Real-Time Water Quality Deployment Report

Rattling Brook Network

Annual Report 2013

January 1, 2013 to December 31, 2013

Newfoundland Labrador

Government of Newfoundland and Labrador

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Introduction

Background

In 2006, before the initial construction stages of a nickel refining plant in Long Harbour, the Department of Environment and Conservation and Vale, a Brazilian nickel producer, have partnered in actively observing the ambient water quality of Rattling Brook – a moderately sized river which flows through the main construction site. Three surface water stations have been deployed to monitor water quality from the upper reaches of Rattling Brook at Big Pond Station; mid-way at Bridge Station; and in the lower reaches at Plant Discharge Station.

Since late 2012, an additional network of groundwater monitoring stations was established to monitor the containment of plant effluent bound for storage in nearby Sandy Pond. This new network consists of monitoring wells located at five stations in the vicinity of Sandy Pond. These stations monitor both groundwater quality and water level elevation, and were located in order to detect if there are changes in groundwater flow or water levels that could indicate seepage from Sandy Pond into either the shallow or deep groundwater regime.

Figure 1: Rattling Brook and Sandy Pond Water Quality Monitoring Networks

Stations in the surface water network take hourly measurements of temperature, pH, specific conductivity, total dissolved solids, dissolved oxygen, turbidity, and stage/flow rate (in cooperation with Water Survey of Canada).

Groundwater stations take hourly measurements of temperature, pH, specific conductivity, total dissolved solids, oxidation-reduction potential (ORP), and water level elevation.

Maintenance and Calibration

Deployment periods for monitoring equipment are timed to address the requirement of excessive travel to perform maintenance and calibration, while avoiding deleterious calibration drift. Typically, surface water deployment periods are scheduled for at least 30 days, while deployment at groundwater stations can be for up to four months (120 days). For the period of this report, groundwater stations were deployed for 97% of the year, while surface water stations were deployed from 88 – 98% of the year. Due to ice conditions posing a risk to equipment, Big Pond station is often taken offline at some point between February and March.

Table 1: Duration of Deployment for Rattling Brook and Sandy Pond stations

Station	Number of Days Deployed	Percent of Year Deployed
Rattling Brook Monitoring Network		
Big Pond	321	88
Bridge	356	98
Plant Discharge	356	98
Sandy Pond Monitoring Network		
Well 1 Deep	353	97
Well 2 Shallow	353	97
Well 2 Deep	353	97
Well 3 Deep	353	97
Well 4 Deep	353	97

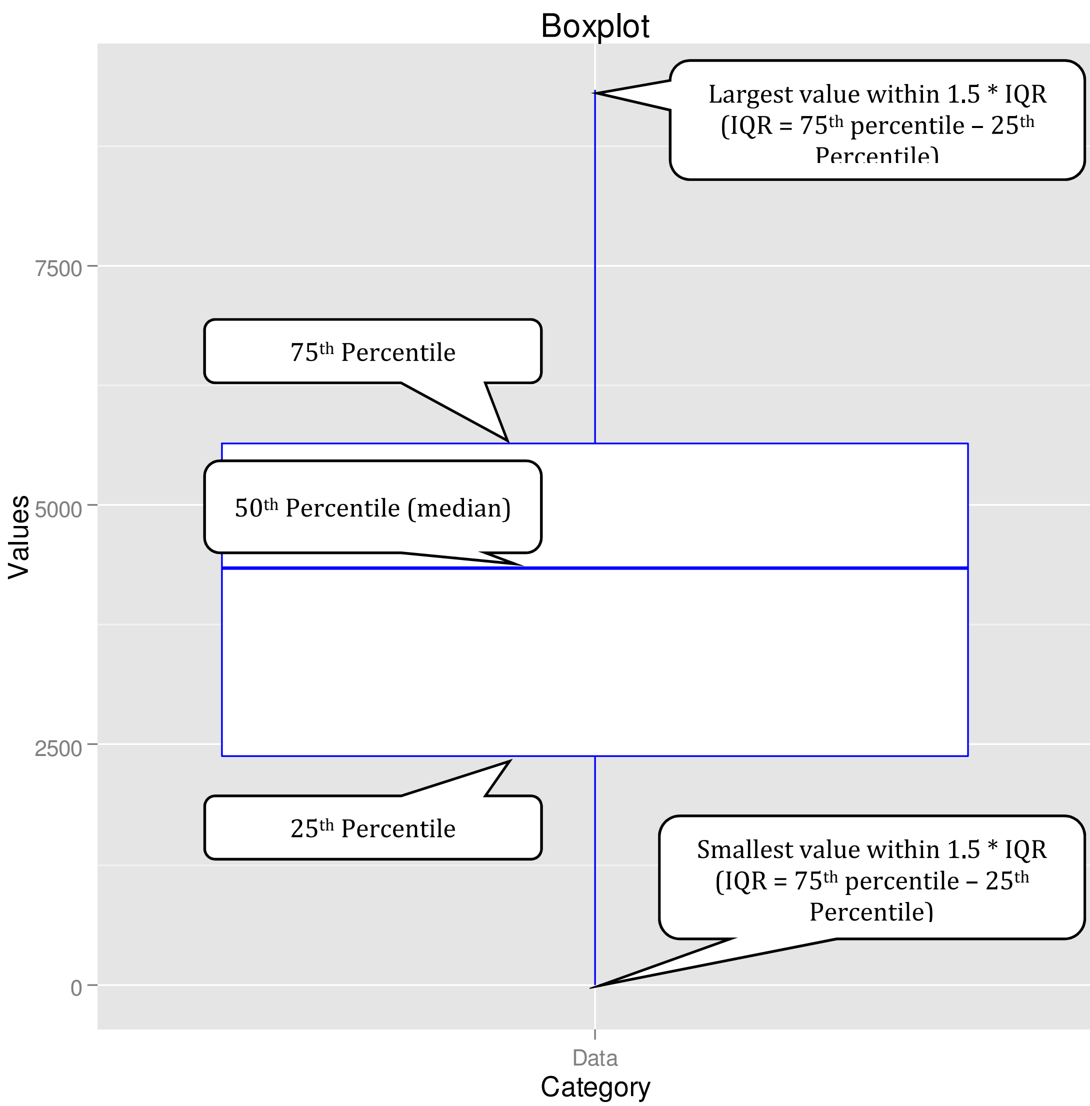
Results and Discussion

The following graphs and figures illustrate the trends in water quality as observed by the Rattling Brook surface water and Sandy Pond groundwater monitoring networks. Data are presented in a series of linear plots and box plots. Linear plots are especially useful in observing long-term trends in data and identifying patterns that may be present while boxplots are useful for observing differences in data between each station.

Anatomy of a Boxplot

In the boxplot in Figure 2, the critical features of a boxplot are identified. Boxplots are a quick method to visualize the central 75% of data. Because of this, when two populations are compared side-by-side, it is relatively easy to determine if one population is substantially different from another.

Figure 2: Anatomy of a Boxplot

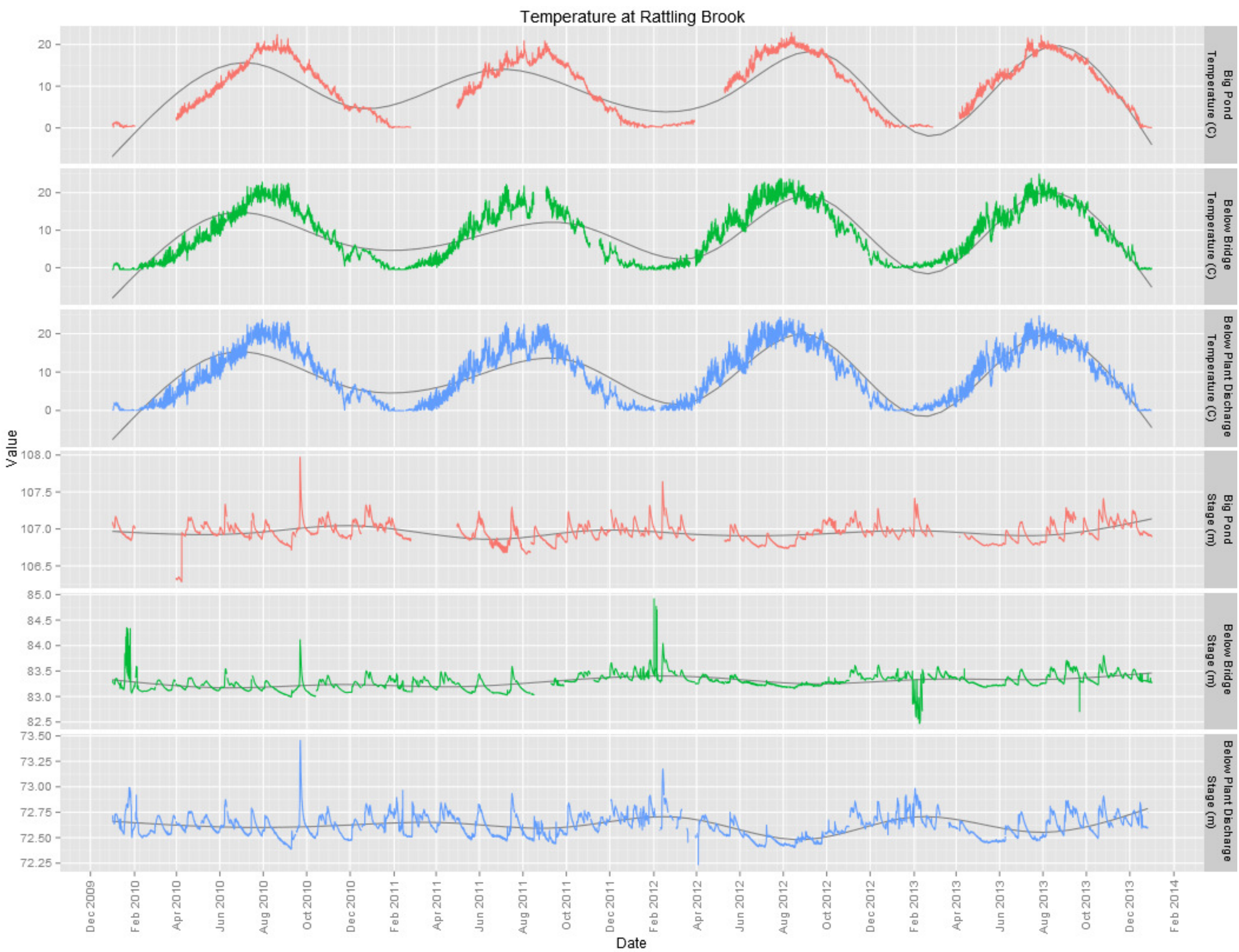


Rattling Brook Network

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 3: Water temperature at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



Median water temperatures were lower in 2013 than 2012, but still higher than those in 2010 and 2011. This is to be expected considering that 2012 was a banner year weather-wise – the nicest in recent memory. Weather conditions in 2013 were also slightly above average.

Over the course of 2010 to 2013, no particular trend in water temperature can be discerned (Figure 3). Indeed, while boxplots in Figure 4 indicate a three-year warming trend in Big Pond, the same trend was not observed at

Bridge and Plant Discharge stations. It must be noted that this discrepancy is probably related to the removal of equipment from Big Pond during the coldest months of the year (due to ice conditions). This biases the temperature at Big Pond to the warm side.

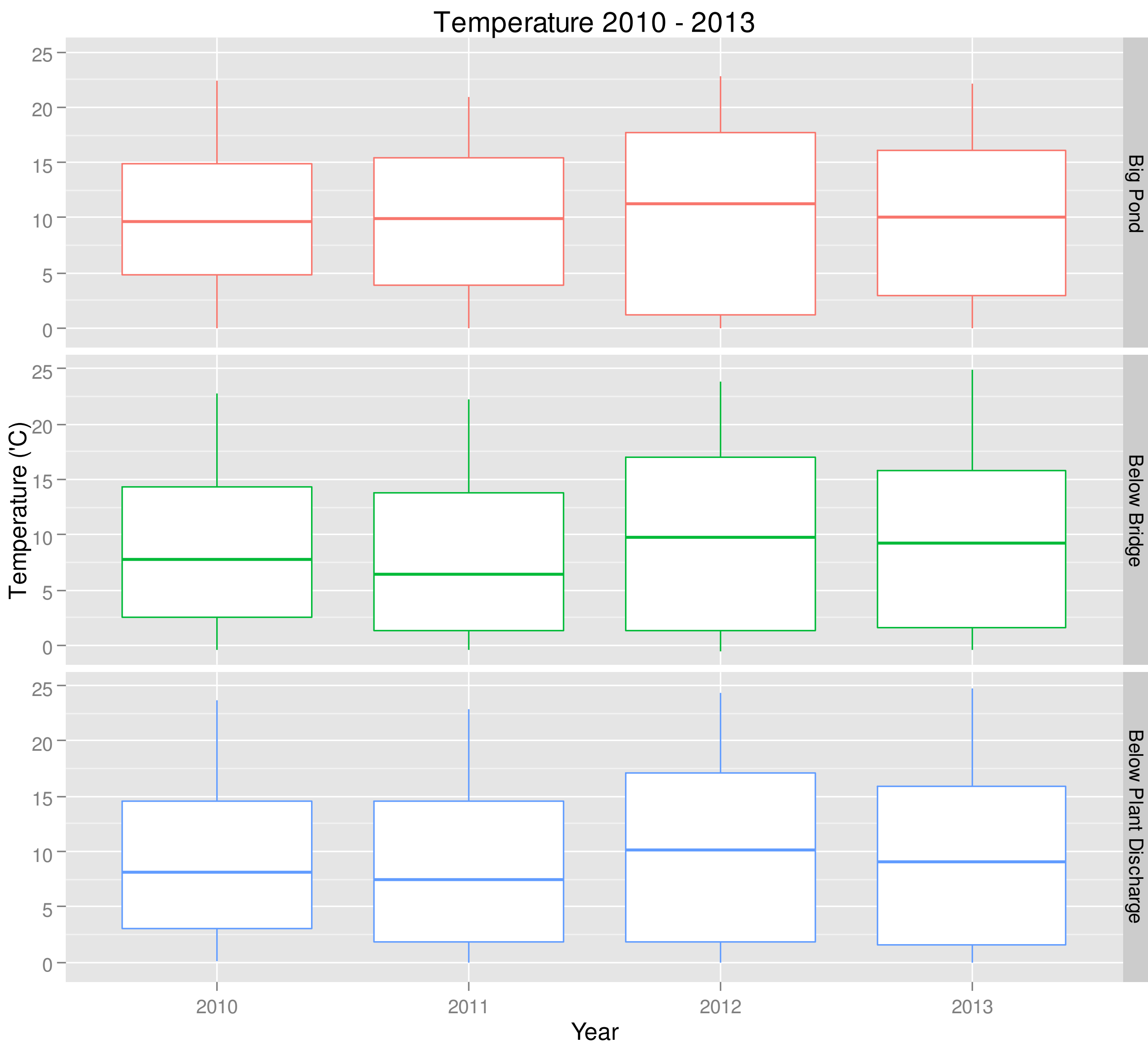
Despite the warm-side bias to Big Pond, it is generally true that mean and median water temperatures increase as water passes through Rattling Brook (Table 2). Maximum and minimum water temperatures are higher at Plant Discharge station compared to Bridge station. Air-water interaction is much greater in the turbulent flowing sections of Rattling Brook where heat transfer is greatest.

