The role that the quantity of sampling wells has on the groundwater quality analysis at the Savannah River Site (SRS)

by

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Abstract

Savannah River Plant was created to produce nuclear-weapons materials during the Cold War. After the end of the Cold War, Savannah River Plant has become Savannah River Site (SRS) with emphasis on environmental stewardship. This research serves as baseline data to contribute to a better understanding of the spatial distribution of the background-groundwater system at the SRS. The methods of this study systematically linearize analyte parameters and establishes rank values, weight values, and aggregates the parameters. The aggregation value establishes a means to determine groundwater quality based on the analytes sampled as a comparison to their respectively recognized Environmental Protection Agency and World Health Organization standards.

1. Introduction:

1.1 Contribution to Science

Since the end of the Cold War, research at Savannah River Site (SRS) has concentrated on remediation of hazardous wastes. These remediation efforts have involved research of known chemicals contaminants at the site and correlating proxies to the known contaminants. Mathes (2002) researched known trichloroethylene and tritium contamination areas at SRS to develop chemical proxy correlation models within zones at the SRS. Such models have been used to (1) define regional groundwater flow patterns on and off the SRS; (2) enhance understanding of contamination migration in the subsurface; (3) support remedial designs; and (4) provide predictive performance assessments of waste disposal facilities. At the SRS, major groundwater modeling efforts have been conducted at main operating areas and waste units to determine groundwater base-flow and impact to groundwater system.

Additionally, since the installation of the background wells at the SRS during the 1980s there has only been one detailed hydrology study to date (Strom & Kaback, 1992). This study interpreted two of the five aquifers at SRS. Groundwater samples were analyzed for major cations and anions, minor and trace elements, gross alpha and beta, tritium, stable isotopes of hydrogen, oxygen, carbon, and carbon-14 to provide a geological and geochemistry interpretation of the Coastal Plain Hydrostratigraphic province.

The data set from the current research is used to generate the first background-groundwater quality analysis at the SRS. Additionally, the current research will create a method to determine what role sampling has on the groundwater analysis for the SRS. Specifically, this research will examine the effects that background-groundwater inputs (e.g., quantity of well clusters) have on the spatial distribution of the output at SRS. The spatial distribution analysis will provide insights regarding the role that sampling patterns and densities have on the groundwater analysis.

1.2 Problem Identification:

South Carolina and Georgia agencies, Federal Agencies including the Environmental Protection Agency (EPA) and Nuclear Regulatory Commission, along with environmental groups associated with requesting Environmental Impact Statements (EIS), Environmental Impact Documents, Performance Assessments (PA), Composite Analysis (CA), groundwater flow and transport models have consistently requested information about the groundwater at the Savannah River Site (SRS) (Savannah River Nuclear Solutions, LLC, 2013). Since the installation of the background wells at the SRS, there has been one comprehensive hydrology study conducted. This study was completed by Strom and Kaback between Fall 1988 and Spring 1989 (Strom & Kaback, 1992).

1.3 Objective:

This research will serve as baseline data to contribute to a better understanding of the spatial distribution of the quality of the background-groundwater system at the SRS. The objective of this research is to sample, analyze, and interpret groundwater using regional groundwater wells at the SRS; conducted through real-time groundwater monitoring and sample collection from an existing groundwater well network at the SRS. Additionally, this research serves as baseline data for spatial distribution and has been calculated by logically examining information obtained from the SRS groundwater system; it is an *a priori* study.

The study will sample, analyze, and interpret groundwater conditions using regional groundwater wells at the SRS. This study will establish baseline measurements utilizing recognized EPA and World Health Organization (WHO) parameters to create a background-groundwater analysis for the SRS. It will use geochemical spatial distribution to show groundwater quality.

1.4 Research Question

What role does sampling have on groundwater quality analysis for the Savannah River Site?

1.5 Hypothesis:

Modifying the quantity and/or sample location will affect the spatial distribution of the groundwater quality analysis.

2. Literature Review

Analysis of groundwater characteristics throughout the site is needed to provide a comprehensive understanding of the quality of the background-groundwater across the Central Savannah River Area (CSRA). The CSRA acronym has been used since approximately 1950 and describes a trade and marketing area within Georgia and South Carolina; 13 counties within Georgia and 5 counties within South Carolina. This research will examine groundwater chemistry at the local scale (e.g., near individual waste units on site) and on a larger scale (e.g., Integrated Operable Units) within the SRS boundary. Surface water flow characteristics have been determined on the regional scale at the SRS in order to ascertain contamination risk to perennial streams since they are the receptors of groundwater discharge. Because the SRS boundary does not represent a groundwater boundary, regional studies have been useful in understanding the movement of groundwater into the SRS from surrounding areas and vice versa. Groundwater modeling has been used extensively at the SRS as an analytical tool for regional and local groundwater investigations. Models have been used to (1) define regional groundwater flow patterns on and off the SRS (Wyatt & Harris, 2004); (2) enhance understanding of contamination migration in the subsurface (Harris, 2004); (3) support remedial designs (Parkinson, 2004); and (4) provide predictive performance assessments of waste disposal facilities (Cook & Hunt, 1994). At the SRS, major groundwater modeling efforts have been conducted at main operating areas and waste units to determine groundwater base-flow and impact to groundwater system.

The SRS uses a hydrostratigraphy classification that is consistent with the U.S. Geological Survey (USGS) standards used in the regional studies. Currently, groundwater monitoring efforts at the SRS focus on the collection and analysis of data to characterize the fate and transport of groundwater concentrations. The SRS employs various methods to collect subsurface data. These methods include, but are not limited to, the following activities (Savannah River Nuclear Solutions, LLC, 2013):

1. Collecting soil and groundwater samples using cone penetrometer technology (CPT) and various drilling methods (i.e., mud rotary, Rotosonic, auger, etc.);
2. Collecting and analyzing geologic soil cores or seismic profiles to better delineate subsurface structural features;
3. Installing wells to allow periodic collection of water level measurements and groundwater samples at strategic locations;
4. Developing water table and potentiometric maps to help define the groundwater velocity in the subsurface; and
5. Performing various types of tests to obtain *in situ* estimates of hydraulic parameters in order to estimate groundwater velocities.

2.1 Site Location, Demographics, and Environment

The SRS was constructed during the early 1950s to produce materials (primarily plutonium-239 and tritium) used in nuclear weapons. The SRS, which borders the Savannah River, covers about 310 square miles in the South Carolina counties of Aiken, Allendale, and Barnwell. The SRS is about 12 miles south of Aiken, South Carolina, and

15 miles southeast of Augusta, Georgia (Figure 1). The Savannah River flows along a portion of the SRS's southwestern border.

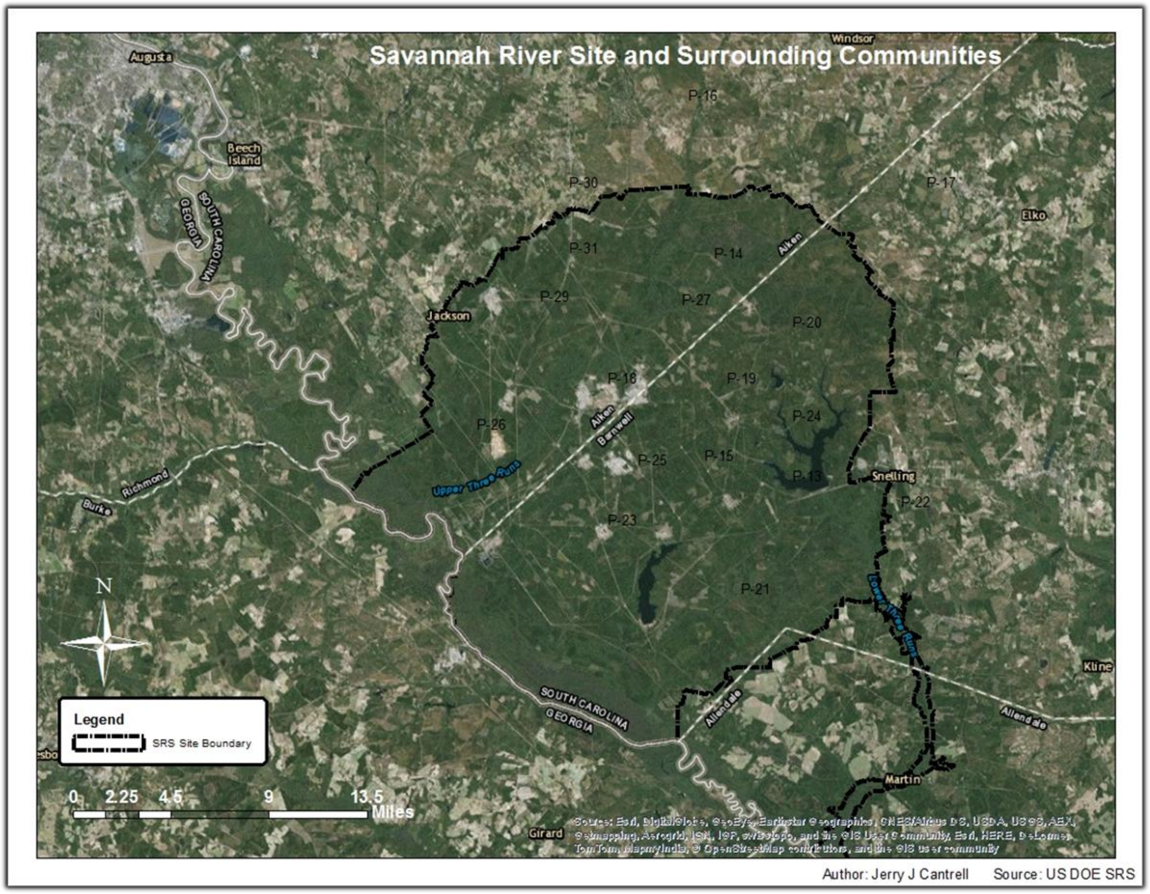

Figure 1: The SRS and Surrounding Communities

Based on the U.S. Census Bureau's 2010 decennial data, the population within a 50-mile radius of the center of the SRS is about 781,060 people (Savannah River Nuclear Solutions, LLC, 2013). This translates to an average population density of about 104 people per square mile outside the SRS boundary, with the largest concentration in the Augusta metropolitan area (Savannah River Nuclear Solutions, LLC, 2013).

Savannah River National Laboratory (SRNL) maintains an extensive network of over 130 regional monitoring wells that are distributed across the SRS (over 300-square miles). These monitoring wells were installed between December 1983 and January 1986 and occurred in three distinct phases. The regional groundwater observation wells are all within 18 widely spaced clusters and are installed in the regional aquifer units (Bledsoe Jr., 1984; Bledsoe, 1987; Bledsoe, 1988; Bledsoe, Aadlad, & Sargent, 1990; Savannah River Nuclear Solutions, LLC, 2013; Strom & Kaback, 1992). The cluster network penetrates the subsurface to depths of 1,000-ft. These clusters are designated as P-Wells and can be identified in Figure 2. Observations from this network are used for the following activities (Savannah River Nuclear Solutions, LLC, 2013):

1. To support South Carolina Department of Natural Resources regional groundwater monitoring usage program;
2. To establish baseline/background concentrations for naturally occurring radioactive material, man-made radionuclides, cations/anions, and basic geochemistry data;
3. For regional groundwater and contaminant flow models used in PA, CA, and environmental assessment models;
4. To determine the impact of varying geochemical conditions (e.g., aerobic and nonaerobic) on waste disposal, tank closure, PA, CA, environmental cleanup, and new facility siting.

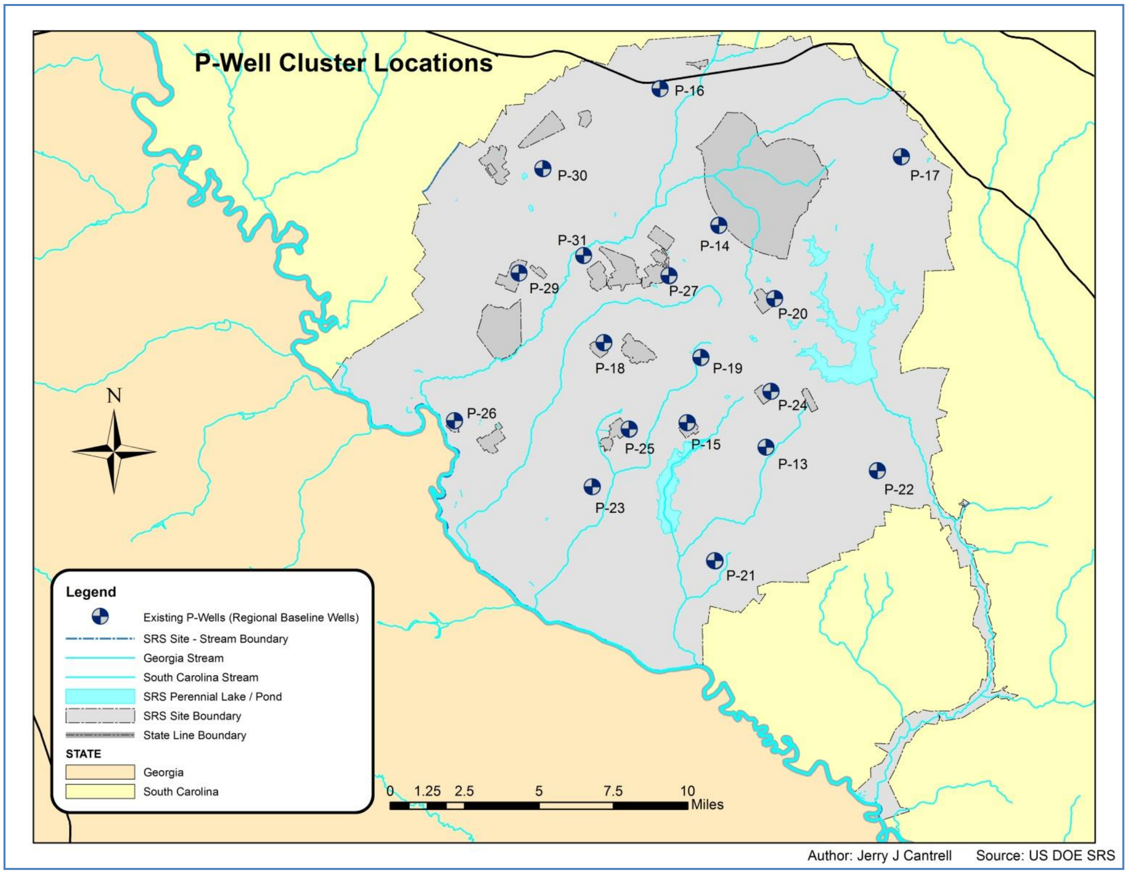

Figure 2: The SRS P-Well Locations and Site Boundary

The SRS is bounded on the southwest by the Savannah River for about 35 river miles and is about 160 river miles from the Atlantic Ocean. Beaufort-Jasper Water and Sewer Authority's Purrysburg Water Treatment Plant is the nearest downriver municipal facility that uses the Savannah River as a drinking water source. It is approximately 90 miles from SRS. Additionally, the Savannah River is utilized for fishing, boating, and recreational activities. There are large farms around the area that have extensive irrigation systems. Additionally, many of the local towns use deep wells for drinking water.

The groundwater flow system at the SRS consists of two major aquifers: the Floridan Aquifer System and the Dublin-Midville Aquifer System (Figure 3) (Aadland, Gellici, & Thayer, 1995; Wyatt & Harris, 2004). The major aquifer systems are subdivided into five distinctive aquifers. The Floridan Aquifer System consists of (1) the Gordon Aquifer, (2) the Upper Three Runs Aquifer, and (3) the Steed Pond Aquifer. The Dublin-Midville Aquifer consists of (4) the Crouch Branch Aquifer and (5) the McQueen Branch Aquifer. Groundwater generally migrates downward as well as laterally. In time, it either discharges into the Savannah River and its tributaries or it migrates into the deeper regional flow system. Furthermore, the SRS groundwater is used for industrial processes and drinking water within the SRS industrial complex (Savannah River Nuclear Solutions, LLC, 2013).

