TECHNICAL MEMORANDUM

DATE:	April 10, 2015	PROJECT NO.	350.0092.000
TO:	K. Bill Clark, NewFields		
FROM:	Joel Jacobson, NewFields		
SUBJECT:	Process Used to Establish Absolute Value Thresholds, Groundwater Monitoring Program, Pinedale Anticline Project Area, Sublette County, Wyoming		

This technical memorandum documents the methods and results for establishing absolute value thresholds that will be used for the Groundwater Pollution Prevention, Monitoring and Response Action Plan (Plan) for the Pinedale Anticline Project Area (PAPA), a natural gas development in Sublette County, Wyoming. Goals and objectives for the Plan were approved by the BLM Pinedale Field Office on June 19, 2014. One of the Plan's goals is to establish a Groundwater Monitoring Program capable of identifying impacts from natural gas activities based on previous groundwater characterization studies and differing levels of risk in different areas of the PAPA. The Program must monitor groundwater for constituents that are: most indicative of impacts from natural gas activities; most likely to appear first at monitoring sites; and, most hazardous to public health and the environment. The specific objective for this goal related to establishing thresholds is:

- **O2.2** – Establish groundwater quality thresholds (actual values and statistically significant changes in concentrations) that, if exceeded, trigger an action that is designed to prevent undesirable change to usable water (i.e., BLM's definition of usable water at <10,000 milligrams per liter Total Dissolved Solids).

The following subsections present the methods and results used to establish absolute value thresholds for the 19 parameters included in the Groundwater Monitoring Program.

METHODS

Absolute value thresholds are single, parameter-specific numerical values applied to all wells in the monitoring network. Two methods were considered to determine absolute value thresholds: (a) defining absolute value thresholds as the WOGCC notification level for dissolved methane and as one-half of applicable water quality standards for other parameters; and (b) statistically computed absolute value thresholds. To determine the appropriate method, parameters in Table 1, Appendix K of WOGCC's baseline groundwater monitoring rule (WOGCC, 2014) were separated into three groups based on a flow chart (see Figure 4-13 of the Groundwater Monitoring Program; NewFields, 2015). If a parameter is not part of the core or supplemental list, an absolute value threshold is not required. For parameters that have a National Primary Drinking Water Standard (EPA MCL), DEQ Standard, or WOGCC Notification Level but are not likely to appear first at monitoring points, the absolute value threshold was set as one-

half of the applicable standard. For the remaining parameters, absolute value thresholds were established through statistical analysis of existing data.

An absolute value threshold was not calculated for bromide because a standard does not exist and there is insufficient existing data within the PAPA to calculate a value. Bromide will be evaluated on an intra-well basis using a statistically significant trend threshold (see Section 4.4.2 of NewFields, 2015). In addition, absolute value thresholds were calculated using Wasatch Formation data and are not applicable to monitoring wells screened in alluvial material. Absolute value thresholds were not calculated for alluvial monitoring wells because insufficient water quality data exists for alluvial groundwater in the monitoring boundary. Data collected from alluvial monitoring wells will be evaluated using one-half the applicable standard or on an intra-well basis using a statistically significant trend threshold.

NewFields applied statistical background techniques using EPA's ProUCL software (EPA, 2013) to calculate absolute value thresholds for six (6) of the 19 parameters involved in the Groundwater Monitoring Program, including: alkalinity, calcium, chloride, potassium, sodium, and total dissolved solids. AMEC (2013) concluded that no widespread impact to groundwater in the PAPA is evident as a result of natural gas activities. Despite this conclusion, groundwater quality data collected pursuant to BLM's 2000 and 2008 RODs (BLM, 2000; BLM, 2008a; BLM 2008b) was subjected to a series of rigorous and thorough outlier analyses. The objective of these analyses was to exclude and remove any measurement which is actually or potentially above background conditions in the PAPA. The investigated dataset included annual groundwater samples collected by the Sublette County Conservation District (SCCD) on behalf of the Operators from 2004 to 2013 and data collected as part of AMEC (2012) and AMEC (2013) from 2010 through 2012. This dataset is compiled in the Pinedale Environmental Data Management System (EDMS), a database structure hosted in Microsoft Access (see Section 1.7.3 of NewFields, 2015).

For calculating absolute value thresholds, sample results from the Pinedale EDMS were compiled for each parameter listed above into separate datasets. The objective of the analysis is to determine background groundwater quality thresholds for previously defined monitoring areas in the PAPA (see Section 4.2.3 of NewFields, 2015). Sample results from wells located outside of these monitoring areas were not considered in the analysis. These exclusions were made in order to avoid any undue bias or distortion associated with unrepresentative data collected outside of the monitoring areas.

To remove sample results that may bias or distort threshold values and determine if geographical differences exists for the evaluated parameters in the PAPA, outlier and spatial analyses were performed on each dataset prior to establishing absolute value thresholds. After completion of these analyses, a background threshold analysis was performed using ProUCL to establish the absolute value threshold for the six parameters. Each of these analyses is described in the following subsections.

Outlier and Spatial Analysis

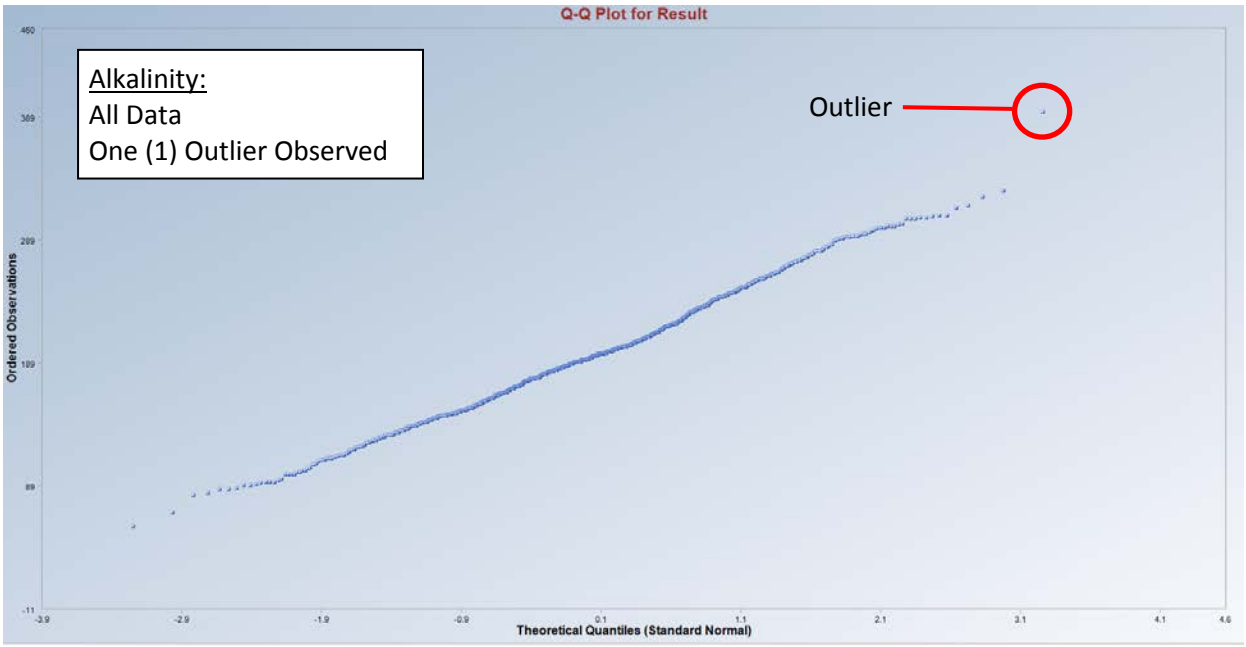
Statistical analyses of the investigated data were initiated by identifying potential outlier values. Outlier data points can distort statistics and yield inflated background threshold values. Outliers can occur for several reasons, including: 1) measurement recording errors; 2) measurement from an impacted well; or 3) rare or unexpected event (Helsel and Hirsch, 2002). To avoid inflated or unrepresentative background threshold values, all outliers were removed from the datasets in two stages.

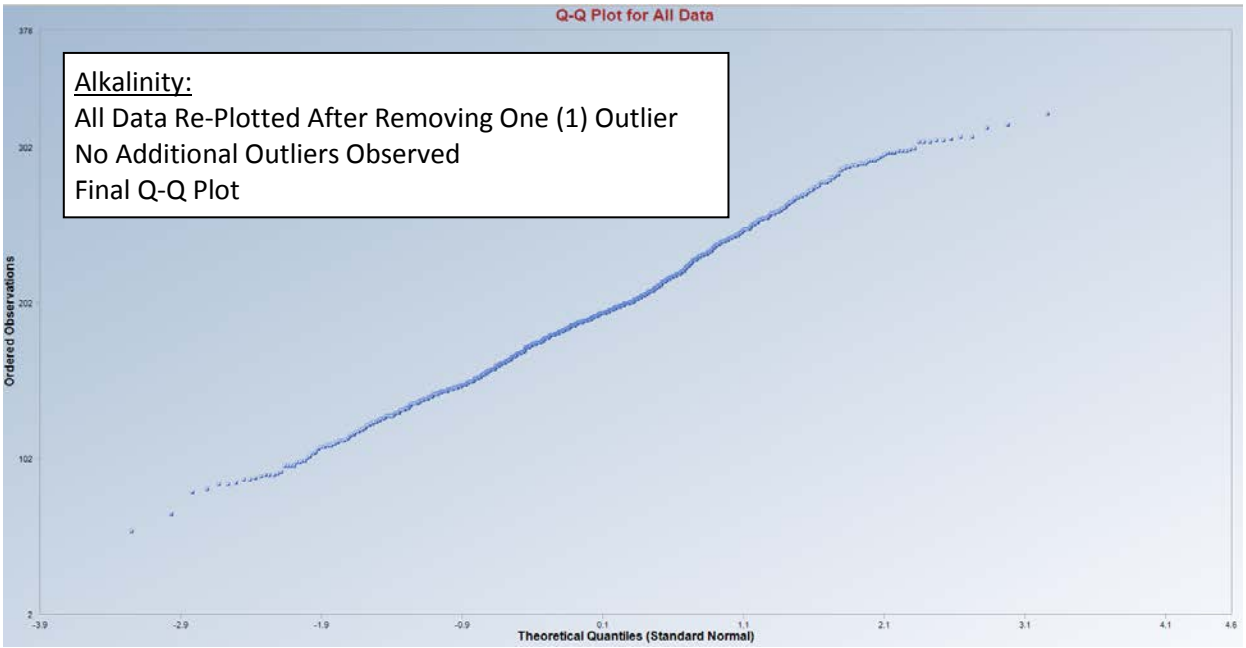
In the first stage, wells enrolled in DEQ's Voluntary Remediation Program (VRP) were identified, as listed in the chart below. These wells were assumed to be potentially impacted, and thus, their associated data were removed from the dataset.

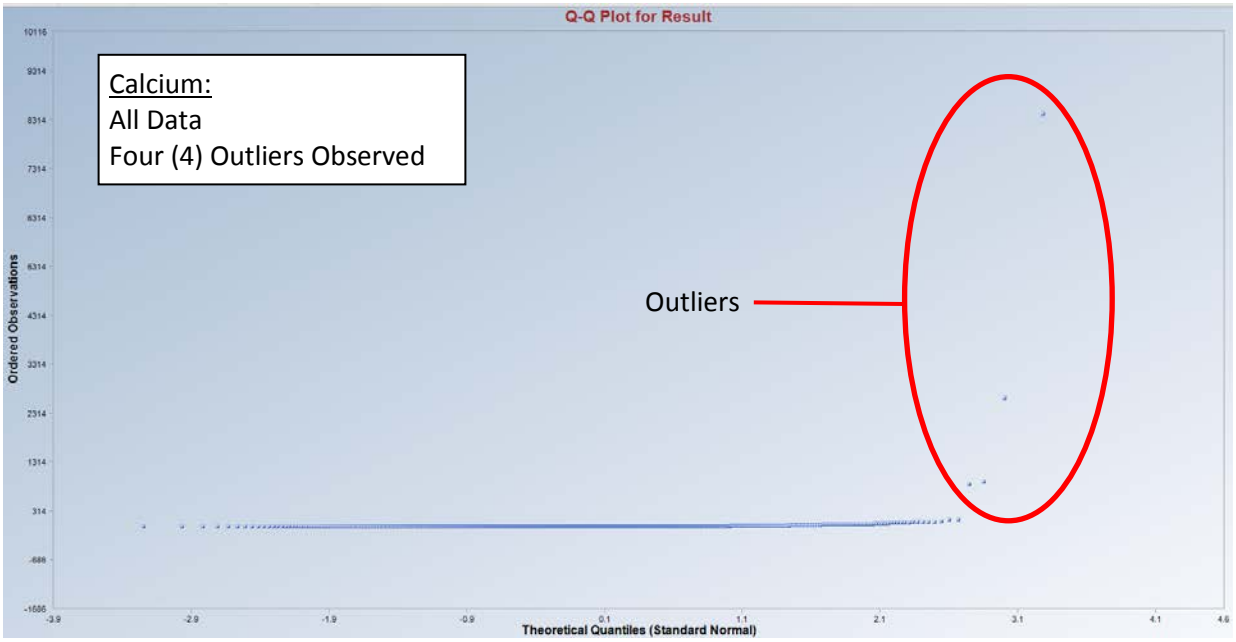
Well ID	SCCD ID	Date Enrolled in VRP
MS 10-33	AMI166	10/15/2007
RS 1-4	AMI078	10/15/2007
RS 11-14	AMI190	10/15/2007
RS 15-12	AMI132	2/24/2009
WB 7-15D	AMI237	10/15/2007

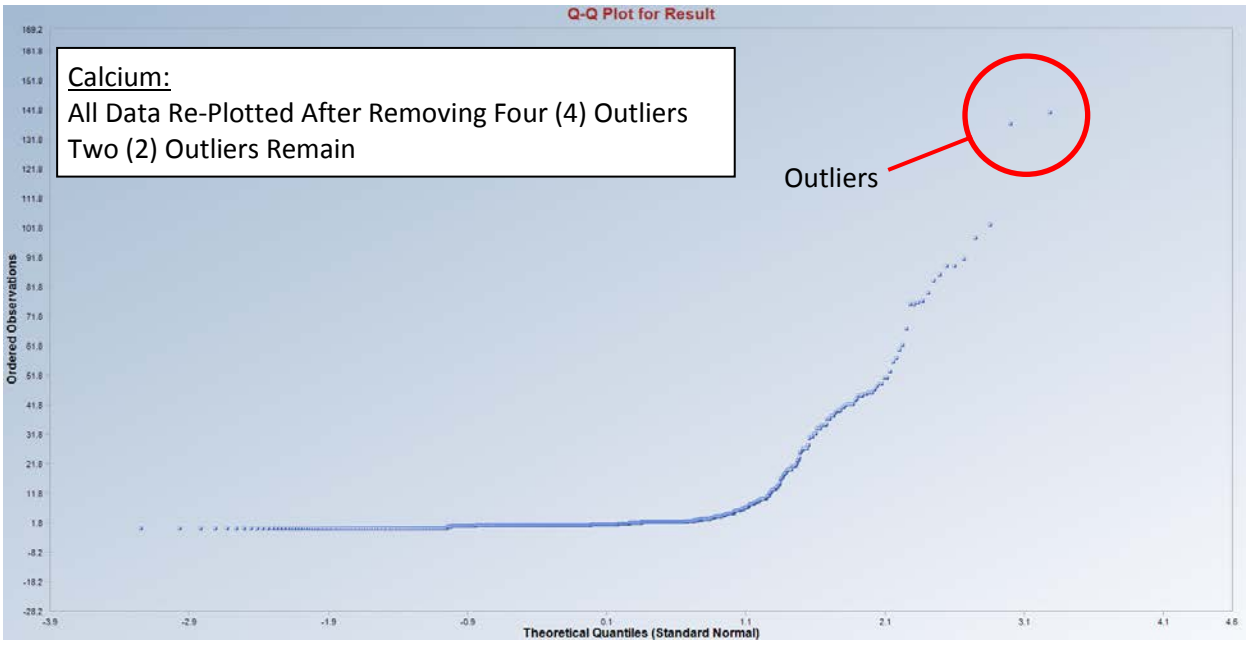
In the second stage, quantile-quantile (Q-Q) probability plots1 were used to visually identify outliers. On a Q-Q plot, elevated measurements that are separated from the majority of data were considered outliers and removed from the dataset. The following images are "screen shots" of parameter-specific Q-Q plots generated using EPA's Scout software (EPA, 2009; EPA, 2010). In these images, dots within red circles are outliers. Each time an outlier is removed, the Q-Q plot is reconstructed to identify if other outliers remain. This process continued until no outlier could be visually detected on the Q-Q plot.

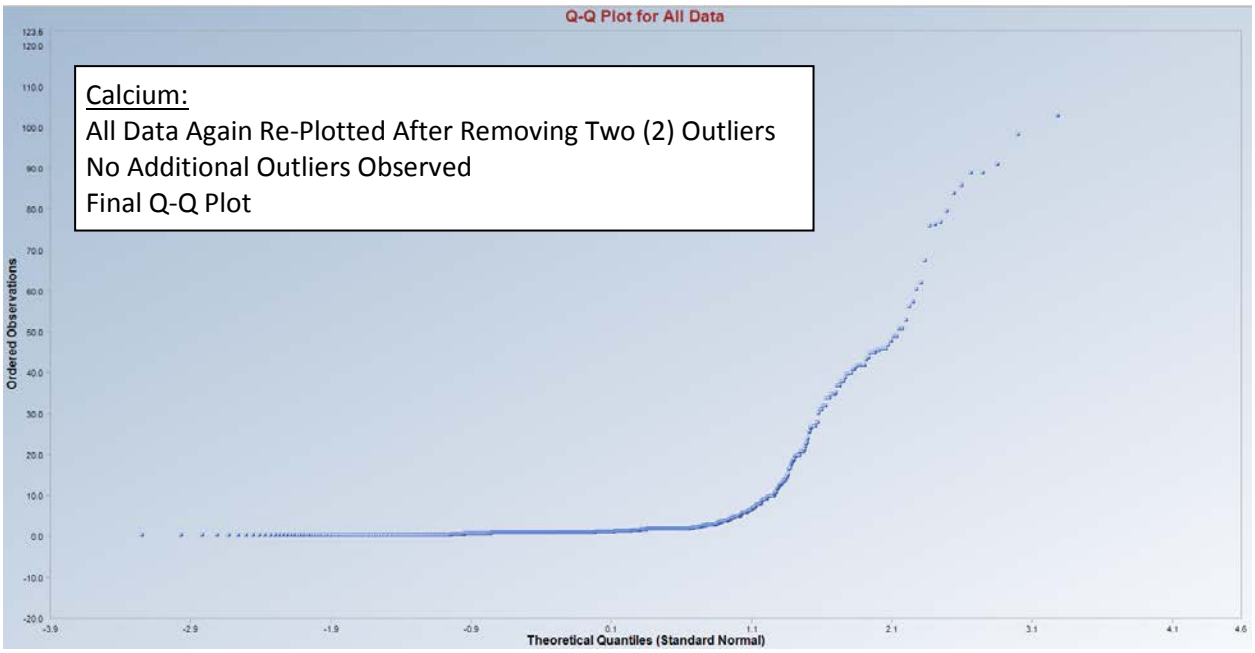
1 Quantile-Quantile or Q-Q plot is a type of a statistical probability plot that displays the investigated data in an ascending order versus their corresponding theoretical quantiles based on an assumed distribution. The most common Q-Q plots are based on assumed normal distributions. In such cases, if a Q-Q plot forms a straight line, then the investigated data are considered as being normally distributed. Q-Q plots with large gaps and/or segmented portions with different slopes are indicative of multiple populations. For more information about probability plots, reviewers are referred to DON (2004; Section 3.3.4)

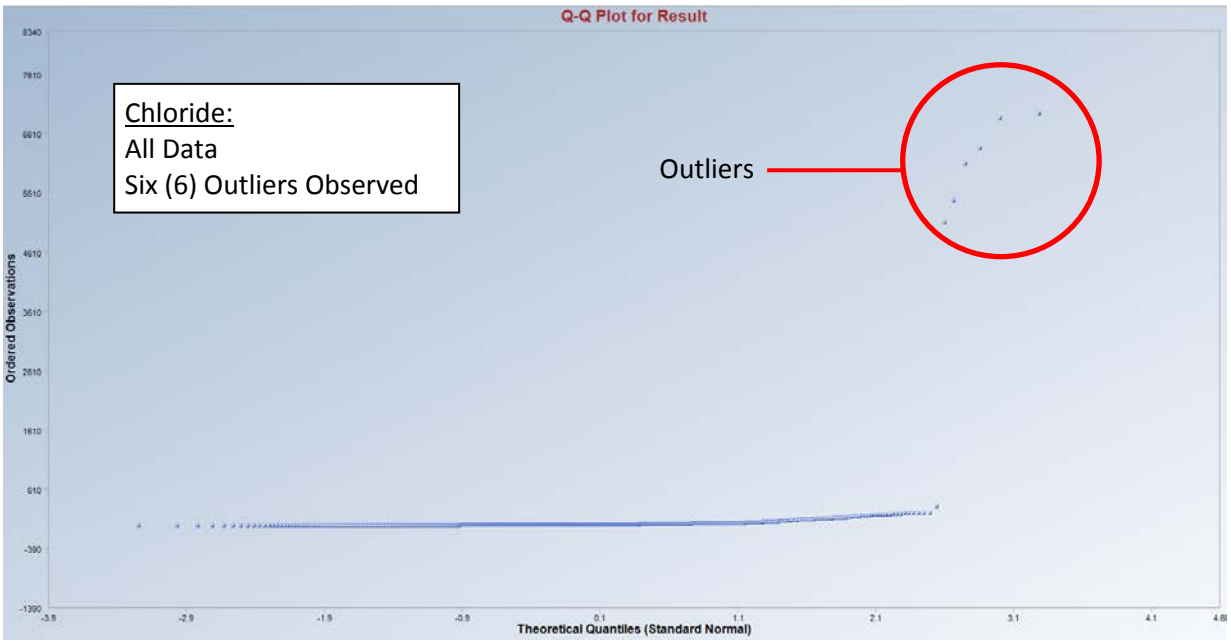

Q-Q Plot for Result
Alkalinity:
All Data
One (1) Outlier Observed
Outlier
Ordered Observations
Theoretical Quantiles (Standard Normal)