Table 2: Summary statistics of water temperature for Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

Year	Station	Mean	Median	Min	Max
2010	Big Pond	10.08	9.65	0.04	22.40
2011	Big Pond	9.58	9.88	-0.02	20.88
2012	Big Pond	10.00	11.28	0.00	22.87
2013	Big Pond	9.67	10.04	-0.02	22.17
2010	Below Bridge	8.65	7.73	-0.50	22.84
2011	Below Bridge	7.70	6.44	-0.48	22.20
2012	Below Bridge	9.52	9.77	-0.51	23.82
2013	Below Bridge	9.03	9.16	-0.49	24.98
2010	Below Plant Discharge	9.04	8.12	0.02	23.67
2011	Below Plant Discharge	8.43	7.50	-0.07	22.89
2012	Below Plant Discharge	9.98	10.16	-0.03	24.33
2013	Below Plant Discharge	9.01	9.00	-0.03	24.70

The upper range of the boxplots in Figure 4 show lower water temperatures in 2013 compared to 2012. Median water temperatures at Bridge and Plant Discharge stations are also notably lower. Big Pond station shows an increasing trend in 2013, however, a close look at Figure 3 shows that the Hydrolab was not in deployed during the coldest portion of 2013, biasing the statistics to the warm side.

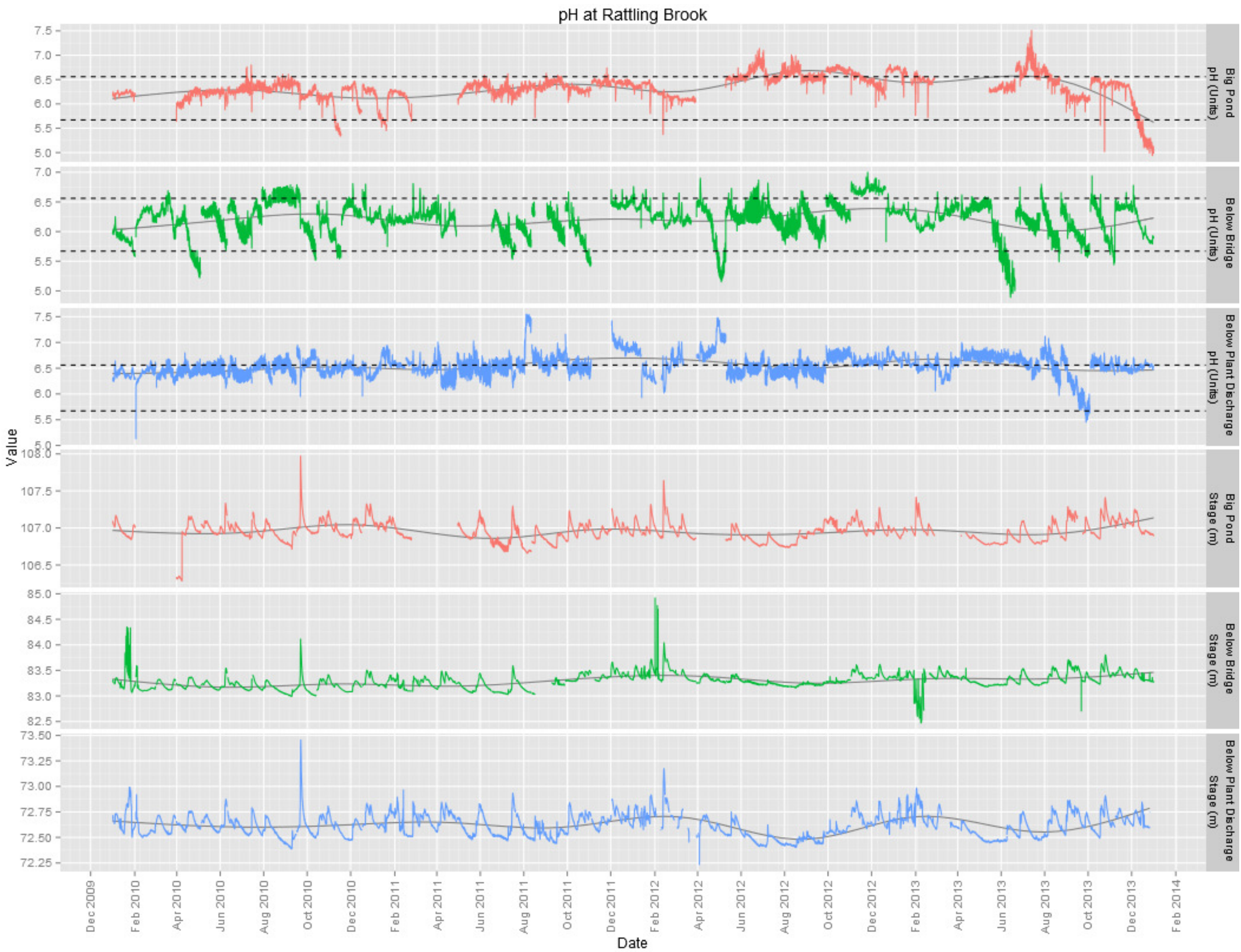
Figure 4: Boxplots of water temperature at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



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.

Figure 5: pH at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



pH values in 2013 are similar to those seen in previous years. As seen in Figure 5, pH is quite variable in Rattling Brook, regardless of season.

The two dotted lines on each of the thee pH plots in Figure 5 indicates the upper and lower site specific guidelines (SSGs) for pH. The guidelines were derived using the 95th and 5th percentile pH values at the three Rattling Brook stations prior to the initiation of major earthworks at the Vale site (CCME, 2003).

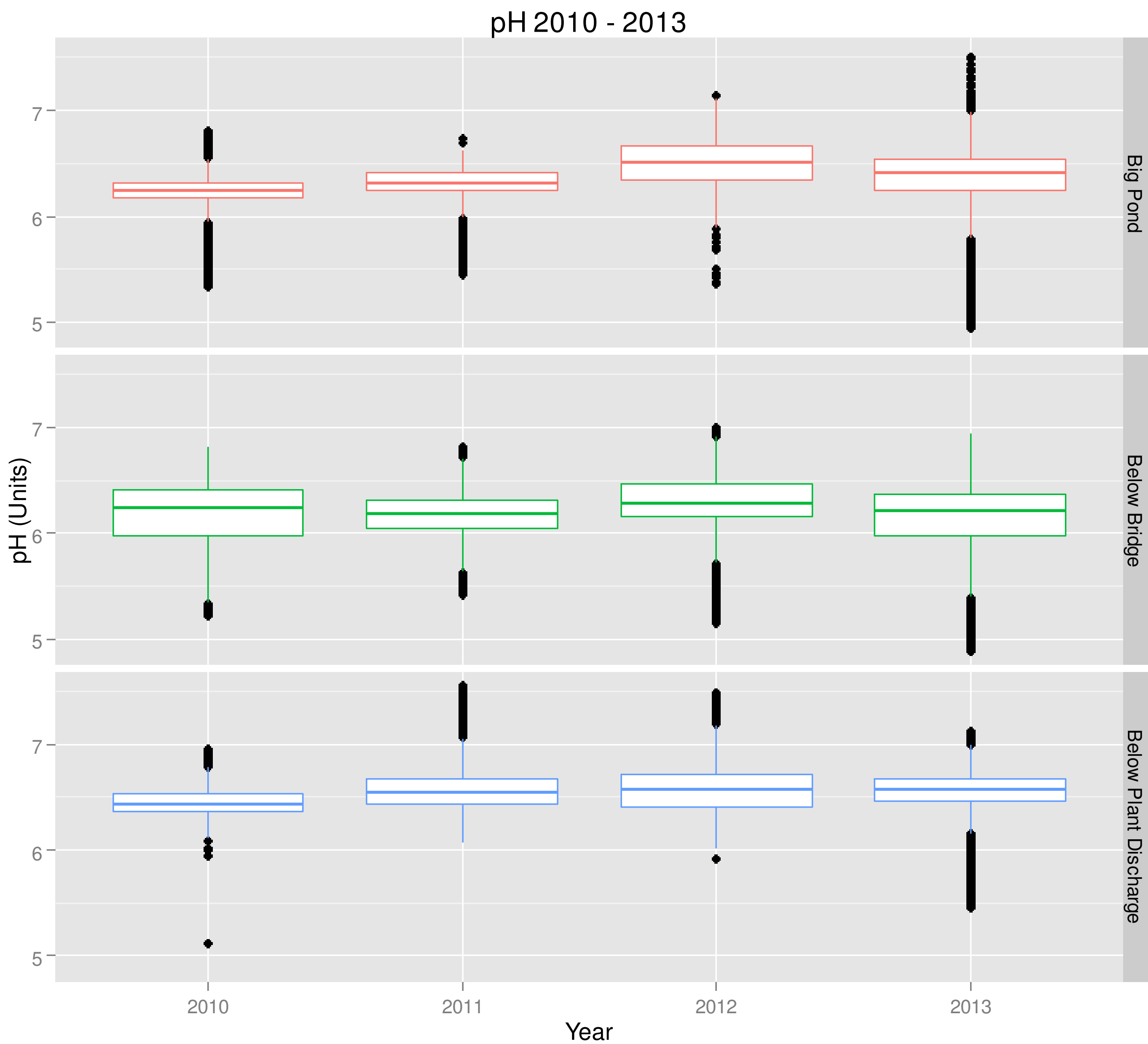
Most pH values fall within the stated SSGs – the statistical method chosen suggests that 90% of all values should fall within the guidelines. From 2010 – 2013, however, only approximately 75% of pH values fell between the SSGs, indicating that pH values are deviating from the guidelines. This may indicate either a shift in overall pH, or that the guidelines themselves may need adjustment.

Table 3: Summary statistics of pH for Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

Year	Station	Mean	Median	Min	Max
2010	Big Pond	6.22	6.25	5.34	6.80
2011	Big Pond	6.29	6.32	5.45	6.74
2012	Big Pond	6.48	6.51	5.37	7.14
2013	Big Pond	6.33	6.41	4.94	7.51
2010	Below Bridge	6.19	6.24	5.22	6.81
2011	Below Bridge	6.16	6.19	5.41	6.81
2012	Below Bridge	6.29	6.29	5.15	7.00
2013	Below Bridge	6.14	6.21	4.89	6.94
2010	Below Plant Discharge	6.45	6.44	5.12	6.95
2011	Below Plant Discharge	6.58	6.55	6.07	7.55
2012	Below Plant Discharge	6.58	6.58	5.92	7.48
2013	Below Plant Discharge	6.54	6.57	5.45	7.12

An examination of Figure 6 indicates an increase in pH levels at Big Pond over time and a slight increase at Plant Discharge. Bridge station appears to be mostly stable with median values showing no consistent trend either way.

Figure 6: Boxplots of pH at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

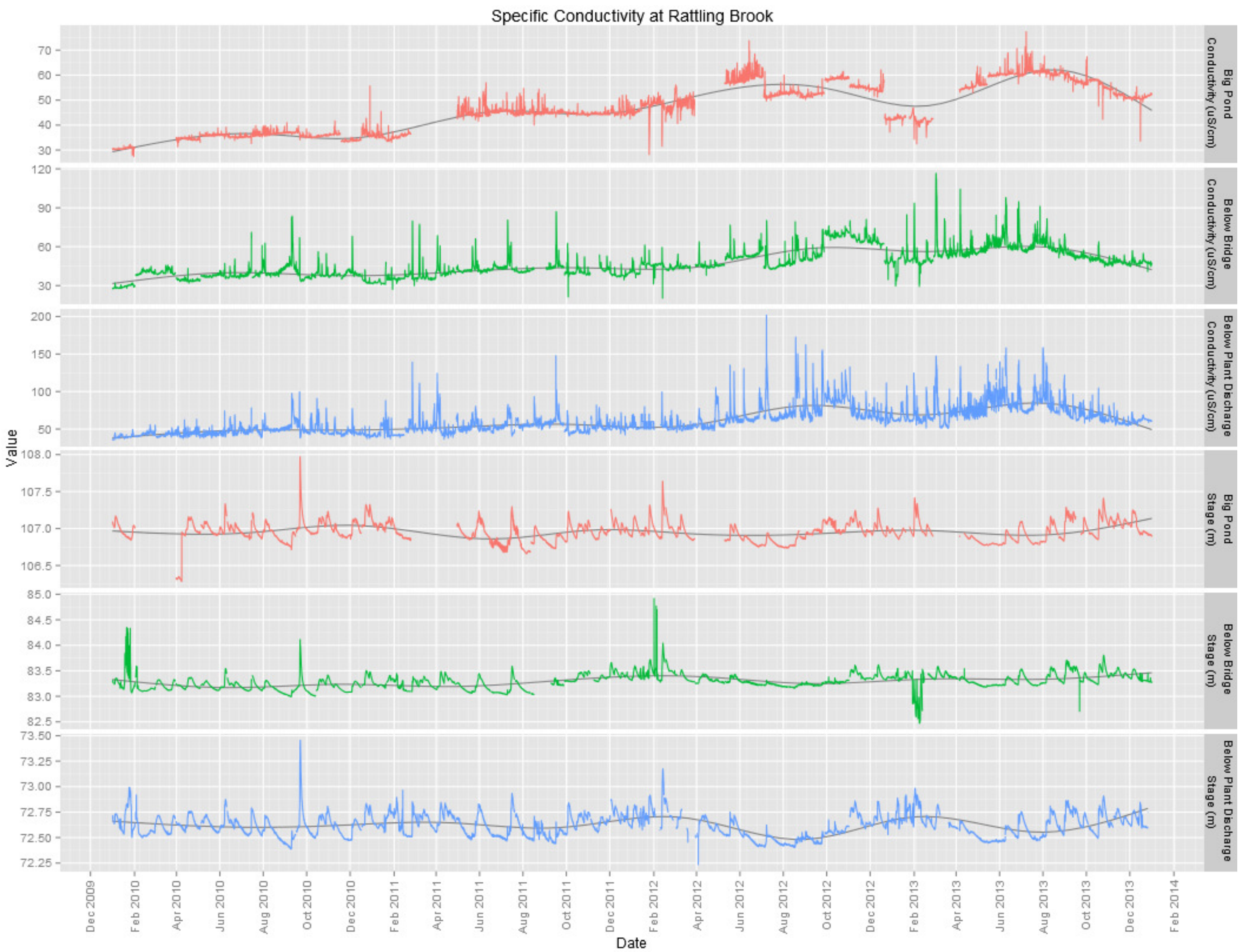


In 2013, there was less variability in the range of pH at Big Pond and Plant Discharge stations, as indicated by smaller box heights in Figure 6. Median pH values in 2013 were lower at all stations compared to 2012 (Table 3). In 2013, pH was found to be highest at Plant Discharge station, followed by Big Pond, and Bridge stations.