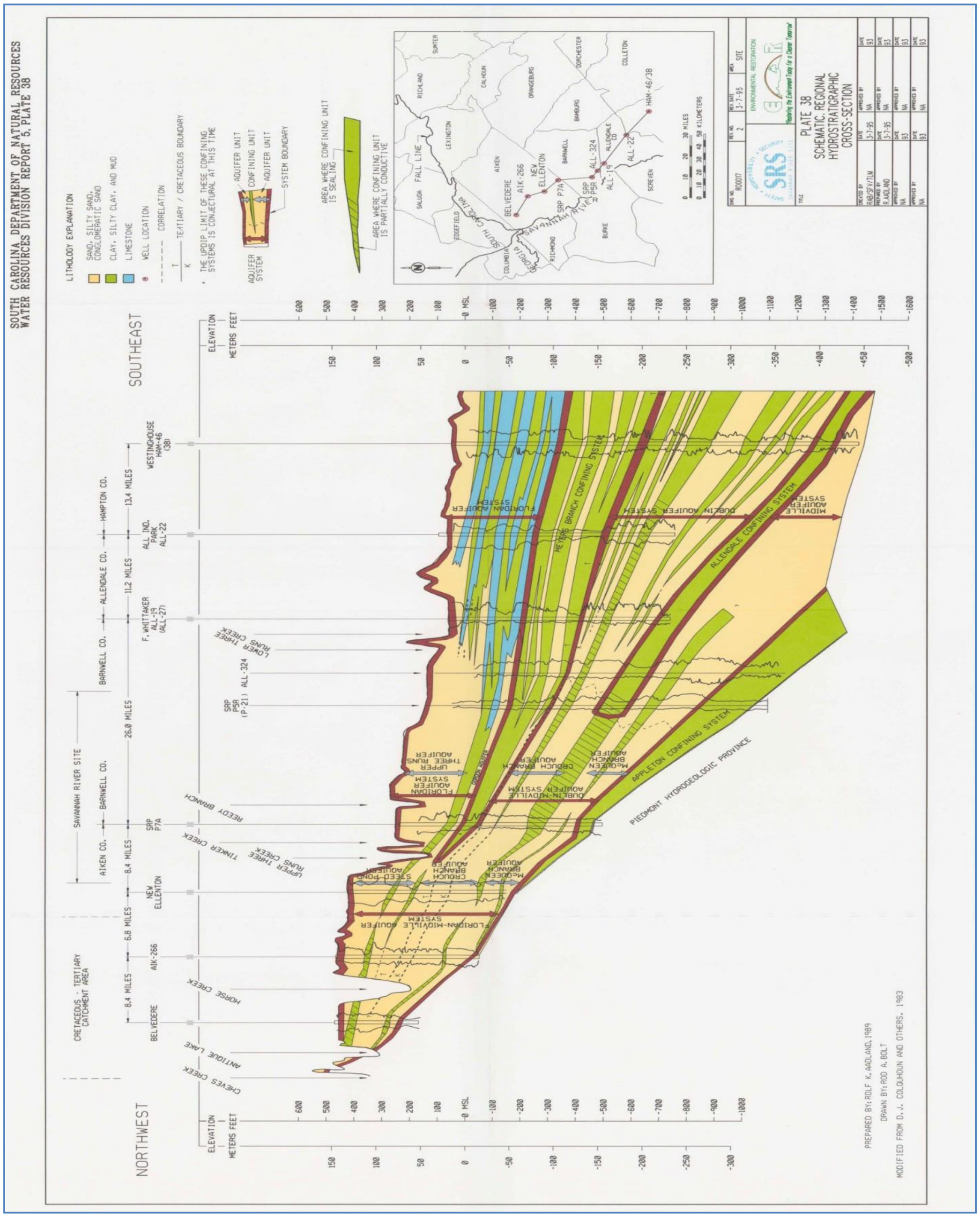

Figure 3: Aquifer Systems for the SRS and Conjoining Areas (Aadland et al., 1995)

2.2 Prior Studies Using Aggregate Indices

Horton proposed the first water quality index systems in 1965 (Jacobs et al., 1965). The determination at the time indicated that a water quality system should require three components: (1) selection of water quality parameters in which the index is defined, (2) establishment of a rating scale for each parameter, and (3) development of a weighting system for the parameters of the index. Horton (1965) suggested that a water quality index may be defined as a rating that reflects the composite influence on the overall quality of a number of individual quality characteristics. The establishment of water quality indices since Horton's conceptual writing intends to provide scientifically rationalized methods to represent water quality information. Specifically, there has been a great deal of consideration given to the development of water quality indices.

A majority of Water Quality Indices (WQI) are created with a limited number of parameters. The parameters of the WQI must be treated by comparison with a standardized value. There are three types of water quality analyses available through WQI: acceptability, health, and drinking (Carr & Rickwood, 2007). Acceptability WQI are based on parameters that would indicate the likelihood that water would be perceived as having an objectionable taste or odor when humans drink it; it is based on color, odor, and clarity regardless of its potential for health risks. Health WQI is based on chemical and radiological parameters that are specifically known to have potential adverse effects on human health. Health WQI does not take into account Acceptability WQI or vice versa. Drinking WQI includes any parameter that is necessary to support the study that is being conducted; it is not limited to parameters of Acceptability WQI and Health WQI and may include any or all parameters outside of the two other indices.

Štambuk-Giljanović (2003) utilized the water quality index developed by Horton as a tool to convert 12 monthly samples taken over a year from 50 sites into a single number representing the water quality of Dalmatia (Croatia). The aggregate index presented eliminates subjective assessments and biases of the nine parameters included into the index. The mathematical model of this study specifically eliminates subjectivity within its algorithm for calculating water quality. Several mathematical extrapolations were reviewed for the index. It was found that modified arithmetic indices provided the most suitable methods to discriminate good versus poor water quality conditions.

Others have attempted to establish WQIs based on various approaches and assumptions. However, there is still lacking an overall measure of water quality around the world. Poor data quality and coverage are largely to blame but other socio-economic and geopolitical issues make it a challenge to create comparable water quality indicators. The following are just a few examples of recent attempts to quantify water quality around the globe.

Liou *et al.* (2002) employed a water quality index in Taiwan that incorporates the scientifically accepted methodologies of WQI and a principle components analysis (PCA). Rating curves are used in the aggregate processing of the index. From the curves, a score of 100 represents the highest quality of water and a score of 0 (zero) represents the poorest quality of water. This WQI relies on the geometric means of three broad categories for its water quality characterization: physical, chemical, and biological.

Kim and Cardone (2005) developed a WQI based on a Scatterscore index that identifies increases and decreases in water quality over time and space. The Scatterscore index does not rely on water quality standards established by EPA or WHO.

Additionally, because this method identifies increases and decreases in water quality parameters, an unlimited number of parameters may be used within the index (Kim & Cardone, 2005; Shiow-Mey Liou, Shang-Lien Lo, & Shan-Hsien Wang, 2004).

Rickwood and Carr (2009) used the Canadian Counsel of Ministers of the Environment (CCME) index as a recommended basis for global water quality comparison. The recommended index only included parameters that met the following criteria: (1) parameters included in the study had to be measured in at least 20% of the countries of major global regions: Asia, Africa, Europe, Oceania, and Americas, and (2) for a station to be included it must have measured at least four variables, four times per year (4 x 4 rule). The CCME index measures the percentage of parameters that exceed the guidelines (scope), the percentage of each individual parameter that exceeds the guidelines (frequency), and the extent of deviation that failed parameters exceed the guidelines (amplitude). These three variables are aggregated and a scaling factor is applied to assure that the scale remains between 0 (zero) and 100; zero representing poor and 100 representing excellent water quality. The three indices of the CCME index allow assessment of water quality temporally when comparing station-by-station parameters and spatially through different regions, countries, and/or watersheds.

Srebotnjak *et al.* (2011) prepared a Water Quality Index (WATQI) based on five commonly reported quality parameters: dissolved oxygen, electrical conductivity, pH, total nitrogen concentration, and total phosphorous concentration. The 2008 Environmental Performance Index (EPI) published by the Yale Center for Environmental Law and Policy (YCELP) and the Center for International Earth Science Information Network (CIESIN) at Columbia University includes the WATQI. The WATQI is the first global attempt to estimate water quality based on these five parameters. Additionally, to provide more substantial geographical coverage incorporates a method to "hot-deck" imputation of missing information into the WATQI. In the context of missing data imputation, these decks represent observations from other cases, called "donor cases" that match the "recipient" case on a set of specified variables from the same data set (Srebotnjak, Carr, de Sherbinin, & Rickwood, 2012). The WATQI value for water quality is the weighted sum of the five proximity-to-target sub-indices. A specific problem noted for this study is the questionable quality of available data that could be used.

Melloul and Collin (1991) prepared a means to identify water quality factors by using the Principal Components statistical method. Sampling occurred between 1959 and 1974 within the Dan metropolitan region of Israel's Coastal Plain Aquifer. The parameters involved in this investigation include major ions, depth to water, distance from the sea, and aquifer recharge. The Israel study utilizes time, multiple samples from individual sites, and ionic ratios to eliminate subjectivity. The study of Melloul and Collin provides a method that enables parallel consideration of chemical and physical parameters in determining the parameters that affect water quality.

Babiker *et al.* (2007) describes water quality as spatially variable with multiple parameters with a wide range of chemical, physical, and biological indicators within the *a priori* study of the Nasuno basin (Japan). The optimum index factor technique allows for selection of the best combination of parameters dictating the variability of background-groundwater quality analysis and enables an objective representation of the overall groundwater quality (Babiker, Mohamed, & Hiyama, 2007). Seven parameters were chosen for the study. These parameters are compared to WHO standards and are standardized against those recommended values. Babiker *et al.* established primary and rank maps that provide a method to rank and weight each parameter. The summation of aggregate parameter scores provides the overall water quality index determination. Within this method of determining water quality, a 0 (zero) represents poor water quality and a 100 represents excellent water quality.

Similar to groundwater quality indices, surface water quality indices employ aggregate scoring. Tsegaye *et al.* (2006) evaluated the impact of land use / land cover changes, seasonal, and location on water quality of streams within the Wheeler Lake Basin of northern Alabama. Water samples were collected from 18 streams over a 2-year period. A chemical water quality index was established based on pH, total nitrogen, dissolved oxygen, soluble lead, and dissolved, particulate, and total phosphorous. Datum of each individual water quality parameter was normalized relative to the maximum value of the water quality parameter within the data set. The summation of the water quality parameters provides an aggregate index representing the overall quality of the stream waters.

Vulnerability indices also utilize aggregate scoring systems that are similar to that of groundwater quality indices. Rosen (1994) prepared a study of DRASTIC methodology and emphasized it with respect to Swedish conditions. DRASTIC utilizes seven key hydrogeologic parameters to classify the vulnerability of the aquifer: **D**epth to water, **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of the vadose zone media, and hydrologic **C**onductivity of the aquifer. These parameters are weighted with their relative importance to the aquifer's potential to be polluted. DRASTIC has a set of weights specific to pollutants in general and an additional set that is specific to pesticides. The index is calculated for an area by aggregate calculations of the weight and rating of each of the seven DRASTIC parameters. The higher the index score, the greater the potential of ground-water pollution.

It is important to recognize that DRASTIC assumes that contaminants are introduced at the ground surface through precipitation, the contaminant has the mobility of water, and the area evaluated is at least 100 acres. The advantage of DRASTIC is that it is quick and simple to use, while maintaining accuracy for early stage applications. However, it does require professional judgments of subjective estimations. A disadvantage of DRASTIC is that the final result may be less distinctive because of the weighting and integrating of values within the final simplistic-index value and must be accompanied by a qualifying explanation. However, DRASTIC does utilize an aggregate scoring system that is similar to the scoring system for water quality indices.

Melloul and Collin (1991) and Prahaj *et al.* (2002) utilize a contamination index that is similar to the normalized difference index equation in which these authors utilized a ratio between the measured concentration and the prescribed maximum acceptable concentration level. Babiker *et al.* (2007) attempted to normalize the data within a range of (-1, 1). Dixon (2009) used a confusion matrix to establish a fuzzy-logic matrix that provides values between (-1, 1). The difference between this study's index and the mentioned author's indices is that the normalized concentration difference index possesses a linear relationship for each parameter's minimum and maximum concentration limit values. This index is proportional in value as each parameter is related to exceeding the minimum or maximum concentration limit.

The methods to describe water quality indices are myriad. Each method may or may not contain subjective qualifications. However, all methods that establish a water quality index contain objective parameter qualifications. The method of establishing an index must take into consideration the quantity of information available as it is measured over time (temporal considerations), the area that the parameters are extracted from (spatial considerations), and the information available to and needed from the study.

3. Methods

The sampling at the SRS is obtained in point form with respect to GIS. This data must be interpolated through IDW to derive the spatial distribution of water quality parameters throughout the five aquifers at the SRS as in prior research studies it has been determined to yield results most consistent with the input data (Mathes & Rasmussen, 2006). This study will sample, analyze, and interpret groundwater conditions using regional background-groundwater wells at the SRS; conducted through real-time groundwater monitoring and sample collection from an existing groundwater well network at the SRS. Samples were transported to an EPA-certified laboratory and analyzed for various geochemical parameters. Additionally, *in situ* analysis was accomplished in the field.

3.1 Field Sampling

Field sampling of all 18 background well clusters at the SRS occurred between the summer of 2014 and the summer of 2015. A Solinst water level detection meter and sounder was used to determine the current depth of the water from the top of the well. The original well depth is known from data provided by the SRS during the P-Well installations. This data is compared to the installation well depth to determine the volume of water within the well structure, which must be known to determine the required 2-well volume quantity that was purged from each well (Hardy, Alley, & Leahy, 1989). Purge rate from the wells is measured using one of two sources: (1) a bucket test with stopwatch and / or (2) calibrated flow meters attached to the wells. Furthermore, the wells were continuously monitored to verify that changes in the purge rate are negligible. Chemetrics V2000 photometers were used to sample for the following parameters: alkalinity (ppm as $CaCO_3$ – total), aluminum (ppm), ammonium (ppm), total iron (ppm), ferrous iron (ppm), manganese (ppm), nitrite (ppm as nitrogen), sulfate (ppm), sulfite (ppm), and zinc (ppm) with calibration (e.g., zeroing) of the V2000 photometer occurring before each sample.

Real-time data collection was collected with YSI Sonde devices (e.g., 600XL, 6820, and 6920 V2) used in conjunction with YSI 650MDS data recorders. The following parameters were recorded: specific conductivity (μS/cm), pH, dissolved oxygen saturation (%), dissolved oxygen (mg/L), oxidation-reduction potential (mV), and temperature (˚C). Daily calibrations occurred for the following parameters: specific conductivity, pH – two-point calibration, and dissolved oxygen (%). In addition, Hach turbidity meter was used to measure turbidity (NTU).

Sampling was conducted in compliance with EPA guidelines for each background well at the SRS. This requires a minimum continuous-purging of two well volumes and stability of periodic readings from the well. After the minimum continuous-purging of two well volumes, stability is determined through periodic measurement of pH and specific conductivity. Stability is determined to be obtained at the time that the readings of pH and specific conductivity vary by no more than 10% from one periodic reading to the next (Hardy et al., 1989). Turbidity must also be less than or equal to 15 NTU to consider a stable well for sampling based on laboratory requirements. Furthermore, well purging continued until stability of pH, specific conductivity, and dissolved oxygen are obtained as well as a turbidity reading of 15 NTU or less is achieved.

Upon stability in the well readings as previously indicated, Chemetrics V2000 photometry tests were conducted and recorded in the field. Additionally, two 237 mL sample bottles were used in the water collection from the well site and transported offsite for further chemical analysis. Analysis included anions, cations, trace elements, radium, and uranium (e.g., Al, Sb, As, Ba, Be, Cd, Ca, Ce, Cr, Co, Cu, Eu, Ga, Ho, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, Nb, K, Se, Aq, Na, Ra, Sr, S, Tl, Th, Sn, Ti, U, V, Zn, Inorganic Carbon, TOC). There were approximately 150 samples collected. These samples were typically taken at a volume of approximately 4 wells per day. The location where groundwater samples were conducted is displayed in Figure 2, which is indicated by cluster grouping.

3.2 Recommended Background-Groundwater Quality Analysis

Seven parameters are listed in the WHO guidelines as possessing a potential to alter the taste, odor, appearance of water, or might cause a health risk to humans: Cl^-, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, TDS (Total Dissolved Solids), and NO_3^- (*Guidelines for drinking-water quality*, 2004). United Nations Environmental Programme (UNEP) recommends that a water quality index include parameters for pH, dissolved oxygen, conductivity, and nitrogen and phosphorous nutrients (Carr & Rickwood, 2007). Based upon the declarations of UNEP and WHO, as well as the available parameters sampled, the following parameters are included to determine the Groundwater Quality Calculation value for this study: Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, TDS, pH, dissolved oxygen, conductivity, and nitrogen nutrients.

Since metric coordinates are more convenient for spatial analysis, geographical latitude/longitude coordinates have been converted to UTM (Universal Transverse Mercator) projection (Babiker et al., 2007). Spatial analysis was conducted using ESRI's

ArcGIS software platform (version 10.4.1). Concentration maps were established for each analyte with a pixel resolution of 50 m on each edge, and extended throughout the study area based on the groundwater sampling locations. The maps have been geo-referenced to the area based on sample coordinates. Because each pixel represents a standardized 50 m space on edge, positional errors may compensate each other (Babiker et al., 2007; Levallois et al., 1998). Therefore, distance computations in the geographic information system (GIS) are subject to error within a range of $\pm$50 m based on the standardized 50 m raster cell (Babiker et al., 2007; Levallois et al., 1998).

3.3 Development of the Background-Groundwater Quality Analysis

To establish the groundwater quality calculation, the data collected had to be interpolated throughout the SRS region. Inverse Distance Weighted (IDW) interpolation is used to interpolate concentration parameters throughout the study maps (Mathes, 2002). IDW interpolates raster from points using inverse weighted distance. The output value for IDW is limited to the range of values contained within the input data; therefore, the interpolated range of ridges and valleys are constrained to the maximum and minimum input values (Comparing interpolation methods.2012). This is an ideal situation regarding interpolation of data at the SRS.

3.3.1 The Raw Concentration Map

A primary map is a map of the phenomena of interest (e.g., pH, DO, Conductivity, etc.) (Lodwick, Monson, & Svoboda, 1990). The Raw Concentration Map includes the raw data for each set of analytes mapped with respect to the maximum extents of the SRS boundary. The range of the analytes depends on the applicable ranges for each specific analyte. Additionally, it incorporates the minimum to maximum value mapped with respect to individual analyte concentration utilizing IDW processing from the ArcGIS software. The Raw Concentration Map is clipped to truncate the IDW processing to a confined spatial distribution within the SRS boundaries.

3.3.2 The Normalization Map

The data from the Raw Concentration Map must be normalized so it may be accurately aggregated. However, the various analytes have different units of measure. This creates cumbersome comparisons and normalization of data allows ease in analyte aggregation. Therefore, each of the data sets for the specific analytes must be normalized with respect to standard values so that aggregation of the data may occur.

In order to normalize the data within Raw Concentration Map, the measured concentration, X, is linearized with respect to the EPA Maximum Concentration Limit (MCL) values, WHO, or Canada's standards (A comparison chart of drinking water standards from around the world.; *Guidelines for drinking-water quality*2011; Science and technology.2014). The normalized concentration difference index provides each pixel of each parameter with an index value that is proportional to, and linear with respect to the EPA MCL, WHO, or Canadian standard value. Furthermore, each of the normalization values is unitless due to the linearization for aggregation. The normalization calculations occur with the ArcGIS Raster Calculator function.