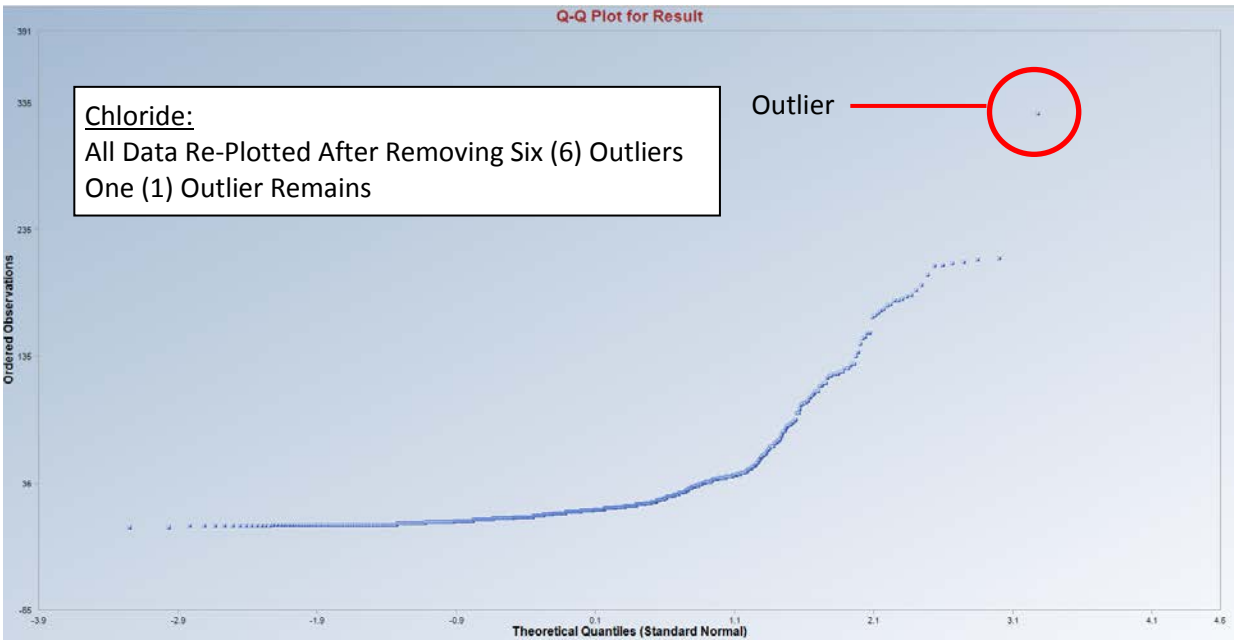

Q-Q Plot for All Data
Alkalinity:
All Data Re-Plotted After Removing One (1) Outlier
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

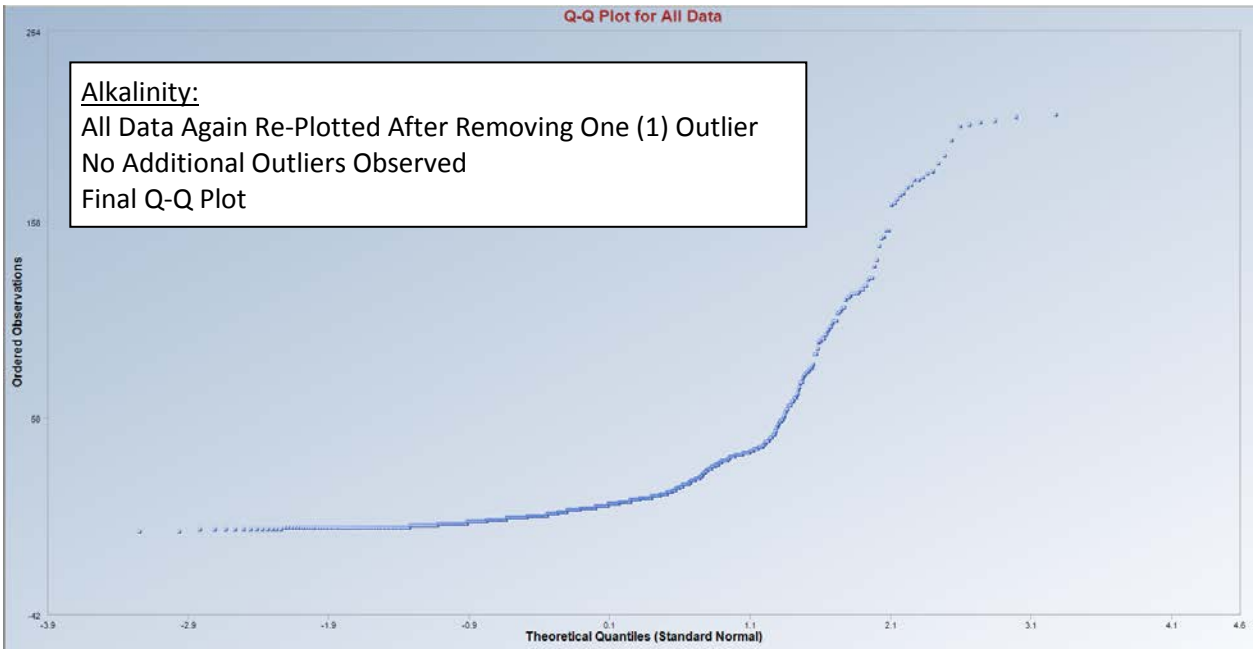

Q-Q Plot for Result
Calcium:
All Data
Four (4) Outliers Observed
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

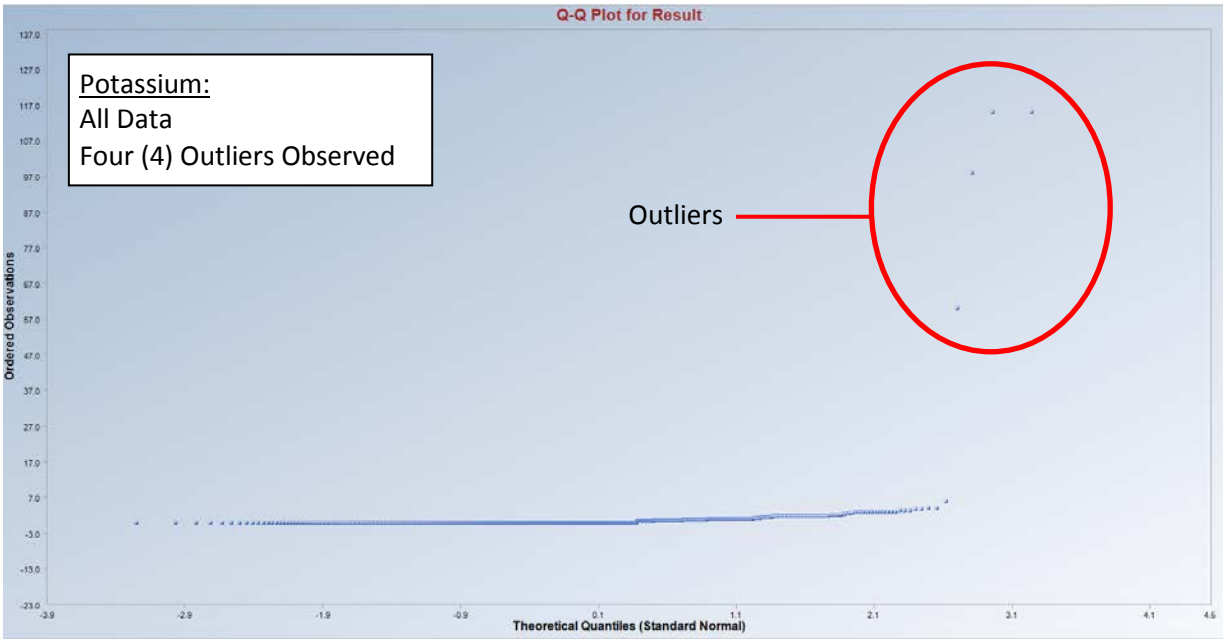

Q-Q Plot for Result
Calcium:
All Data Re-Plotted After Removing Four (4) Outliers
Two (2) Outliers Remain
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

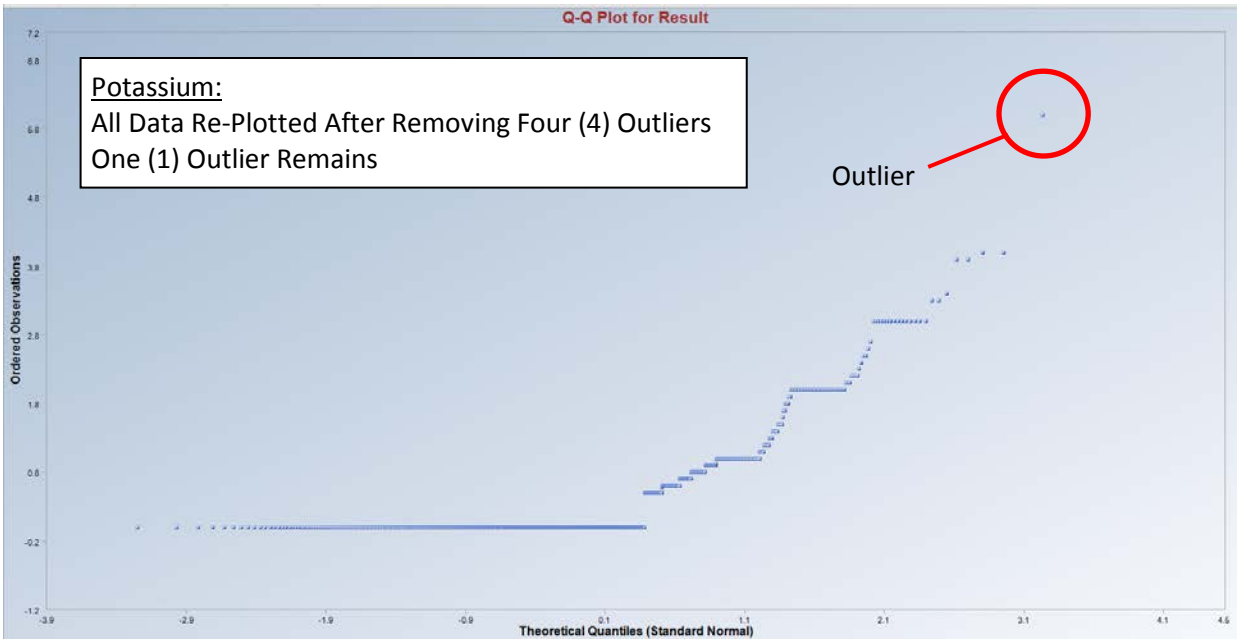

Q-Q Plot for All Data
Calcium:
All Data Again Re-Plotted After Removing Two (2) Outliers
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

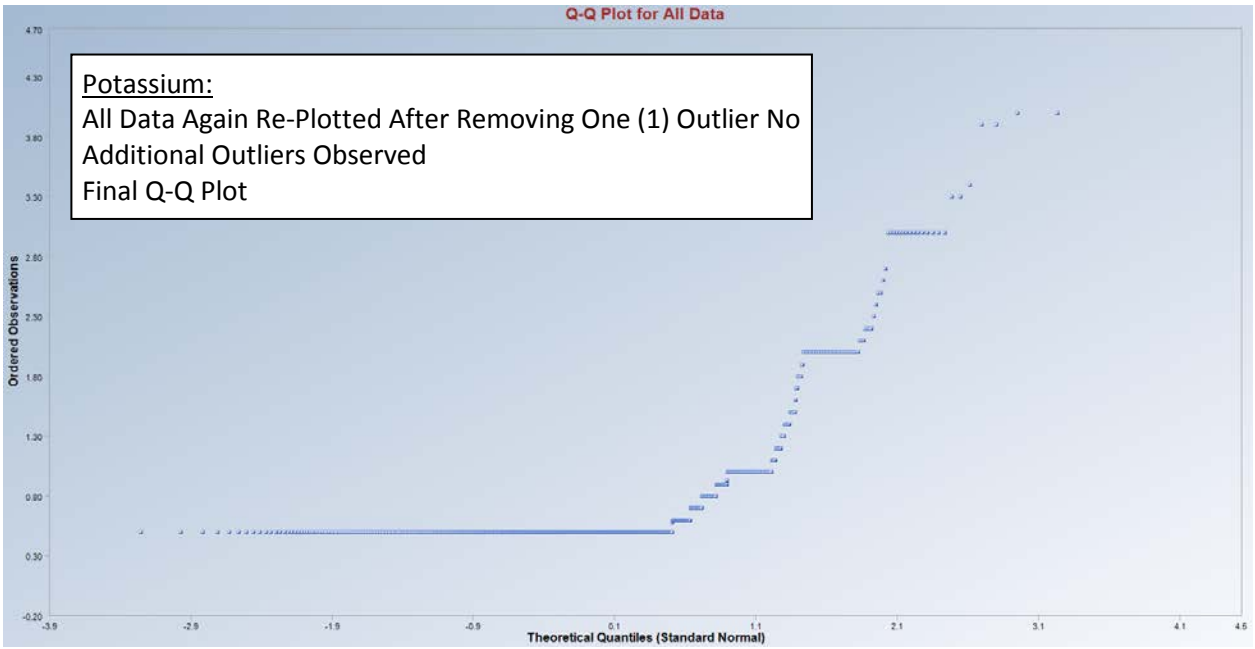

Q-Q Plot for Result
Chloride:
All Data
Six (6) Outliers Observed
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

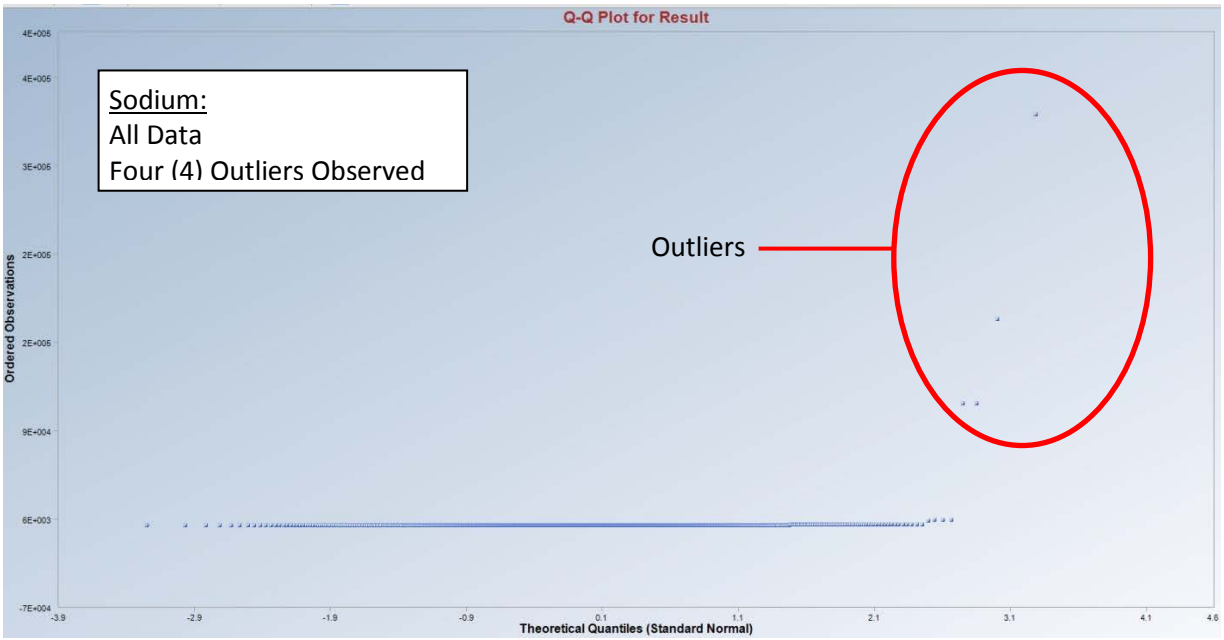

Q-Q Plot for Result
Chloride:
All Data Re-Plotted After Removing Six (6) Outliers
One (1) Outlier Remains
Outlier
Ordered Observations
Theoretical Quantiles (Standard Normal)

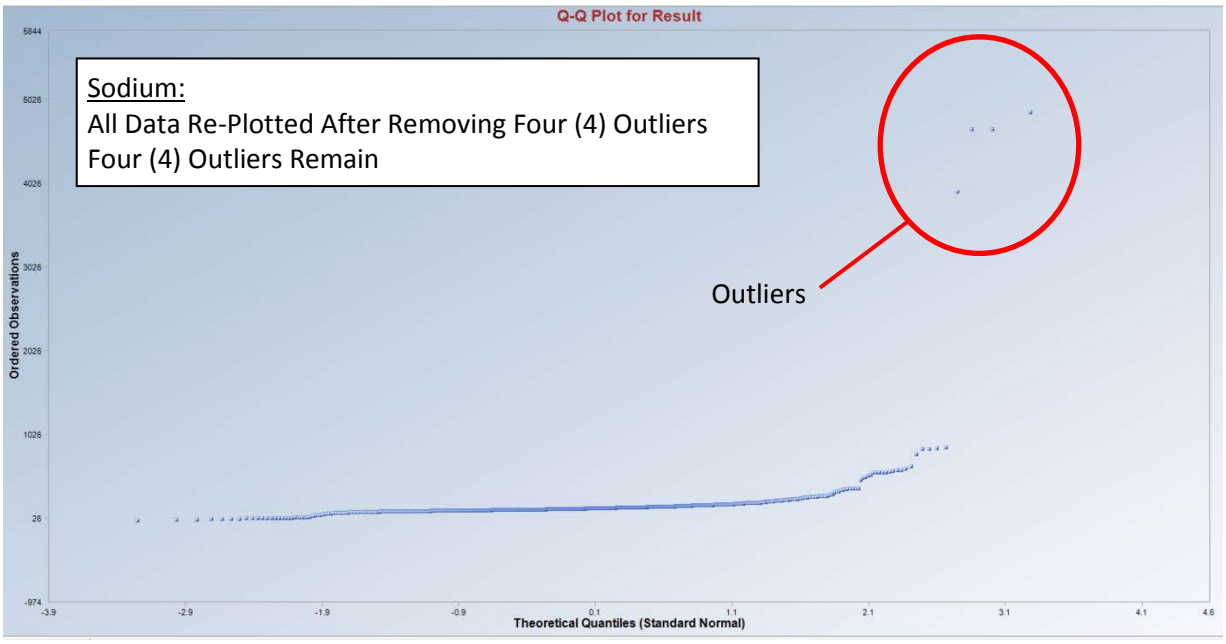

Q-Q Plot for All Data
Alkalinity:
All Data Again Re-Plotted After Removing One (1) Outlier
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

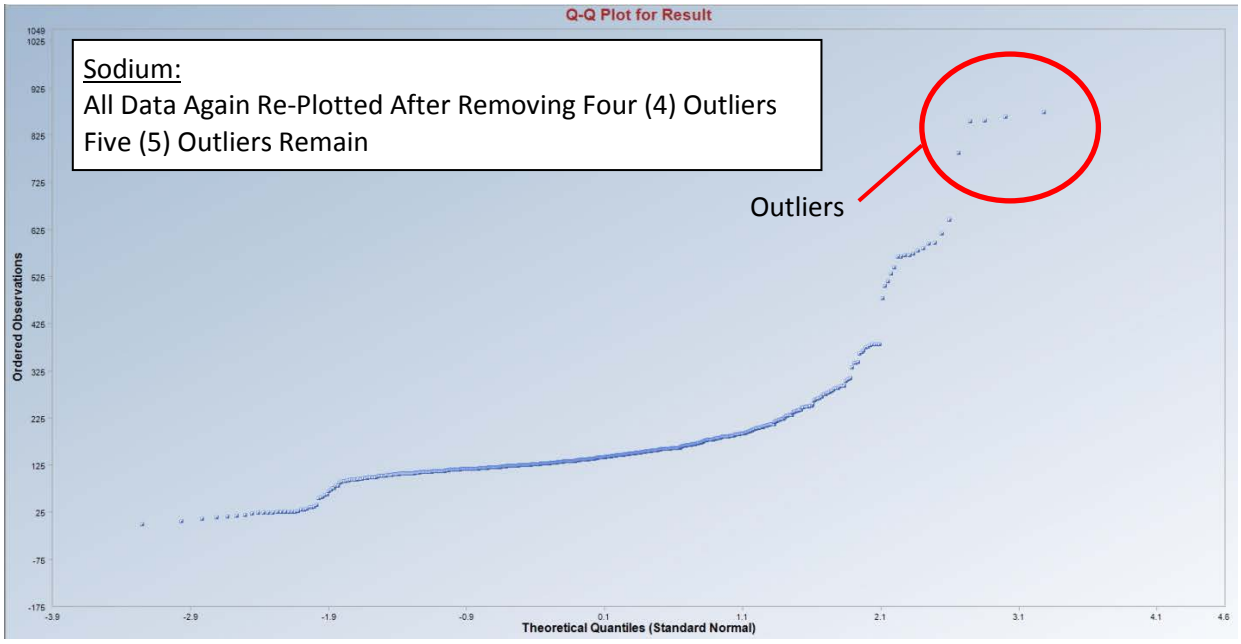

Q-Q Plot for Result
Potassium:
All Data
Four (4) Outliers Observed
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