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.

Figure 7: Specific Conductivity at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



Since 2010, the data indicate that conductivity has been increasing (Figure 7). This could be due to the increased construction activity at the site, including construction of earthworks, road building, and increased activity in the area around Rattling Brook, which has resulted in the mobility of dissolved solids that were previously held in place by consolidated soils.

Additionally, in 2012 and 2013, a series of in-stream work projects were carried out to improve fish-spawning habitat. These projects involved replacing streambed strata with spawning beds, and dredging silt and mud from

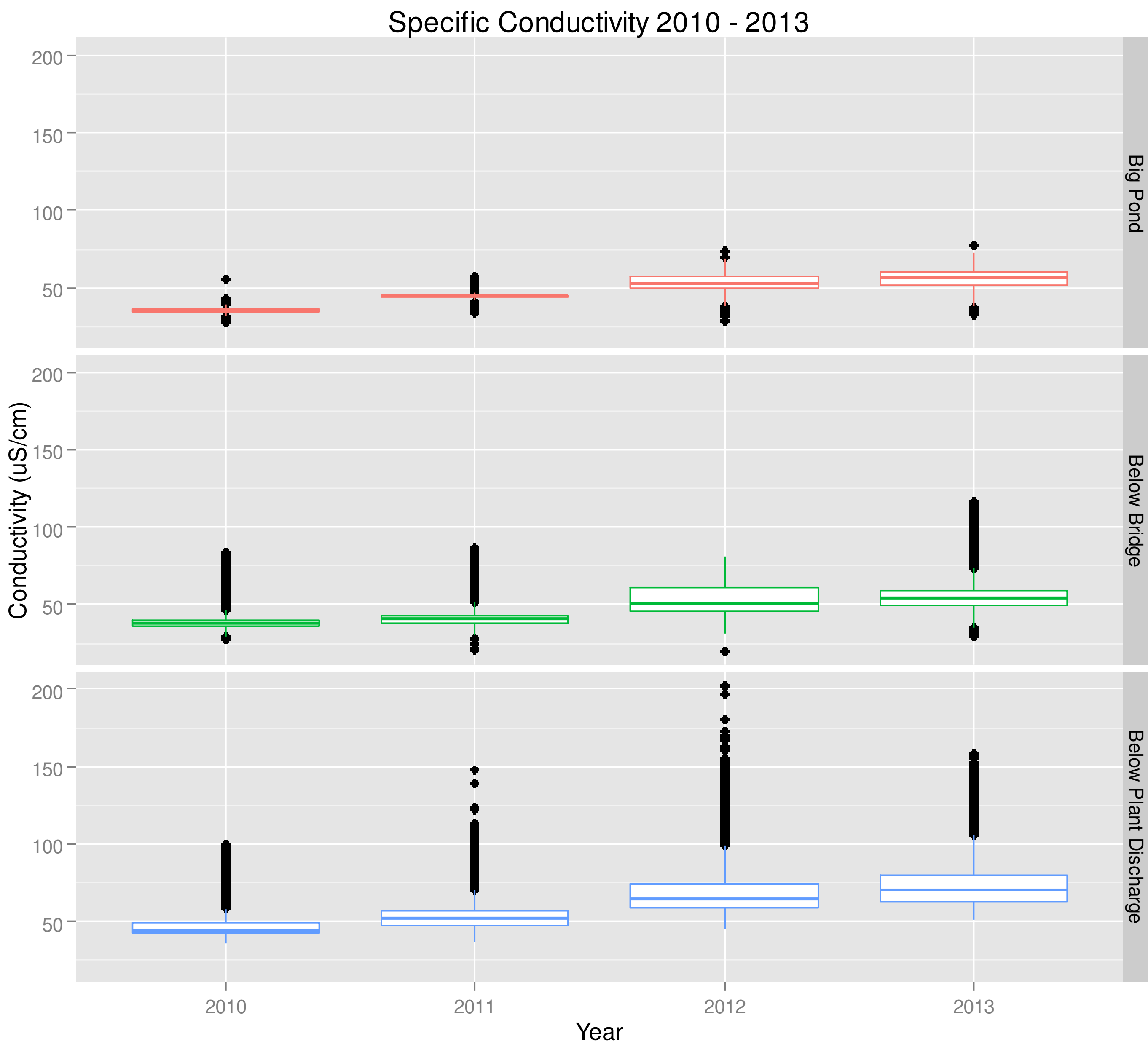
Forgotten Pond. As a result, sediments were mobilized, leading to highly variable conductivity, especially after storm events.

Table 4: Summary statistics of specific conductivity for Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

Year	Station	Mean	Median	Min	Max
2010	Big Pond	35.2	35.6	27.4	55.7
2011	Big Pond	43.4	44.6	33.1	57.0
2012	Big Pond	53.0	52.8	28.2	73.8
2013	Big Pond	54.8	56.5	32.5	77.4
2010	Below Bridge	38.1	38.0	27.4	83.6
2011	Below Bridge	40.8	40.6	21.2	87.1
2012	Below Bridge	52.9	50.1	20.2	81.1
2013	Below Bridge	55.1	53.9	29.3	116.6
2010	Below Plant Discharge	46.5	44.9	35.5	99.8
2011	Below Plant Discharge	53.4	51.9	36.5	147.9
2012	Below Plant Discharge	69.1	64.7	45.5	202.0
2013	Below Plant Discharge	73.6	70.3	51.0	158.7

As shown in Table 4, mean and median conductivity values have increased each year since 2010 at all Rattling Brook stations. Figure 8 illustrates the widening range of conductivity values and the increasing trend over time at each station. With the completion of in-stream work at the Vale site, conductivity may be expected to plateau in 2014, followed by decline over time as soils and sediments begin to stabilize.

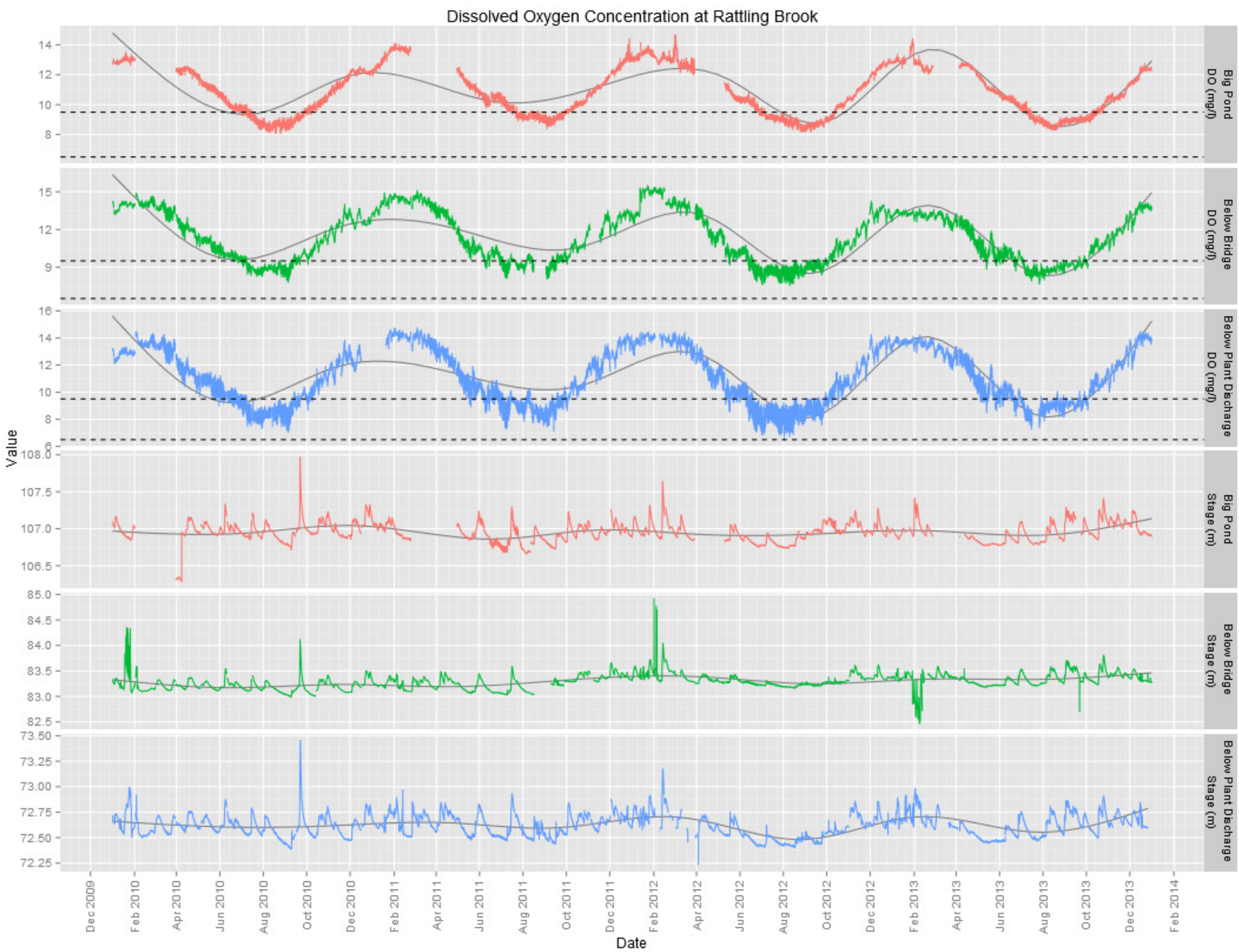
Figure 8: Boxplots of specific conductivity at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



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.

Figure 9: Dissolved Oxygen at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



Because of the close link between water temperature and dissolved oxygen, the absence of a long-term temperature trend explains the annual stability in dissolved oxygen concentration. Seasonal trends are observed related to the inverse temperature relationship, such as high concentrations of oxygen in winter and lower concentrations in the summer.

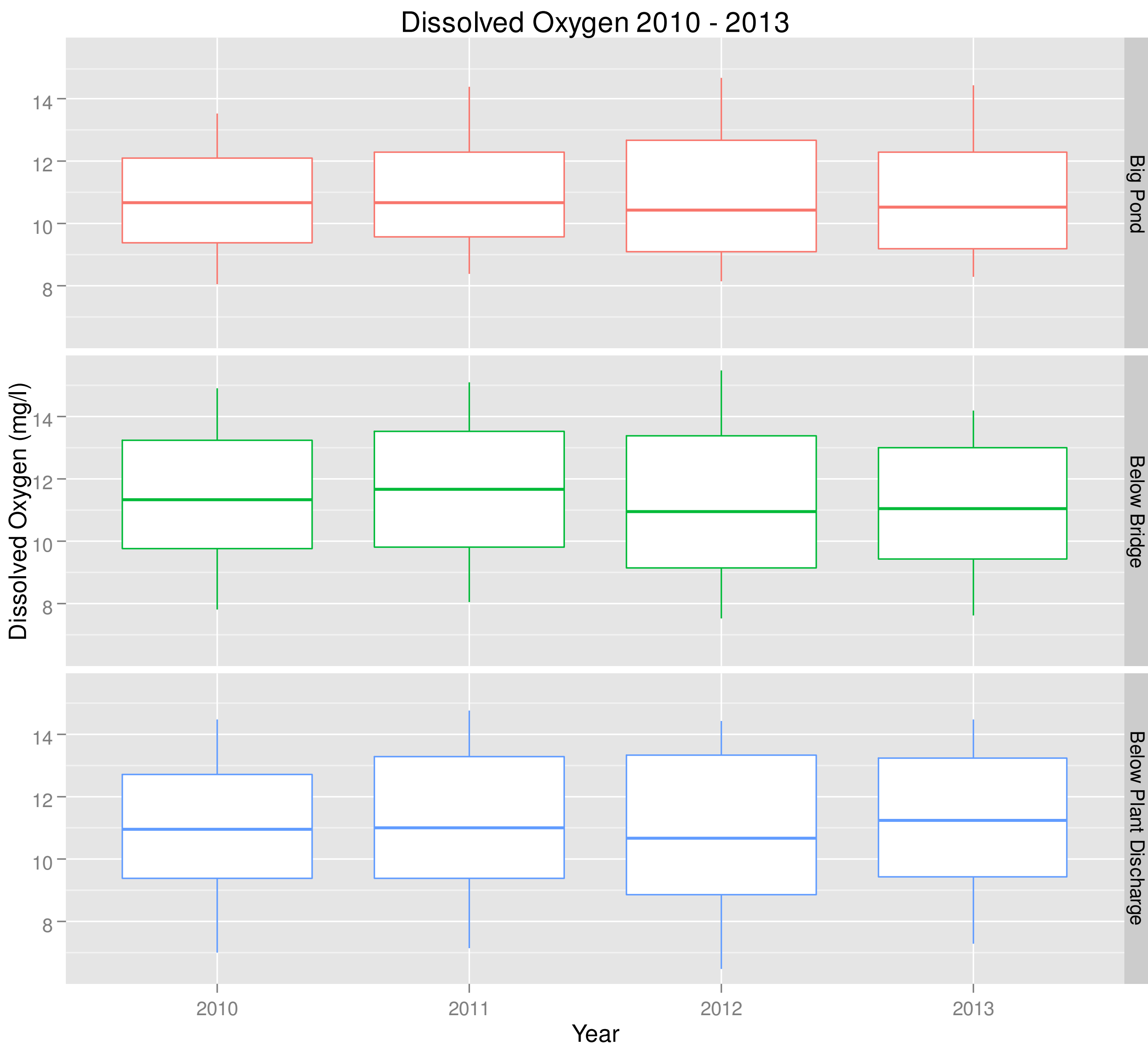
In Figure 9, CCME guidelines for the protection of cold water biota are presented as dashed lines, the lower line for “early life stages” (6.5 mg/l) and the upper line for “other life stages” (9.5 mg/l). Only one instance of a DO concentration lower than 6.5 mg/l was recorded since 2010.