The normalized concentration difference (C_i) index (Equation 1) is valid for all parameters of this study. It is most easily represented for parameters that have a 0 (zero) value for the respective minimum standard (S_{min}); in this research it includes all values except pH. The respective maximum standard value is represented by S_{max}. The normalized concentration difference index equation for all parameters other than pH is as follows and can be found in Appendix 7.1:

$$C_i = \frac{(X - S_{\min})}{(S_{\max} + S_{\min})}$$

Equation 1: Normalized Concentration Difference Index (Excluding pH)

3.3.3 The Rank Map

A Rank Map is a map whose attributes are numerical and comprise the mathematical relationships of the attributes of one or more maps (Lodwick et al., 1990). The Normalization Map data provides a rank index that has values that are ideally expected to be bounded within the range of (0, 10), assuming that the measured value (X) is within the minimum and ten times the maximum boundaries of the standard values. There are normalized values that exceed the maximum of 10. Therefore, the Rank Map scales the values from 1 to 10, which is necessary for aggregating data. A rank of 0 indicates minimum concentration impact to the water quality, which represents optimal water quality. A rank of 1 indicates that the concentration from the normalized data matched the expected standardized value. A rank of 2 indicates that the concentration from the normalized data was twice the expected standardized value. A rank of 3 is three times, etc. A rank of 10 indicates maximum concentration impact to the water quality, which represents a complete degradation in water quality. Any normalized value exceeding a value of 10 is reclassified in ArcGIS to a value of 10, the maximum rank associated with the ground water quality. The reclassification standardizes the normalized data to an integral range of 0 to 10. Effectively, it reclassifies the normalized difference index ($\boldsymbol{C_i}$) to a corresponding rank map value ($\boldsymbol{r_i}$). Each raster pixel is assigned the integer based on its unique value from the Rank Map, which is the ($\boldsymbol{r_i}$) value.

3.3.4 The Groundwater Quality Calculation Map

The integral value obtained from each parameter's Rank Map is utilized to determine the groundwater quality calculation. The groundwater quality calculation is calculated using Equation 2:

$$GQI = 100 - \left(\frac{\sum_{i=1}^{N} r_i w_i}{N} \right)$$

Equation 2: Groundwater Quality Index

For Equation 2, (r_i) represents the pixel value from the Rank Map; (w_i) represents the relative weight of the parameter – this corresponds to the "mean" rating of $(\bar{r})$ for each rank map parameter. The mean rating for each parameter is obtained through calculation within ArcGIS. Concentrations that impose a higher mean rank are assumed to have greater impact on the groundwater quality calculation. Therefore, the (w_i) weight is proportional to the impact that each individual parameter possesses within the groundwater quality calculation.

Babiker *et al.* (2007) used an objective scale of (-1, 1) to eliminate subjective interpretations of parameter values. However, Babiker did include a subjective penalty to all nitrate parameters regardless of magnitude within the objective scale. Melloul *et al.* (1991) utilized principal components analysis to indicate the magnitude of influence that parameters have on water quality. Time, multiple samples, and ionic ratios were used to eliminate subjectivity within Melloul's research. Prahaj *et al.* (2001) used a concentration index that was calculated for only the values that exceeded maximum concentration values to avoid subjectivity. This research differs from those studies by eliminating subjectivity through proportionally ranking concentration values based on the minimum and maximum standardized values.

3.4 Sensitivity

For this study, analyses must be performed between the measured parameters to identify differences within the spatial distribution of the overall groundwater quality (Babiker et al., 2007). To determine the centrality method to statistically test sensitivity, the statistical assumptions are based on what is known regarding the data available. First, the chemical constituents within groundwater are correlated spatially. Second, the analytes may not be normally distributed and the measurements may not be independent of each other. This is because the shallow aquifers are mostly unconfined, which allows for vertical migration of contaminants and mixing of groundwater; a Shapiro-Wilk test for normality is used to determine normality with IBM SPSS Statistics 24 software. However, the deeper units, generally from the Gordon Confining Unit down, are confined aquifer systems and the lithological makeup, thicknesses, and pressure gradients (i.e., head reversals) challenge or limit vertical migration of groundwater. Third, it is not justifiable to remove outliers from the data set (e.g., a statistical test that is not sensitive to outliers is necessary). These are three items that must be taken into consideration in statistically determining the sensitivity of the measurements.

The statistical analysis employed must be nonparametric because it is assumed that the data will not be normally distributed. Additionally, it is not justifiable to remove outlier measurements from the dataset. The nonparametric test employed is the One-Sample Wilcoxon Signed Rank Test from SPSS software. *A priori* knowledge of error within the perturbations upon the imposed inputs as well as underlying assumptions of the geographical analysis are not required to determine or to gain knowledge about the behavior of the spatial distribution of the groundwater quality analysis (Babiker et al., 2007; Lodwick et al., 1990). This indicates that the study can be statistically tested by analyzing perturbations from the known observations and that IDW is ideal because it restrains that dataset to the maximum and minimum input values.

Each map contains 745 x 851 raster pixels (columns v rows at 50m x 50m per raster), or 633,955 raster pixels per IDW map. After a Clip function is performed with ArcGIS, there are typically 320,400 raster pixels available for processing. The 320,400 pixels are processed through a Calculation function, Reclassification, and an overall Calculation. The overall Calculation provides the mean value for the groundwater quality analysis.

The original datasets (no perturbations) have all 9 parameters included into the calculations. Each of the 9 groundwater quality parameter series is individually interpolated across the SRS area (9 sets of 633,955 raster calculations). After the Clip process, there are 320,400 remaining raster pixels. All 9 groundwater quality parameters are processed with the Clip function in ArcGIS. Subsequently, each of the 9 individual parameters has a unique Calculation applied to normalize the raster data (Appendix 7.1). After normalization occurs, the raster datasets that have a value ≥ 1 are reclassified to constrain the values between 0 and 10. The final process with ArcGIS is to aggregate the data through a Calculation based on the formula provided in Equation 3.

It is important to note that if an entire raster dataset does not exceed a value of 1, it has been reclassified to a value of 0. Therefore, because the IDW interpolation does not exceed the minimum or maximum value of the inputs, a parameter with an overall reclassification of less than 1 becomes 0. Hence, the dataset will have a value of 0 in the weighted aggregation and further manipulation of the specific data series is no longer required within the perturbations. Gordon aquifer has 5 parameters that have a weight greater than 1: Conductivity, pH, Turbidity, Magnesium, and Calcium. Upper Three Runs aquifer has 4 parameters that have a weight greater than 1: Conductivity, pH, Turbidity, Calcium. McQueen Branch and Crouch branch have 3 parameters that have a weight greater than 1: Conductivity, pH, and Turbidity.

For the original data (no perturbations) the raster is calculated or reclassified between 12.8 x 10^6 and 13.4 x 10^6 times, dependent on the aquifer's parameters, to obtain the final 320,400 raster pixels (per parameter). The final 320,400 raster pixels per parameter are aggregated into one final raster dataset, which provides the overall groundwater quality calculation for each aquifer.

The original series sets the precedence for calculations within the perturbations. There are 8.3 x 10^6 calculations/reclassifications for the Gordon aquifer, 7.3 x 10^6 calculations/reclassifications for the Upper Three Runs aquifer, and 6.4 x 10^6 calculations/reclassifications for both the McQueen Branch and Crouch Branch aquifers. These calculations/reclassifications result in the final 320,400 raster pixels that are used to determine the overall groundwater quality for each perturbation.

When comparing the 320,400 raster pixels for the aggregated, perturbated groundwater quality calculations, and taking into consideration that there are 40 perturbations for each aquifer, the data comparison ranges from 255 x 10^6 to 332 x 10^6 perturbated raster pixels. This is compared to the original aquifer's raster data of approximately 322,400 pixels. Therefore, this study will use the principles employed from the law of large numbers because the mean of the individual cells is respective of the overall mean of the dataset under consideration.

4. Analysis

4.1 Randomization of Well Clusters for Perturbations

The 18 well clusters extend through various depths of five aquifers at the SRS. The clusters are listed in Table 1 by red squares. Typically, there is one well at the top of the aquifer and one at the bottom of the aquifer within each cluster. The red spaces without an X represent a cluster/aquifer location that could not be sampled due to all pumps being defective or missing at that location.

Table 1: Active Well Designated by Cluster

Cluster/Aquifer	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	29	30	31
Steed Pond				X												X	X	
Gordon	X	X	X		X		X	X		X	X	X		X				X
Upper Three Runs	X	X	X		X	X	X	X	X	X	X	X	X		X			X
Crouch Branch	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
McQueen Branch	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X

Statistical sampling requires a systematic and methodical process of creating perturbations in the collected data. Therefore, a process is utilized to create the 40 necessary perturbations: a random selection from the well clusters to create perturbations in the data. Elimination of two clusters is chosen to begin the process because each aquifer has at least one well that is not operational and two of the aquifers have at least one cluster without operational wells. Additionally, the Gordon aquifer required additional review after analysis of two-well perturbations and a three-well perturbation was conducted for that data set.

There is one exception to the perturbations, which is the Steed Pond aquifer. Steed Pond aquifer has 3 clusters, containing a total of 10 wells. Of the 10 wells, only 4 are operational. Additionally, removing two clusters to create perturbations within the data can only yield 3 random outcomes for data. The necessary 40 perturbations would consist entirely of these 3 perturbations and the data would not be reliable for analysis. Therefore, analysis is not being conducted on the Steed Pond aquifer.

Microsoft Excel was used to establish the random selection from the data. For Gordon, Upper Three Runs, McQueen Branch, and Crouch Branch aquifers, perturbations were created in the data by eliminating the following clusters from the respective datasets:

Table 2: Gordon 2-Cluster Perturbation Selection

1	20	24	**11**	23	31	**21**	13	27	**31**	20	19
2	22	19	**12**	24	14	**22**	24	18	**32**	19	23
3	19	14	**13**	27	22	**23**	13	19	**33**	20	18
4	26	13	**14**	17	13	**24**	15	17	**34**	23	22
5	20	31	**15**	26	24	**25**	20	15	**35**	18	13
6	31	24	**16**	17	31	**26**	13	23	**36**	19	15
7	31	22	**17**	18	31	**27**	27	14	**37**	24	19
8	24	23	**18**	15	24	**28**	17	20	**38**	31	14
9	27	18	**19**	20	26	**29**	14	13	**39**	13	24
10	18	19	**20**	20	27	**30**	24	27	**40**	17	23

Table 3: Upper Three Runs Perturbation Selection

1	23	17	**11**	19	20	**21**	21	26	**31**	22	27
2	21	22	**12**	22	19	**22**	26	23	**32**	31	21
3	23	22	**13**	13	21	**23**	18	17	**33**	19	31
4	20	18	**14**	26	31	**24**	25	27	**34**	21	24
5	31	14	**15**	14	25	**25**	23	25	**35**	22	18
6	15	22	**16**	24	25	**26**	25	26	**36**	27	22
7	15	20	**17**	24	26	**27**	24	31	**37**	14	21
8	25	18	**18**	15	19	**28**	13	18	**38**	15	23
9	21	27	**19**	24	21	**29**	14	19	**39**	14	13
10	24	17	**20**	25	15	**30**	13	26	**40**	26	15

Table 4: McQueen Branch Perturbation Selection

1	29	23	**11**	13	26	**21**	17	21	**31**	30	21
2	17	19	**12**	23	13	**22**	15	29	**32**	19	15
3	23	22	**13**	22	18	**23**	30	26	**33**	26	21
4	24	19	**14**	22	18	**24**	22	21	**34**	14	30
5	19	21	**15**	26	28	**25**	22	24	**35**	14	29
6	27	21	**16**	23	24	**26**	26	21	**36**	30	26
7	30	13	**17**	15	25	**27**	14	31	**37**	18	30
8	21	19	**18**	24	17	**28**	22	17	**38**	15	24
9	30	13	**19**	31	15	**29**	29	27	**39**	15	21
10	22	19	**20**	13	19	**30**	28	23	**40**	26	14

Table 5: Crouch Branch Perturbation Selection

1	21	14	**11**	18	15	**21**	26	29	**31**	26	18
2	25	28	**12**	28	31	**22**	20	30	**32**	30	23
3	19	29	**13**	18	28	**23**	14	23	**33**	26	27
4	30	28	**14**	31	29	**24**	28	14	**34**	17	30
5	21	18	**15**	19	29	**25**	21	15	**35**	21	26
6	26	18	**16**	23	13	**26**	23	28	**36**	18	14
7	31	23	**17**	24	21	**27**	21	15	**37**	29	27
8	14	18	**18**	29	13	**28**	19	27	**38**	31	29
9	15	17	**19**	26	30	**29**	21	14	**39**	14	28
10	23	31	**20**	15	27	**30**	26	30	**40**	15	19

Table 6: Gordon 3-Well Perturbation

1	23	22	17	**11**	15	31	24	**21**	23	13	23	**31**	24	27	17
2	18	26	17	**12**	18	26	22	**22**	17	13	31	**32**	27	31	16
3	26	25	14	**13**	17	15	14	**23**	31	15	20	**33**	23	27	20
4	22	14	27	**14**	19	20	23	**24**	26	27	31	**34**	17	13	19
5	17	26	23	**15**	27	14	17	**25**	31	17	24	**35**	13	20	19
6	31	24	20	**16**	24	18	23	**26**	26	17	23	**36**	24	15	27
7	13	27	22	**17**	31	27	22	**27**	31	14	26	**37**	22	26	31
8	26	22	17	**18**	17	18	19	**28**	13	14	27	**38**	13	23	18
9	19	15	23	**19**	20	26	31	**29**	19	26	13	**39**	15	28	20
10	22	17	23	**20**	20	18	17	**30**	15	23	17	**40**	31	26	17

4.2 Original Dataset Analysis (without Perturbations)

To establish an expected centrality value for each aquifer (Gordon, Upper Three Runs, McQueen Branch, and Crouch Branch), the complete dataset was initially analyzed. Within the analysis, the 9 parameters for the ground water quality analysis provide the basis for determining what data must be processed within the perturbations. Each of the values (mean and standard deviation) is unitless as they have been linearized for aggregation. Each aquifer's 9 parameters are listed within the following tables:

Table 7: Original Dataset Rank Mean for Gordon Aquifer

Series	Mean	STD
Conductivity	5.70	1.97
H^+	6.56	3.47
DO	0	0
Turbidity	9.67	1.21
N	0	0
SO_4^{2-}	0	0
Na	0	0
Mg	0.0232	0.151
Ca	1.28	1.41

Table 8: Original Dataset Rank Means for Upper Three Runs Aquifer

Series	Mean	STD
Conductivity	2.34	0.972
H^+	9.80	1.10
DO	0	0
Turbidity	9.99	0.244
N	0	0
SO_4^{2-}	0	0
Na	0	0
Mg	0	0
Ca	0.000808	0.0895

Table 9: Orginal Dataset Rank Means for McQueen Branch Aquifer

Series	Mean	STD
Conductivity	1.95	0.9
H ion	9.18	2.18
DO	0	0
Turbidity	9.76	1.03
N	0	0
SO_4^{2-}	0	0
Na	0	0
Mg	0	0
Ca	0	0

Table 10: Original Dataset Rank Means for Crouch Branch Aquifer

Series	Mean	STD
Conductivity	2.40	1.12
H ion	9.90	0.809
DO	0	0
Turbidity	9.91	0.474
N	0	0
SO_4^{2-}	0	0
Na	0	0
Mg	0	0
Ca	0	0

The mean value of the groundwater quality calculations for each aquifer is derived from the parameter's mean value (w_i) and its application to Equation 3. The mean parameter values are each listed in Tables 7 – 10 for the respective aquifer. The overall mean value of the groundwater quality calculations are as follows:

1. Gordon – 81.0
2. Upper Three Runs – 77.6
3. McQueen Branch – 79.6
4. Crouch Branch – 77.6

4.2.1 Original Dataset Maps (without Perturbations)

The map calculations allowed for determination of which maps required quality mapping. For instance, if the original dataset for Gordon aquifer yielded a map calculation for SO_4^{2-} that had all values less than 1, the quality values would be zero. Therefore, the need to produce a quality map for SO_4^{2-} become unnecessary as a quality value of zero provides an overall mean of zero for SO_4^{2-}. However, if any of the individual parameters yielded a calculation maps with a value equal to or above a value of 1 it was necessary to produce quality maps for those specific parameters. The quality map means are the multiplication (weighted) factor for the impact of each parameter; hence, if any calculation value was greater than a value of 1 then the quality map for that parameter had to be generated.

The following figures of this section provide the calculation maps for all nine parameters in each aquifer. The calculation maps that yielded values greater than or equal to a value of 1 are followed by a quality map for the respective parameter.

Additionally, the maps are listed in the following sequence: Gordon, Upper Three Runs, McQueen Branch, and Crouch Branch aquifers.