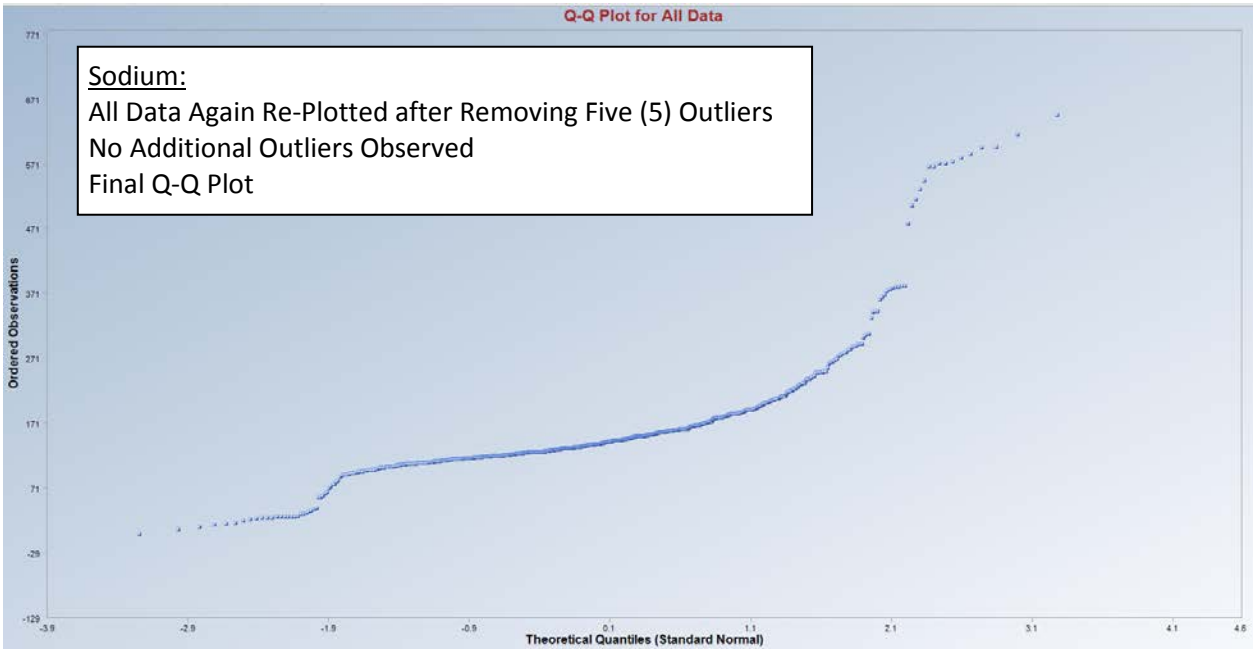

Q-Q Plot for Result
Potassium:
All Data Re-Plotted After Removing Four (4) Outliers
One (1) Outlier Remains
Outlier
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for All Data
Potassium:
All Data Again Re-Plotted After Removing One (1) Outlier No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

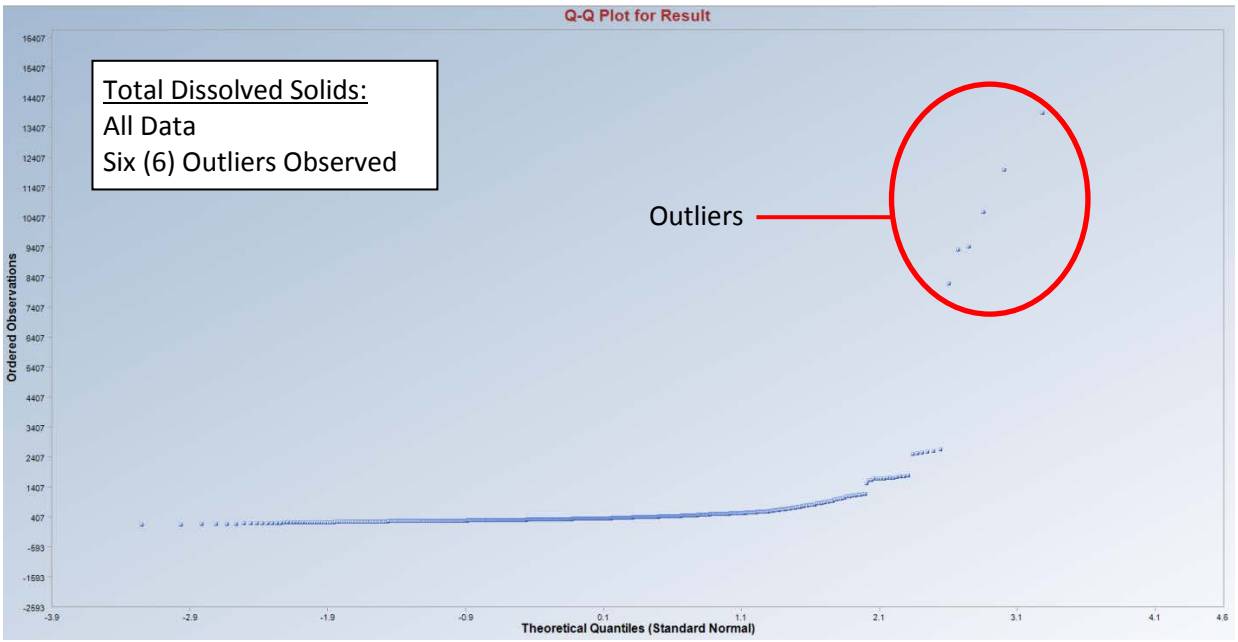

Q-Q Plot for Result
Sodium:
All Data
Four (4) Outliers Observed
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

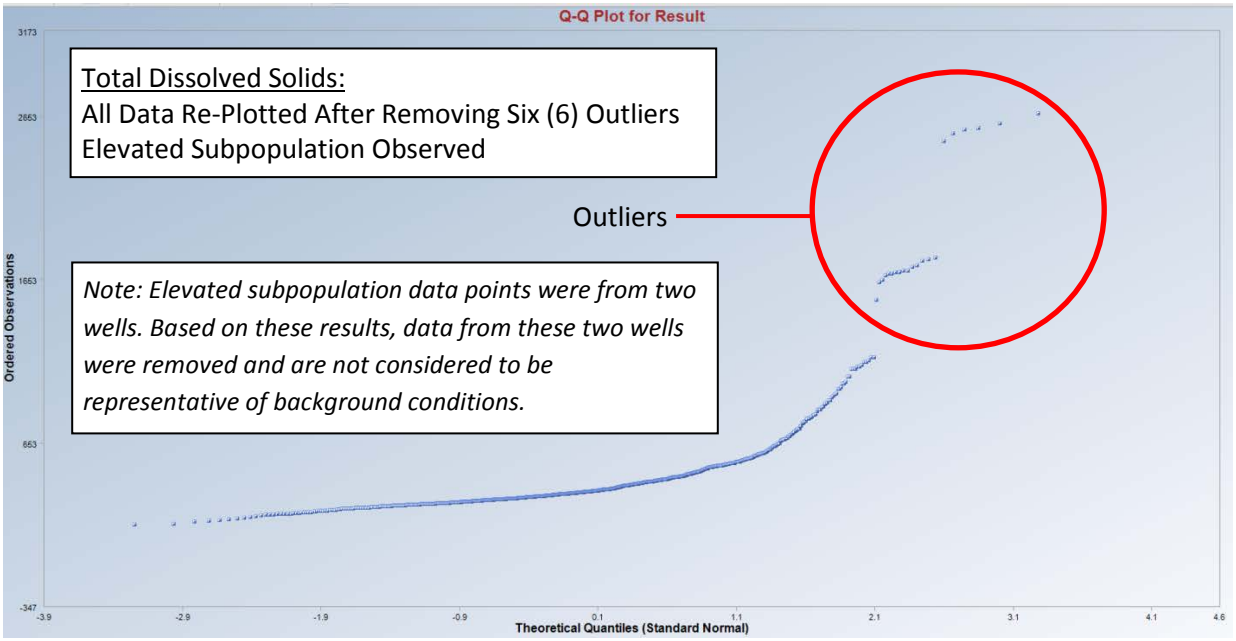

Q-Q Plot for Result
Sodium:
All Data Re-Plotted After Removing Four (4) Outliers
Four (4) Outliers Remain
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

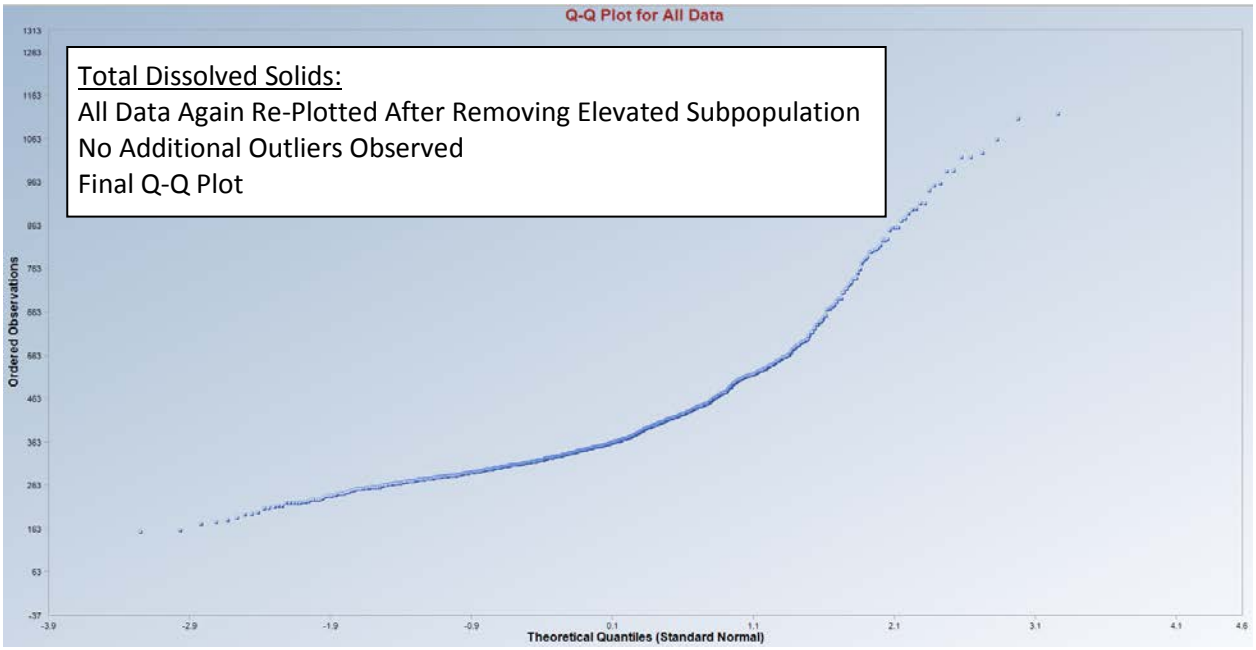

Q-Q Plot for Result
Sodium:
All Data Again Re-Plotted After Removing Four (4) Outliers
Five (5) Outliers Remain
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for All Data
Sodium:
All Data Again Re-Plotted after Removing Five (5) Outliers
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

TOTAL DISSOLVED SOLIDS, ALL DATA; SIX (6) OUTLIERS OBSERVED:







After outliers were removed, the remaining data were separated based on the defined monitoring areas (see Section 4.2.3 of NewFields, 2015) into North Zone, South Zone, and River Corridor Envelope (RCE). An analysis of variance (ANOVA) test was then performed for each parameter to determine if statistically significant differences exist between measurements in the three areas.

The ANOVA test is a commonly used method of comparing the means of multiple groups of data (Field, 2009). The test is performed by producing an F statistic, which is the ratio of the variance calculated between the group means to the variance calculated within the groups. If the groups to be compared have similar means, the F statistic will be small, otherwise, F will be large. Each F statistic is associated with a p-value which is the probability of obtaining that F statistic. The p-value is compared to a pre-defined significance level to determine if a statistically significant difference exists between the group means. In this work, a 5 percent significance level was used for the test, thus if the calculated p-value is less than or equal to 0.05, there is a statistically significant difference between the mean values in the three areas.

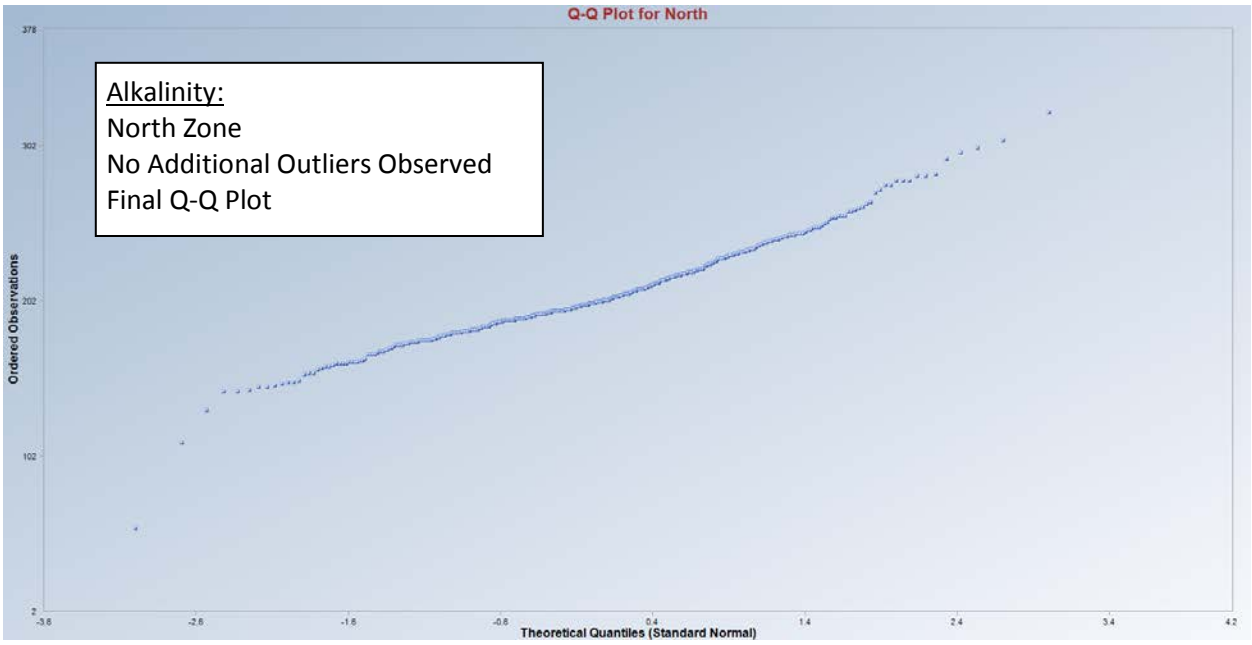
When the ANOVA test indicates that at least one of three areas are significantly different from others, *post-hoc* pair-wise comparisons can be performed to identify which pair of areas causes the significant difference. *Tukey post-hoc* comparison was used for this analysis, where for each parameter, mean values for any two areas are compared. Each comparison produces a *Tukey* p-value. Differences between two areas are considered as statistically significant if their corresponding *Tukey* p-value is less than or equal 5 percent. The following table presents results of the *post-hoc* pair-wise comparisons:

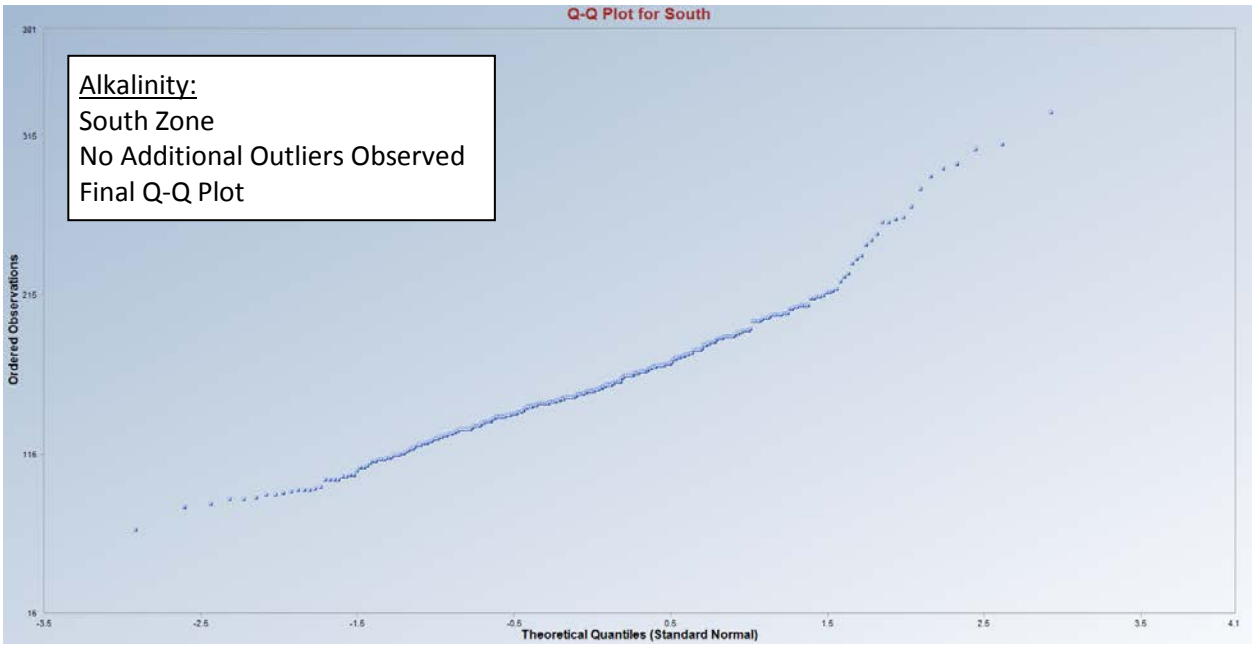
Analyte	Area (I)	Area (J)	Mean Difference (I-J)	p-value
Alkalinity, Total as CaCO3	North	RCE	-15.5	0.00
Alkalinity, Total as CaCO3	North	South	45.5	0.00
Alkalinity, Total as CaCO3	RCE	South	61.0	0.00
Calcium	North	RCE	-3.3	0.01
Calcium	North	South	1.3	0.21
Calcium	RCE	South	4.6	0.00
Chloride	North	RCE	-3.0	0.01
Chloride	North	South	-39.9	0.00
Chloride	RCE	South	-36.9	0.00
Potassium	North	RCE	-0.2	0.00
Potassium	North	South	0.0	0.62
Potassium	RCE	South	0.3	0.00
Sodium	North	RCE	8.5	0.03
Sodium	North	South	-36.3	0.00
Sodium	RCE	South	-44.8	0.00
Total Dissolved Solids	North	RCE	17.9	0.16
Total Dissolved Solids	North	South	-96.1	0.00
Total Dissolved Solids	RCE	South	-114.0	0.00

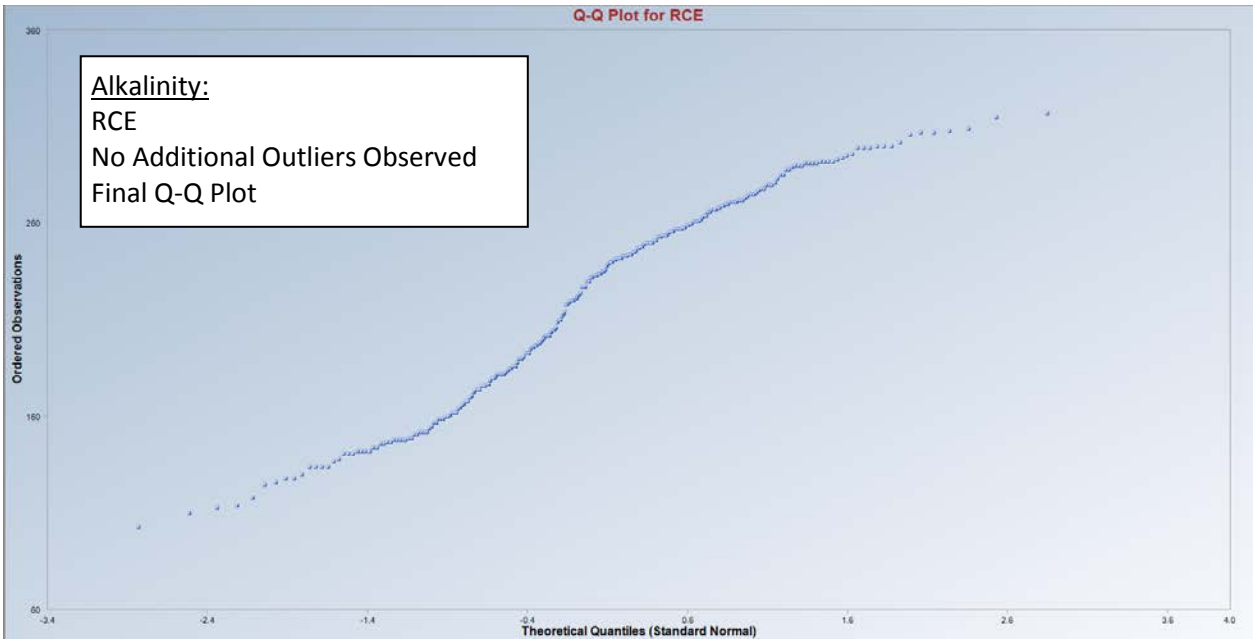
Note: Highlighted (green) values represent a statistically significant difference.