Table 5: Summary statistics of dissolved oxygen for Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

Year	Station	Mean	Median	Min	Max
2010	Big Pond	10.68	10.69	8.06	13.53
2011	Big Pond	10.99	10.71	8.39	14.42
2012	Big Pond	10.86	10.47	8.17	14.69
2013	Big Pond	10.74	10.55	8.29	14.43
2010	Below Bridge	11.43	11.36	7.81	14.90
2011	Below Bridge	11.74	11.70	8.08	15.11
2012	Below Bridge	11.31	10.95	7.54	15.51
2013	Below Bridge	11.17	11.04	7.65	14.21
2010	Below Plant Discharge	10.94	10.95	7.02	14.48
2011	Below Plant Discharge	11.24	10.99	7.12	14.76
2012	Below Plant Discharge	10.91	10.66	6.46	14.45
2013	Below Plant Discharge	11.29	11.24	7.28	14.49

In 2013, median DO concentrations at all stations were slightly higher than 2012, but lower than 2010 – 2011 (Table 5 and Figure 10).

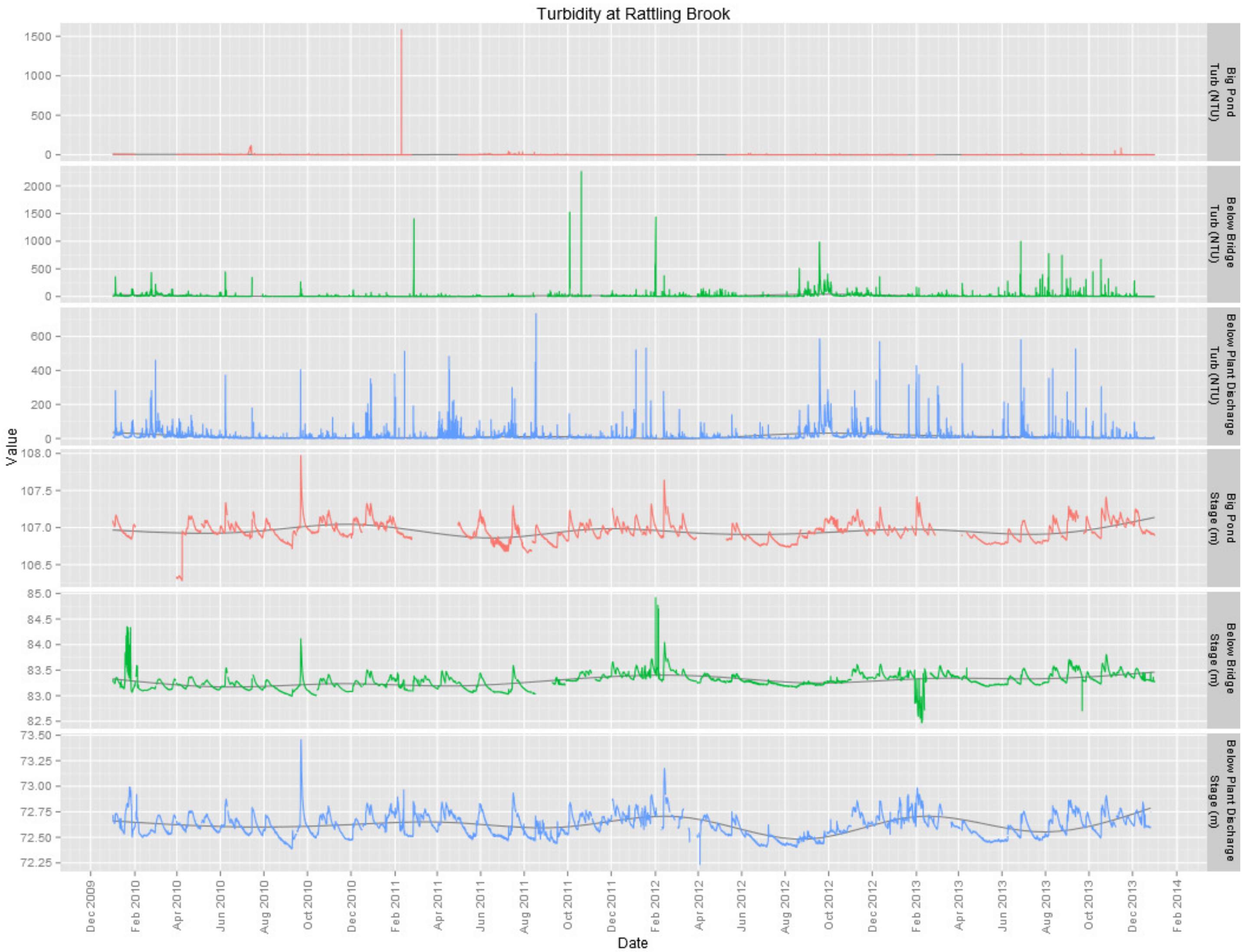
Figure 10: Boxplots of dissolved oxygen at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



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

Figure 11: Turbidity at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



Over the course of Vale's project in Long Harbour, turbidity levels have varied considerably. Initially, earth works disturbed previously consolidated soils and allowed silt to move easily into Rattling Brook during storm events. The addition of storm water management structures reduced this impact. A series of in-stream projects in 2012 and 2013 resulted in continuously elevated turbidity levels at Bridge and Plant Discharge stations. Since the completion of in-stream activities, turbidity levels have begun to decline.

Table 6: Summary statistics of turbidity for Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013

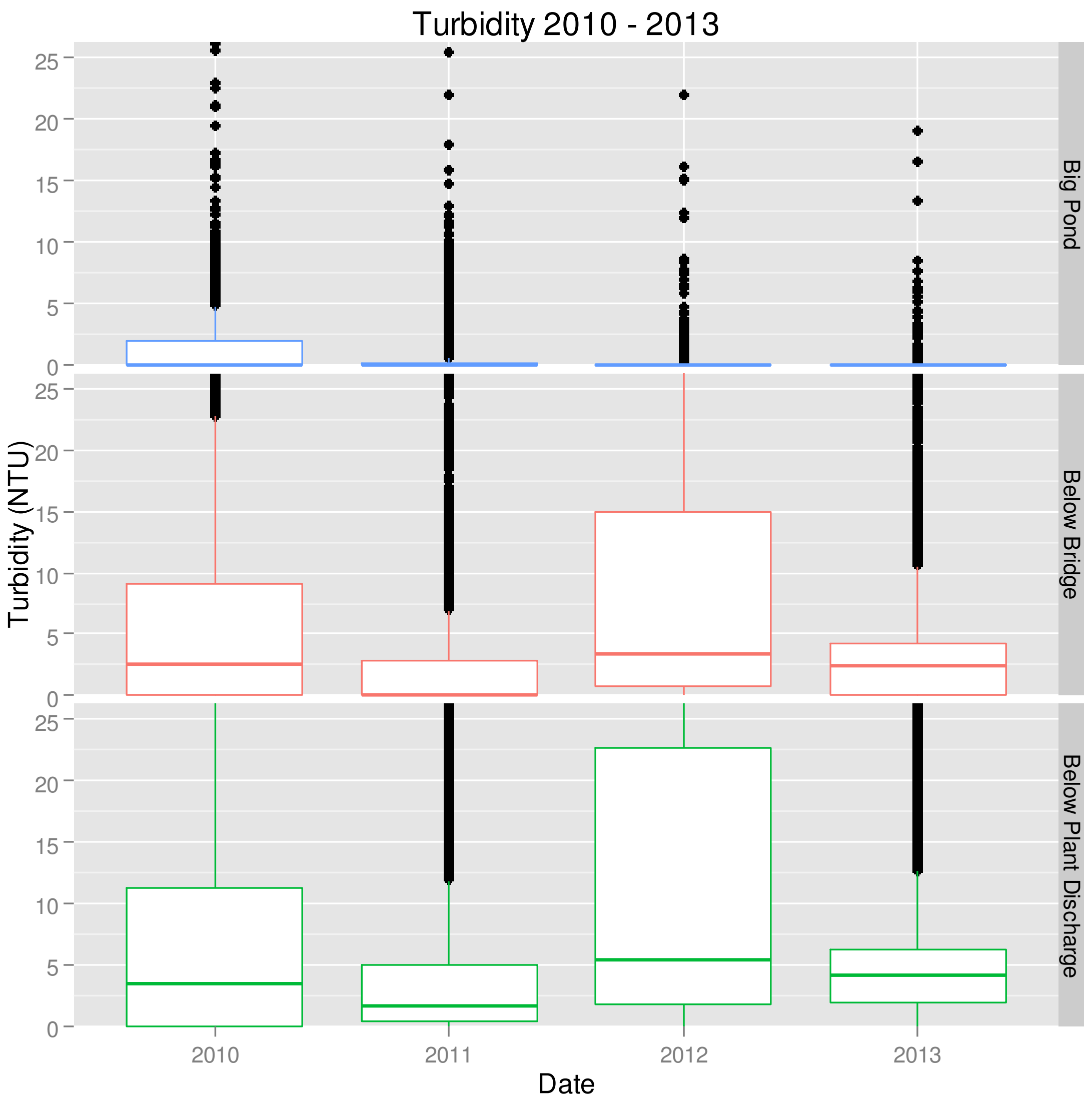
Year	Station	Mean	Median	Min	Max
2010	Big Pond	2.4	0.0	0.0	116.6
2011	Big Pond	1.0	0.0	0.0	1586.0
2012	Big Pond	0.2	0.0	0.0	22.0
2013	Big Pond	0.1	0.0	0.0	84.8
2010	Below Bridge	10.2	2.5	0.0	445.0
2011	Below Bridge	6.0	0.4	0.0	2259.0
2012	Below Bridge	22.6	3.4	0.0	1437.0
2013	Below Bridge	6.4	2.4	0.0	998.0
2010	Below Plant Discharge	11.5	3.3	0.0	460.0
2011	Below Plant Discharge	6.7	1.7	0.0	734.0
2012	Below Plant Discharge	19.4	4.8	0.0	586.0
2013	Below Plant Discharge	9.9	4.1	0.0	580.0

Relatively little construction has taken place in the vicinity of Big Pond. Turbidity levels are consistently low at Big Pond station due to a combination of still waters and a lack of disturbance. Because Plant Discharge receives water from a large settling pond, turbidity levels tend to peak at this station higher than at Bridge station (

Table 6).

As shown in Figure 12, the range of typical turbidity values at Bridge and Discharge stations decreased substantially in 2013. It is expected that turbidity values will continue to decline into 2014 as construction in the area slows and soils begin to stabilize.

Figure 12: Boxplots of turbidity at Big Pond, Bridge, and Plant Discharge stations from 2010 to 2013



Sandy Pond Network

A series of five monitoring wells were drilled around Sandy Pond in the configuration outlined in Figure 1. The depth of each well and the depth of monitoring equipment are outlined in Table 7.

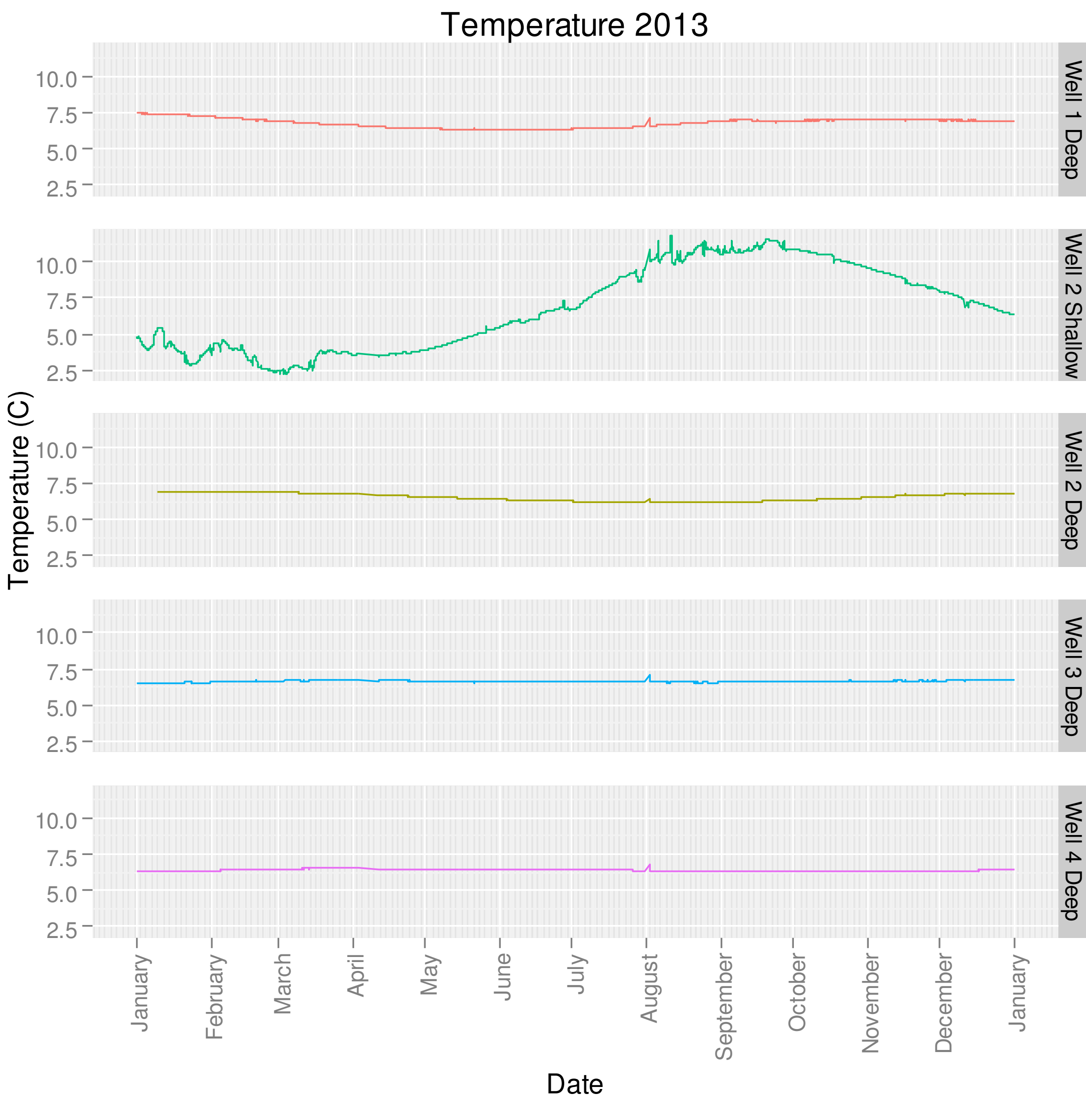
Table 7: Summary of Monitoring Well Records

Well	Surface Elevation (m)	Bore Depth (m)	Monitoring Depth (m)
Well 1 Deep	133.99	28.20	23.50
Well 2 Shallow	115.50	4.54	3.50
Well 2 Deep	115.39	13.09	12.50
Well 3 Deep	135.84	28.35	17.00
Well 4 Deep	143.37	31.4	17.00

Temperature

In deep aquifers, water temperature is normally very stable due to the insulating effect of the surrounding bedrock. 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.