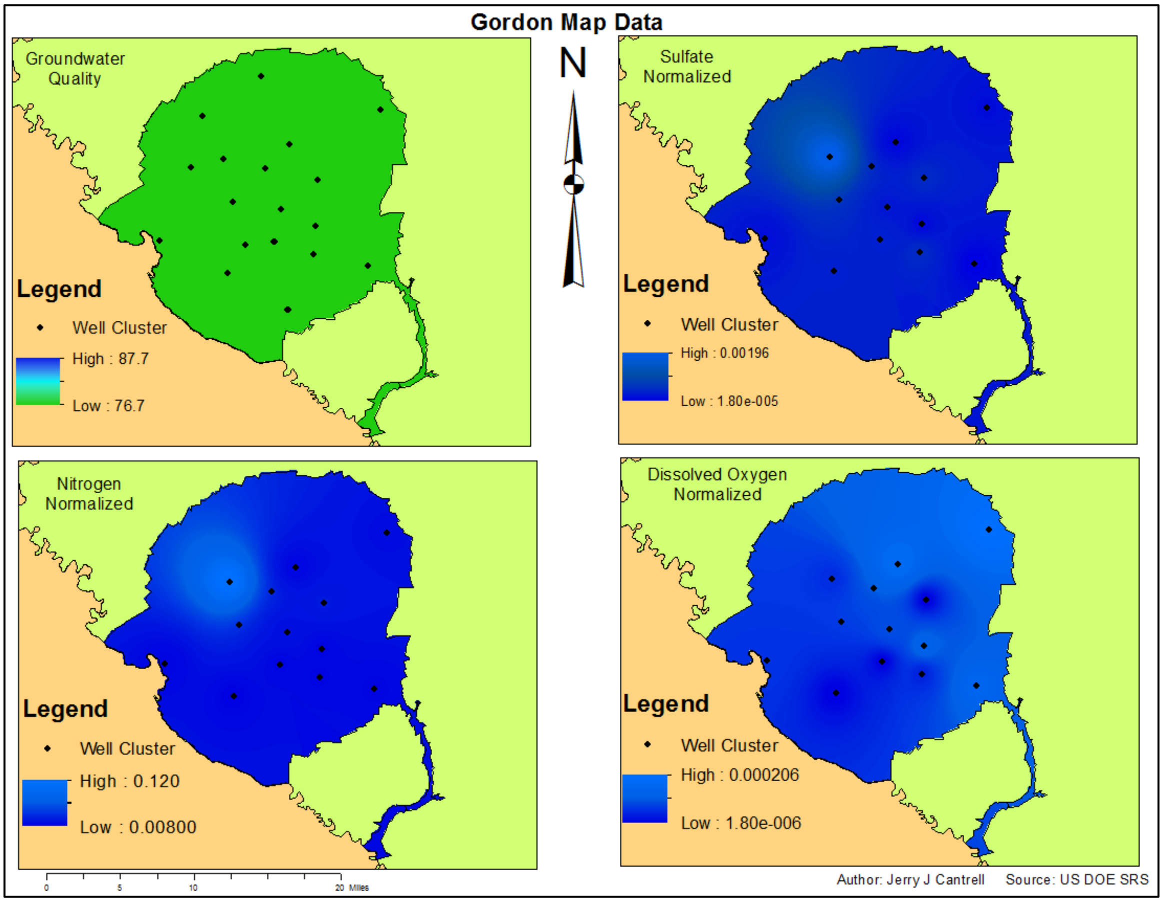

Figure 4: Gordon Aquifer SO_4^{2-}, N, and DO Normalized Values

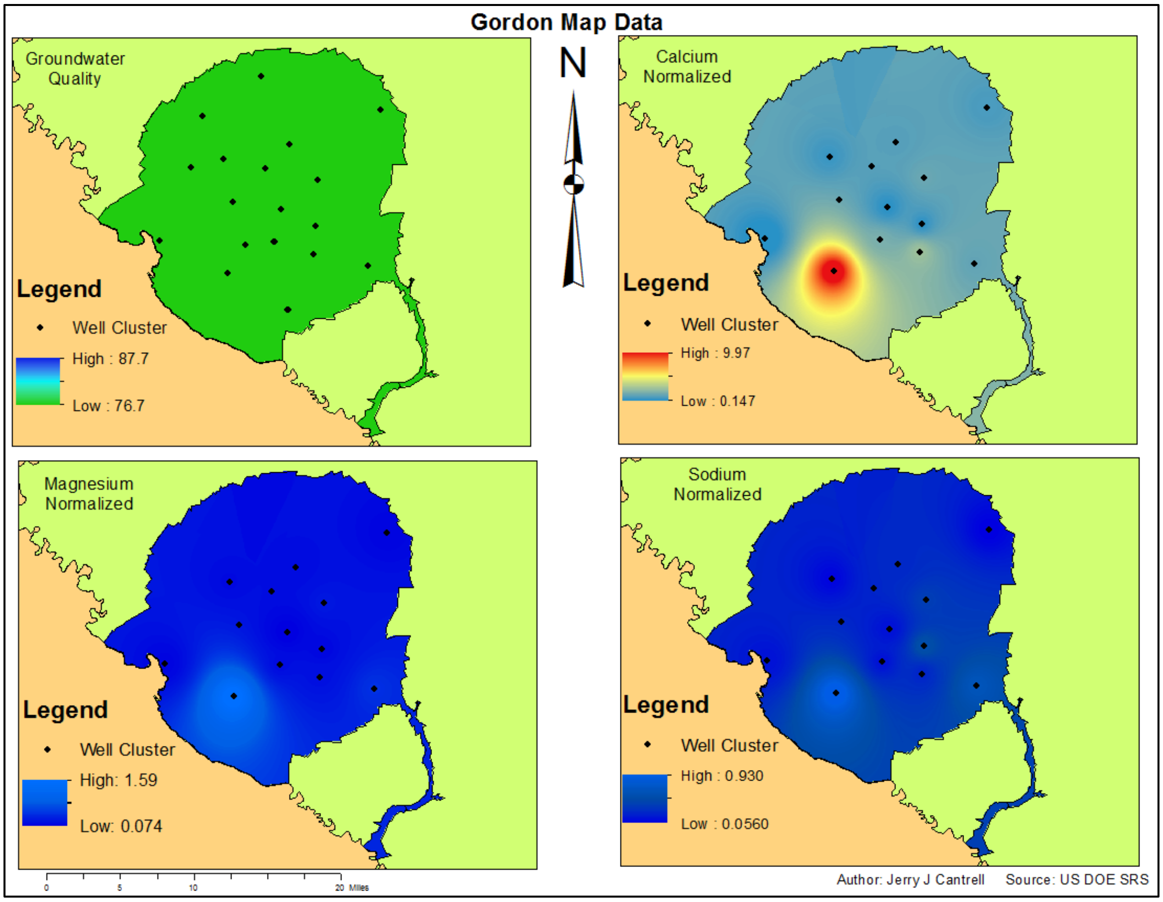

Figure 5: Gordon Aquifer Ca, Mg, and Na Normalized Values

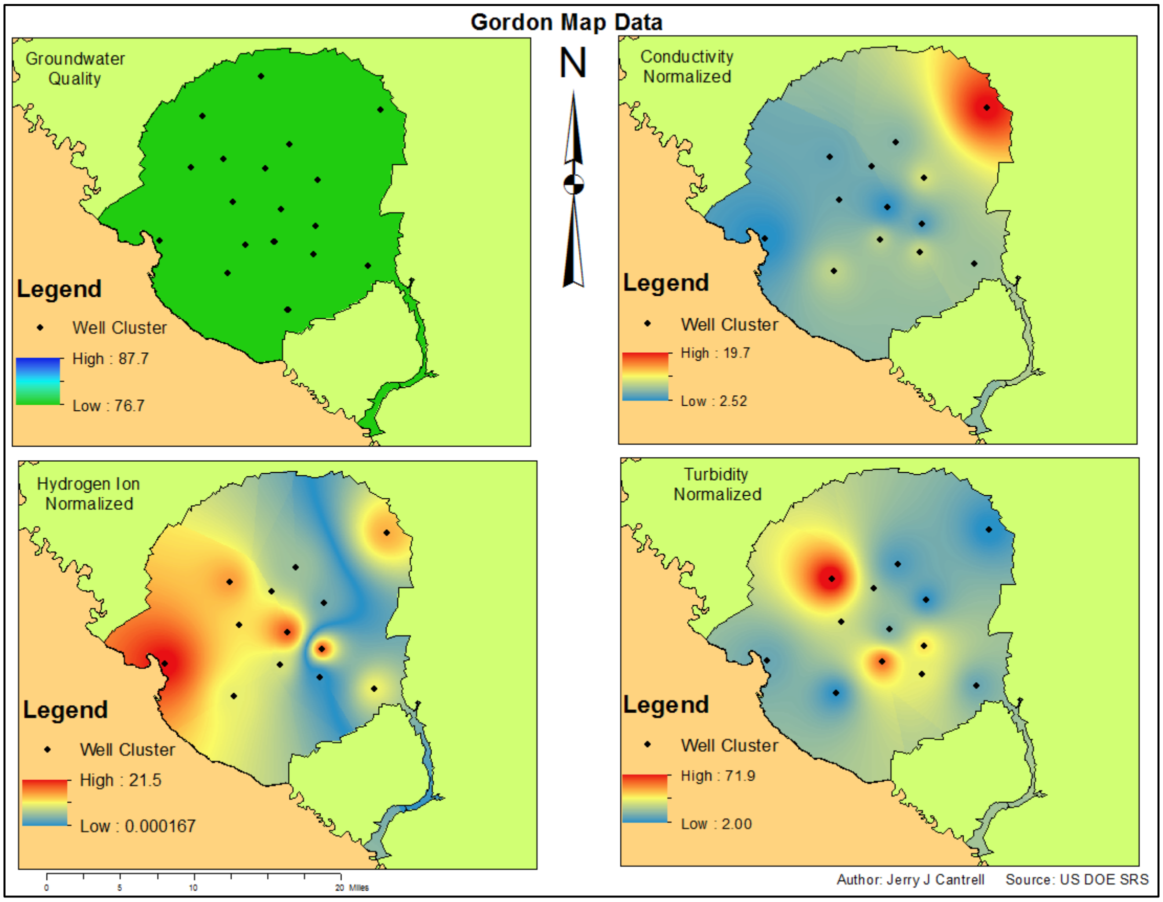

Figure 6: Gordon Aquifer Conductivity, H^+, and Turbidity Normalized Values

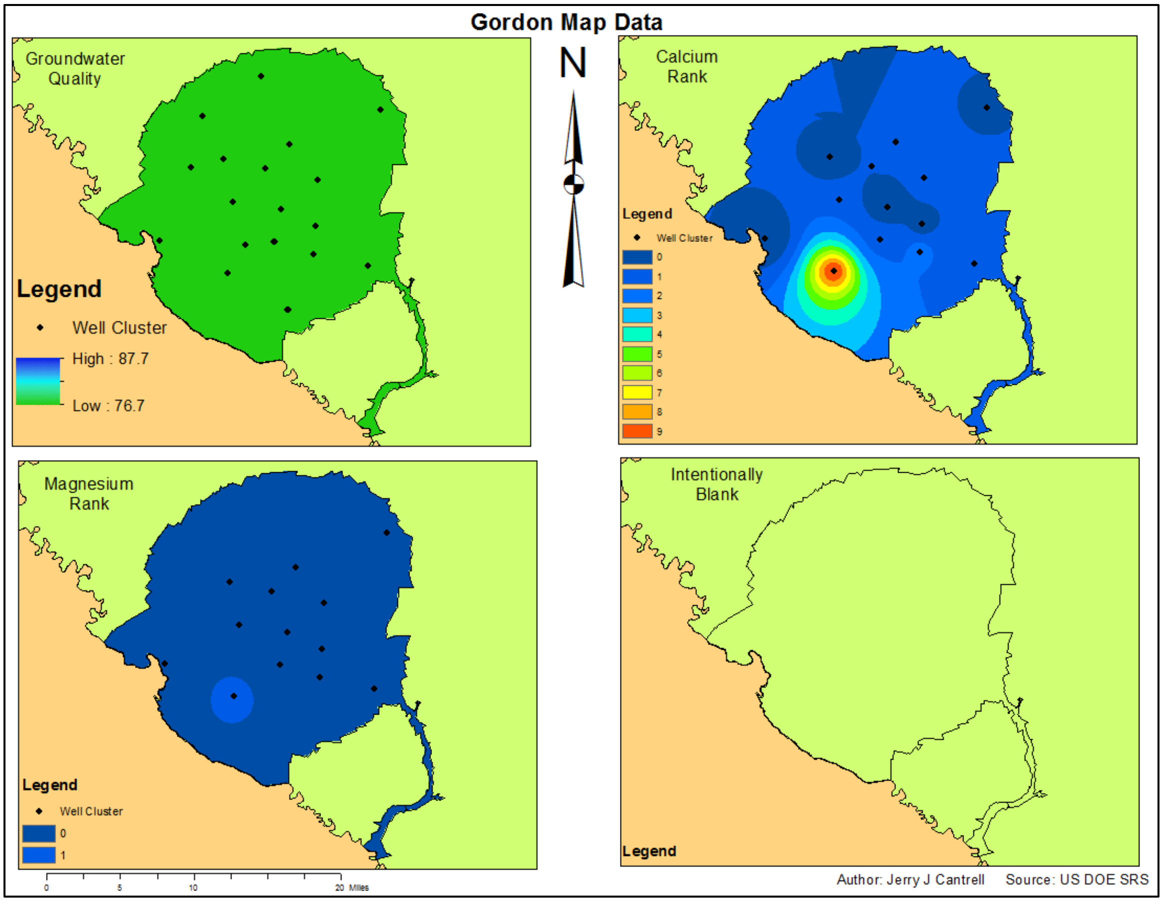

Figure 7: Gordon Aquifer Ca and Mg Rank Values

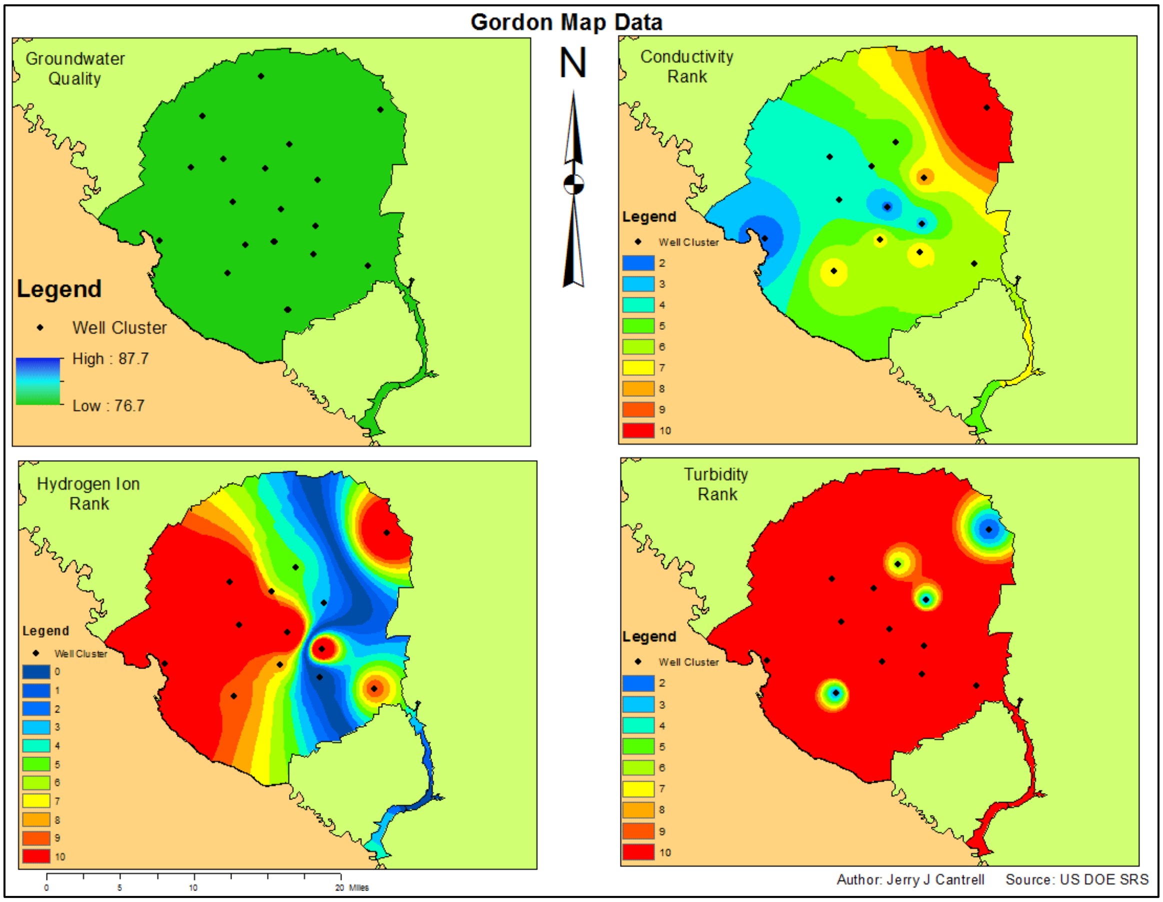