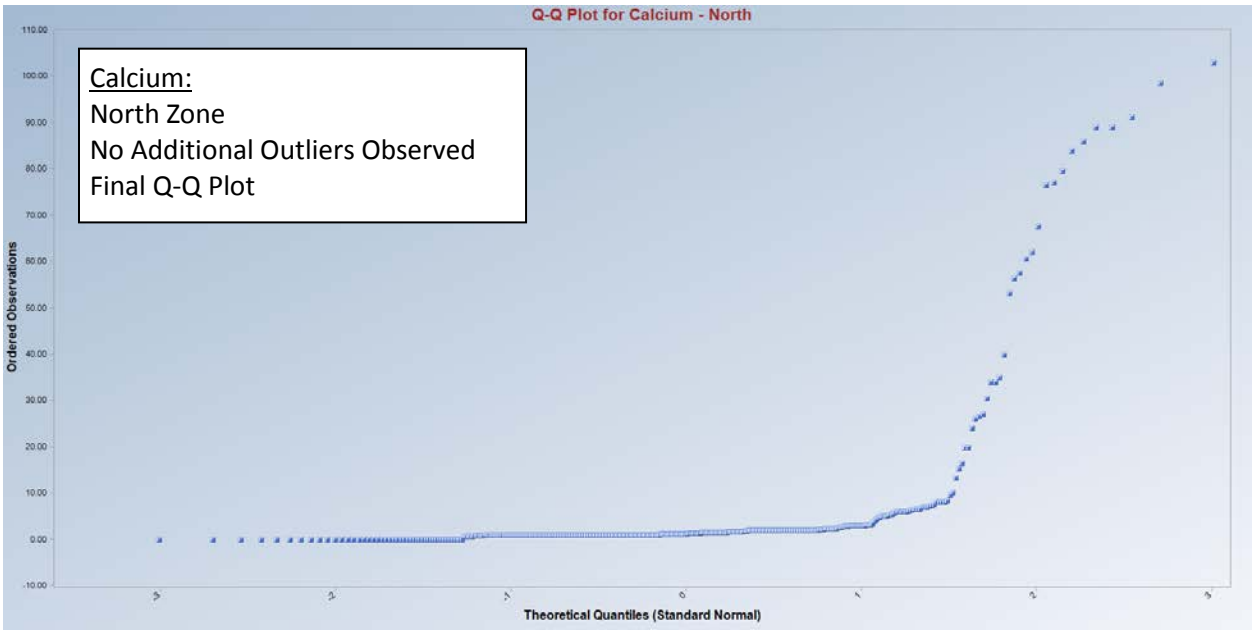
Based on results of the ANOVA/*post-hoc* pair-wise comparisons, there is a statistically significant difference between the three monitoring areas in the PAPA for a majority of the parameters. Therefore, area-specific absolute value thresholds were calculated for each parameter.

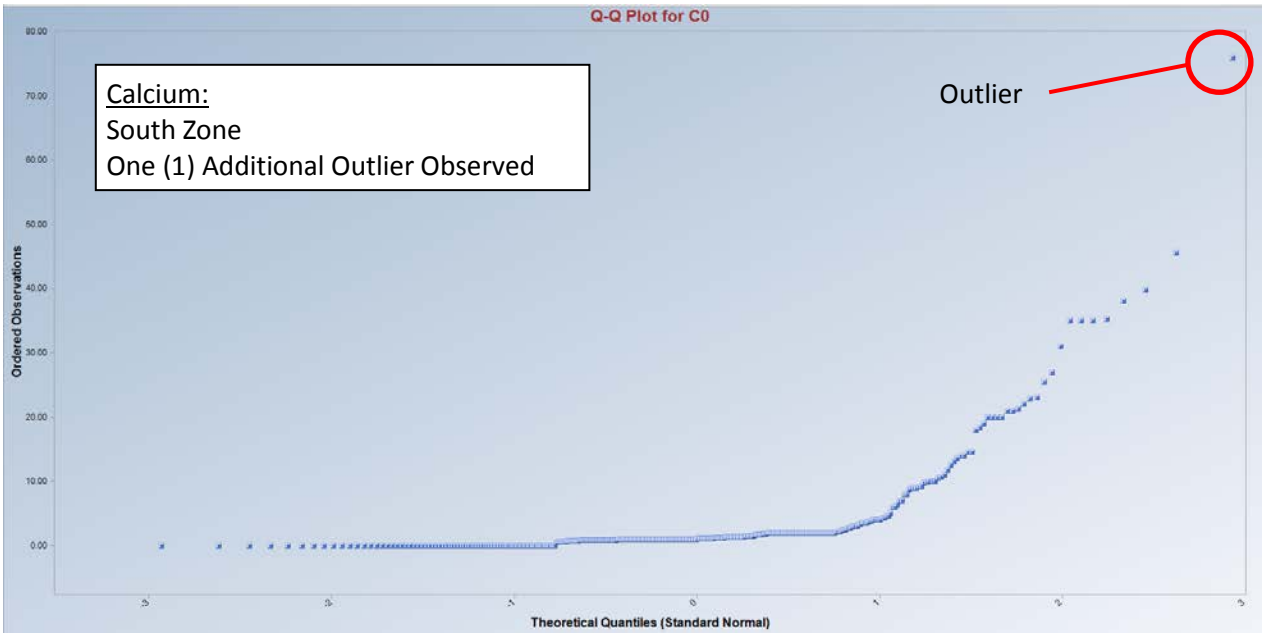
Prior to absolute threshold analysis, parameter datasets in each monitoring area were re-analyzed using Q-Q plots to remove any remaining area-specific outliers. The following images are “screen shots” of Q-Q plots generated using EPA’s Scout software (EPA, 2009; EPA, 2010) for each parameter of concern in each monitoring area; potential outliers are highlighted with red circles.

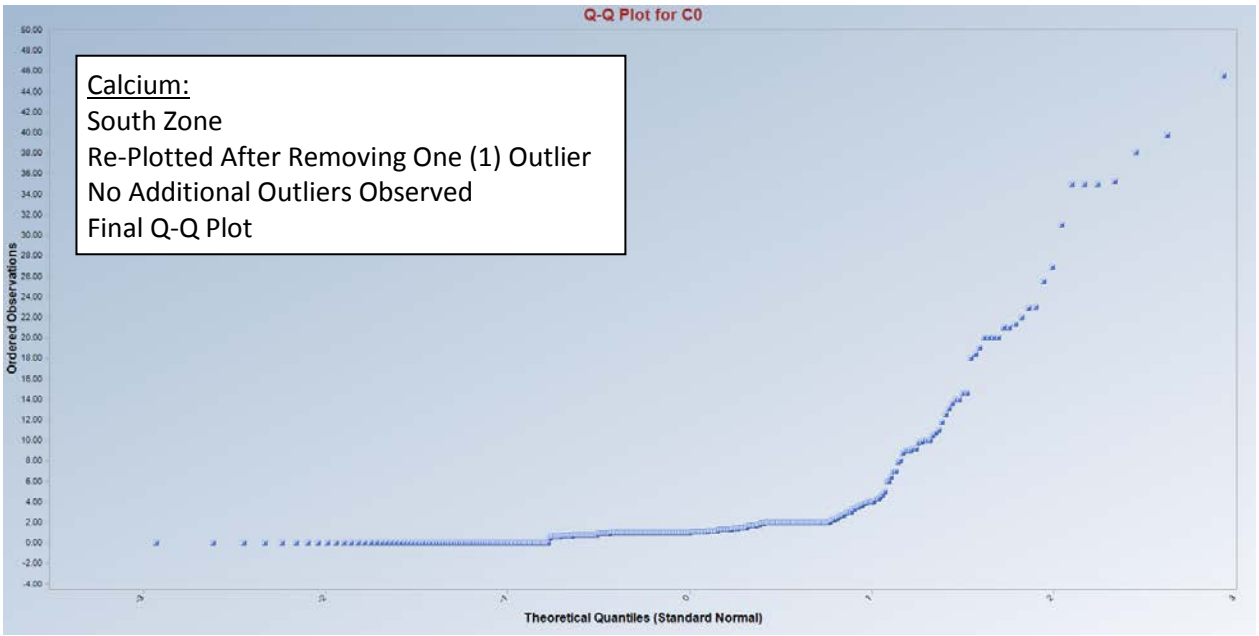

Q-Q Plot for North
Alkalinity:
North Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

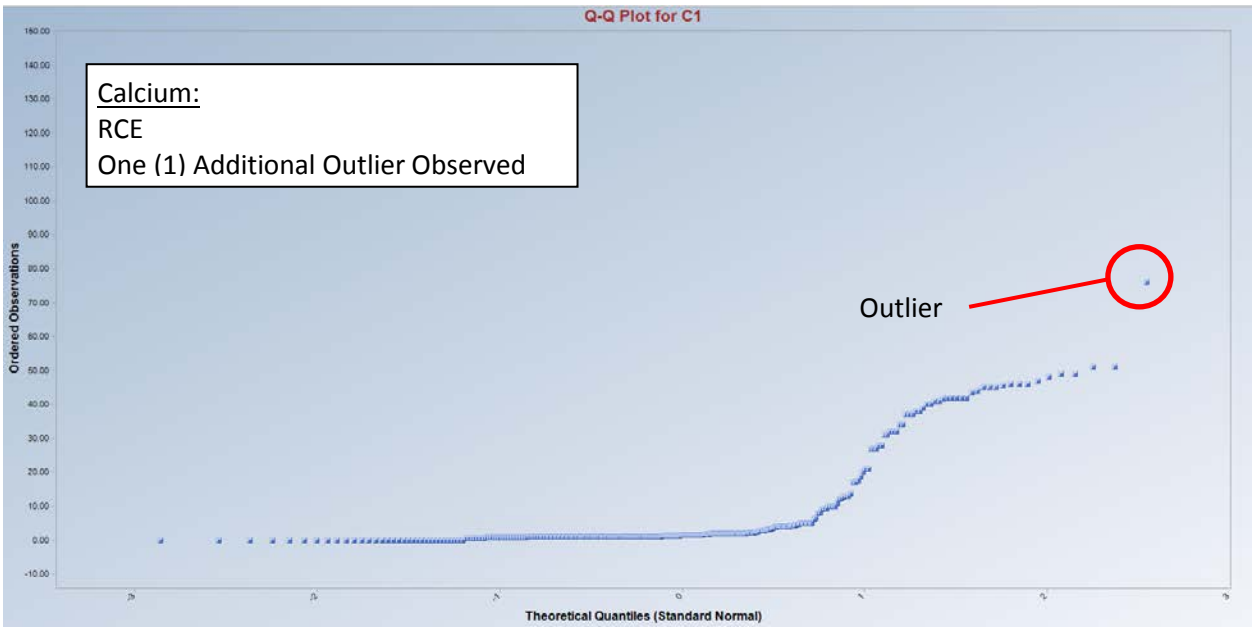

Q-Q Plot for South
Alkalinity:
South Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

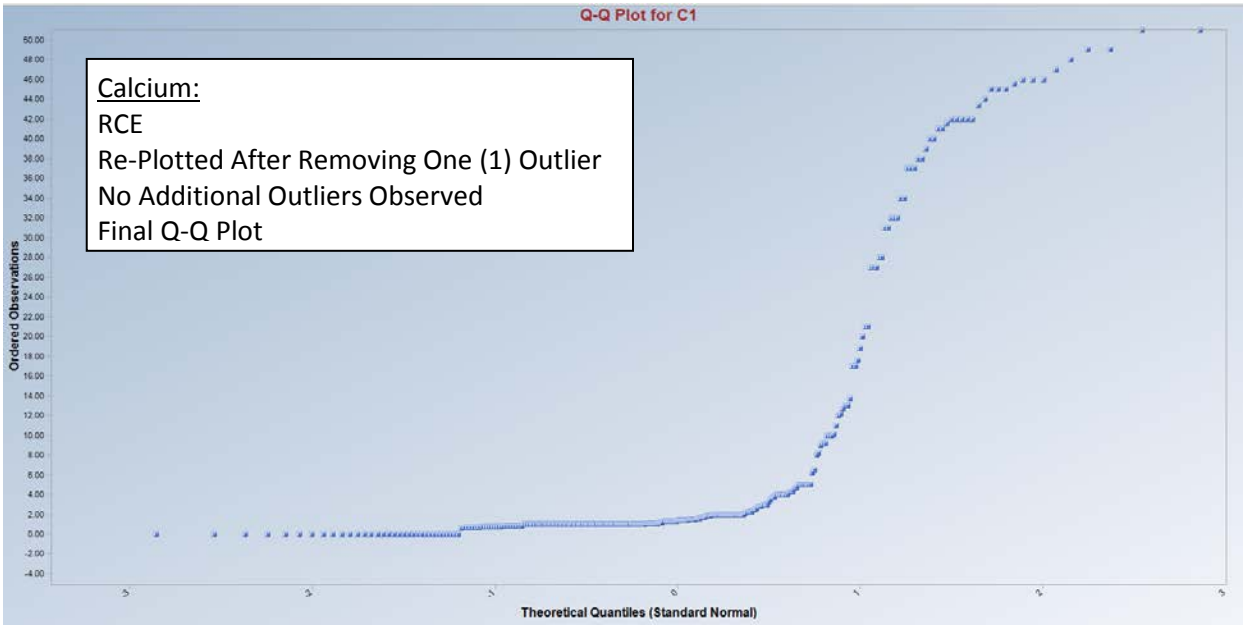

Q-Q Plot for RCE
Alkalinity:
RCE
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

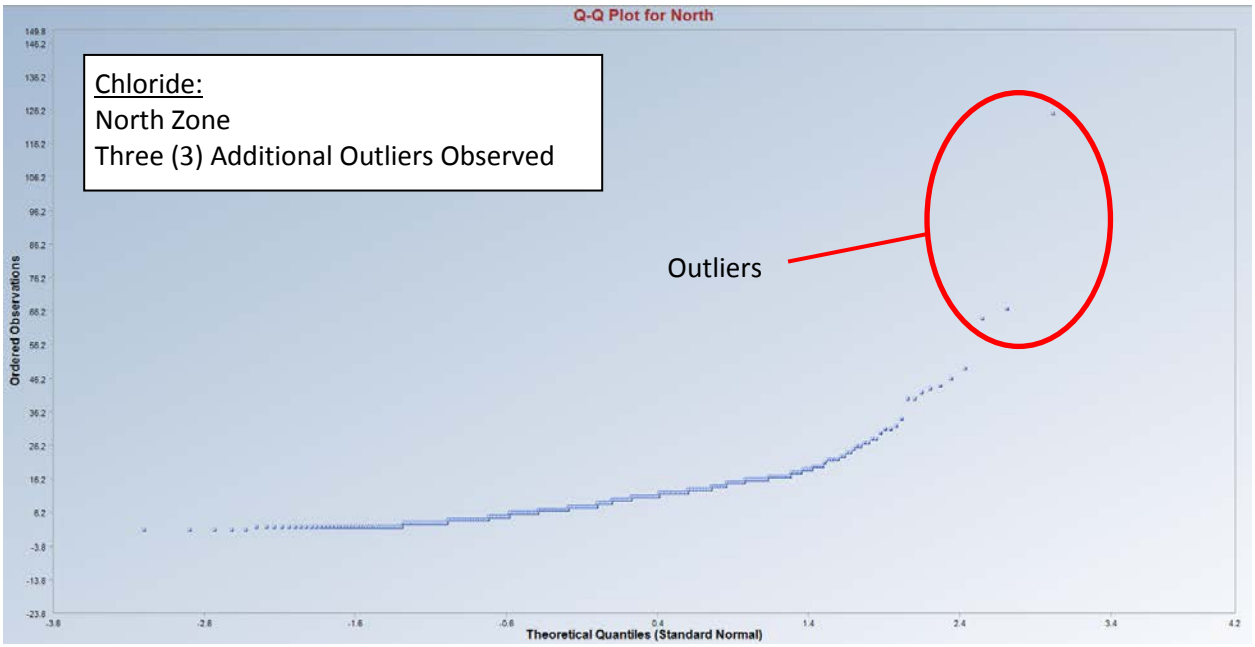

Q-Q Plot for Calcium - North
Calcium:
North Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

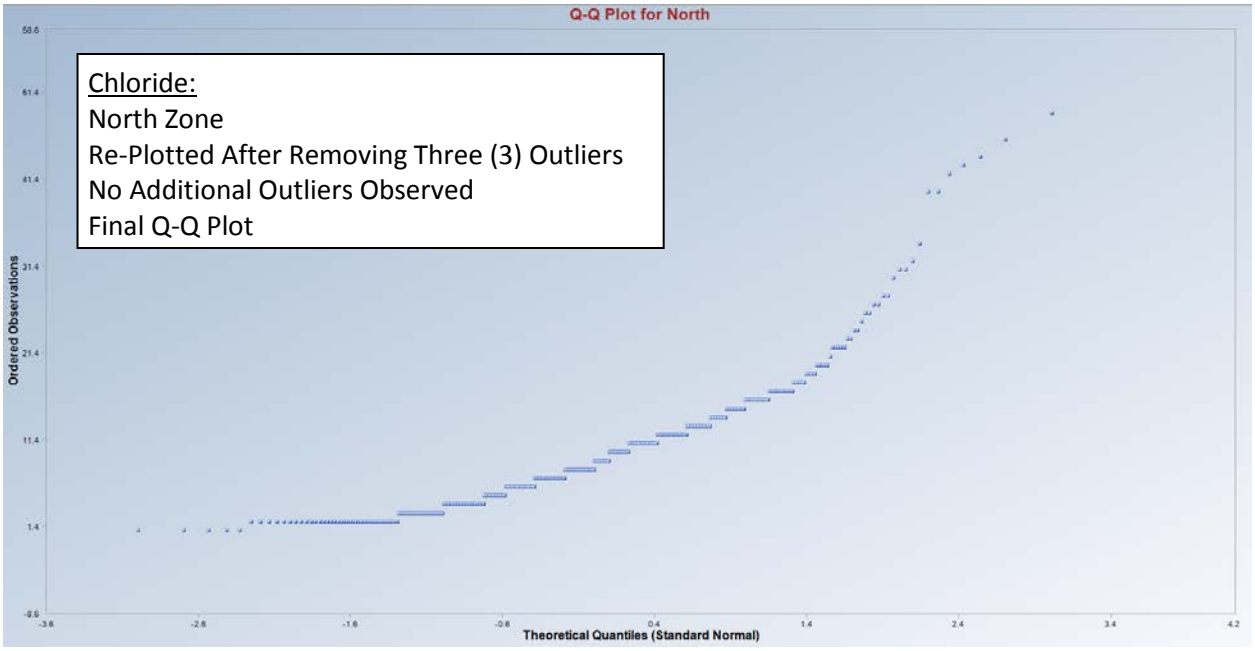

Q-Q Plot for C0
Calcium:
South Zone
One (1) Additional Outlier Observed
Outlier
Ordered Observations
Theoretical Quantiles (Standard Normal)