Figure 13: Groundwater temperature at Sandy Pond monitoring stations in 2013



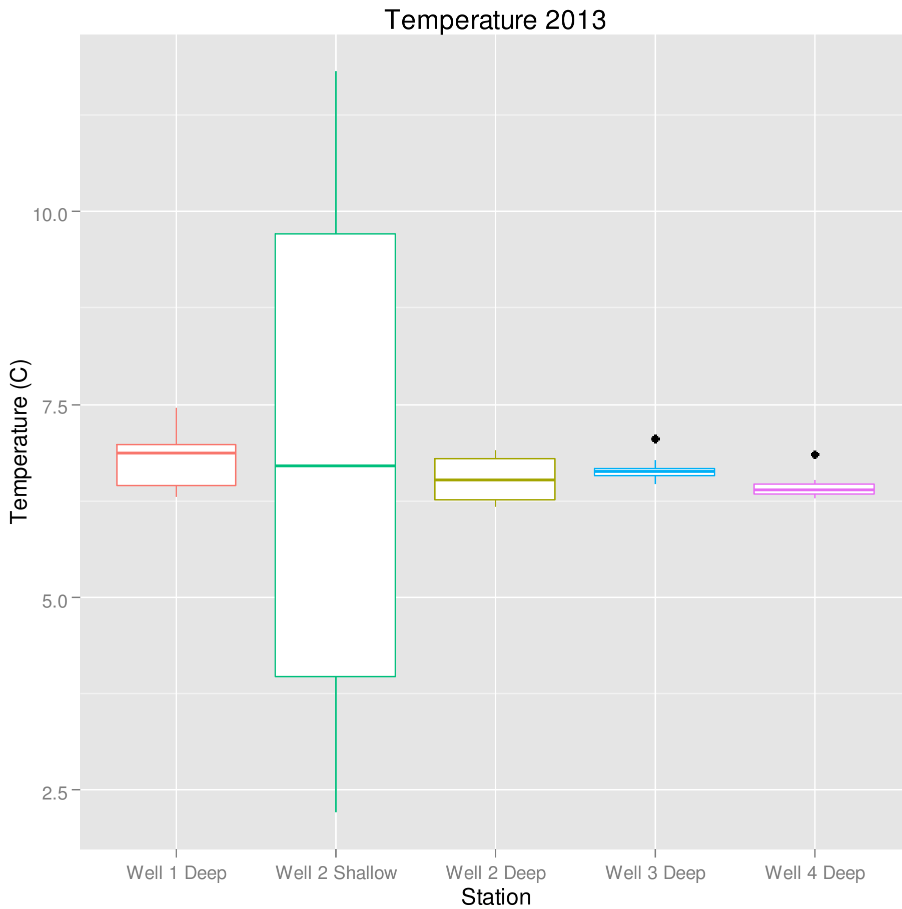
More than most parameters, the groundwater temperature profiles in Figure 13 illustrate that Well 2 Shallow is greatly influenced by surface water. Whereas Well 2 Shallow shows peak temperatures in late summer, all other wells have maximum water temperatures from January to March. The depth to which water must percolate to recharge Well 2 Shallow is much less than depth of recharge to the deep wells. As a result, a significant lag of five or six months separates the maximum surface water temperature at Rattling Brook and maximum groundwater temperature around Sandy Pond.

Table 8: Summary statistics of groundwater temperature at Sandy Pond monitoring stations in 2013

Station	Mean	Median	Min	Max
Well 1 Deep	6.78	6.87	6.30	7.45
Well 2 Shallow	6.83	6.71	2.22	11.81
Well 2 Deep	6.53	6.53	6.17	6.91
Well 3 Deep	6.62	6.63	6.46	7.05
Well 4 Deep	6.40	6.39	6.25	6.85

Although median water temperatures are within 0.48°C of one another (Table 8), Figure 14 gives an indication of the variability seen at each monitoring well around Sandy Pond. Very little variation is seen at Well 3 (range: 0.17C) and Well 4 (range: 0.14C). A greater degree of variation is observed at Well 1 and Well 2 Deep, possibly due to higher rates of hydraulic conductivity. Well 2 Shallow, however, tends to be highly variable – due to the greater interaction with surface water.

Figure 14: Boxplots of groundwater temperature at Sandy Pond monitoring stations in 2013



pH

pH refers to the concentration of H+ ions in solution, where a low pH is due to a high concentration of H+ ions (acidic) while a high pH is due to a low concentration of H+ ions (basic). pH has a wide ranging effect on such things as metal solubility and microbiological growth.

Figure 15: pH at Sandy Pond monitoring stations in 2013

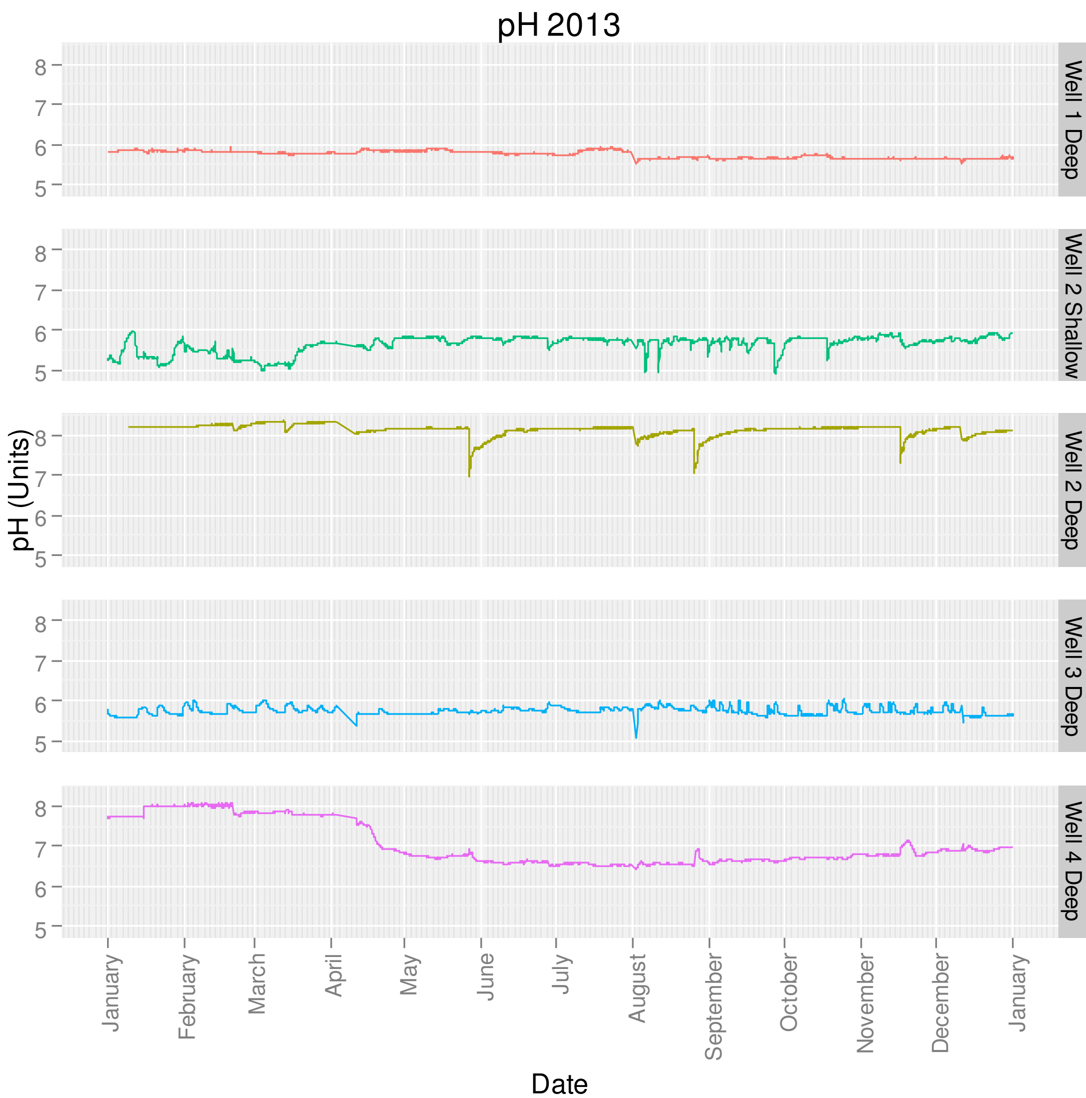


Figure 15 is useful for gauging the annual trend in pH at each well around Sandy Pond. pH is generally stable at Well 1 and Well 2 Deep, except for some perturbations related to instrument withdrawal during calibration or sampling. Well 2 Shallow and Well 3 Deep exhibit frequent peaks and dips reminiscent of impact from rainfall events, suggesting a connection to surface water at Well 3. While this evidence is contradictory to the lack of temperature range, it could indicate that recharge to Well 3 lags behind what is seen in Well 2 Shallow, which could suggest that groundwater recharge temperatures equilibrate before measurements of pH are made in the deeper aquifer. An event that lowers the pH in Well 2 Shallow is followed by a similar decrease in pH in Well 3 after at least thirty days. Additionally, the data for Well 2 Deep also indicates response to the same events as Well 2 Shallow. Even Well 1 Deep responds to an event in August that is recorded at all sites.

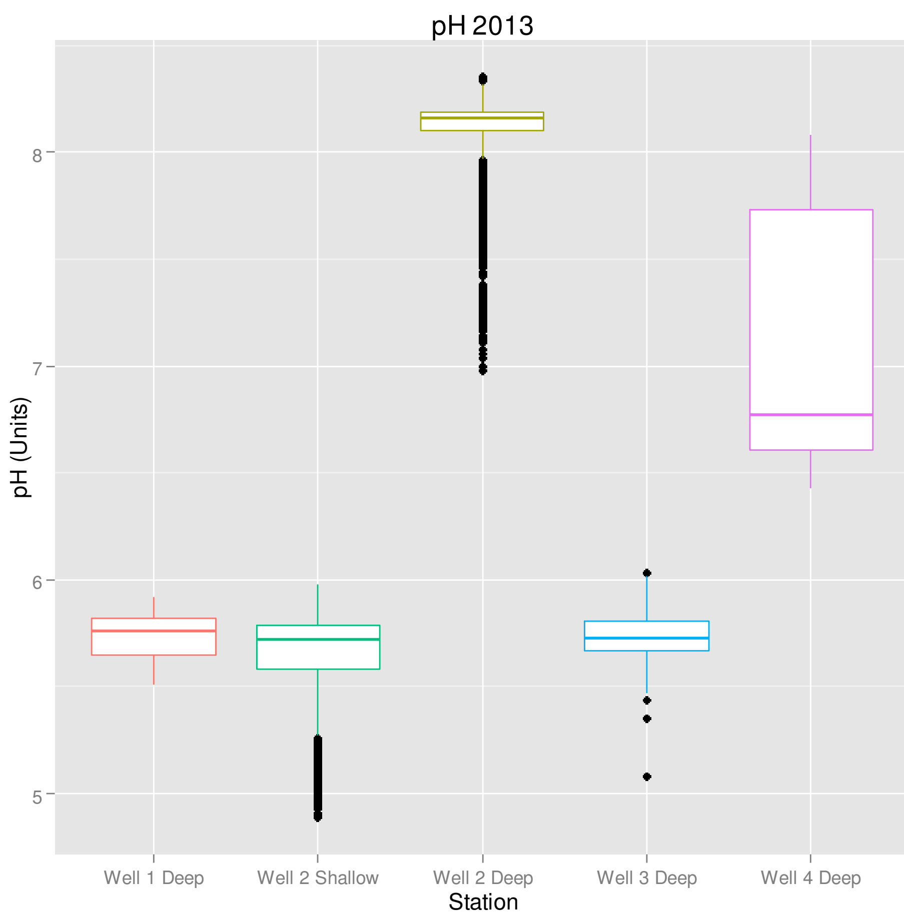
Of all the sites, data from Well 4 indicates a decline in pH mid-April that was slowly recovering through December 2013.

Table 9: Summary statistics of pH at Sandy Pond monitoring stations in 2013

Station	Mean	Median	Min	Max
Well 1 Deep	5.75	5.76	5.51	5.92
Well 2 Shallow	5.64	5.72	4.89	5.98
Well 2 Deep	8.13	8.16	6.98	8.35
Well 3 Deep	5.75	5.73	5.08	6.03
Well 4 Deep	7.03	6.77	6.43	8.08

Most of the monitoring wells at Sandy Pond tend to be acidic with median pH levels well below 7. Well 2 Deep, however, tends to be quite alkaline with a median pH value of 8.16 (Figure 16 and Table 9).