Figure 8: Gordon Aquifer Conductivity, H^+, and Turbidity Rank Values

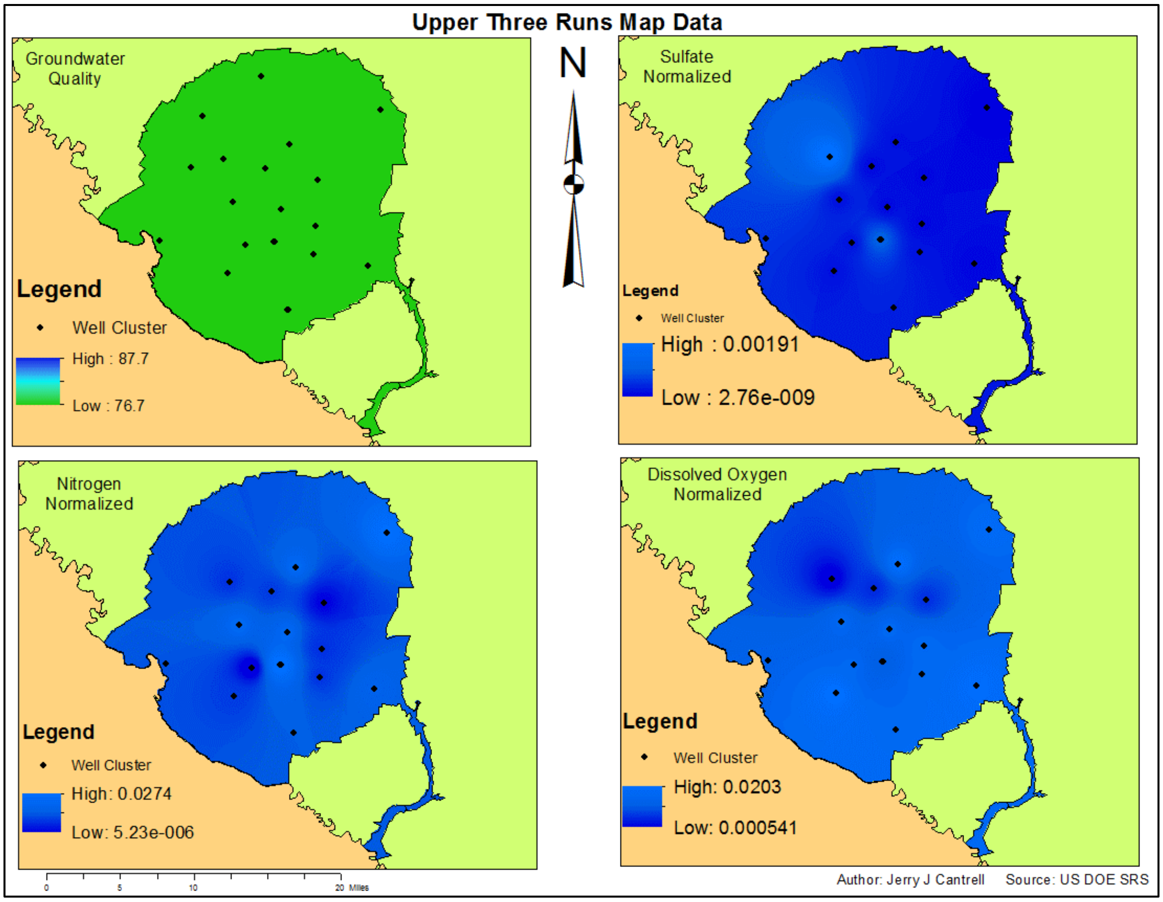

Figure 9: Upper Three Runs Aquifer SO_4^{2-}, N, and DO Normalized Values

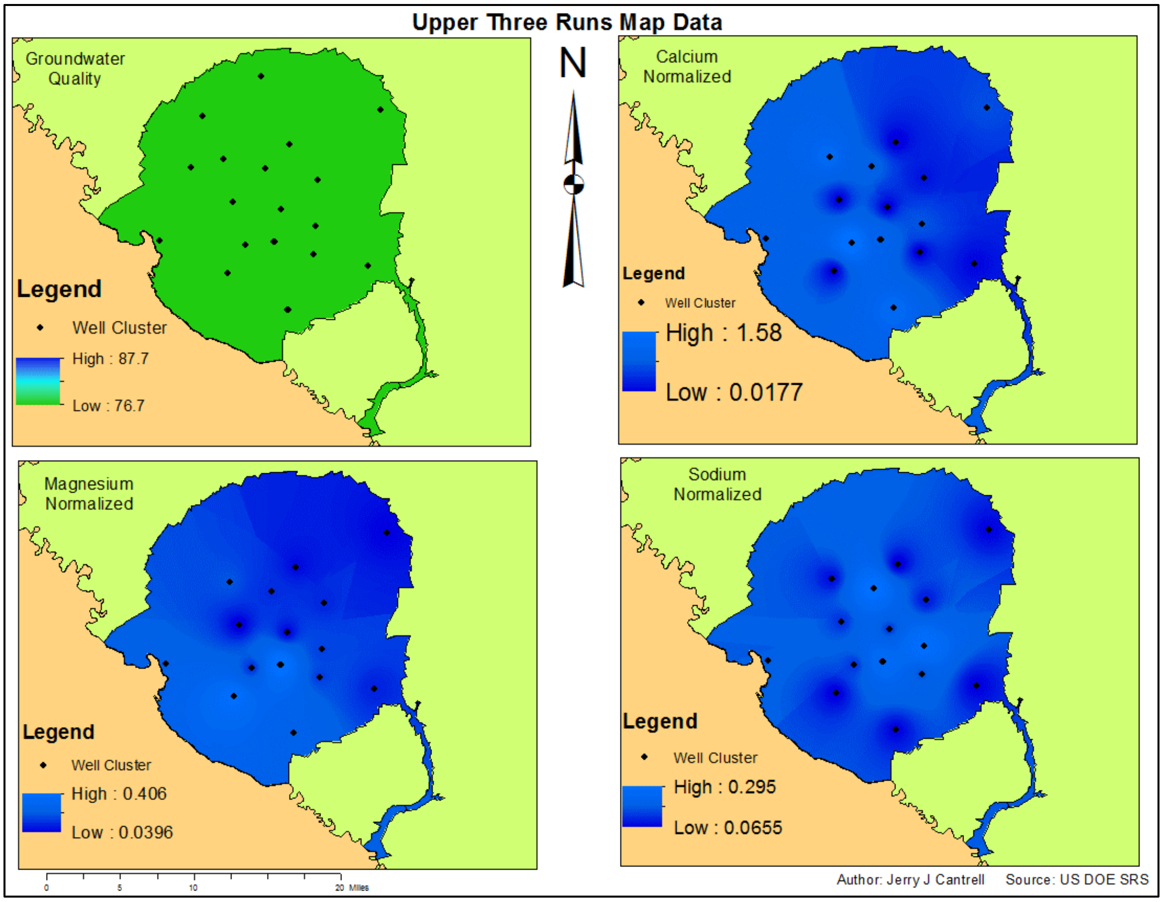

Figure 10: Upper Three Runs Aquifer Ca, Mg, and Na Normalized Values

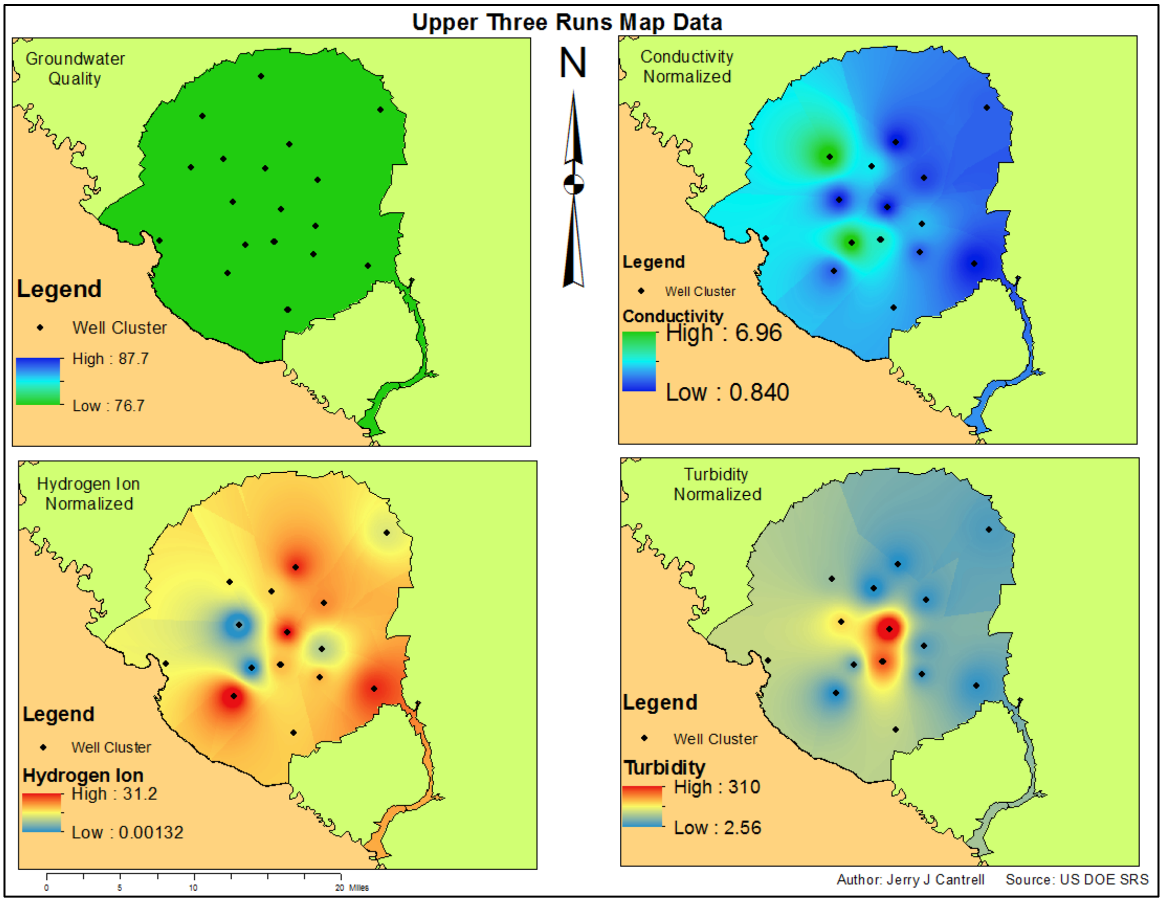

Figure 11: Upper Three Runs Aquifer Conductivity, H^+, and Turbidity Normalized Values