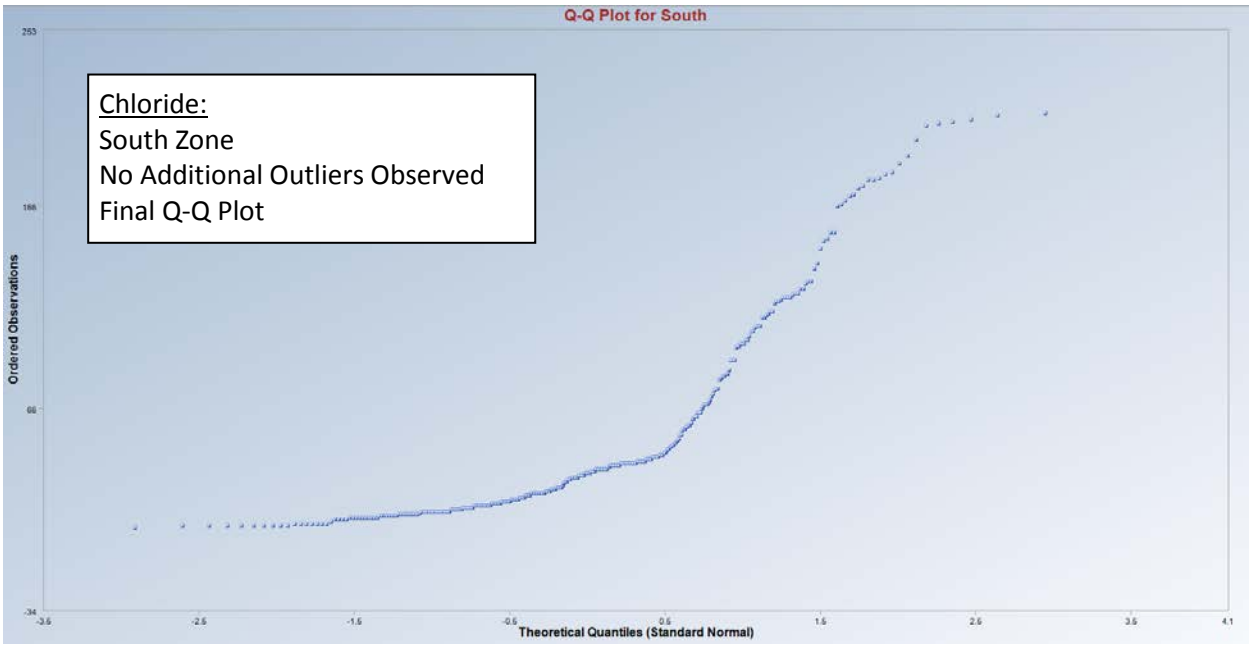

Q-Q Plot for C0
Calcium:
South Zone
Re-Plotted After Removing One (1) Outlier
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

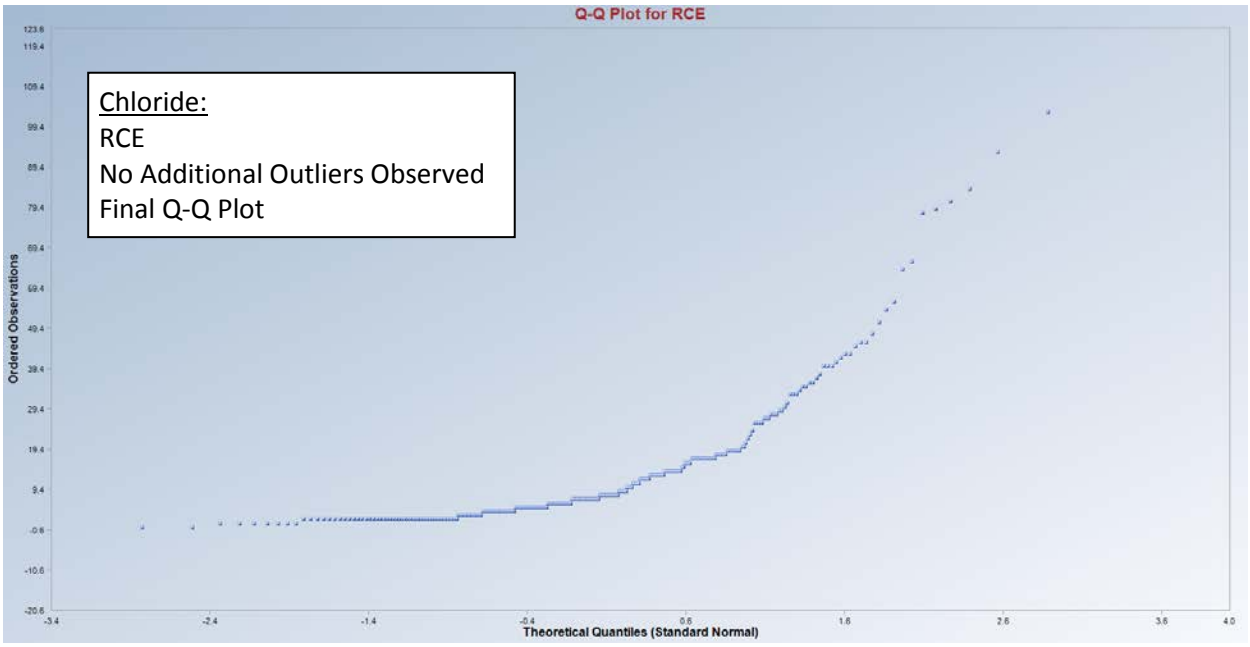

Q-Q Plot for C1
Calcium:
RCE
One (1) Additional Outlier Observed
Outlier
Ordered Observations
Theoretical Quantiles (Standard Normal)

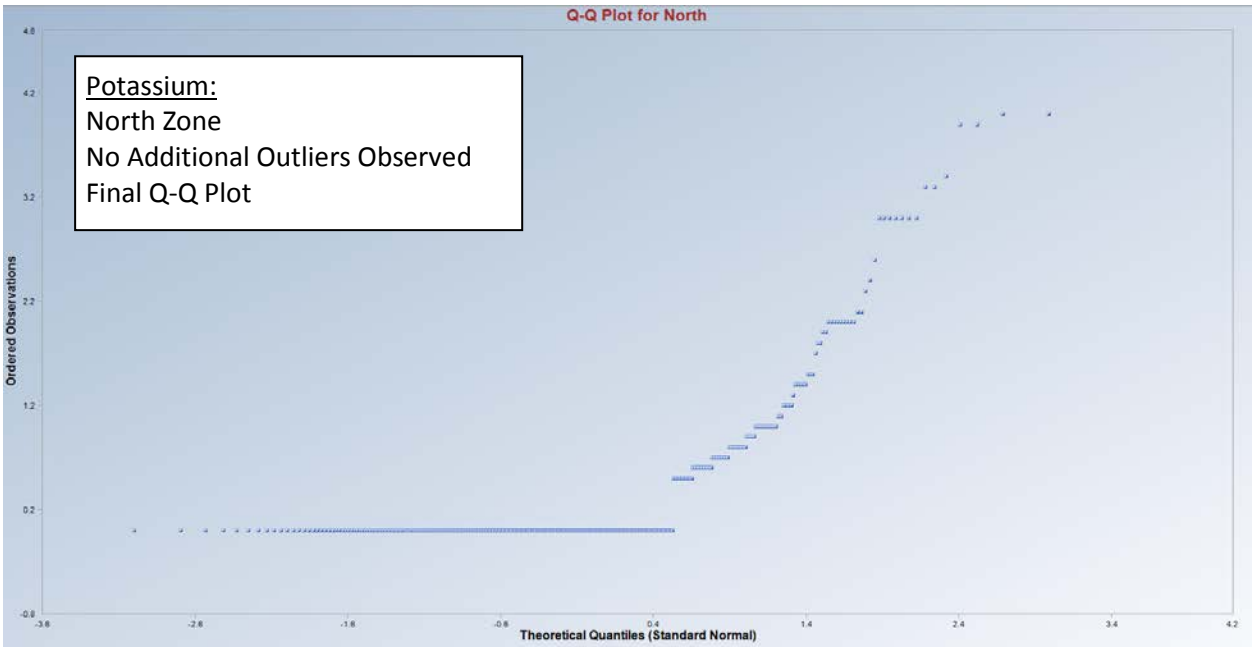

Q-Q Plot for C1
Calcium:
RCE
Re-Plotted After Removing One (1) Outlier
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

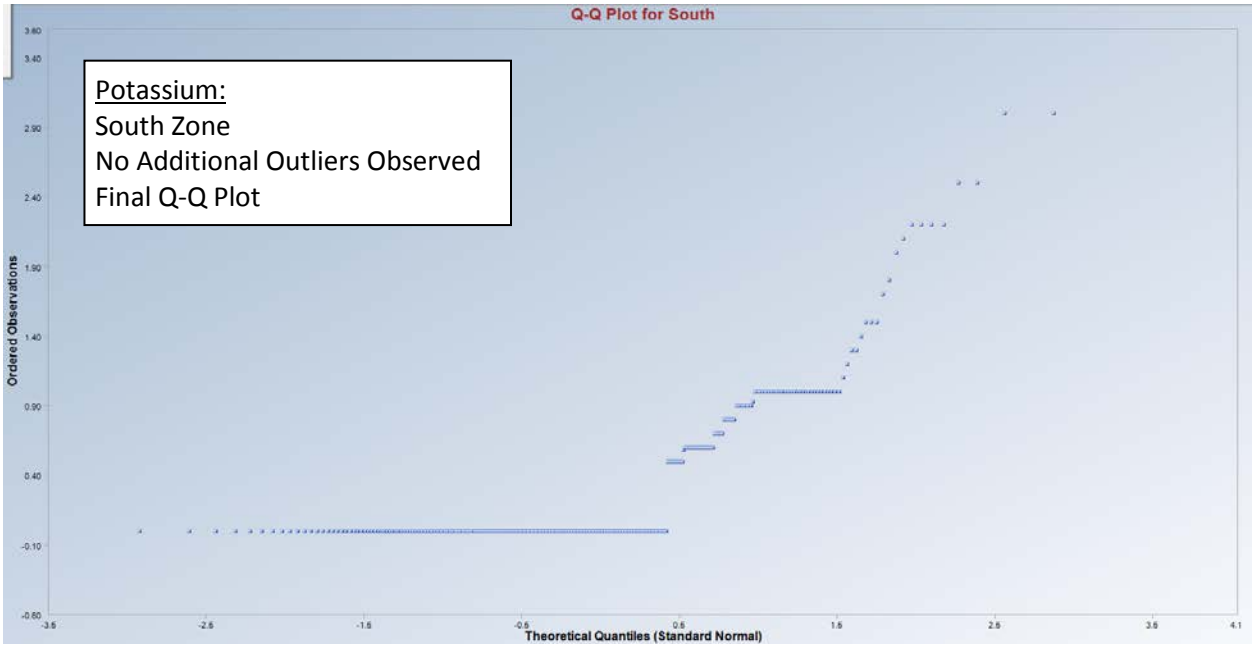

Q-Q Plot for North
Chloride:
North Zone
Three (3) Additional Outliers Observed
Outliers
Ordered Observations
Theoretical Quantiles (Standard Normal)

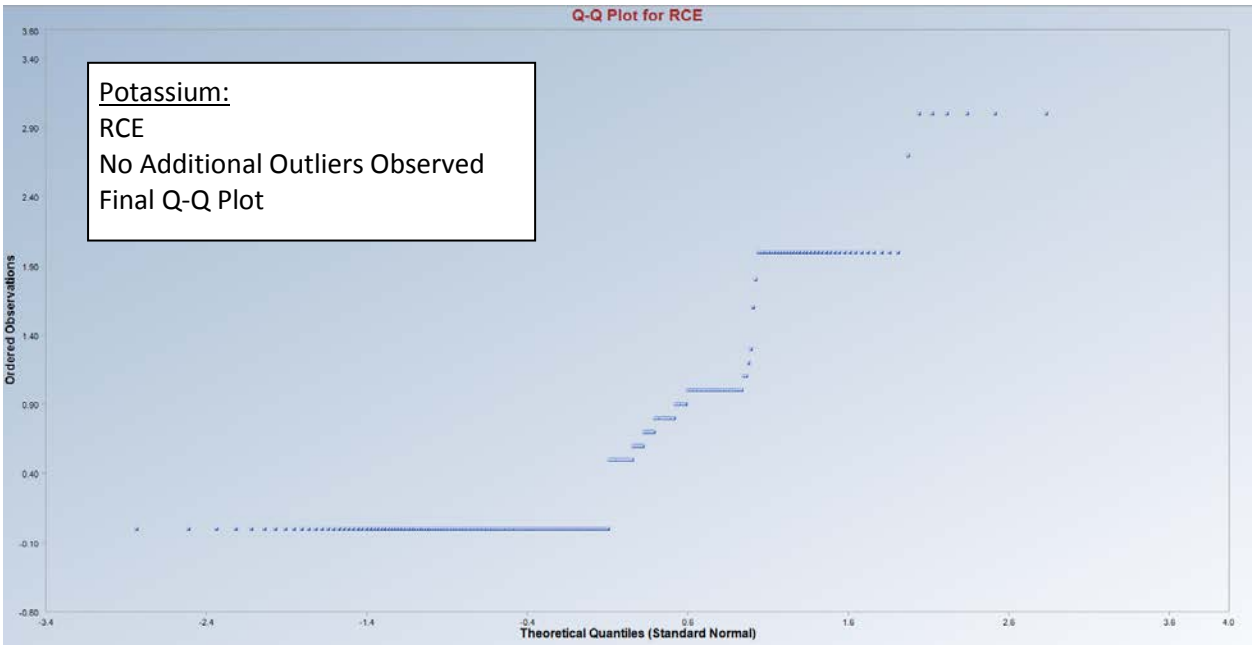

Q-Q Plot for North
Chloride:
North Zone
Re-Plotted After Removing Three (3) Outliers
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

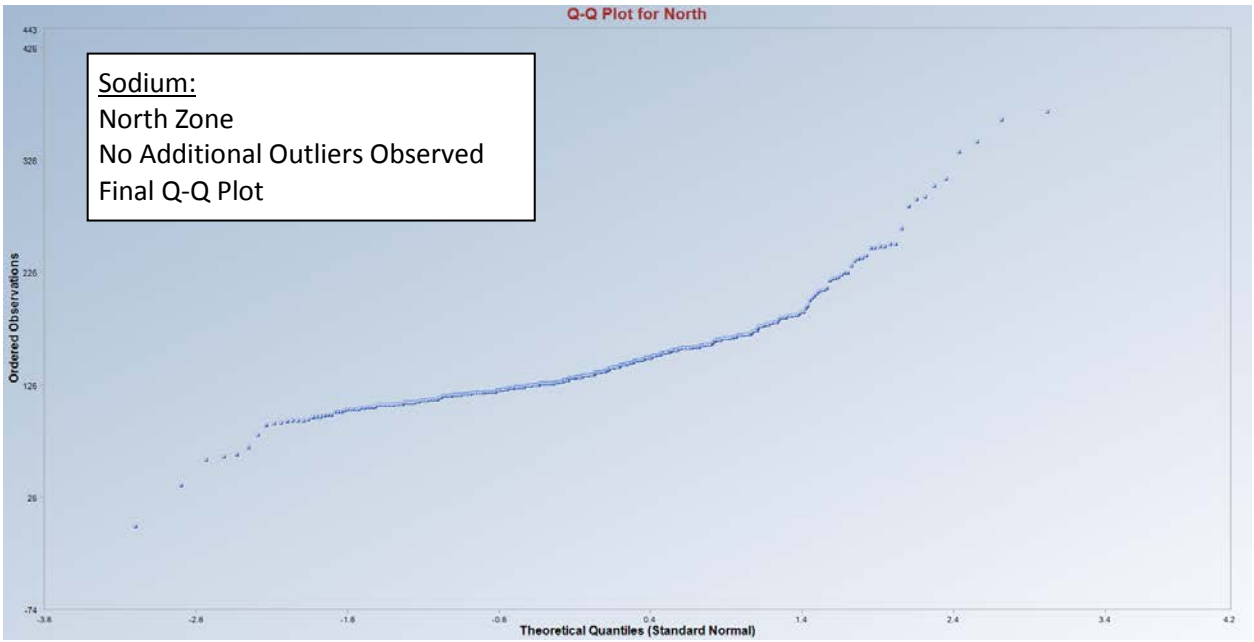

Q-Q Plot for South
Chloride:
South Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

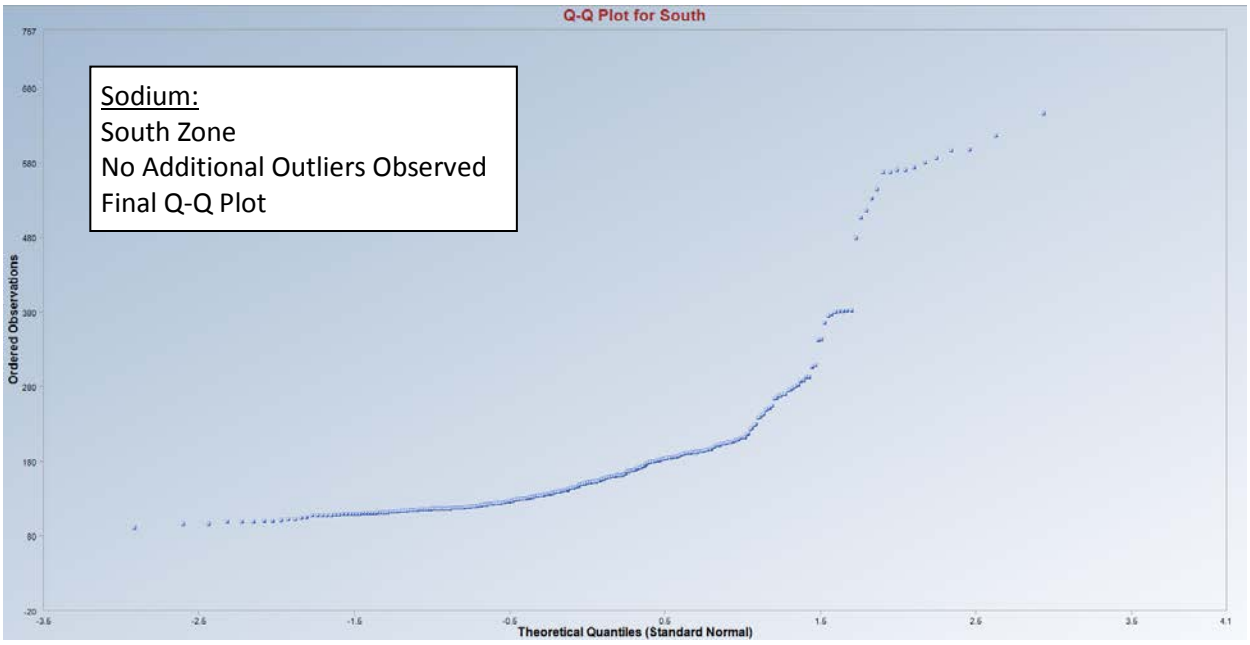

Q-Q Plot for RCE
Chloride:
RCE
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

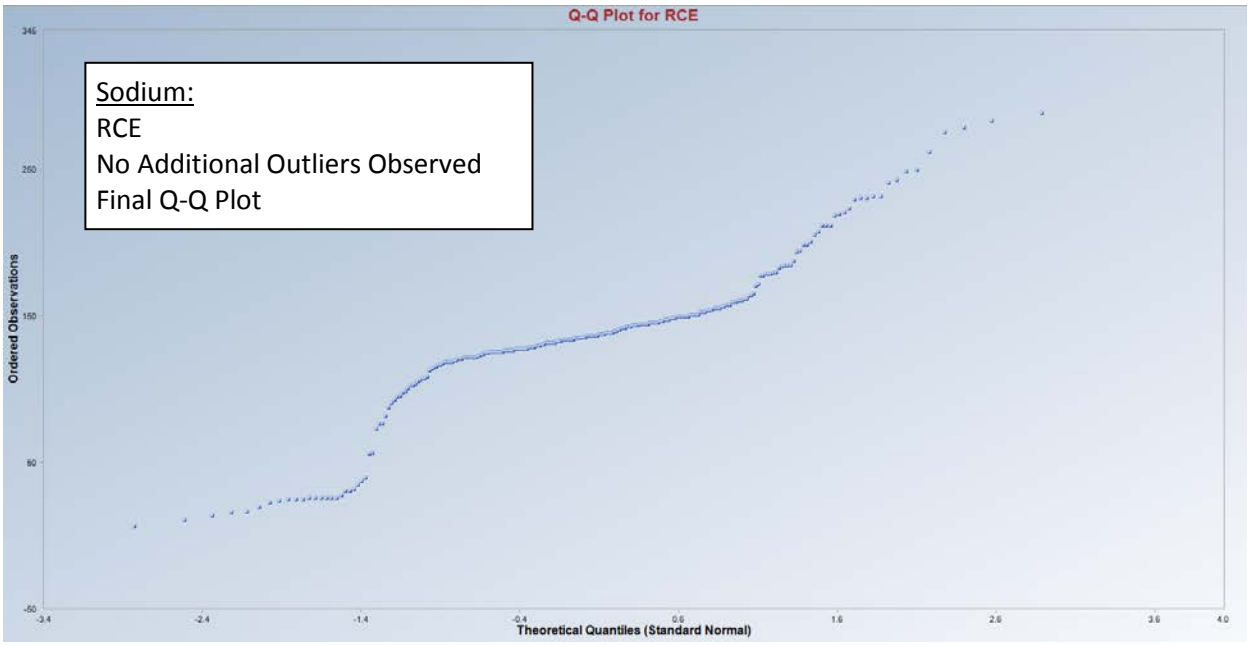

Q-Q Plot for North
Potassium:
North Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