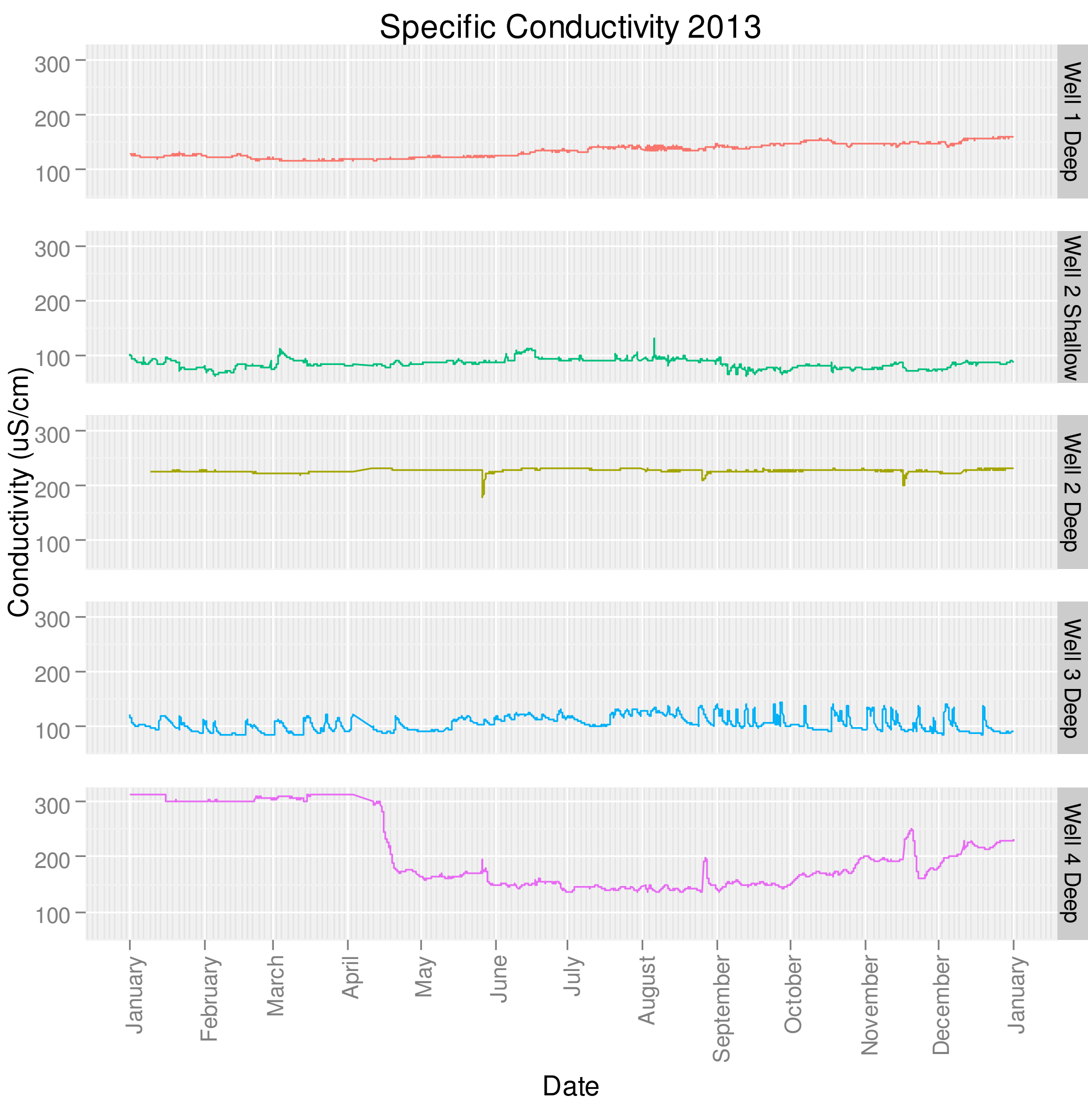
Figure 16: Boxplots of pH at Sandy Pond monitoring stations in 2013



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.

Figure 17: Specific Conductivity at Sandy Pond monitoring stations in 2013



Examination of Figure 17 indicates a rising trend in conductivity at Well 1 throughout 2013. At Well 3, conductivity appears to rise through the summer months and decline into the fall and winter. Conductivity at Well 4 fell considerably from ~300 uS/cm to ~150 uS/cm in mid-April and remained low through the summer months. In December, a rising trend appears to show conductivity approaching pre-drop levels.

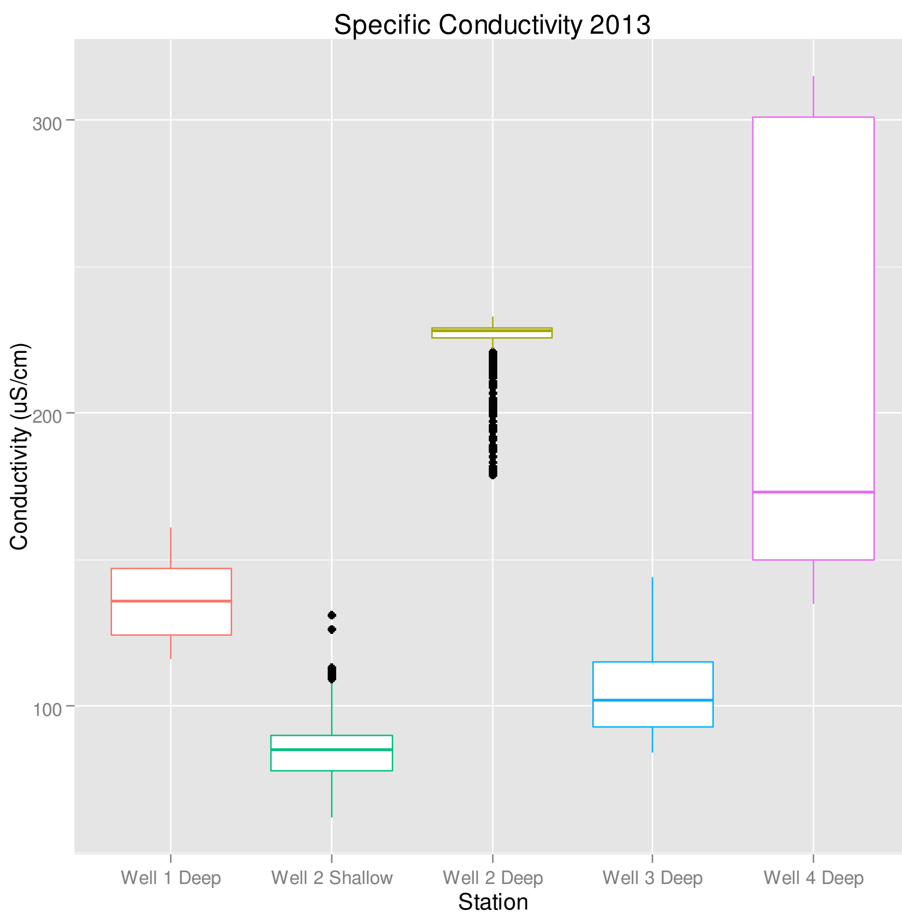
Specific conductivity in Well 2 Deep and Well 3 reflects a similar tendency as pH in both wells, hinting at a direct influence of surface water on both wells.

Table 10: Summary statistics of specific conductivity at Sandy Pond monitoring stations in 2013

Station	Mean	Median	Min	Max
Well 1 Deep	135	136	116	161
Well 2 Shallow	85	85	62	131
Well 2 Deep	228	228	179	233
Well 3 Deep	105	102	84	144
Well 4 Deep	206	173	135	315

Table 10 and Figure 18 highlight the differences in specific conductivity between each monitoring well. At most stations, conductivity falls within a fairly narrow range except for Well 4 which showed considerable variation through 2013.

Figure 18: Boxplots of specific conductivity at Sandy Pond monitoring stations in 2013



Oxidation-Reduction Potential

Oxidation-Reduction Potential (ORP) gives an indication of whether oxidative or reductive processes will be prevalent in a given water sample. Positive ORP values indicated that oxidative conditions are present while negative values indicated a reducing environment. For example, waters with a source of oxygen will tend towards oxidative conditions while anaerobic environments will tend towards reductive conditions.

Figure 19: ORP at Sandy Pond monitoring stations in 2013

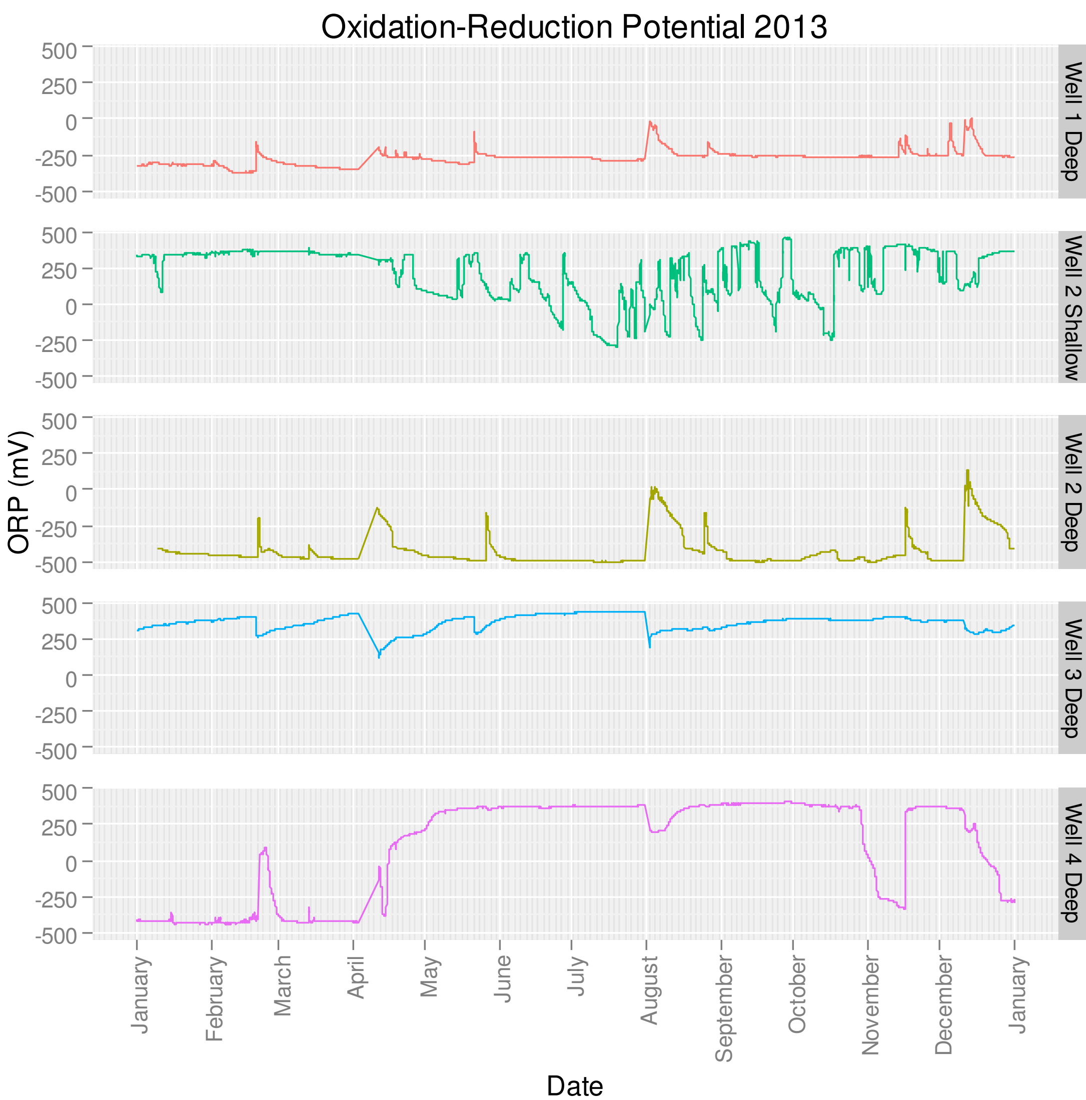


Figure 19 indicates that Well 1 and Well 2 Deep are predominantly reducing wells while Well 2 Shallow and Well 3 are oxidative wells. Well 4 falls in between – in early 2013 it was reductive, until mid-April when it quickly changed to an oxidative well (though the median ORP in Table 11 indicates it was predominately oxidative).

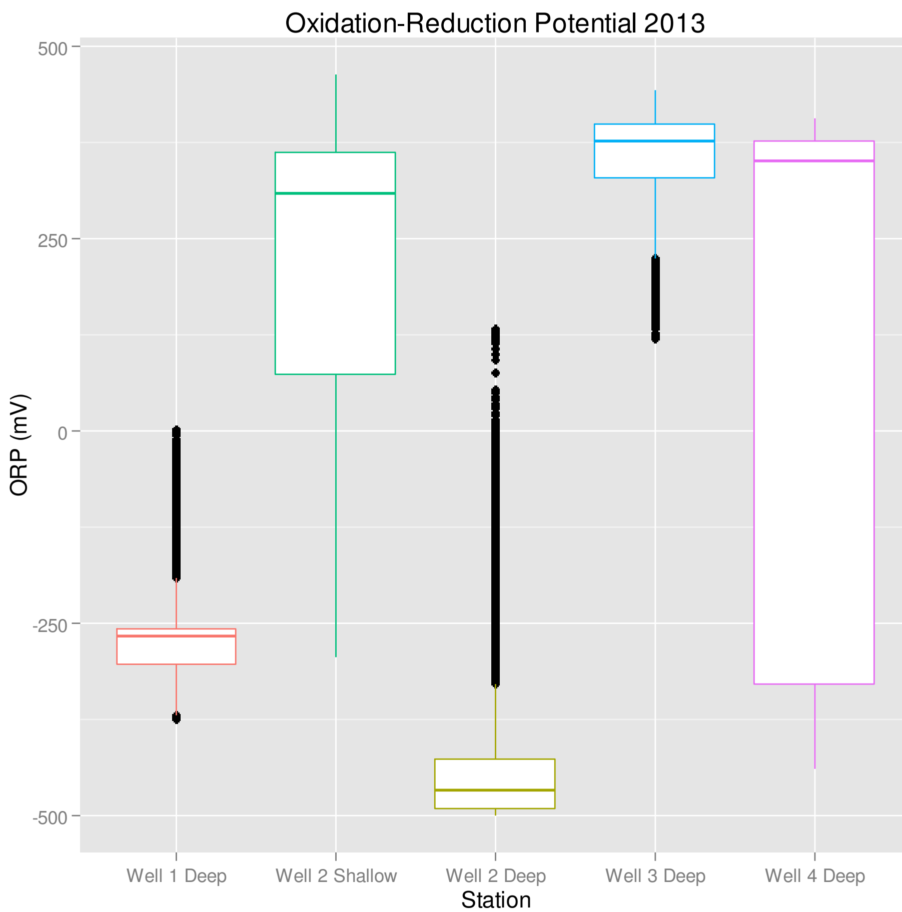
Table 11: Summary statistics of oxidation-reduction potential at Sandy Pond monitoring stations in 2013

Station	Mean	Median	Min	Max
Well 1 Deep	-271.9	-266.4	-375.2	1.7
Well 2 Shallow	208.0	309.0	-293.7	461.7
Well 2 Deep	-428.7	-467.7	-499.5	131.9
Well 3 Deep	364.2	375.9	119.7	442.0
Well 4 Deep	98.5	349.6	-439.7	404.7

Additional factors besides the presence of oxygen in the Well 2 Shallow, Well 3, and Well 4 drives the oxidative condition of the three wells. The shallow depth of Well 2 Shallow allows for ready access to oxygen, yet the median ORP is higher at Well 3, a 30 m deep borehole.