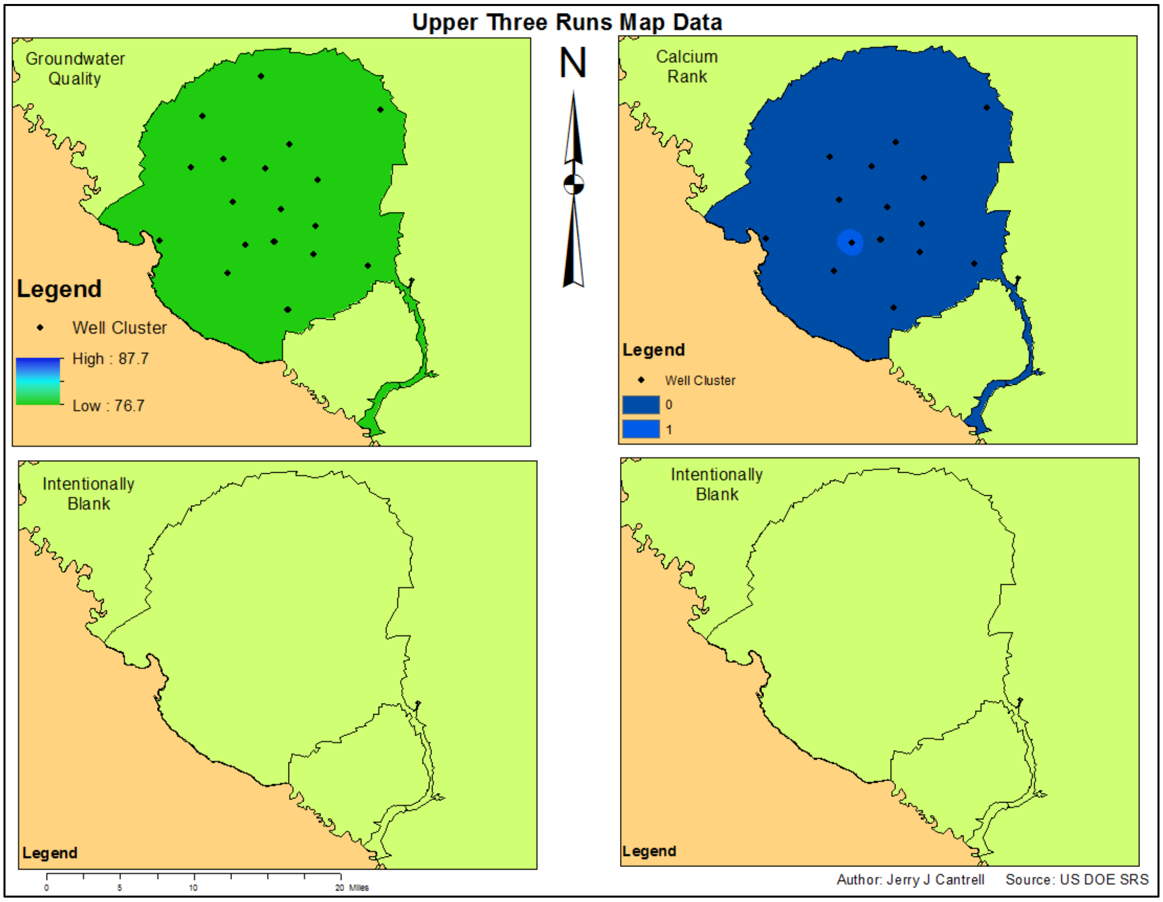

Figure 12: Upper Three Runs Aquifer Ca Rank Values

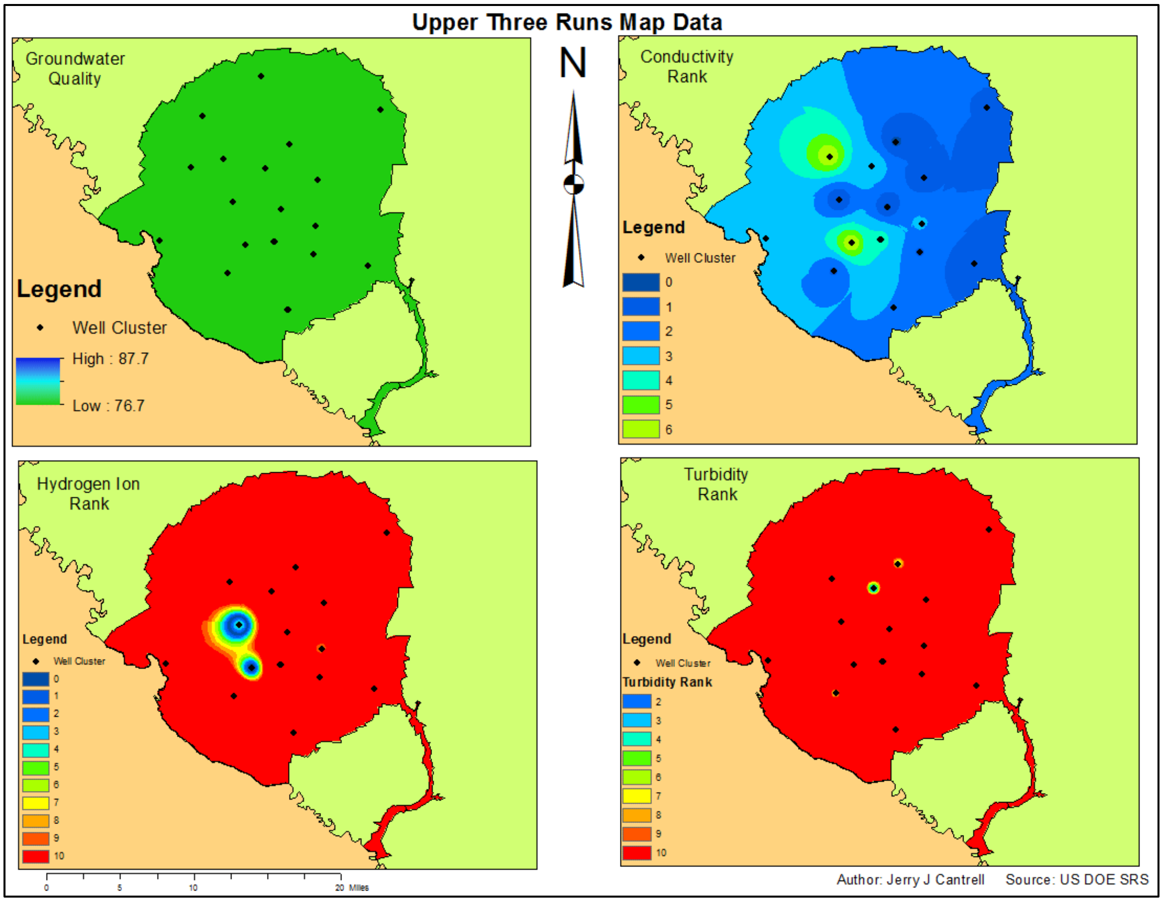

Figure 13: Upper Three Runs Aquifer Conductivity, H^+, and Turbidity Rank Values

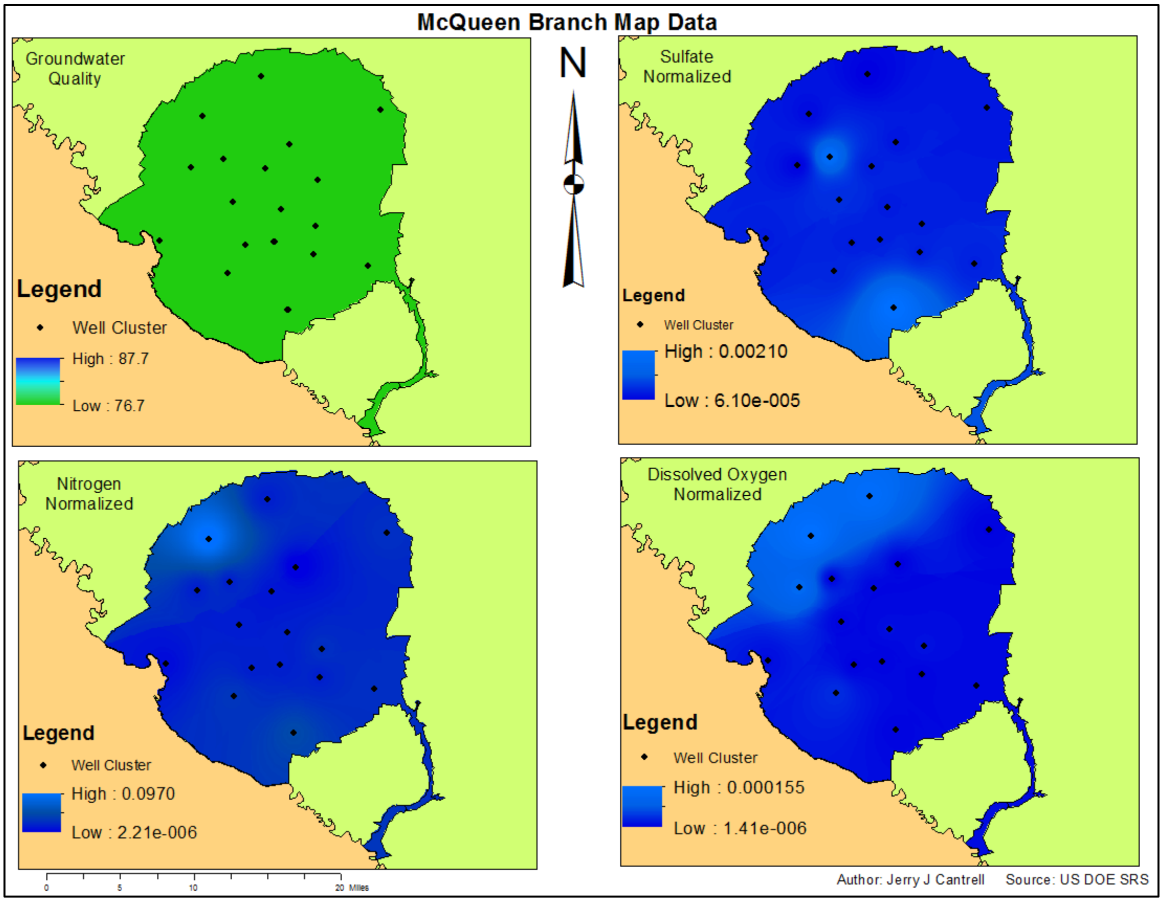

Figure 14: McQueen Branch Aquifer SO_4^{2-}, N, and DO Normalized Values

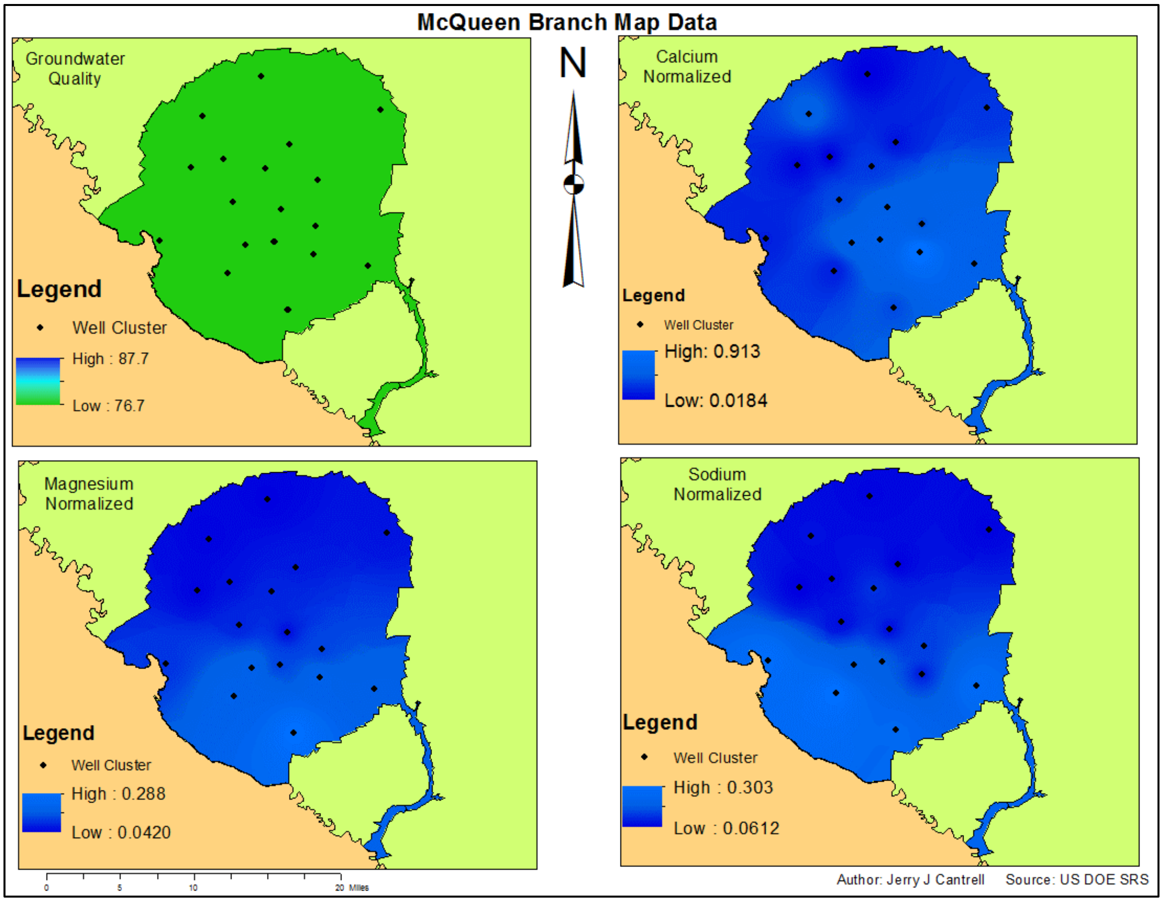

Figure 15: McQueen Branch Aquifer Ca, Mg, and Na Normalized Values

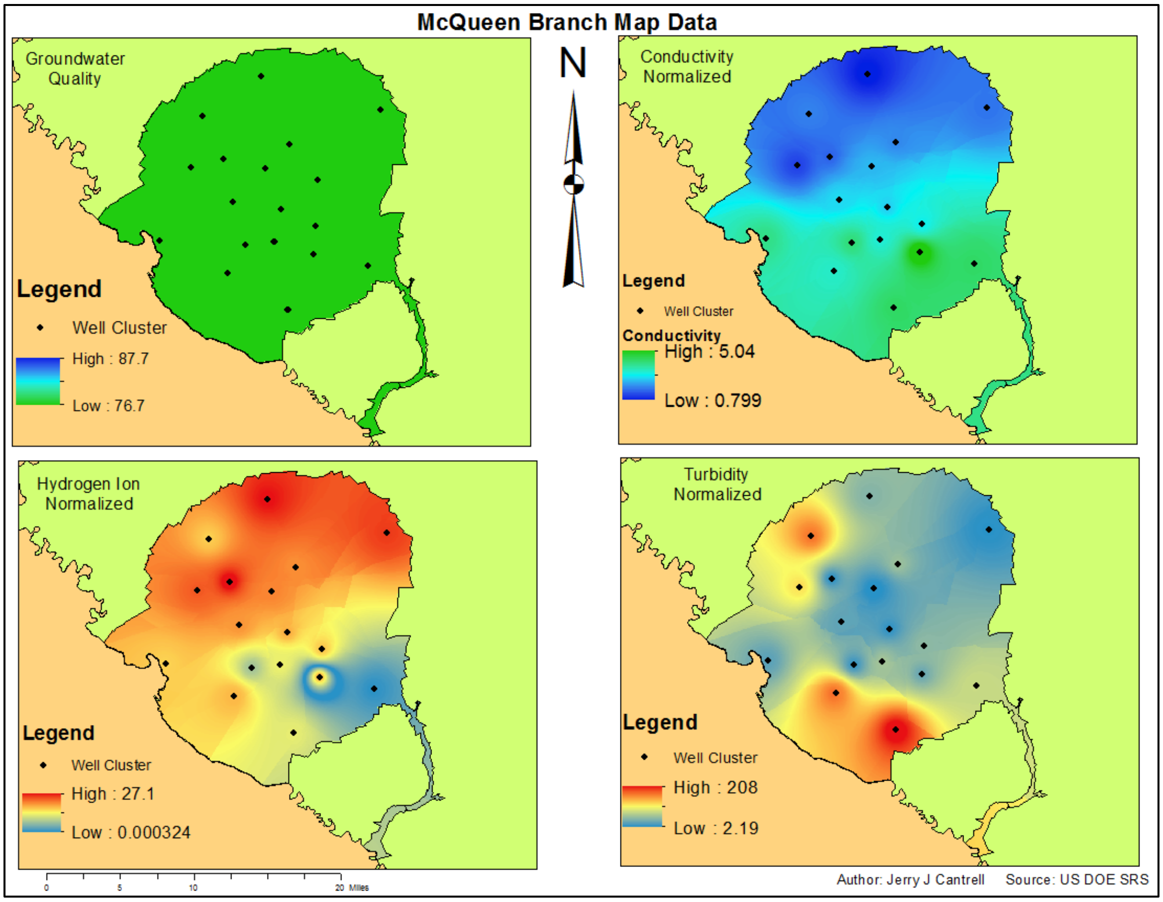

Figure 16: McQueen Branch Aquifer Conductivity, H^+, and Turbidity Normalized Values