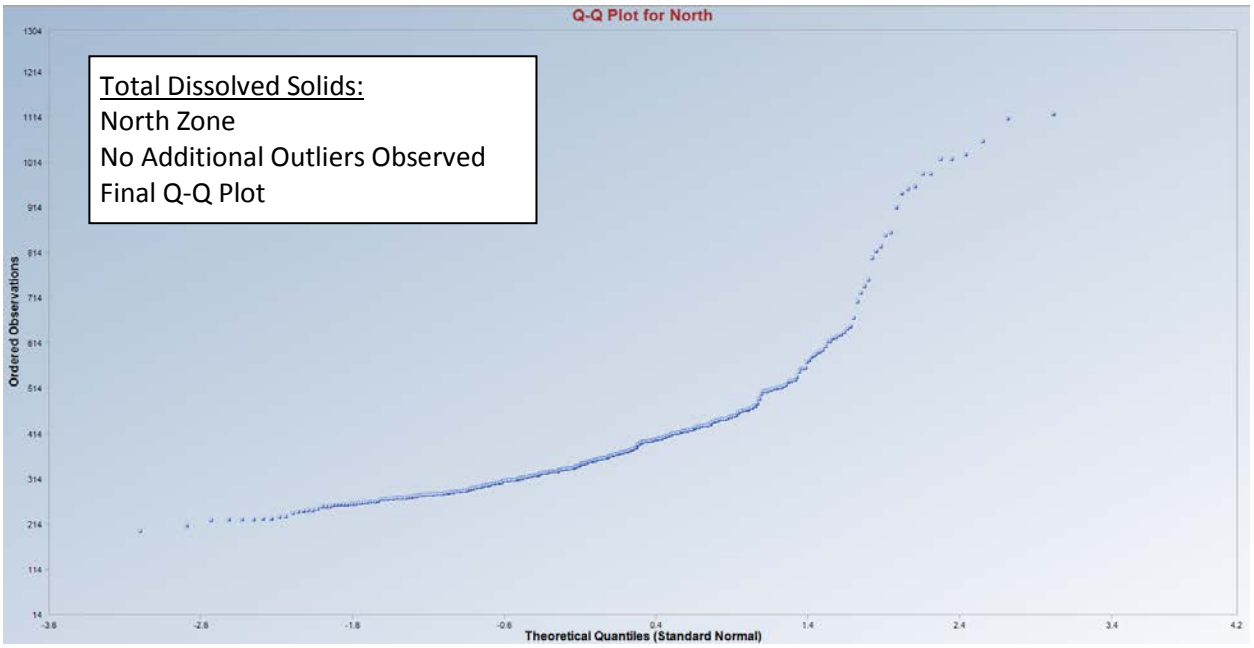

Q-Q Plot for South
Potassium:
South Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

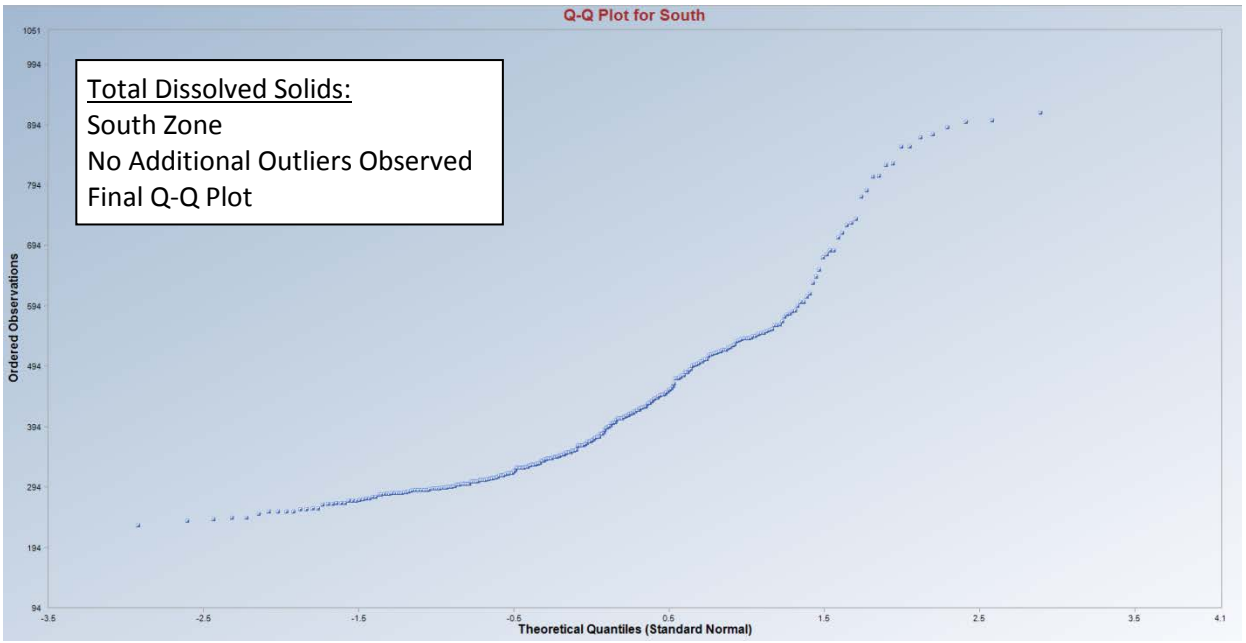

Q-Q Plot for RCE
Potassium:
RCE
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)

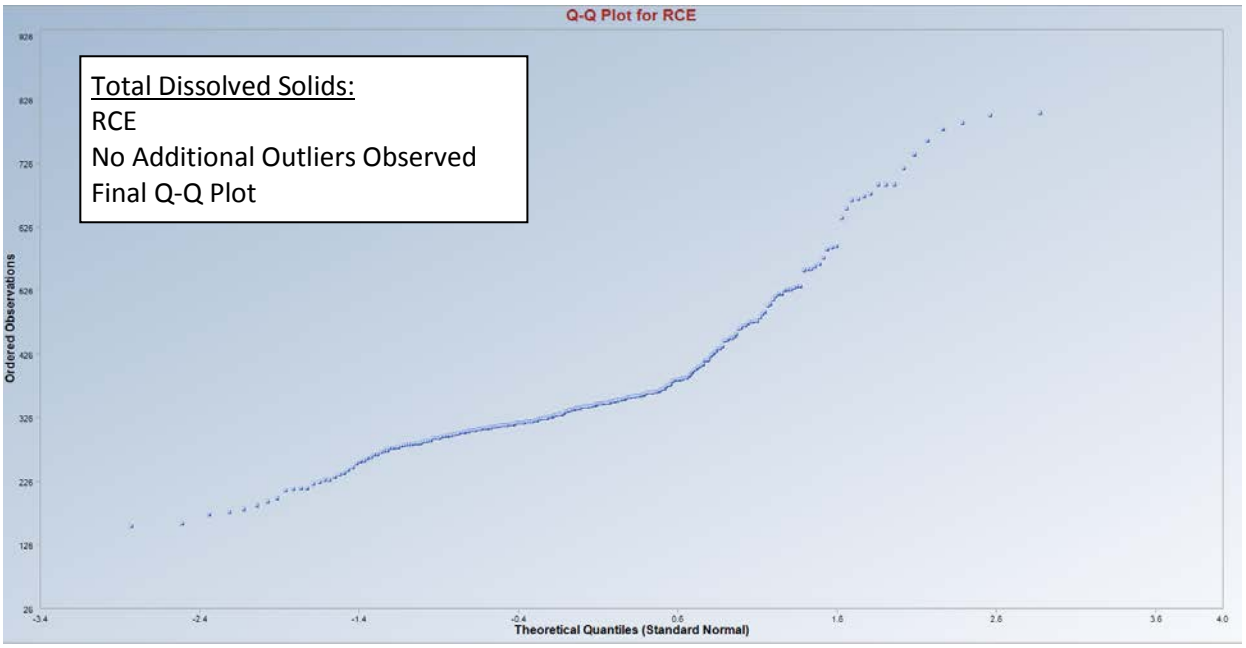

Q-Q Plot for North
Sodium:
North Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for South
Sodium:
South Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for RCE
Sodium:
RCE
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for North
Total Dissolved Solids:
North Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for South
Total Dissolved Solids:
South Zone
No Additional Outliers Observed
Final Q-Q Plot
Ordered Observations
Theoretical Quantiles (Standard Normal)



After completing outlier and spatial analysis, descriptive statistics were calculated for each parameter (see chart below). Over 270 groundwater quality results were used for each parameter in each monitoring area.

Analyte	Count	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation (mg/L)	Median (mg/L)
NORTH ZONE						
Alkalinity	465	56	324	205.3	30.2	201
Calcium	476	Below Detection	103	5	14.5	1.2
Chloride	470	1	49	10	7.2	8.5
Potassium	456	Below Detection	4	0.7	0.6	Below Detection
Sodium	476	Below Detection	369	144.7	41.1	135
Total Dissolved Solids	476	198	1,120	392	144.9	356
SOUTH ZONE						
Alkalinity	357	67	309	159.3	39.5	154
Calcium	370	Below Detection	76	3.7	7.8	1
Chloride	371	7	212	50.4	47.2	34
Potassium	332	Below Detection	3	0.7	0.4	Below Detection
Sodium	364	91	646	180.9	100.1	152
Total Dissolved Solids	340	231	914	414.5	141.4	370
RCE						
Alkalinity	278	103	317	220.8	52.7	232.5
Calcium	293	Below Detection	51	8.1	13.8	1.4
Chloride	290	1	103	13.5	16.2	7
Potassium	271	Below Detection	3	0.9	0.6	Below Detection
Sodium	293	6.8	289	136.2	48.1	137
Total Dissolved Solids	288	156	805	371.8	117	344

Note:
mg/L = milligrams per liter.
Below Detection means the result was below the analytical laboratory's reporting limit.

ABSOLUTE THRESHOLD ANALYSIS

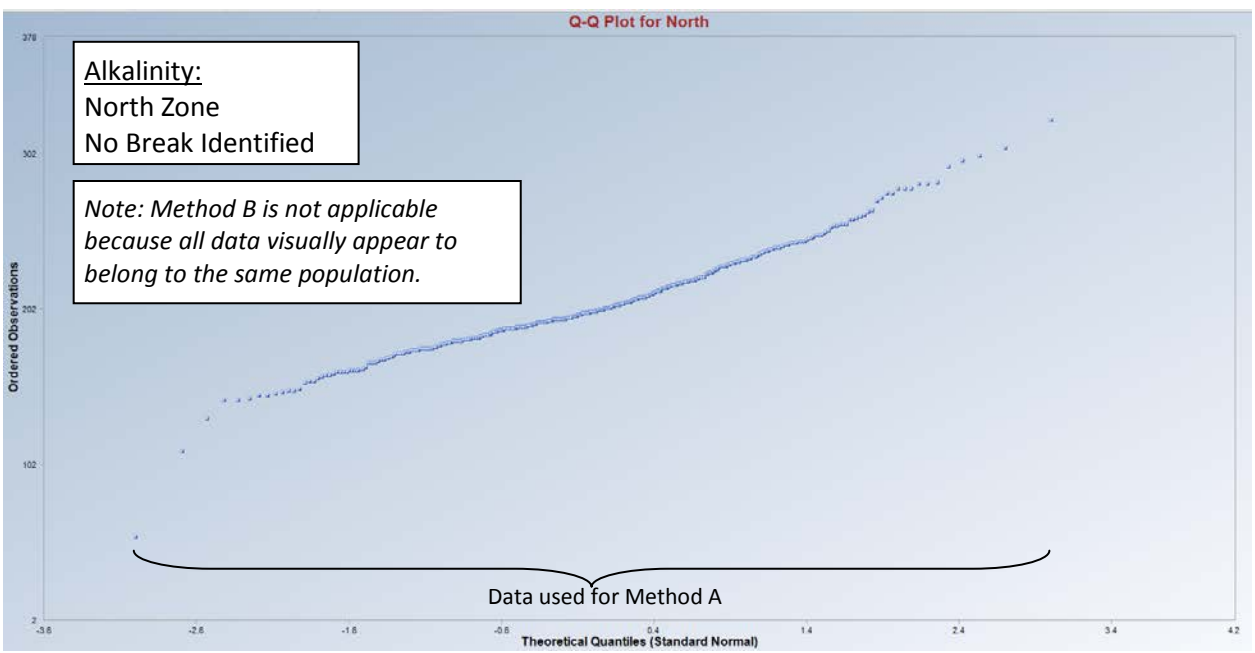
Upon completion of thorough analyses of outliers and spatial differences, absolute value thresholds were established. Given the fact that there is no evidence of widespread contamination in the PAPA from natural gas activities (AMEC, 2013), the datasets, excluding outliers, were considered as representative of background conditions for each of the three monitoring areas.

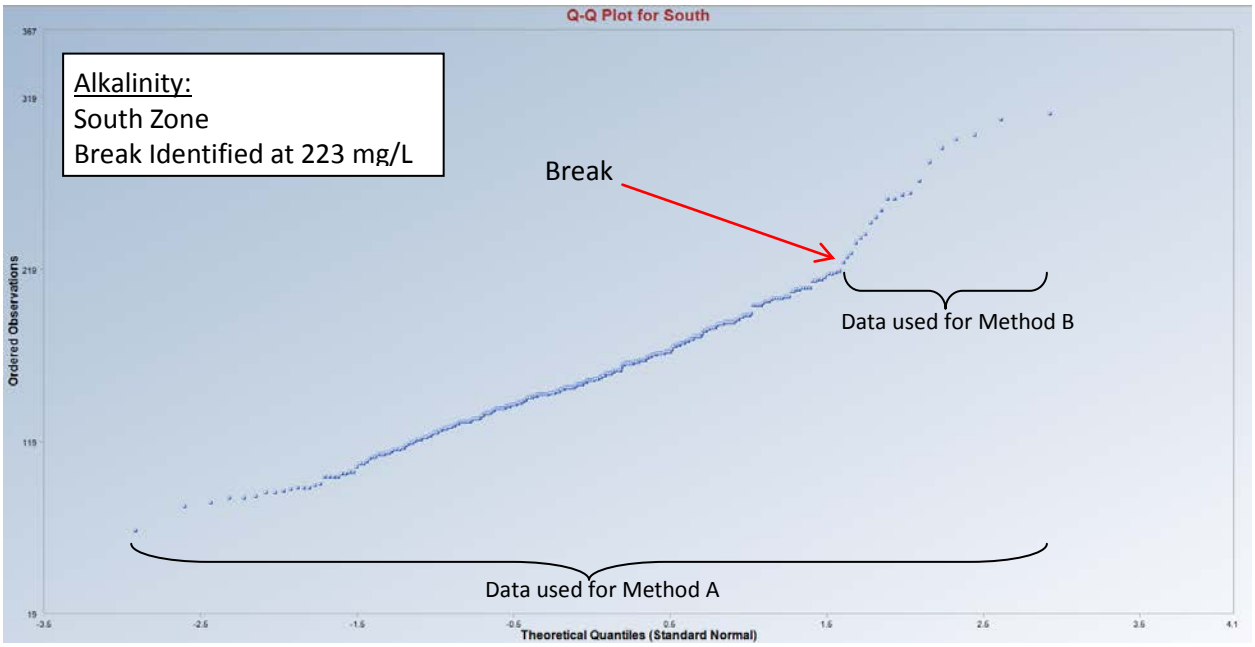
Two methods were used to calculate absolute value thresholds:

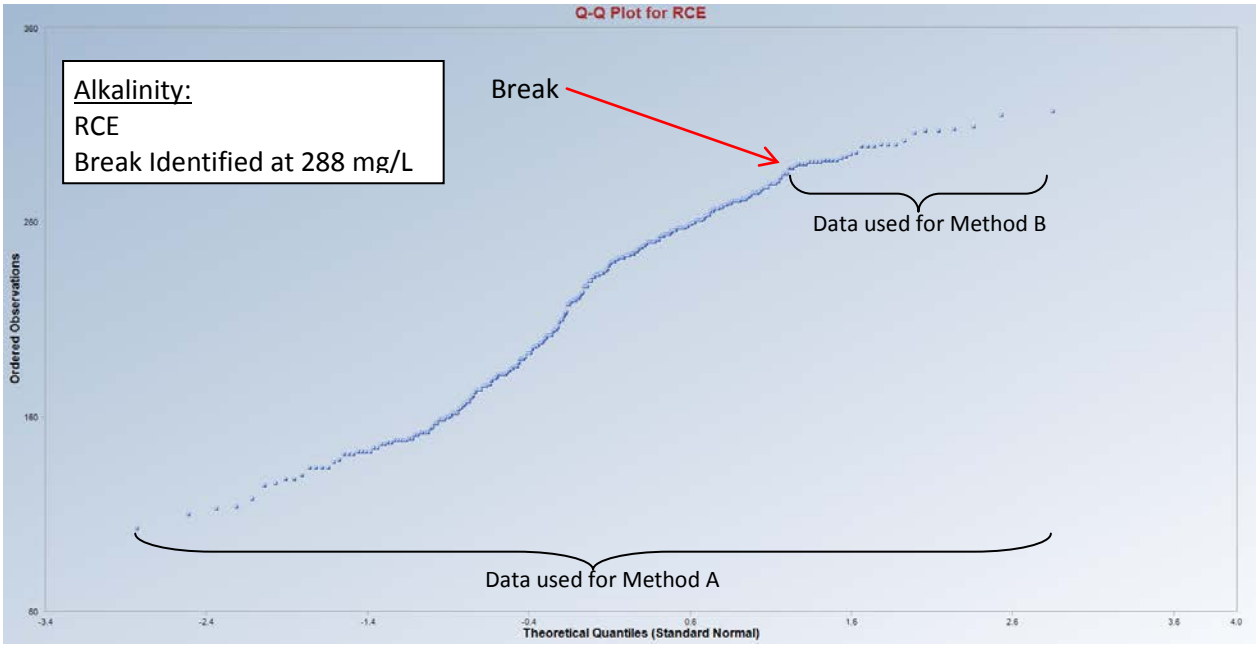
(a) Method A - Using all available data for a monitoring area as a single population. This is a common approach where the upper threshold value of the dataset is set as the absolute value threshold.

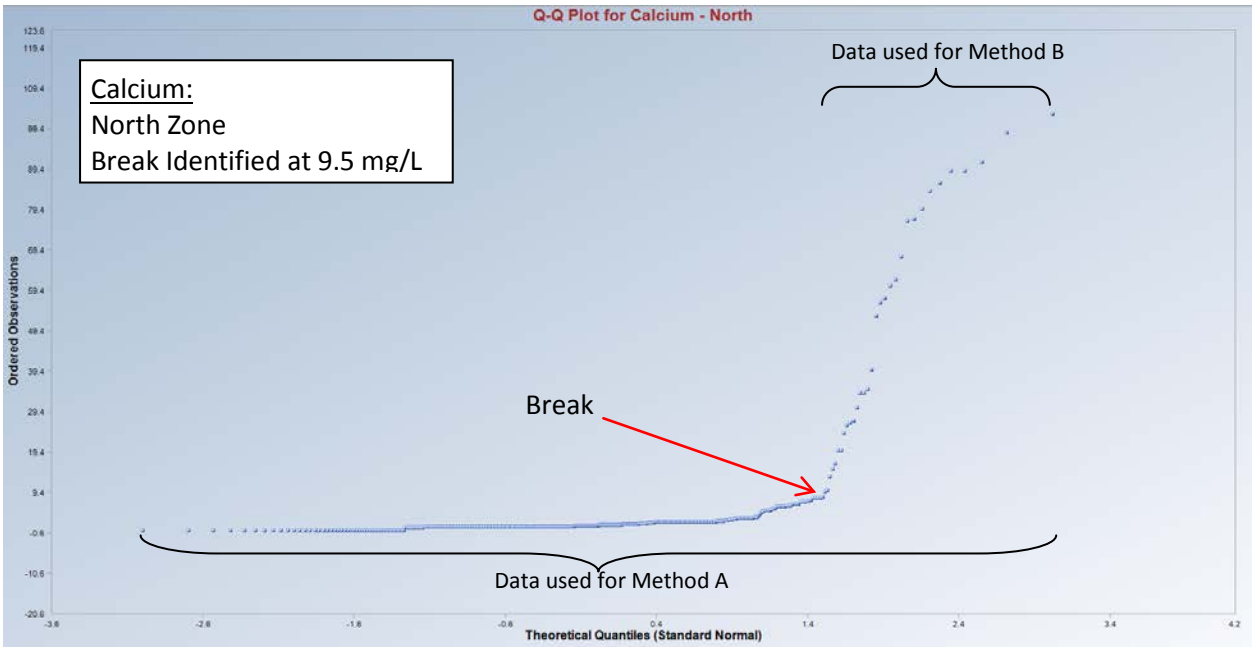
(b) Method B - Using only the highest concentration subpopulation, as determined based on visual identification of a 'break' in the Q-Q plot. Consistent with Singh et. al. (2014), a 'break' in a dataset is defined as a visually discernable jump or change in slope of the Q-Q plot.