Below, Figure 20 gives a clear indication that wells near Sandy Pond are predominately oxidative. Wells 1 Deep and 2 Deep are almost entirely reducing.

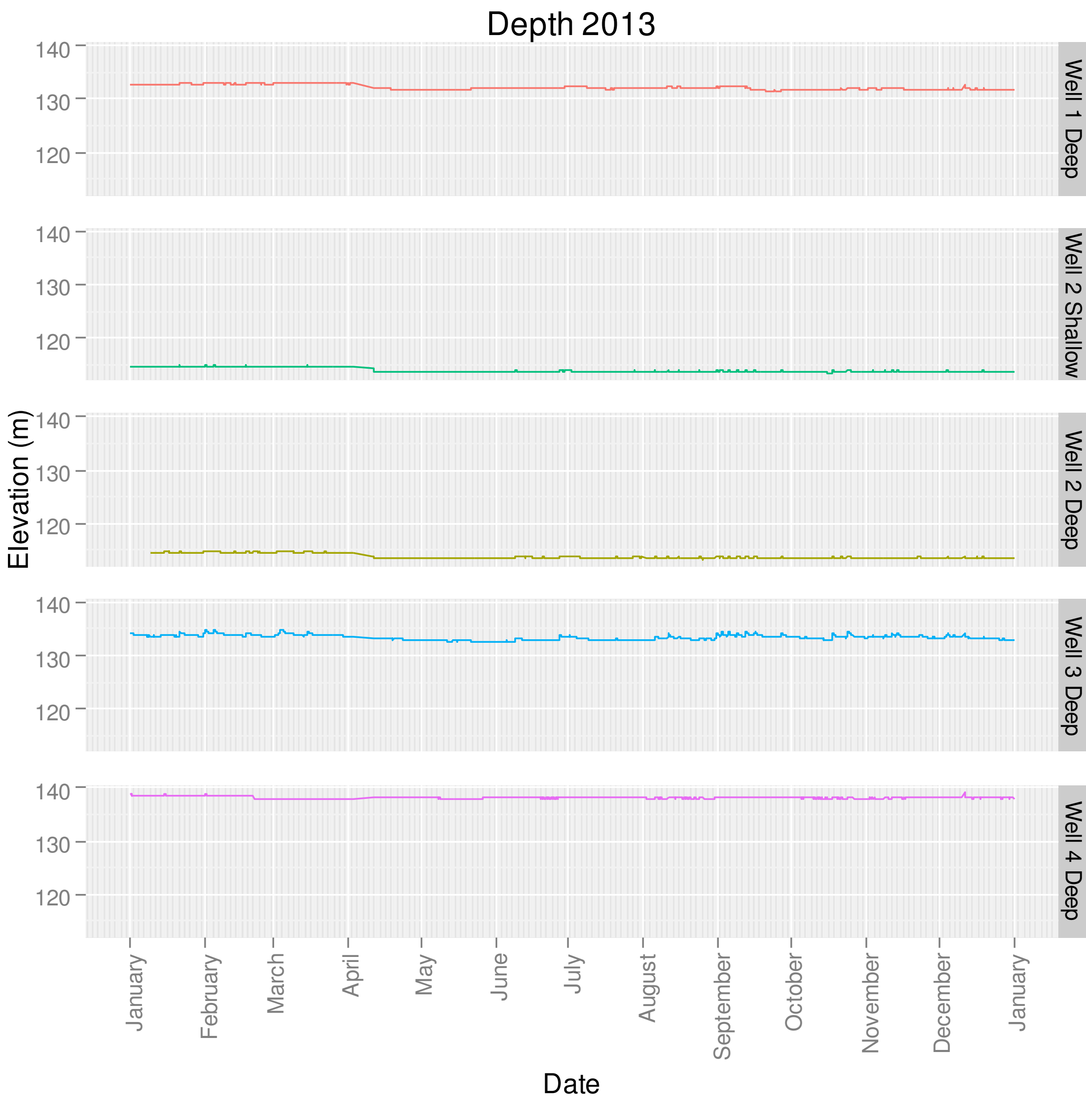
Figure 20: Boxplots of oxidation-reduction potential at Sandy Pond monitoring stations in 2013



Groundwater Elevation

The Sandy Pond monitoring network reports the height of water above the instrument suspended at a known level in the borehole. This water height is mathematically converted to the geodetic elevation of the static water level. Fluctuations in water level are due to changes in the water table.

Figure 21: Water Level Elevations at Sandy Pond monitoring stations in 2013



Because there is no water use in the area around Sandy Pond, stable water levels were observed at each well in 2013 (Figure 21). Slight downward trends were observed at all wells; with further monitoring, it is likely that well recharge will be shown to occur mainly in the spring as snow cover melts.

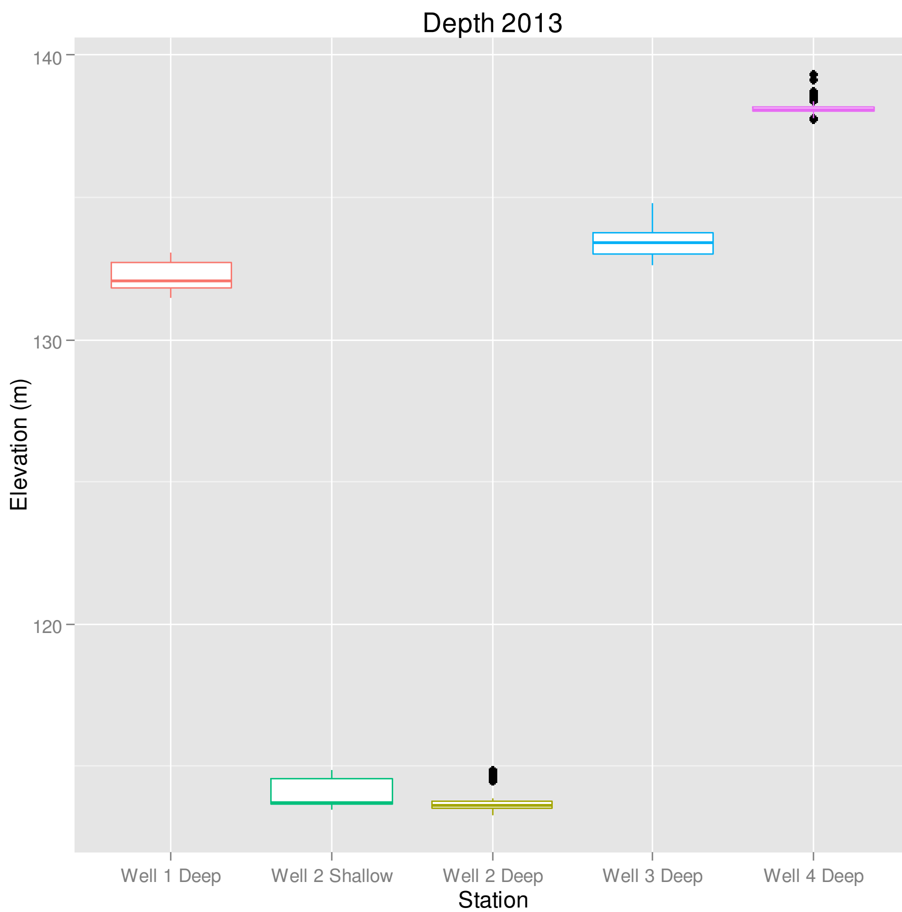
Table 12: Summary statistics of depth at Sandy Pond monitoring stations in 2013

Station	Mean	Median	Min	Max
Well 1 Deep	132.1857	132.0650	131.4862	133.0616
Well 2 Shallow	113.9495	113.7498	113.4821	114.8793

Well 2 Deep	113.8357	113.6258	113.2945	114.8597
Well 3 Deep	133.4164	133.4347	132.5933	134.8164
Well 4 Deep	138.1344	138.1077	137.7581	139.3048

Water level elevation varies at each well according to local geography. Static water level below the ground surface tends to be similar across all monitoring wells. Because of this, water elevation mirrors ground elevation closely. Geographically, Well 4 Deep is at a local highpoint in the Sandy Pond vicinity, while Wells 2 Shallow and 2 Deep are at the local low point – at the natural outflow of Sandy Pond. This is illustrated well in Figure 22.

Figure 22: Boxplots of depth at Sandy Pond monitoring stations in 2013



Conclusions

Rattling Brook Network

Since construction began at the Vale construction site in Long Harbour, the predominant water quality impacts observed have been annual increases in specific conductivity at Big Pond, Bridge, and Plant Discharge stations, variable turbidity levels at Bridge and Plant Discharge stations, and some indications of increasing pH at Big Pond station.

These changes indicate that land use in the area has resulted in dissolved solids and sediments entering Rattling Brook. Much of this change is explained by intensive in-stream habitat compensation work taking place from 2011 to 2012. The work, involving spawning bed creation and dredging of Forgotten Pond intends to enhance the spawning habitat of fish in the river system in the long term but has caused short-term disturbance in water quality.

Over time, it is expected that declining construction activity in and around the river will allow turbidity levels to fall back to near-normal background levels and specific conductivity to plateau. Both Vale and the Department of Environment and Conservation will continue to closely monitor water quality trends in the future.

Sandy Pond Network

Evidence of surface water influence on groundwater quality is evident in Well 2 Shallow, and Well 3 Deep due to the variations in pH and conductivity.

As of 2013, the nickel refinery has yet to be commissioned and no effluent has yet to be discharged into Sandy Pond. As of December 2013, all data can be considered baseline. Discharge into Sandy Pond is expected sometime in 2014.

Path Forward

- Efforts to deploy a turbidity categorization scheme are ongoing. This program will seek to reduce the amount of inconsequential and often erroneous instances of individual turbidity alerts. Instead, turbidity alerts will be automatically categorized into one of three levels of severity. Each individual receiving turbidity alerts can determine which level of severity is of interest to them.
- Maintenance and calibration will be carried out monthly on the Rattling Brook network and quarterly on the Sandy Pond network through 2014. Reports will be generated for each of these deployment periods. Additionally, monitoring equipment will be subjected to proficiency testing in the fall of 2014 to ensure accuracy of measured data.
- Work will continue to develop the Automatic Data Retrieval System to incorporate new capabilities as well as the creation of value-added products using real-time water quality data, remote sensing, and water quality indices.

Appendix

Appendix 1: Deployment Schedule for Rattling Brook and Sandy Pond Monitoring Networks

Deployment	Removal	Duration
Big Pond		
2013-01-01	2013-02-27	57
2013-04-05	2013-05-14	39
2013-05-15	2013-06-20	36
2013-06-21	2013-07-25	34
2013-07-26	2013-08-22	27
2013-08-23	2013-10-03	41
2013-10-04	2013-11-07	34
2013-11-08	2013-12-31	53
Total		321
Deployment Efficiency		88%
Bridge		
2013-01-01	2013-02-27	57
2013-02-28	2013-04-03	34
2013-04-05	2013-05-14	39
2013-05-14	2013-06-20	37
2013-06-21	2013-07-25	34
2013-07-26	2013-08-22	27
2013-08-23	2013-10-03	41
2013-10-04	2013-11-07	34
2013-11-08	2013-12-31	53
Total		356
Deployment Efficiency		98%
Plant Discharge		
2013-01-01	2013-02-27	57
2013-02-28	2013-04-03	34
2013-04-05	2013-05-14	39
2013-05-15	2013-06-20	36
2013-06-21	2013-07-25	34
2013-07-26	2013-08-23	28
2013-08-23	2013-10-03	41
2013-10-04	2013-11-07	34
2013-11-08	2013-12-31	53
Total		356
Deployment Efficiency		98%

Deployment	Removal	Duration
Well 1 Deep		
2013-01-01	2013-04-03	92
2013-04-11	2013-07-31	111
2013-08-02	2013-12-10	130
2013-12-11	2013-12-31	20
Total		353
Deployment Efficiency		97%
Well 2 Shallow		
2013-01-01	2013-04-03	92
2013-04-11	2013-07-31	111
2013-08-02	2013-12-10	130
2013-12-11	2013-12-31	20
Total		353
Deployment Efficiency		97%
Well 2 Deep		
2013-01-01	2013-04-03	92
2013-04-11	2013-07-31	111
2013-08-02	2013-12-10	130
2013-12-11	2013-12-31	20
Total		353
Deployment Efficiency		97%
Well 3 Deep		
2013-01-01	2013-04-03	92
2013-04-11	2013-07-31	111
2013-08-02	2013-12-10	130
2013-12-11	2013-12-31	20
Total		353
Deployment Efficiency		97%
Well 4 Deep		
2013-01-01	2013-04-03	92
2013-04-11	2013-07-31	111
2013-08-02	2013-12-10	130
2013-12-11	2013-12-31	20
Total		353
Deployment Efficiency		97%

Appendix 2: Descriptive Statistics for Rattling Brook Monitoring Network, 2010 – 2013