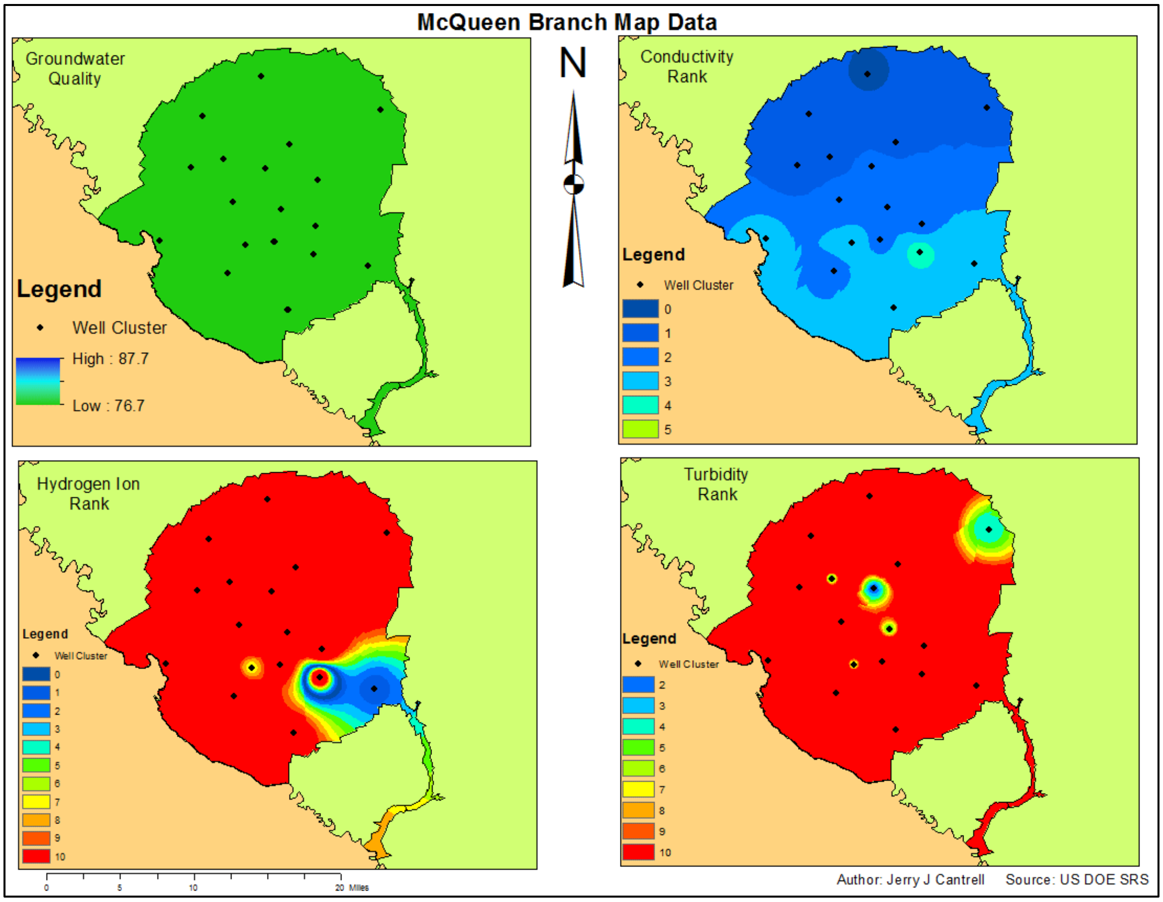

Figure 17: McQueen Branch Aquifer Conductivity, H^+, and Turbidity Rank Values

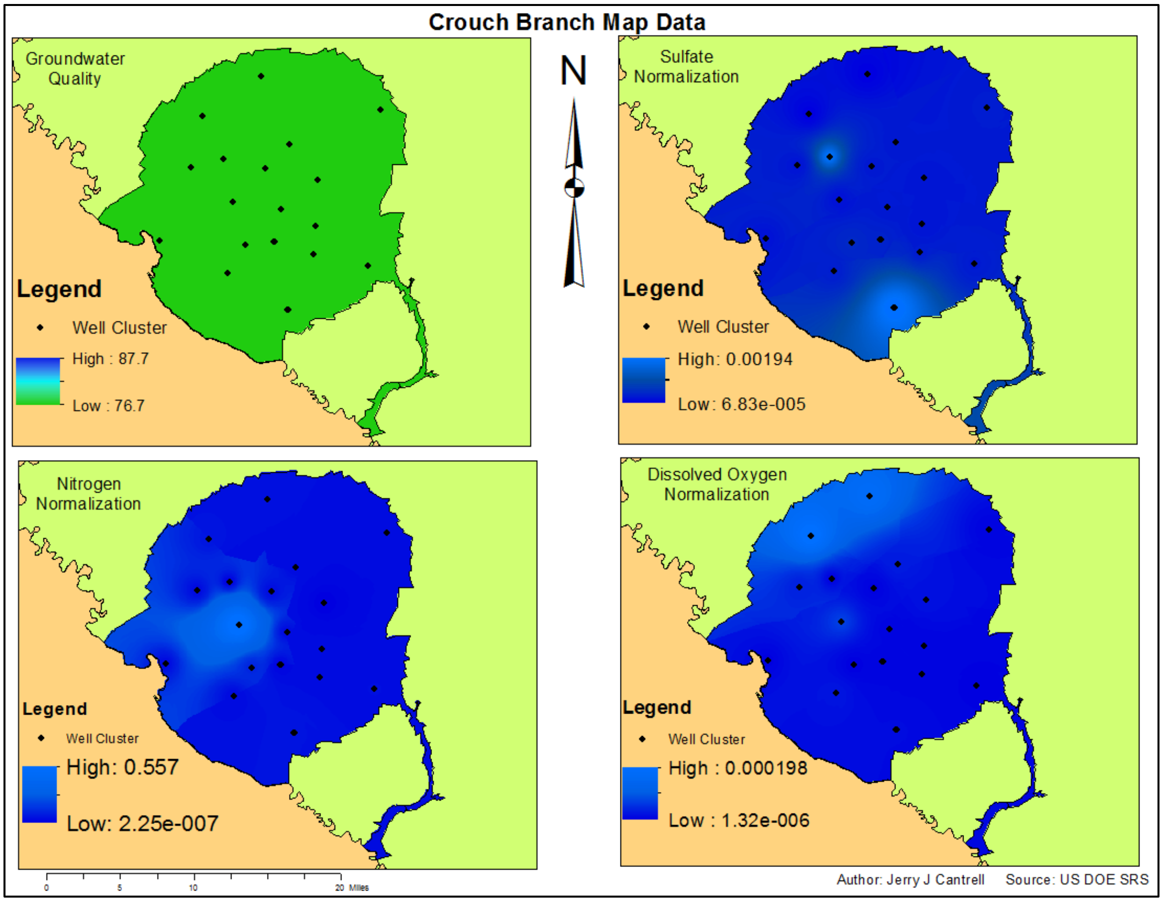

Figure 18: Crouch Branch Aquifer SO_4^{2-}, N, and DO Normalized Values

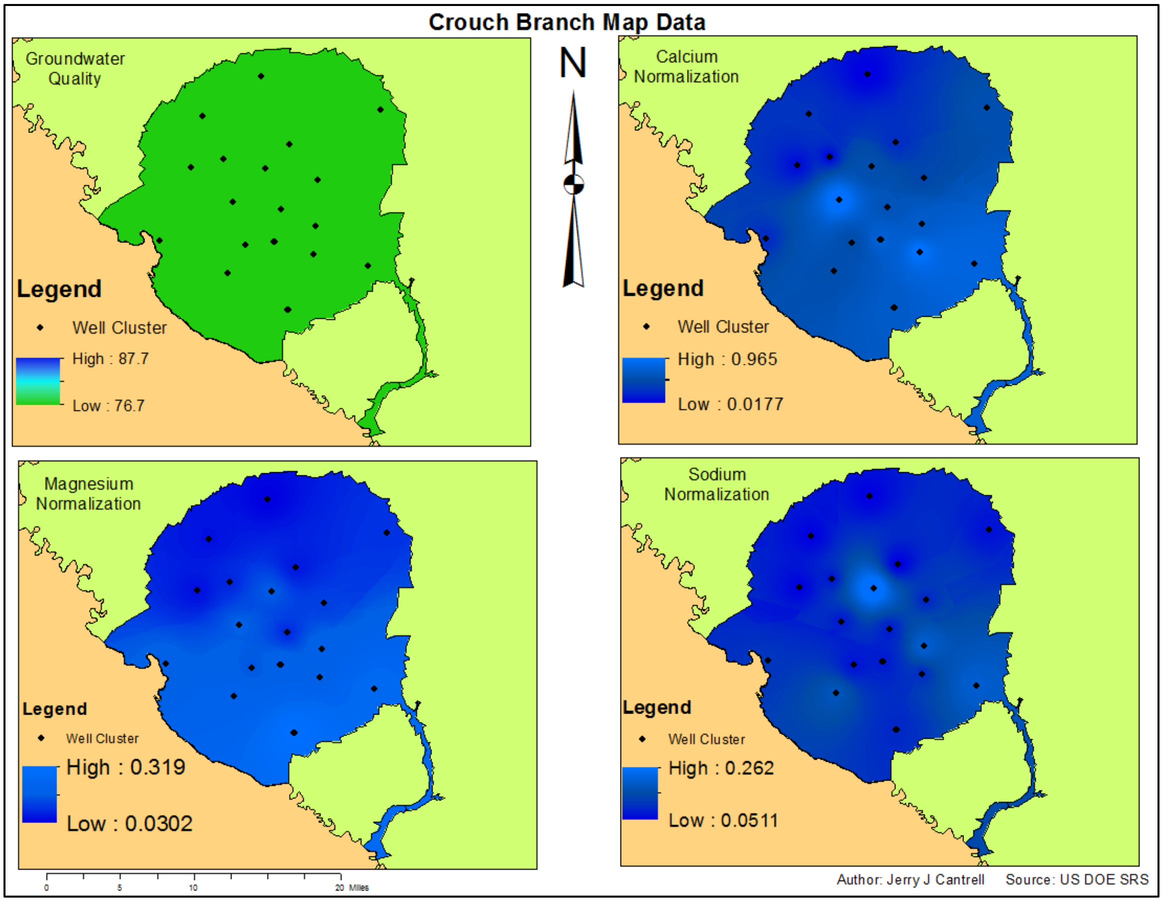

Figure 19: Crouch Branch Aquifer Ca, Mg, and Na Normalized Values

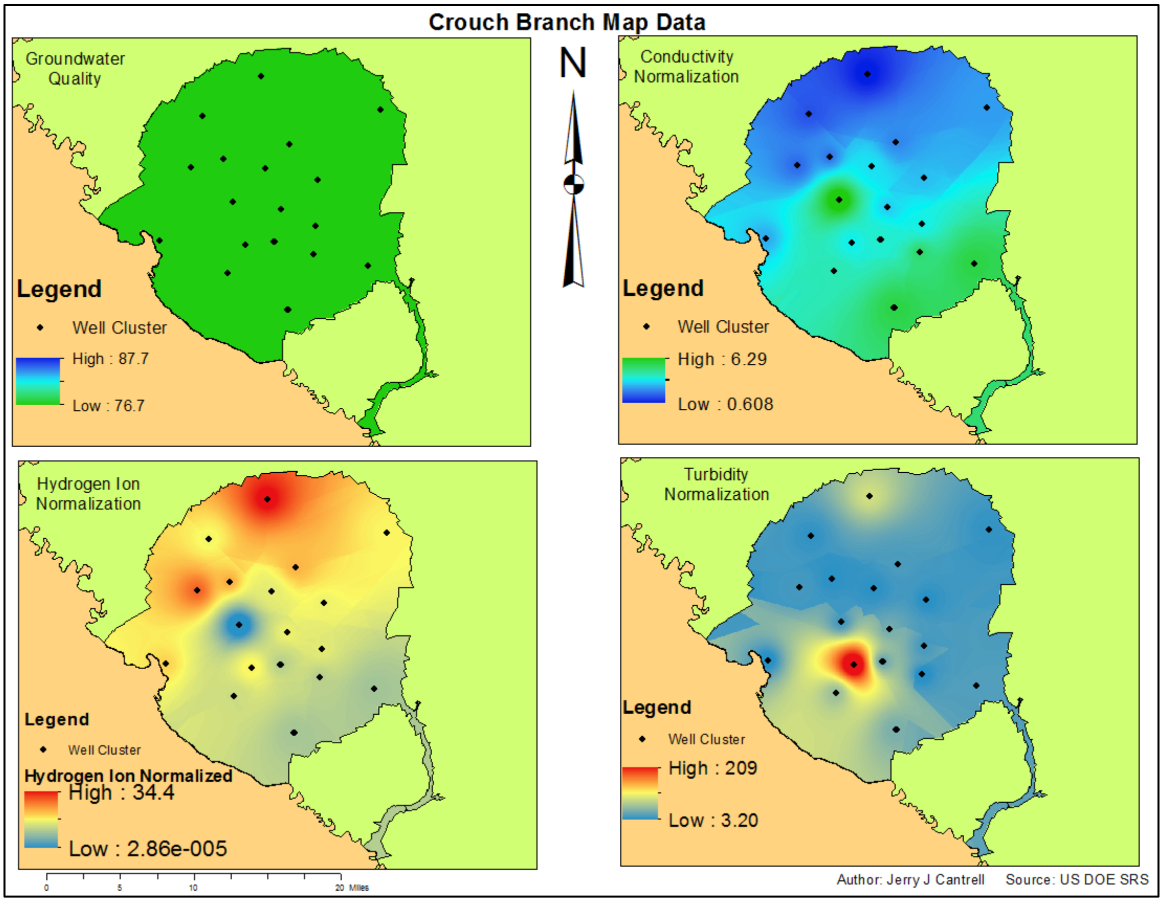

Figure 20: Crouch Branch Aquifer Conductivity, H^+, and Turbidity Normalized Values

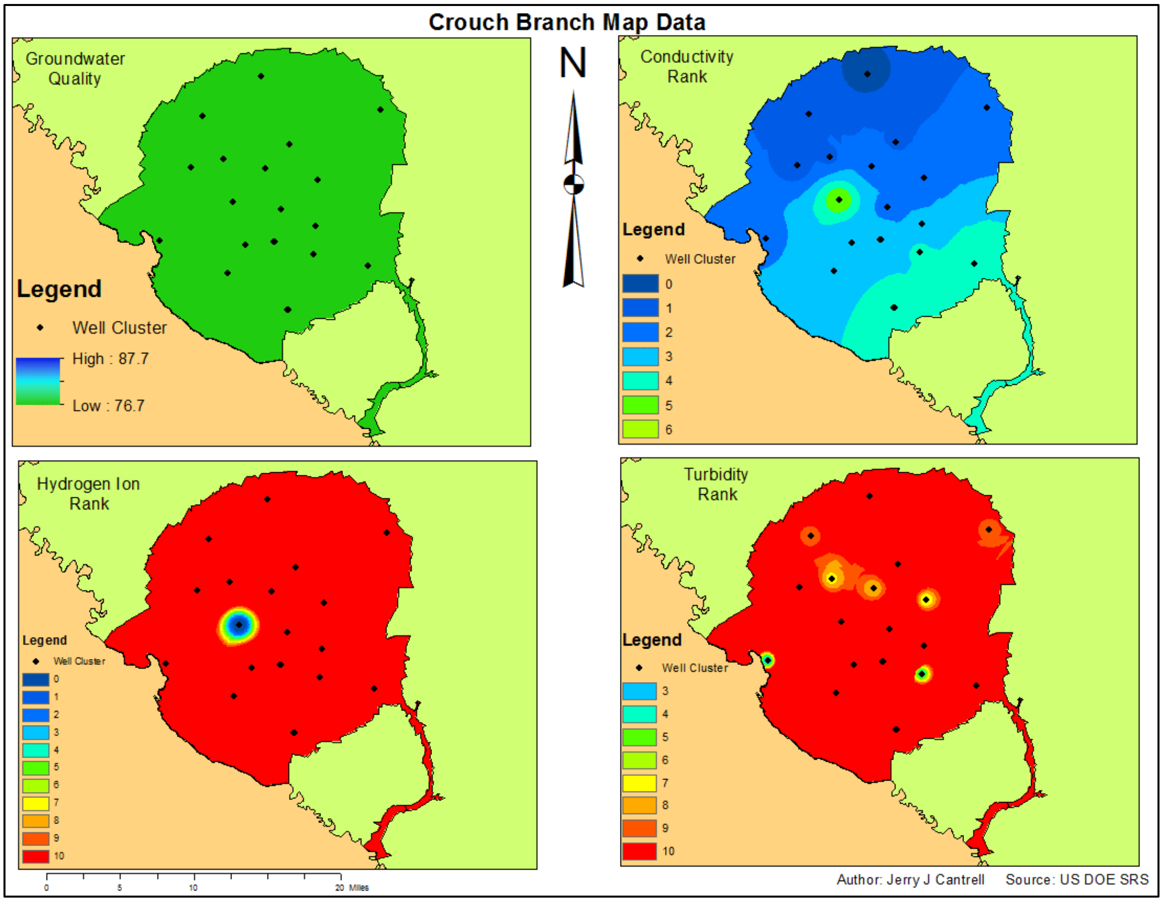

Figure 21: Crouch Branch Aquifer Conductivity, H^+, and Turbidity Rank Values

4.3 Dataset Analysis with Perturbations

The cluster perturbations were applied by eliminating the randomly selected clusters from the respective aquifer dataset. The Map process listed previously was used to create the perturbation index for each aquifer. Appendices 7.2 – 7.6 provide the individual perturbation indices as well as the overall mean set for the two-cluster perturbated groundwater quality analysis calculations. It is important to note that the 2-cluster perturbation for Gordon aquifer did not yield statistically significant changes in data; the statistical analysis is discussed in a later section. Therefore, a 3-cluster perturbation was also conducted for the Gordon aquifer. The overall mean of the groundwater quality analysis calculations subjected to perturbations is listed here; the parameter means and overall perturbation means are listed in the respective Appendices:

1. Gordon Perturbations
    a. 2-Cluster – 80.9 (Appendix 7.2)
    b. 3-Cluster – 81.7 (Appendix 7.3)
2. Upper Three Runs (2-Cluster) – 77.9 (Appendix 7.4)
3. McQueen Branch (2-Cluster) – 79.7 (Appendix 7.5)
4. Crouch Branch (2-Cluster) – 78.4 (Appendix 7.6)

4.4 Statistical Analysis with Perturbations

The background water quality analysis has been rigorously evaluated using ArcGIS software. Using IDW, the groundwater quality has been statistically characterized. The final process requires defining thresholds against which future measurements can be compared to identify potential water quality degradation (Dai et al., 2014).

IBM SPSS Statistics 24 statistical analysis software was used to verify the normality and centrality of the datasets. Normality was determined using the Shapiro-Wilk test for normality. In the conditions that statistical significance indicated that the dataset was not normal, the One-Sampled Wilcoxon Signed Rank Test was used to determine the significance of the median mean value. The only instance that the dataset indicated statistical significance for a normal dataset was the 2-Cluster Perturbation for the Gordon aquifer; all other tests rejected normality. To test the mean centrality of the 2-Cluster Perturbation for the Gordon aquifer, a one-sample, two-tailed t-test was employed. To test all other 2-Cluster Perturbations, the non-parametric one-sample Wilcoxon signed rank test was employed.

Figure 22 illustrates the histogram and frequency distribution of the Gordon aquifer for a 2-Cluster perturbation. For this dataset, the mean value of the 2-cluster perturbation dataset was 80.9. The original (no perturbations) dataset for Gordon aquifer has a mean value of 81.0. With respect to IBM SPSS Statistic 24 statistical analysis, there is not sufficient evidence to support that the mean Gordon groundwater quality calculation value changes with 2-cluster perturbation changes. The statistical analysis proof and software verification is contained in Appendix 7.7.

The calibration equation that the 2-Cluster Perturbations are compared to is derived from the original dataset. The original dataset is first interpolated using IDW in ArcGIS and subsequently processed with a Clip algorithm in order to constrain calculations within the borders of the SRS. Next, calculations are performed to normalize data for aggregation. Then, the data is processed with a Reclassify algorithm used to constrain the values between 0 and 10. The final algorithm calculates the rasters to aggregate the data into a groundwater quality value for each raster location. This calibration equation is represented as follows:

$$Groundwater\ Quality = 100 - \frac{((5.70 \times Conductivity) - (6.56 \times pH) - (9.67 \times Turbidity) - (0.0232 \times Mg) - (1.28 \times Ca))}{9}$$

Equation 3: Gordon Aquifer Groundwater Quality Calibration Equation

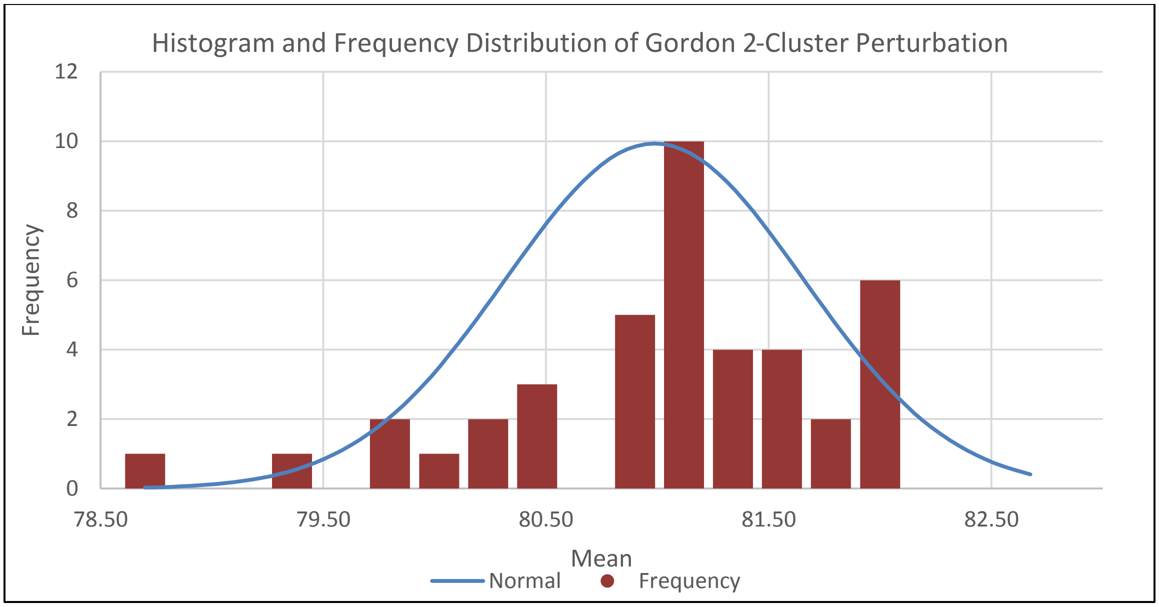

Figure 22: Histogram and Frequency Distribution of Gordon 2-Cluster Perturbation

Figure 23 illustrates the histogram and frequency distribution of the Gordon aquifer for a 3-Cluster perturbation. For this dataset, the mean value of the 3-cluster perturbation dataset was 81.7. The original (no perturbations) dataset for Gordon aquifer has a mean value of 81.0. With respect to IBM SPSS Statistic 24 statistical analysis, there is sufficient evidence to support that the Gordon groundwater quality calculation median value changes with 3-cluster quantities change. The statistical analysis proof and software verification is contained in Appendix 7.8.

The calibration equation that the 3-Cluster Perturbations are compared to is derived from the original dataset. The original dataset is first interpolated using IDW in ArcGIS, then processed with a Clip algorithm to constrain calculations within the borders of the SRS, calculations are performed normalize data for aggregation, then the data is processed with a Reclassify algorithm to constrain the values between 0 and 10, and the final algorithm Calculates the rasters to aggregate the data into a groundwater quality value for each raster location. This calibration equation is represented as follows:

$$Groundwater\ Quality = 100 - \frac{((5.70 \times Conductivity) - (6.56 \times pH) - (9.67 \times Turbidity) - (0.0232 \times Mg) - (1.28 \times Ca))}{9}$$

Equation 4: Gordon Aquifer Groundwater Quality Calibration Equation

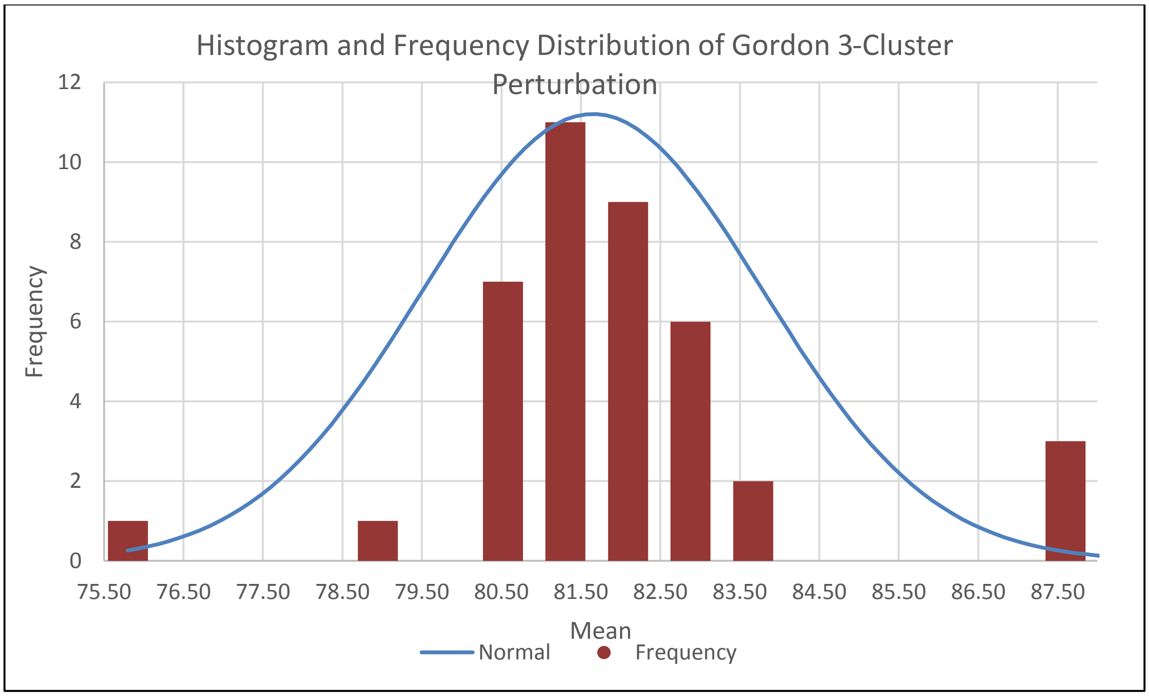

Figure 23: Histogram and Frequency Distribution of Gordon 3-Cluster Perturbation

Figure 24 illustrates the histogram and frequency distribution of the Upper Three Runs aquifer for a 2-cluster perturbation. For this dataset, the mean value of the 2-cluster perturbation dataset was 77.9. The original (no perturbations) dataset for Upper Three Runs aquifer has a mean value of 77.6. With respect to IBM SPSS Statistic 24 statistical analysis, there is sufficient evidence to support that the Upper Three Runs groundwater quality calculation median value changes with 2-cluster quantities change. The statistical analysis proof and software verification is contained in Appendix 7.9.