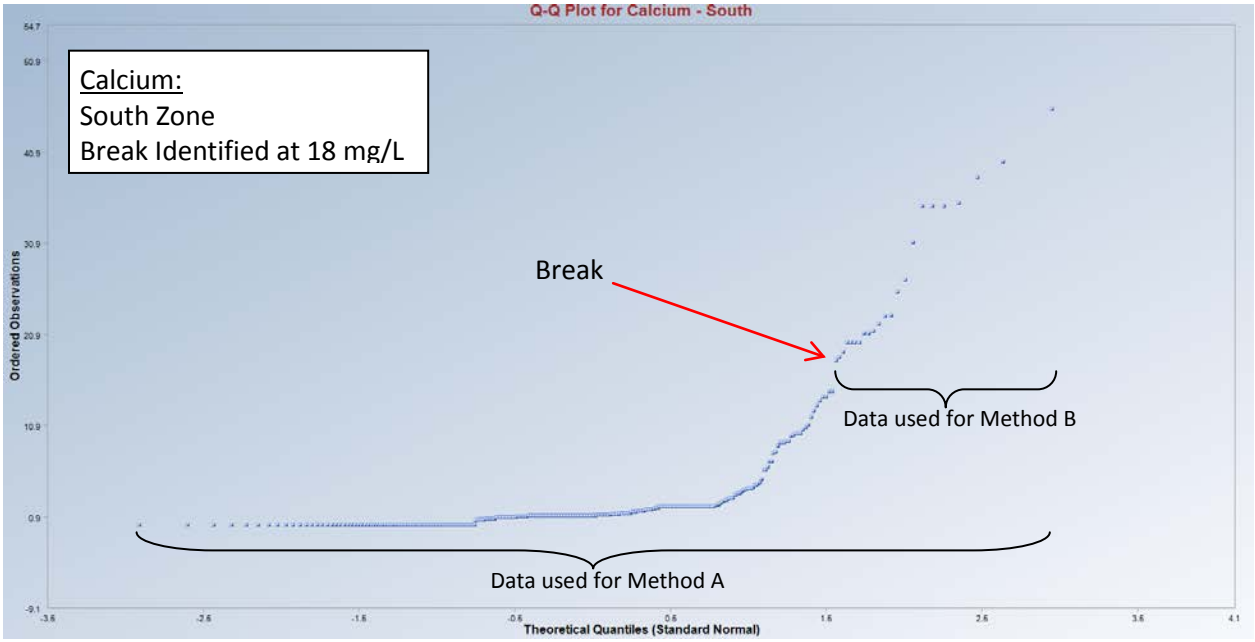
Background threshold values were calculated for each parameter using both methods. The following images are "screen shots" of the final Q-Q plots for each dataset as described above, where breaks are identified with red arrows.

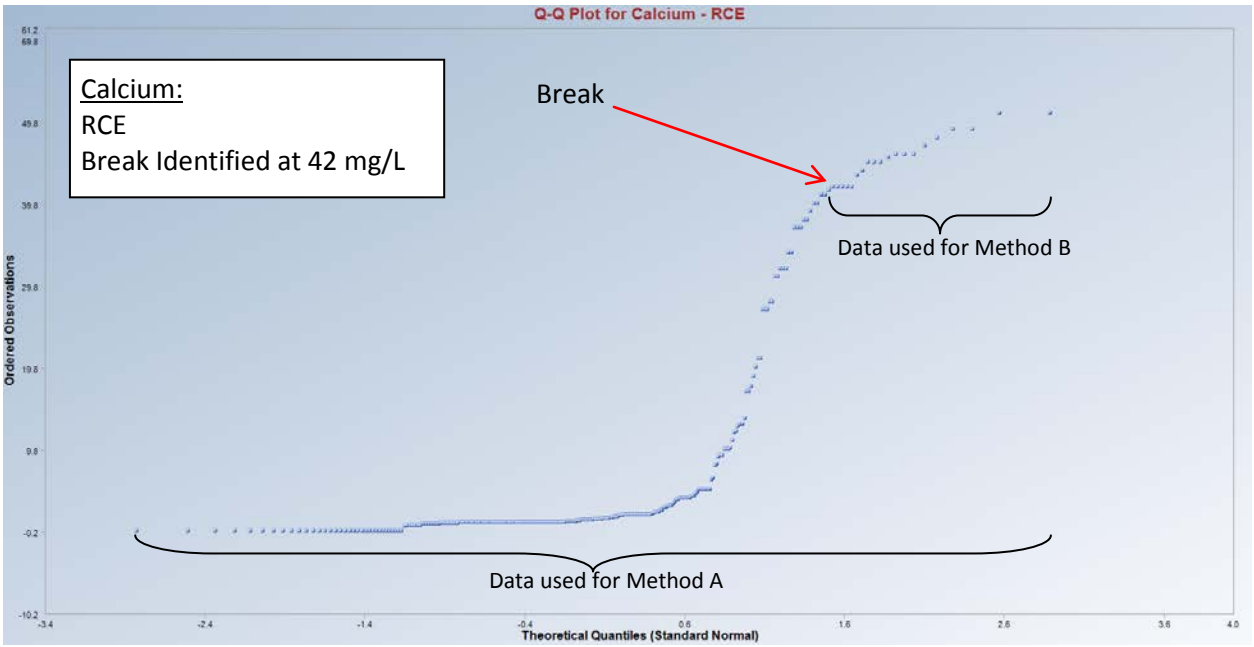


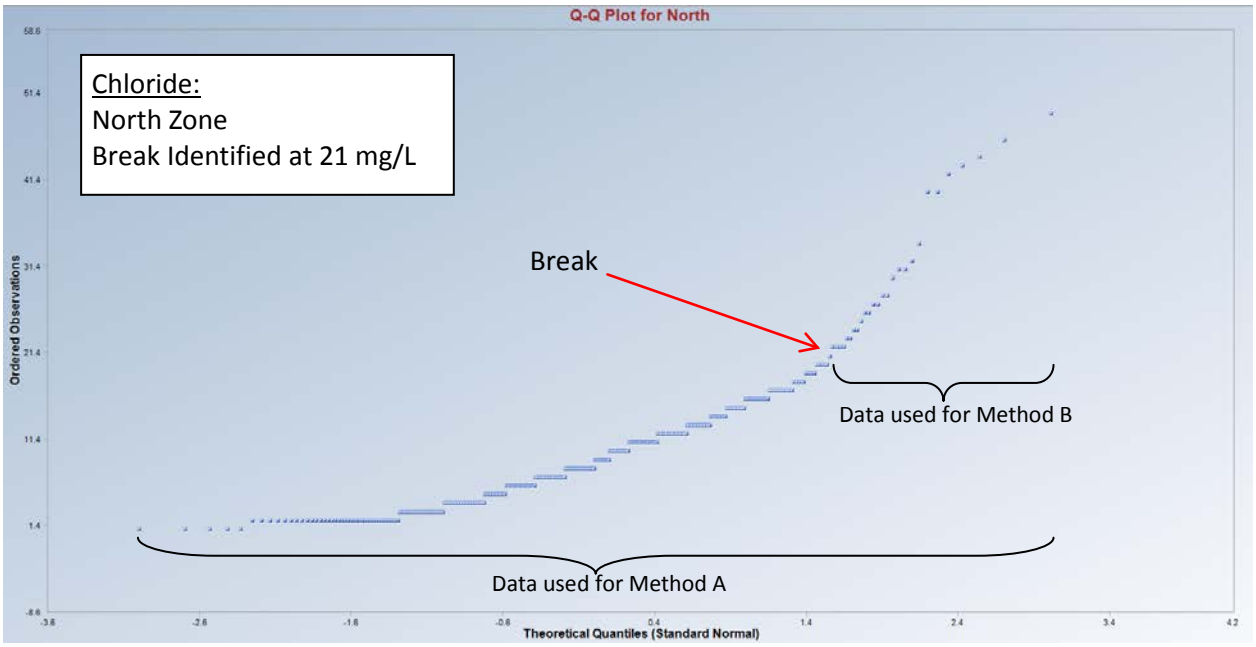

Q-Q Plot for South
Alkalinity:
South Zone
Break Identified at 223 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

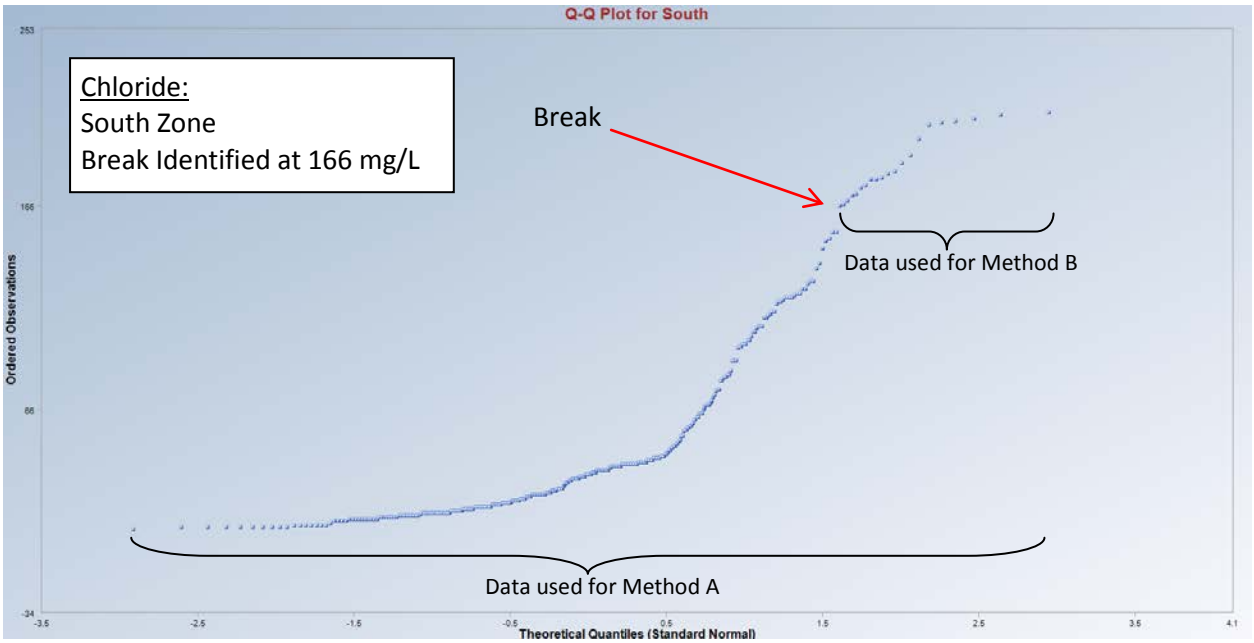

Q-Q Plot for RCE
Alkalinity:
RCE
Break Identified at 288 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

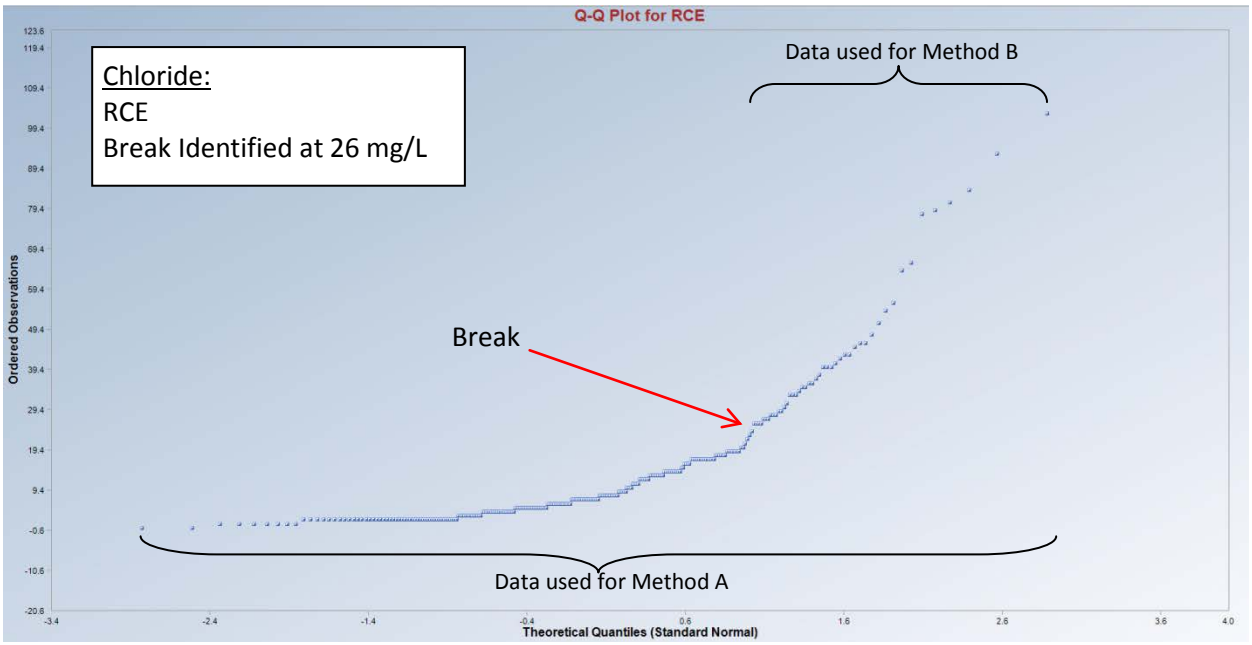

Q-Q Plot for Calcium - North
Calcium:
North Zone
Break Identified at 9.5 mg/L
Data used for Method B
Break
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

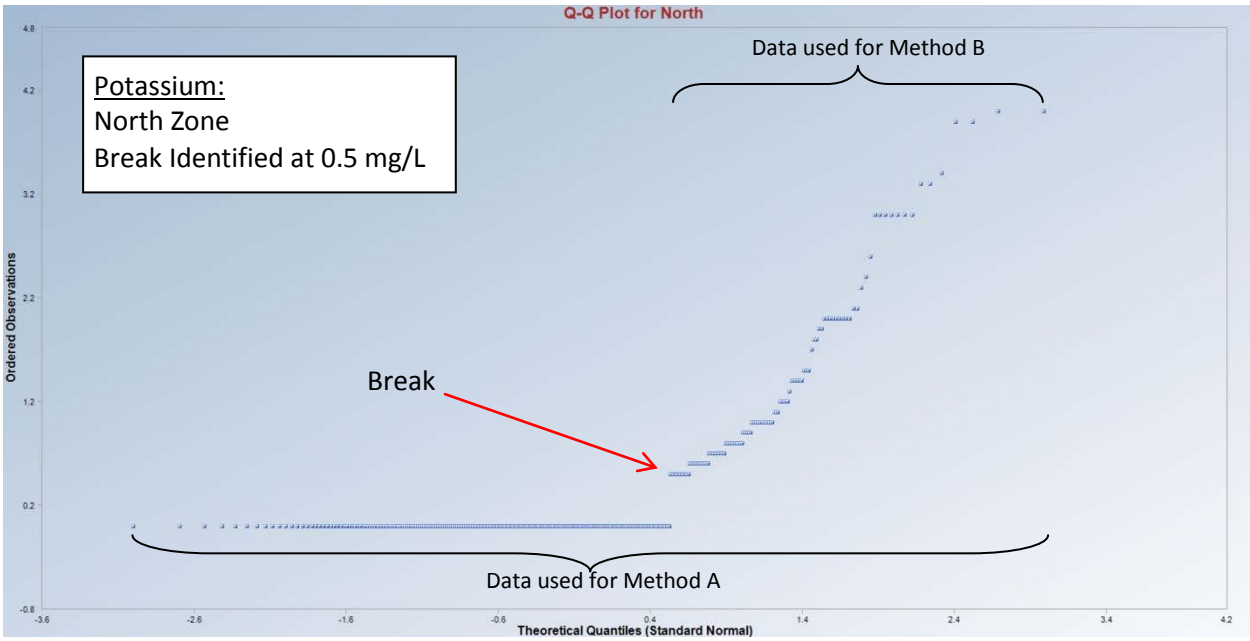

Q-Q Plot for Calcium - South
Calcium:
South Zone
Break Identified at 18 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

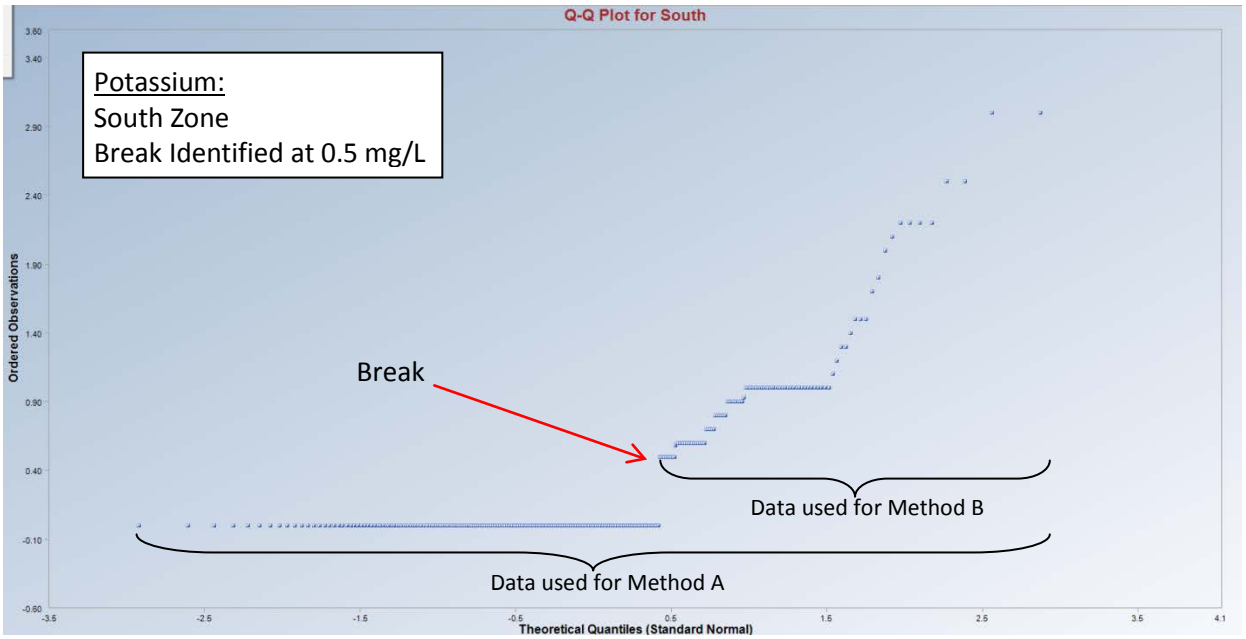

Q-Q Plot for Calcium - RCE
Calcium:
RCE
Break Identified at 42 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

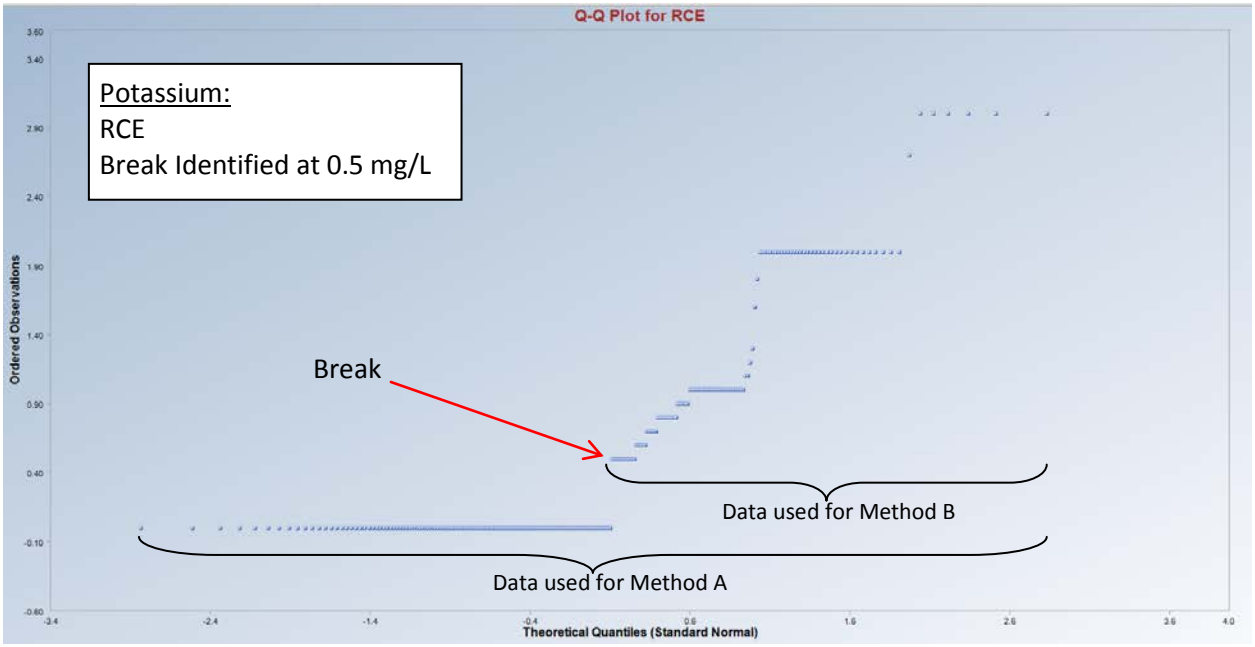

Q-Q Plot for North
Chloride:
North Zone
Break Identified at 21 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