Year	Station	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Temperature ('C)													
2010	Big Pond	7146	10.08	6.07	9.65	10.10	7.29	0.04	22.40	22.36	0.089138	-1.21028	0.0718
2011	Big Pond	7044	9.58	6.14	9.88	9.69	8.36	-0.02	20.88	20.90	-0.164	-1.38801	0.07312
2012	Big Pond	7563	10.00	7.49	11.28	9.95	10.96	0.00	22.87	22.87	-0.06143	-1.57701	0.086111
2013	Big Pond	7614	9.67	6.75	10.04	9.61	9.67	-0.02	22.17	22.19	-0.04613	-1.36688	0.077373
2010	Below Bridge	8490	8.65	6.73	7.73	8.36	8.78	-0.50	22.84	23.34	0.295272	-1.20464	0.073043
2011	Below Bridge	7830	7.70	6.56	6.44	7.37	8.43	-0.48	22.20	22.68	0.277703	-1.38104	0.074115
2012	Below Bridge	8419	9.52	7.54	9.77	9.32	11.79	-0.51	23.82	24.33	0.096319	-1.43831	0.082214
2013	Below Bridge	8573	9.03	7.17	9.16	8.75	10.54	-0.49	24.98	25.47	0.176011	-1.36891	0.077384
2010	Below Plant Discharge	8462	9.04	6.69	8.12	8.73	8.69	0.02	23.67	23.65	0.306895	-1.16332	0.072742
2011	Below Plant Discharge	8508	8.43	6.74	7.50	8.12	9.21	-0.07	22.89	22.96	0.23582	-1.36052	0.07304
2012	Below Plant Discharge	8268	9.98	7.43	10.16	9.79	11.31	-0.03	24.33	24.36	0.079342	-1.41971	0.08172
2013	Below Plant Discharge	8500	9.01	7.12	9.00	8.74	10.53	-0.03	24.70	24.73	0.159496	-1.39792	0.077223
pH (Units)													
2010	Big Pond	7146	6.22	0.18	6.25	6.24	0.10	5.34	6.80	1.46	-2.14931	6.992045	0.002132
2011	Big Pond	7044	6.29	0.18	6.32	6.32	0.13	5.45	6.74	1.29	-1.93845	4.600538	0.002175
2012	Big Pond	7563	6.48	0.22	6.51	6.49	0.22	5.37	7.14	1.77	-0.49816	-0.13565	0.00253
2013	Big Pond	5928	6.44	0.22	6.44	6.44	0.21	5.02	7.51	2.49	0.243857	1.544323	0.002813
2010	Below Bridge	8490	6.19	0.30	6.24	6.21	0.30	5.22	6.81	1.59	-0.59845	-0.08716	0.003255
2011	Below Bridge	6328	6.16	0.23	6.19	6.17	0.19	5.41	6.81	1.40	-0.5861	0.350583	0.00293
2012	Below Bridge	8417	6.29	0.29	6.29	6.31	0.21	5.15	7.00	1.85	-0.86427	2.033322	0.003144
2013	Below Bridge	8107	6.19	0.24	6.24	6.21	0.24	5.44	6.94	1.50	-0.59334	-0.28564	0.002697
2010	Below Plant Discharge	8460	6.45	0.12	6.44	6.45	0.12	5.95	6.95	1.00	0.433906	0.350829	0.001359
2011	Below Plant Discharge	8508	6.61	0.25	6.57	6.59	0.21	6.07	7.67	1.60	0.959841	1.219762	0.002763
2012	Below Plant Discharge	7856	6.58	0.22	6.58	6.57	0.24	5.92	7.48	1.56	0.683857	1.005844	0.002517
2013	Below Plant Discharge	8499	6.54	0.23	6.57	6.57	0.16	5.45	7.12	1.67	-1.73932	4.144267	0.002538
Specific Conductivity (uS/cm)													
2010	Big Pond	7146	35.2	1.9	35.6	35.4	1.2	27.4	55.7	28.3	-0.86511	3.037424	0.02277

Year	Station	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
2011	Big Pond	7044	43.4	3.9	44.6	43.9	0.9	33.1	57.0	23.9	-1.19645	0.699066	0.046925
2012	Big Pond	7563	53.0	4.9	52.8	53.2	5.8	28.2	73.8	45.6	-0.3289	0.164333	0.056429
2013	Big Pond	7614	54.8	6.6	56.5	55.5	6.1	32.5	77.4	44.9	-0.84785	-0.23226	0.075961
2010	Below Bridge	8489	38.1	5.2	38.0	37.9	3.1	27.4	83.6	56.2	1.971558	12.29776	0.056102
2011	Below Bridge	7831	40.8	5.7	40.6	40.3	4.0	21.2	87.1	65.9	2.499568	13.34628	0.064169
2012	Below Bridge	8390	52.9	9.5	50.1	52.0	7.7	20.2	81.1	60.9	0.719596	-0.69137	0.103306
2013	Below Bridge	8573	55.1	8.3	53.9	54.2	7.1	29.3	116.6	87.3	1.976548	8.651623	0.089714
2010	Below Plant Discharge	8461	46.5	6.9	44.9	45.5	4.6	35.5	99.8	64.3	2.661353	11.2491	0.075436
2011	Below Plant Discharge	8508	53.4	9.5	51.9	52.2	7.0	36.5	147.9	111.4	2.165732	8.967333	0.103344
2012	Below Plant Discharge	8266	69.1	17.4	64.7	66.6	12.1	45.5	202.0	156.5	1.81996	4.941108	0.191912
2013	Below Plant Discharge	8497	73.6	15.2	70.3	71.4	12.5	51.0	158.7	107.7	1.691693	4.177878	0.165438
Total Dissolved Solids (g/l)													
2010	Big Pond	7146	0.0225	0.0012	0.0228	0.0227	0.0007	0.0175	0.0357	0.0182	-0.85833	3.064058	1.46E-05
2011	Big Pond	7044	0.0278	0.0025	0.0285	0.0281	0.0006	0.0212	0.0365	0.0153	-1.19617	0.700119	3.00E-05
2012	Big Pond	7563	0.0339	0.0031	0.0338	0.0340	0.0037	0.0180	0.0473	0.0293	-0.32835	0.166916	3.61E-05
2013	Big Pond	6757	0.0346	0.0043	0.0355	0.0350	0.0043	0.0208	0.0495	0.0287	-0.69453	-0.46049	5.21E-05
2010	Below Bridge	8490	0.0244	0.0033	0.0243	0.0242	0.0021	0.0176	0.0535	0.0359	1.969249	12.27844	3.59E-05
2011	Below Bridge	7831	0.0261	0.0036	0.0260	0.0258	0.0025	0.0136	0.0557	0.0421	2.499222	13.3452	4.11E-05
2012	Below Bridge	8391	0.0338	0.0061	0.0321	0.0333	0.0049	0.0129	0.0519	0.0390	0.719463	-0.69152	6.61E-05
2013	Below Bridge	8573	0.0353	0.0053	0.0345	0.0347	0.0044	0.0187	0.0746	0.0559	1.975256	8.645913	5.74E-05
2010	Below Plant Discharge	8461	0.0297	0.0044	0.0287	0.0291	0.0028	0.0227	0.0639	0.0412	2.661296	11.25021	4.83E-05
2011	Below Plant Discharge	8506	0.0342	0.0061	0.0332	0.0334	0.0044	0.0234	0.0946	0.0712	2.168666	8.994206	6.62E-05
2012	Below Plant Discharge	8265	0.0442	0.0112	0.0414	0.0426	0.0082	0.0291	0.1290	0.0999	1.83186	4.957054	0.000123
2013	Below Plant Discharge	8493	0.0459	0.0129	0.0450	0.0457	0.0080	0.0000	0.1016	0.1016	-0.55324	5.331457	0.000139
DO (mg/l)													
2010	Big Pond	7146	10.68	1.49	10.69	10.68	2.09	8.06	13.53	5.47	0.009074	-1.34027	0.017569
2011	Big Pond	7044	10.99	1.57	10.71	10.91	2.00	8.39	14.42	6.03	0.361697	-1.13251	0.018715
2012	Big Pond	7563	10.86	1.74	10.47	10.82	2.37	8.17	14.69	6.52	0.170724	-1.4472	0.020052
2013	Big Pond	7614	10.74	1.52	10.55	10.71	2.22	8.29	14.43	6.14	0.14679	-1.28535	0.017374
2010	Below Bridge	8487	11.43	1.90	11.36	11.44	2.55	7.81	14.90	7.09	-0.0098	-1.35195	0.02063
2011	Below Bridge	7829	11.74	2.00	11.70	11.74	2.76	8.08	15.11	7.03	0.017256	-1.4708	0.022582
2012	Below Bridge	8418	11.31	2.26	10.95	11.24	3.05	7.54	15.51	7.97	0.199631	-1.3288	0.024615

Year	Station	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
2013	Below Bridge	8573	11.17	1.78	11.04	11.19	2.64	7.65	14.21	6.56	-0.03474	-1.46799	0.019247
2010	Below Plant Discharge	8066	10.94	1.87	10.95	10.97	2.45	7.02	14.48	7.46	-0.08702	-1.2106	0.020849
2011	Below Plant Discharge	8044	11.24	2.08	10.99	11.25	2.80	7.12	14.76	7.64	0.043951	-1.3948	0.023211
2012	Below Plant Discharge	8265	10.91	2.25	10.66	10.93	3.16	6.46	14.45	7.99	0.014445	-1.39212	0.024715
2013	Below Plant Discharge	8280	11.29	1.93	11.24	11.30	2.83	7.28	14.49	7.21	-0.01878	-1.45013	0.021196
Turbidity (NTU)													
2010	Big Pond	7131	2.4	9.6	0.0	0.9	0.0	0.0	116.6	116.6	8.844175	83.87442	0.113292
2011	Big Pond	7042	0.6	1.9	0.0	0.2	0.0	0.0	44.9	44.9	7.57501	110.6648	0.022602
2012	Big Pond	7563	0.2	0.7	0.0	0.1	0.0	0.0	22.0	22.0	13.83802	316.6331	0.007617
2013	Big Pond	7614	0.1	1.2	0.0	0.0	0.0	0.0	84.8	84.8	54.62532	3437.8	0.014034
2010	Below Bridge	8178	10.2	27.0	2.5	4.6	3.7	0.0	445.0	445.0	7.656157	82.72184	0.298349
2011	Below Bridge	7772	4.6	35.6	0.4	1.2	0.6	0.0	1405.0	1405.0	23.43198	661.7566	0.403906
2012	Below Bridge	8417	22.6	75.5	3.4	8.1	5.0	0.0	1437.0	1437.0	9.238951	114.3512	0.822689
2013	Below Bridge	8572	6.4	27.2	2.4	2.5	3.3	0.0	998.0	998.0	17.79233	455.2954	0.29351
2010	Below Plant Discharge	8424	11.5	26.3	3.3	5.8	4.9	0.0	460.0	460.0	6.463881	61.80921	0.286432
2011	Below Plant Discharge	8471	6.7	21.4	1.7	2.8	2.5	0.0	734.0	734.0	13.35278	295.2579	0.232571
2012	Below Plant Discharge	8072	19.4	42.2	4.8	10.2	6.2	0.0	586.0	586.0	5.828673	49.71921	0.469503
2013	Below Plant Discharge	8462	9.9	29.3	4.1	4.4	3.1	0.0	580.0	580.0	8.741708	102.3218	0.318379

Appendix 3: Descriptive Statistics for Sandy Pond Monitoring Network, 2013

Station	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Temperature ('C)												
Well 1 Deep	8439	6.78	0.31	6.87	6.76	0.28	6.30	7.45	1.15	0.011101	-0.96511	0.0034
Well 2 Shallow	8484	6.83	2.88	6.71	6.82	4.12	2.22	11.81	9.59	0.092799	-1.4425	0.031224
Well 2 Deep	8275	6.53	0.26	6.53	6.53	0.39	6.17	6.91	0.74	0.073056	-1.47989	0.002841
Well 3 Deep	8418	6.62	0.06	6.63	6.62	0.07	6.46	7.05	0.59	-0.35184	0.267403	0.000626
Well 4 Deep	8396	6.40	0.07	6.39	6.39	0.09	6.25	6.85	0.60	0.379478	-1.0058	0.000756
pH (Units)												
Well 1 Deep	8439	5.75	0.09	5.76	5.75	0.13	5.51	5.92	0.41	0.003117	-1.44532	0.000969
Well 2 Shallow	8484	5.64	0.21	5.72	5.68	0.12	4.89	5.98	1.09	-1.29385	0.613114	0.002329
Well 2 Deep	8275	8.13	0.15	8.16	8.15	0.06	6.98	8.35	1.37	-2.8199	12.60514	0.001632
Well 3 Deep	8418	5.75	0.10	5.73	5.74	0.09	5.08	6.03	0.95	0.556839	0.007195	0.001059

Station	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Well 4 Deep	8395	7.03	0.54	6.77	6.97	0.28	6.43	8.08	1.65	0.861965	-0.97351	0.005845
Conductivity (uS/cm)												
Well 1 Deep	8439	135	13	136	135	18	116	161	45	0.167044	-1.27415	0.136086
Well 2 Shallow	8484	85	8	85	85	7	62	131	69	0.324087	0.47667	0.091091
Well 2 Deep	8275	228	3	228	228	1	179	233	54	-4.41192	42.98929	0.038295
Well 3 Deep	8418	105	14	102	104	15	84	144	60	0.588952	-0.58781	0.151114
Well 4 Deep	8394	206	66	173	201	43	135	315	180	0.67535	-1.24168	0.72439
Total Dissolved Solids (g/l)												
Well 1 Deep	8439	0.088	0.008	0.088	0.088	0.012	0.075	0.105	0.030	0.169091	-1.27166	8.85E-05
Well 2 Shallow	8484	0.055	0.005	0.055	0.055	0.006	0.040	0.085	0.045	0.339	0.497929	5.92E-05
Well 2 Deep	8275	0.148	0.002	0.148	0.148	0.001	0.116	0.151	0.035	-4.26233	40.77513	2.52E-05
Well 3 Deep	8418	0.068	0.009	0.066	0.067	0.010	0.055	0.094	0.039	0.588163	-0.58605	9.83E-05
Well 4 Deep	8392	0.134	0.043	0.112	0.131	0.028	0.087	0.205	0.118	0.675176	-1.24207	0.000471
Oxidation-Reduction Potential (mV)												
Well 1 Deep	8439	-271.9	51.6	-266.4	-275.7	24.0	-375.2	1.7	376.9	1.590062	5.792695	0.561921
Well 2 Shallow	8484	208.0	184.6	309.0	231.3	142.0	-293.7	461.7	755.4	-0.84751	-0.18835	2.004207
Well 2 Deep	8275	-428.7	108.1	-467.7	-456.1	37.5	-499.5	131.9	631.4	2.440475	5.559188	1.187953
Well 3 Deep	8416	364.2	51.7	375.9	368.0	44.5	119.7	442.0	322.3	-0.86503	0.991474	0.563304
Well 4 Deep	8388	98.5	343.7	349.6	127.6	73.2	-439.7	404.7	844.4	-0.65534	-1.38548	3.752681
Depth (m)												
Well 1 Deep	8439	132.1857	0.4380	132.0650	132.1540	0.3529	131.4862	133.0616	1.5754	0.688512	-0.98771	0.004767
Well 2 Shallow	8484	113.9495	0.4118	113.7498	113.9075	0.1265	113.4821	114.8793	1.3972	0.992069	-0.84111	0.004471
Well 2 Deep	8274	113.8357	0.4537	113.6258	113.7817	0.1426	113.2945	114.8597	1.5652	1.113639	-0.59304	0.004988
Well 3 Deep	8416	133.4164	0.4624	133.4347	133.4011	0.5323	132.5933	134.8164	2.2231	0.243915	-0.57427	0.005041
Well 4 Deep	8345	138.1344	0.2007	138.1077	138.1153	0.1091	137.7581	139.3048	1.5467	0.977651	0.895573	0.002197

Figure 23: Mean Daily Temperature and Total at Argentia Weather Station, near Long Harbour