	-411.1	-495.4	84.4
Well 2 Shallow	2013	208.0	309.0	-293.7	461.7
	2014	155.6	225.5	-269.0	466.5
Well 3 Deep	2013	364.2	375.9	119.7	442.0
	2014	388.2	422.1	147.2	448.4
Well 4 Deep	2013	98.5	349.5	-439.7	404.7

Station	Year	Mean	Median	Min	Max
	2014	44.7	64.0	-501.0	370.1

Table 10 and Figure 18 both show that Well 1 Deep and Well 2 Deep have reducing environments while Well 2 Shallow, Well 3 Deep, and Well 4 Deep have predominantly oxidative environments. Long term changes in oxidative vs reductive environments could signal a major chemical change in groundwater chemistry and will be followed.

Figure 18: Boxplots of Oxidation-Reduction Potential at Residue Storage Area Stations from 2013 to 2014



Conclusions

Rattling Brook Network

Water quality continues to be relatively less impacted at Big Pond station compared to stations downstream, although specific conductivity continues to increase year over year. Major water quality events appear to be declining in magnitude and frequency as heavy construction lightens and ground stabilizes in the Rattling Brook area. Turbidity levels at Bridge and Plant Discharge stations declined for the third consecutive year, finally reaching median values of 0.0 NTU at each station.

Additional ground rehabilitation and re-vegetation will likely result in further improvements over time.

Sandy Pond (Residue Storage Area) Network

The first production of nickel began in late 2014, however, no solids have been released to the Residue Storage Area at this time – only treated water. Currently, residue from the refining process has been kept within the plant and release isn't anticipated until early 2016.

Acquisition of background data continues, although with the production of First Nickel, discharge of effluent into the Residue Storage Area is underway. Monitoring for changes to groundwater chemistry is under close scrutiny.

Path Forward

Continue monthly calibration and reporting on surface water quality for the Rattling Brook Network.

Continue quarterly calibration and annual reporting on groundwater quality for the Sandy Pond (Residue Storage Area) Network.

Field equipment will undergo routine Proficiency Testing and Evaluation in 2015 to ensure proper function of water quality instrumentation.

Environment and Conservation will continue to enhance the function of its Automatic Data Retrieval System to incorporate new functionality.

Appendix

Figure 19: Mean Daily Temperature and Total Precipitation in 2014: Argentia Weather Station