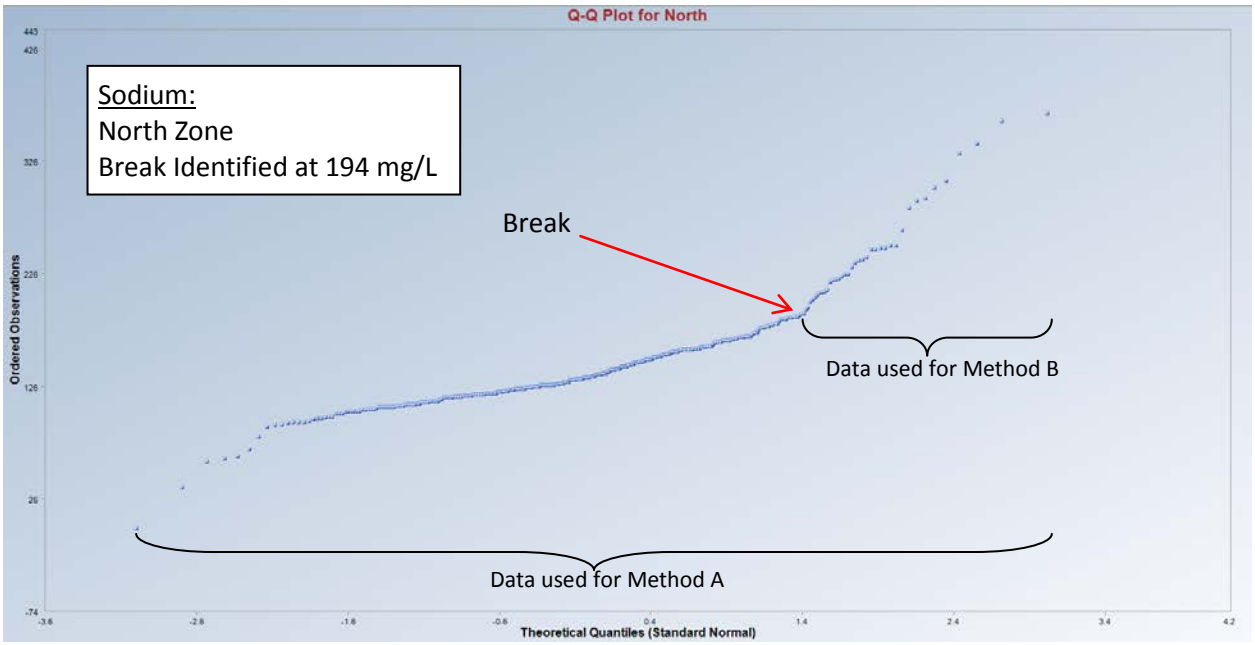

Q-Q Plot for South
Chloride:
South Zone
Break Identified at 166 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

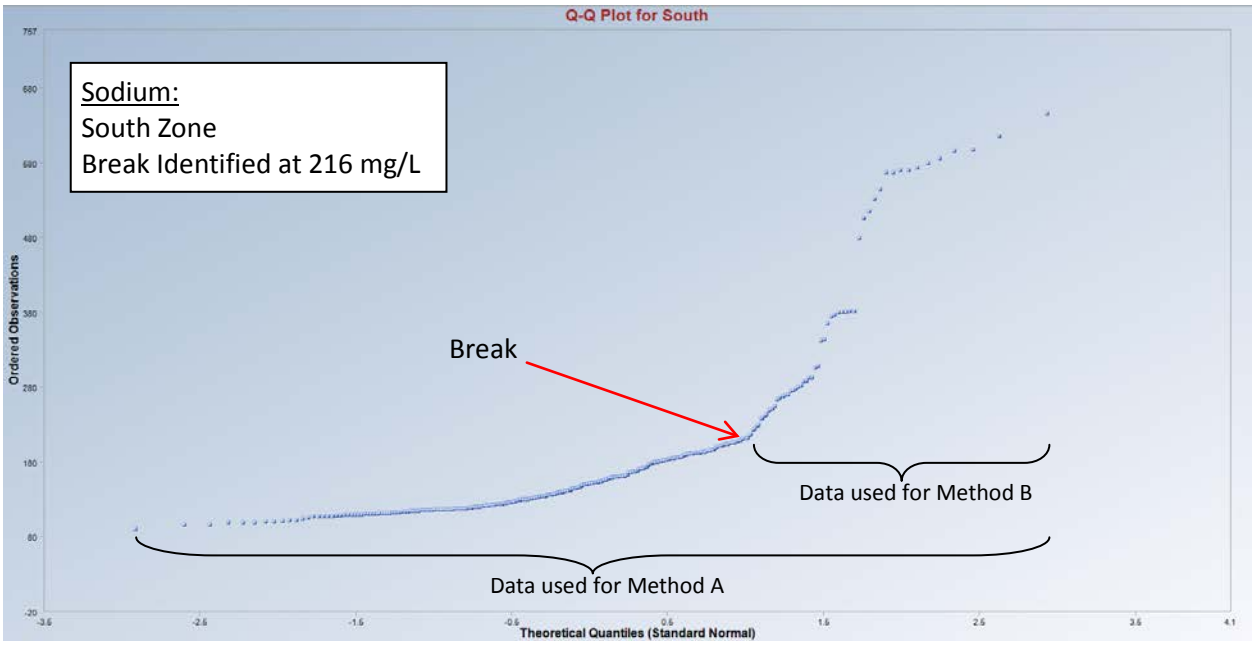

Q-Q Plot for RCE
Chloride:
RCE
Break Identified at 26 mg/L
Data used for Method B
Break
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

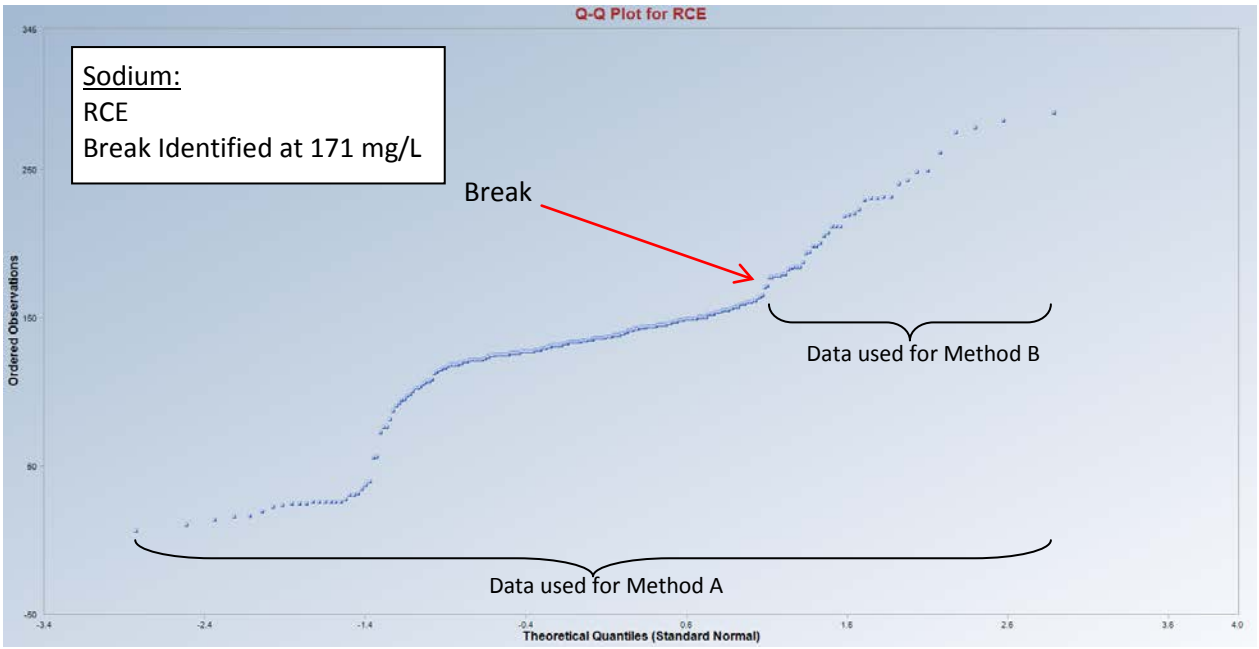

Q-Q Plot for North
Potassium:
North Zone
Break Identified at 0.5 mg/L
Data used for Method B
Break
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

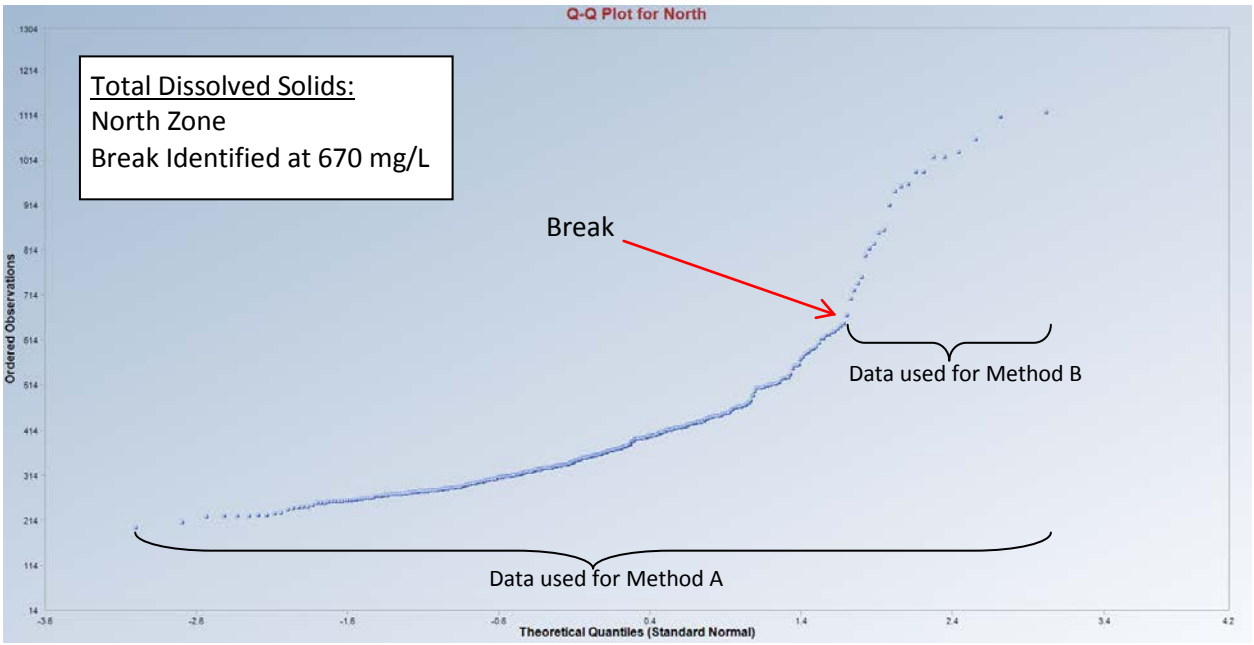

Q-Q Plot for South
Potassium:
South Zone
Break Identified at 0.5 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

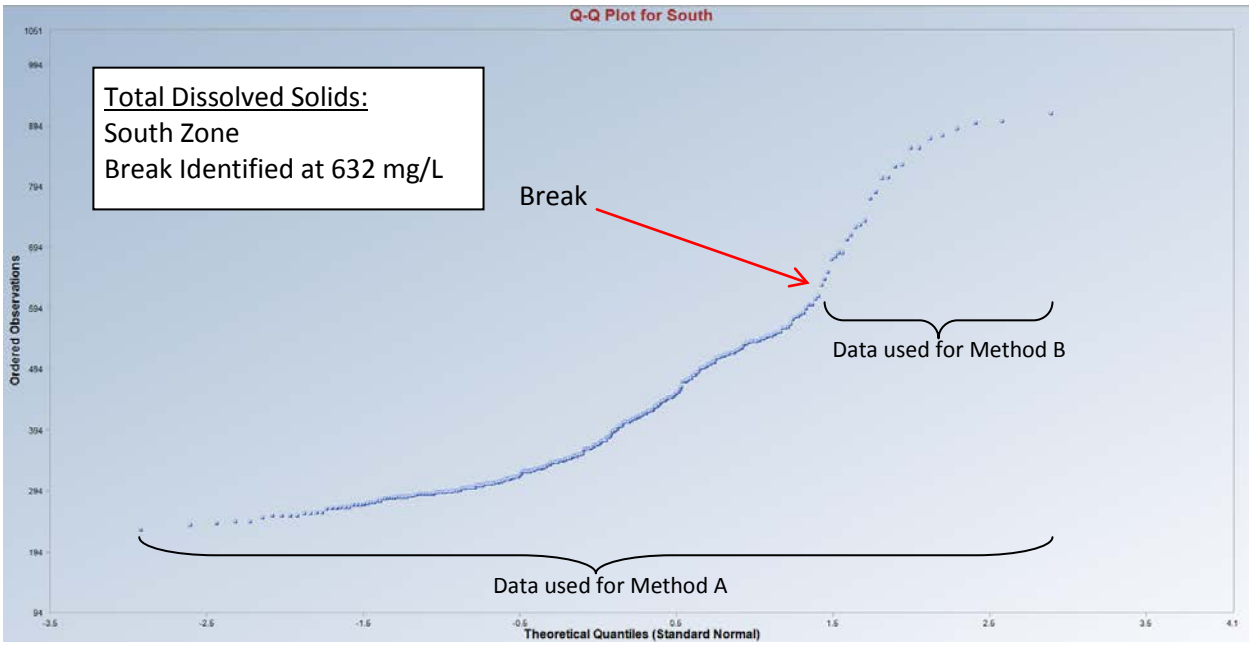

Q-Q Plot for RCE
Potassium:
RCE
Break Identified at 0.5 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)

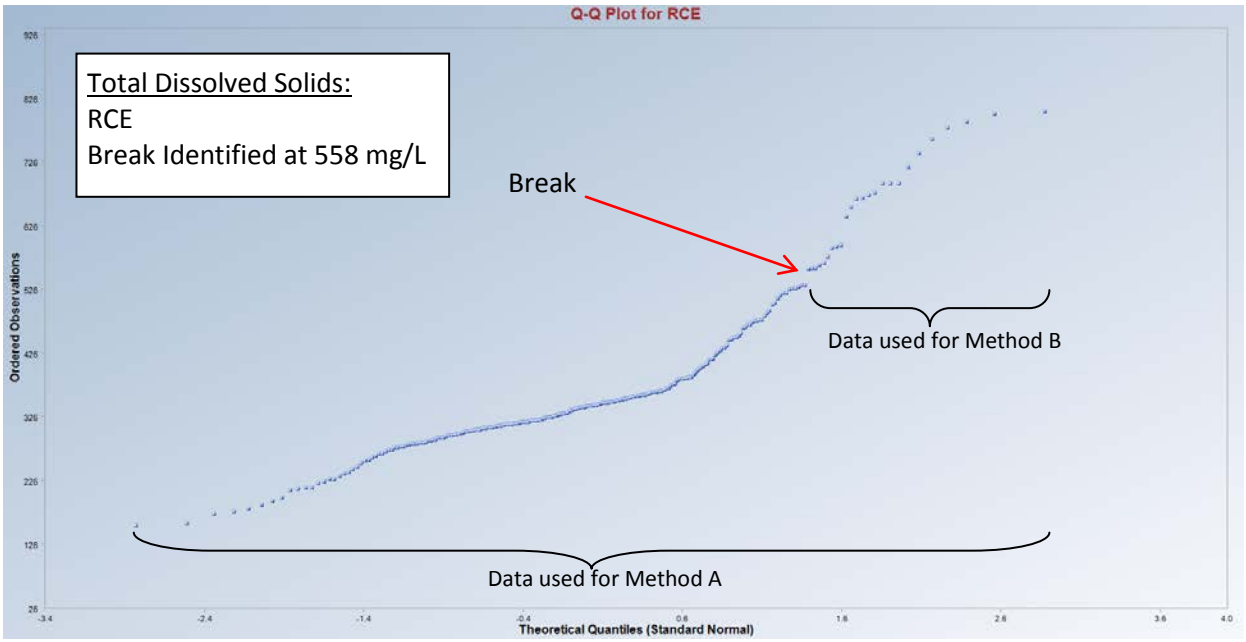

Q-Q Plot for North
Sodium:
North Zone
Break Identified at 194 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for South
Sodium:
South Zone
Break Identified at 216 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for RCE
Sodium:
RCE
Break Identified at 171 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for North
Total Dissolved Solids:
North Zone
Break Identified at 670 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)


Q-Q Plot for South
Total Dissolved Solids:
South Zone
Break Identified at 632 mg/L
Break
Data used for Method B
Data used for Method A
Ordered Observations
Theoretical Quantiles (Standard Normal)



After breaks were identified and datasets were compiled for Methods A and B, ProUCL was used to calculate background threshold values using both methods, as recommended by Dr. Singh (comments dated October 20, 2014 and January 23, 2015, on file with the BLM Pinedale Field Office). Dr. Singh also recommended using upper tolerance limits (UTL) with 95 percent confidence and 95 percent coverage. ProUCL provides UTL calculated based on normal, gamma and log-normal distributions, as well as non-parametric UTL. The software also provides statistical tests to identify if the data follow normal, gamma, or log-normal distribution. When data follow normal or gamma distribution, the corresponding distribution-specific UTL was used; otherwise, non-parametric UTL was used. In addition, when there are non-detects in the data, the Kaplan-Meier method was used to calculate more accurate UTL values.

RESULTS

This section presents results of the absolute threshold analysis for the six parameters in each monitoring area. The following charts present results for each parameter for the two methods.

Analyte	Method A: Threshold Value Using All Data (mg/L)	Distribution	Method B: Threshold Value Using Highest Background Subpopulation (mg/L)	Distribution
NORTH ZONE				
Alkalinity	265	Non-parametric 95% UTL with 95% Coverage	NA	NA
Calcium	35	Non-parametric 95% UTL with 95% Coverage	146.4	95% WH Approx. Gamma UTL with 95% Coverage
Chloride	26	Non-parametric 95% UTL with 95% Coverage	50.9	95% WH Approx. Gamma UTL with 95% Coverage
Potassium	2.3	Non-parametric 95% UTL with 95% Coverage	3.9	Non-parametric 95% UTL with 95% Coverage
Sodium	239	Non-parametric 95% UTL with 95% Coverage	369	Non-parametric 95% UTL with 95% Coverage
Total Dissolved Solids	754	Non-parametric 95% UTL with 95% Coverage	1,219	Normal 95% UTL with 95% Coverage
SOUTH ZONE				
Alkalinity	236.8	95% WH Approx. Gamma UTL with 95% Coverage	336.3	Normal 95% UTL with 95% Coverage
Calcium	22.9	Non-parametric 95% UTL with 95% Coverage	76	Non-parametric 95% UTL with 95% Coverage
Chloride	179	Non-parametric 95% UTL with 95% Coverage	225.2	Normal 95% UTL with 95% Coverage
Potassium	1.7	Non-parametric 95% UTL with 95% Coverage	2.5	Non-parametric 95% UTL with 95% Coverage
Sodium	532	Non-parametric 95% UTL with 95% Coverage	616	Non-parametric 95% UTL with 95% Coverage
Total Dissolved Solids	808	Non-parametric 95% UTL with 95% Coverage	983.7	Normal 95% UTL with 95% Coverage

Note: WH = Wilson Hilferty; UTL = upper tolerance limit; mg/L = milligram per liter; % = percent; NA = Not applicable - Alkalinity data in the North Zone represents one population.

Analyte	Method A: Threshold Value Using All Data (mg/L)	Distribution	Method B: Threshold Value Using Highest Background Subpopulation (mg/L)	Distribution
RCE				
Alkalinity	300	Non-parametric 95% UTL with 95% Coverage	317	Non-parametric 95% UTL with 95% Coverage
Calcium	45.6	Non-parametric 95% UTL with 95% Coverage	52.6	Normal 95% UTL with 95% Coverage
Chloride	54	Non-parametric 95% UTL with 95% Coverage	93	Non-parametric 95% UTL with 95% Coverage
Potassium	2	Non-parametric 95% UTL with 95% Coverage	3	Non-parametric 95% UTL with 95% Coverage
Sodium	232	Non-parametric 95% UTL with 95% Coverage	281.9	Normal 95% UTL with 95% Coverage
Total Dissolved Solids	693	Non-parametric 95% UTL with 95% Coverage	855.1	Normal 95% UTL with 95% Coverage

Note: WH = Wilson Hilferty; UTL = upper tolerance limit; mg/L = milligram per liter; % = percent.

CONCLUSIONS

In general, absolute value thresholds calculated using the highest background subpopulations (i.e., Method B) were selected. These choices were driven by the following facts:

- Throughout the background analysis, absolute care was taken to remove any actual and potential outliers from background datasets. These exclusions and removals were performed at multiple stages by first identifying and removing potentially impacted wells, followed by parameter- and area-specific outliers analyses, resulting in the removal of 64 measured values from the background datasets.
- The remaining background datasets clearly consisted of multiple subpopulations. Under such conditions, absolute value thresholds must accommodate all of the background subpopulations present in the datasets. This means that only the thresholds associated with the highest subpopulation would meet such criterion.

Based on results of the outlier analysis, spatial analysis, and background threshold analysis, the following are the calculated parameter-specific absolute value thresholds for the monitoring areas in the PAPA.

Area	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Total Dissolved Solids (mg/L)
North	265	146	51	3.9	369	1,219
South	336	76	225	2.5	616	984
RCE	317	53	93	3.0	282	855

Note: mg/L = milligrams per liter.

Table 4-4 in NewFields (2015) presents the absolute value thresholds for all 19 parameters on the core or supplemental lists.

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Wyoming Oil and Gas Conservation Commission (WOGCC). 2014. Wyoming Oil and Gas Conservation Rules and Regulations, Chapter 3: Operational Rules, Drilling Rules; Section 46 and Appendix K. Accessed on-line: http://soswy.state.wy.us/Rules/RULES/9411.pdf