The calibration equation that the 2-Cluster Perturbations are compared to is derived from the original dataset. The original dataset is first interpolated using IDW in ArcGIS, then processed with a Clip algorithm to constrain calculations within the borders of the SRS, calculations are performed normalize data for aggregation, then the data is processed with a Reclassify algorithm to constrain the values between 0 and 10, and the final algorithm Calculates the rasters to aggregate the data into a groundwater quality value for each raster location. This calibration equation is represented as follows:

$$Groundwater\ Quality = 100 - \frac{((2.34 \times Conductivity) - (9.80 \times pH) - (9.99 \times Turbidity) - (0.00808 \times Ca))}{9}$$

Equation 5: Upper Three Runs Groundwater Quality Calibration Equation

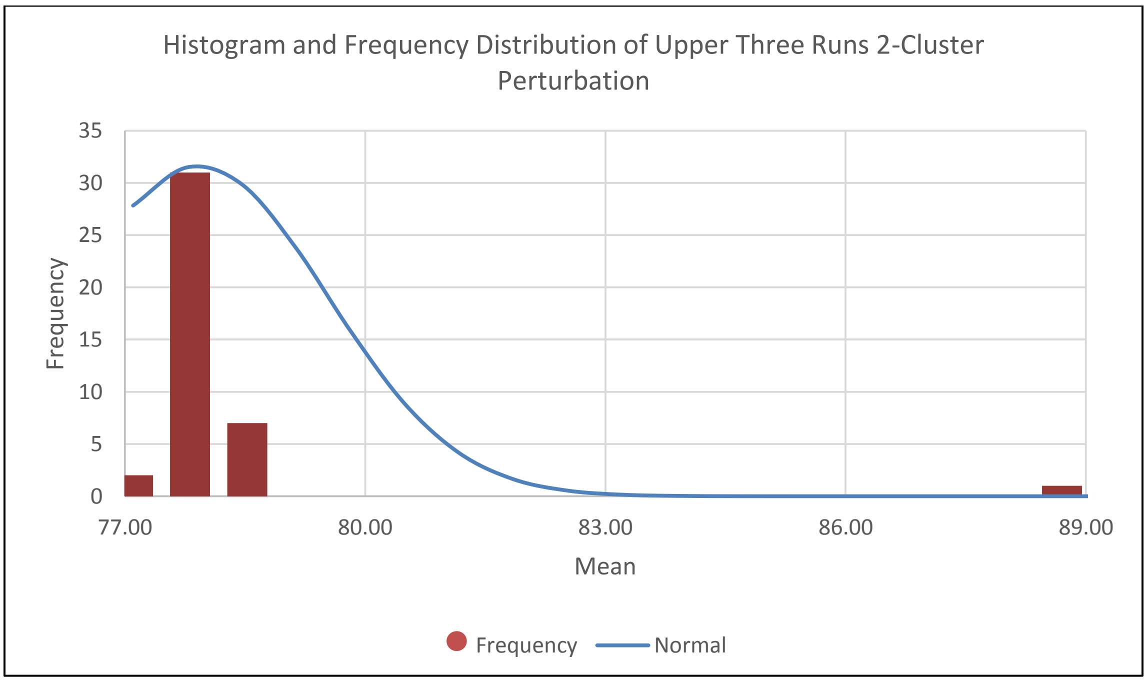

Figure 24: Histogram and Frequency Distribution of Upper Three Runs 2-Cluster Perturbation

Figure 25 illustrates the histogram and frequency distribution of the McQueen Branch aquifer for a 2-cluster perturbation. For this dataset, the mean value of the 2-cluster perturbation dataset was 79.7. The original (no perturbations) dataset for

McQueen Branch aquifer has a mean value of 79.6. With respect to IBM SPSS Statistic 24 statistical analysis, there is sufficient evidence to support that the McQueen Branch groundwater quality calculation median value changes with 2-cluster quantities change. The statistical analysis proof and software verification is contained in Appendix 7.10.

The calibration equation that the 2-Cluster Perturbations are compared to is derived from the original dataset. The original dataset is first interpolated using IDW in ArcGIS, then processed with a Clip algorithm to constrain calculations within the borders of the SRS, calculations are performed normalize data for aggregation, then the data is processed with a Reclassify algorithm to constrain the values between 0 and 10, and the final algorithm Calculates the rasters to aggregate the data into a groundwater quality value for each raster location. This calibration equation is represented as follows:

$$Groundwater\ Quality = 100 - \frac{((1.95 \times Conductivity) - (9.18 \times pH) - (9.76 \times Turbidity))}{9}$$

Equation 6: McQueen Branch Groundwater Quality Calibration Equation

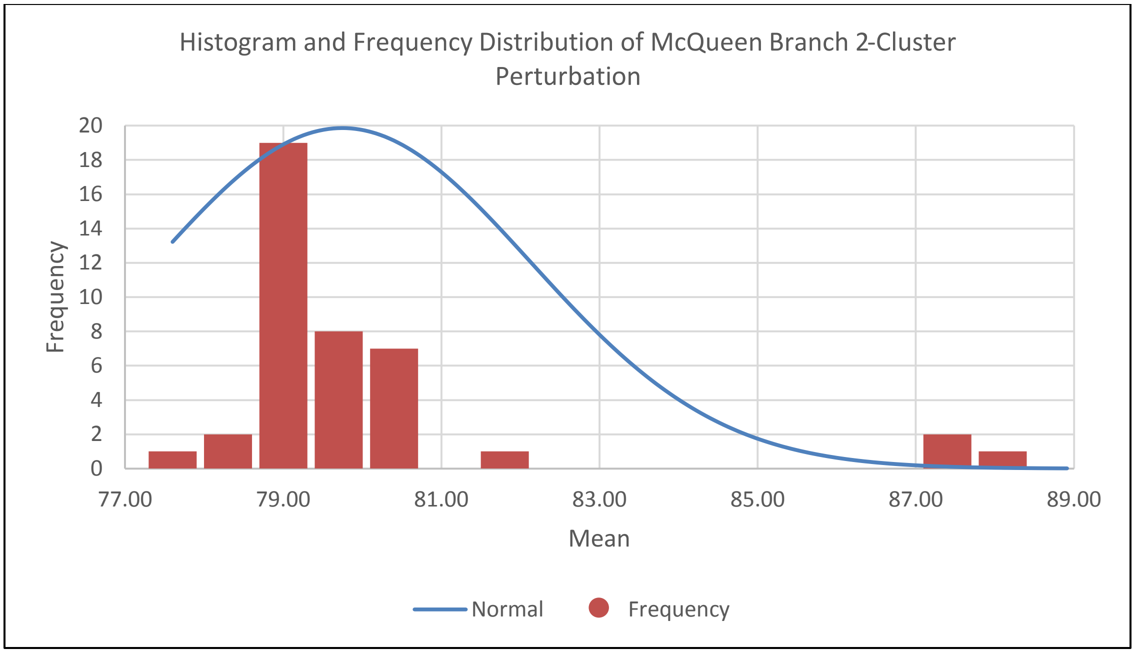

Figure 25: Histogram and Frequency Distribution of McQueen Branch 2-Cluster Perturbation

Figure 26 illustrates the histogram and frequency distribution of the Crouch Branch aquifer for a 2-cluster perturbation. For this dataset, the mean value of the 2-cluster perturbation dataset was 78.4. The original (no perturbations) dataset for Crouch Branch aquifer has a mean value of 77.6. With respect to IBM SPSS Statistic 24 statistical analysis, there is sufficient evidence to support that the Crouch Branch groundwater quality calculation median value changes when 2-cluster quantities change. The statistical analysis proof and software verification is contained in Appendix 7.11.

The calibration equation that the 2-Cluster Perturbations are compared to is derived from the original dataset. The original dataset is first interpolated using IDW in ArcGIS, then processed with a Clip algorithm to constrain calculations within the borders of the SRS, calculations are performed to normalize data for aggregation, then the data is processed with a Reclassify algorithm to constrain the values between 0 and 10, and the final algorithm Calculates the rasters to aggregate the data into a groundwater quality value for each raster location. This calibration equation is represented as follows:

$$Groundwater\ Quality = 100 - \frac{((2.40 \times Conductivity) - (9.90 \times pH) - (9.91 \times Turbidity))}{9}$$

Equation 7: Crouch Branch Aquifer Groundwater Quality Calibration Equation

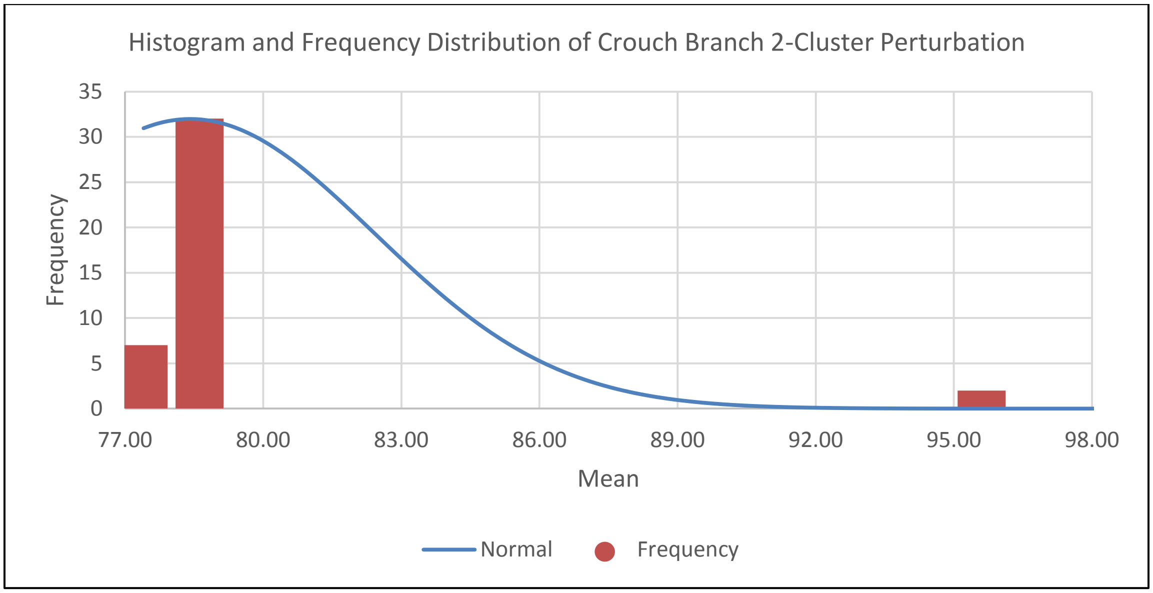

Figure 26: Histogram and Frequency Distribution of Crouch Branch 2-Cluster Perturbation

5. Conclusion

The range of water quality parameters and their respective spatial distribution creates complex situations when attempting to describe the overall groundwater quality. Additionally, increasing populations translates into greater consumption and a rise in agricultural and industrial applications of the water supply. Overuse may stress both the quality and quantity of the available water resources. Therefore, assessment of groundwater quality is needed to assure its sustainability and safe levels of water resources.

This GIS-based spatial distribution analysis of groundwater aggregates parameters based on water quality indicators. It is a straightforward method of evaluating the results of the spatial distribution models. The method allows for a statistical analysis that compares the calculated (perturbation) values with respect to the measured-interpolated values. This research indicates that GIS is a functional tool for aggregating the water quality parameters contained within a water quality index.

This spatial distribution interpretation provides an initial evaluation regarding the usefulness of the model and the need for more detailed analysis of the data. This method of analyzing spatial distribution has several advantages. The primary advantage is that this method is easy to implement, use, and understand. This spatial distribution analysis has the potential to be adopted for general use. The advantages outweigh the disadvantages: the analysis is entirely empirical and therefore limits bias within the model. The analysis employs a quantitative evaluation of predictive, spatial distribution accuracy that cannot be duplicated using a qualitative description. Additionally, the interpreter should exercise caution to prevent over-interpretation or incorrect interpretation of the spatial distribution analysis.

The ability of GIS to interpolate the spatial distribution of groundwater quality parameters provides an initial assessment of the SRS groundwater quality. The WHO provides a standardization scale based on scoring groundwater quality within a scale that ranges from 0 to 100 (Carr and Rickwood 1-60). It is separated into five separate designations, which are listed in Table 11. The groundwater designations for the SRS are provided in Table 12.

Table 11: WHO Groundwater Quality Designation Matrix

Designation	Index Value
Excellent	95-100
Good	80-94
Fair	65-79
Marginal	45-64
Poor	0-44

Table 12: Groundwater Quality and Designation for the SRS Aquifers

Aquifer	Groundwater Quality	Designation
Gordon	81.0	Good
Upper Three Runs	77.6	Fair
McQueen Branch	79.6	Fair
Crouch Branch	77.6	Fair

Randomization of the well sampling location and quantity indicates that a loss of sampling locations will create variations in the spatial distribution readings within the groundwater quality of the SRS. Additionally, the weight assigned to conductivity, hydrogen ion (pH), and turbidity has a negative impact on all the groundwater quality calculations. It was also observed that calcium has a negative impact on the Floridan

Aquifer System (Gordon and Upper Three Runs). The weight of each parameter is listed in Table 13. Nitrogen, sodium, sulfate, and dissolved oxygen all have a weight of zero within this water quality index. Therefore, the parameters of nitrogen, sodium, sulfate, and dissolved oxygen have no impact on the groundwater quality calculation.

Table 13: Weighted Impact of Parameter on Aquifer Groundwater Quality

	Gordon	Upper Three Runs	McQueen Branch	Crouch Branch
Conductivity	**5.70**	**2.34**	**1.95**	**2.40**
H^+	**6.56**	**9.80**	**9.18**	**9.90**
Turbidity	**9.67**	**9.90**	**9.76**	**9.91**
Magnesium	**0.0232**	0.00	0.00	0.00
Calcium	**1.28**	**0.000808**	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00
Sodium	0.00	0.00	0.00	0.00
Sulfate	0.00	0.00	0.00	0.00
Dissolved Oxygen	0.00	0.00	0.00	0.00

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7. Appendices

7.1 Formulas to Normalize Parameters

The nine parameters have been standardized to either EPA, WHO or Canadian standards for drinking water. WHO guidelines were utilized when a specific EPA standard for drinking water was not found. With respect to magnesium (Mg), neither the EPA nor WHO have a definitive standard. Therefore, Mg was normalized using Canada's standard for drinking water.

The EPA has a secondary standard for pH. This standard calls for the pH to range between 6.5 and 8.5. This brings about a challenge in determining the calculation as the minimum value must be defined as it relates to the two maximum range values. Aligning this to a central number for a minimum value requires identification of the value that is half-way between the two numbers; this is 7.5. Additionally, the pH values must be converted to H^+ (hydrogen ion) values for scientific linearization (e.g., $H^+ = 10^{-pH}$). Therefore, the normalized concentration difference index for pH is provided in Equation 8.

$$C_{pH-left} = \frac{X - 7.5}{6.5 - 7.5} \quad C_{pH-right} = \frac{X - 7.5}{8.5 - 7.5}$$

$$C_{pH-left} = X - 7.5 \quad C_{pH-right} = 7.5 - X$$

$$C_{pH} = \left| X - 7.5 \right|$$

$$C_{H^+} = \left| X - 3.16 \times 10^{-8} \right|$$

Equation 8: Normalized Concentration Difference Index for pH (H^+)

The readings provided for N (nitrogen) are detected in parts per million; one ppm is equivalent to one mg/L. Additionally, N is presented as nitrite. The EPA has a primary drinking water standard of 10 mg/L for N (e.g., 10 ppm). Therefore, the normalized concentration difference index for N is provided in Equation 9.

$$C_N = \frac{X - 0\,ppm}{10\,ppm - 0\,ppm}$$

$$C_N = \frac{X ppm \times \frac{mg/L}{ppm}}{10\,ppm \times \frac{mg/L}{ppm}}$$

$$C_N = \frac{X}{10}$$

Equation 9: Normalized Concentration Difference Index for N

The readings provided for Na (sodium) are in parts per billion. WHO has a standard for drinking water of 200 mg/L for Na; one mg/L equals 1000 ppb. Therefore, the normalized concentration difference index for Na is provided in Equation 10.

$$C_{Na} = \frac{Xppb}{200\frac{mg}{L}}$$

$$C_{Na} = \frac{Xppb}{200\frac{mg}{L} \times \frac{1000ppb}{\frac{mg}{L}}}$$

$$\therefore C_{Na} = \frac{X}{200{,}000}$$

Equation 10: Normalized Concentration Difference Index for Na

The readings provided for Ca (calcium) are in parts per billion. WHO indicates a maximum range for drinking water of 300 mg/L for Ca. Therefore, the normalized concentration difference index for Ca is provided in Equation 11.

$$C_{Ca} = \frac{Xppb}{300\frac{mg}{L}}$$

$$C_{Ca} = \frac{Xppb}{300\frac{mg}{L} \times \frac{1000ppb}{\frac{mg}{L}}}$$

$$\therefore C_{Ca} = \frac{X}{300{,}000}$$

Equation 11: Normalized Concentration Difference Index for Ca

The readings provided for Mg (magnesium) are in parts per billion. The EPA does not list a drinking water standard for this parameter. WHO indicates that the parameter must be less than Mg. Canada lists a drinking water standard of 50 mg/L for Mg. Therefore, the normalized concentration difference index for Mg is based on the Canadian standard and is provided in Equation 12.

$$C_{Mg} = \frac{Xppb}{50\frac{mg}{L}}$$

$$C_{Mg} = \frac{Xppb}{50\frac{mg}{L} \times \frac{1000ppb}{\frac{mg}{L}}}$$

$$\therefore C_{Mg} = \frac{X}{50{,}000}$$

Equation 12: Normalized Concentration Difference Index for Mg

The readings provided for SO_4^{2-} (sulfate) are in parts per billion. The EPA has a secondary drinking water standard for SO_4^{2-} of 250 mg/L. Therefore, the normalized concentration difference index for SO_4^{2-} is provided in Equation 13.

$$C_{SO4} = \frac{Xppb}{250\frac{mg}{L}}$$

$$C_{SO4} = \frac{Xppb}{250\frac{mg}{L} \times \frac{1000ppb}{\frac{mg}{L}}}$$

$$\therefore C_{SO4} = \frac{X}{250{,}000}$$

Equation 13: Normalized Concentration Difference Index for SO_4^{2-}

The readings provided for turbidity are in NTU (Nephelometric Transmittance Units). The EPA has a primary standard for drinking water of 1 NTU for turbidity. Therefore, the normalized concentration difference index for NTU is provided in Equation 14. It is important to note that the turbidity requirement for sampling by the EPA certified laboratory call3 for the NTU value to be less than 15 NTU. The value used for drawing samples is 15 NTU, whereas with the EPA value for turbidity is 1 NTU.

$$C_{Turbidity} = \frac{X\ NTU - 0\ NTU}{1\ NTU - 0\ NTU}$$

$$C_{Turbidity} = \frac{X\ NTU}{1\ NTU}$$

$$C_{Turbidity} = X$$

Equation 14: Normalized Concentration Difference Index for Turbidity

The readings provided for DO (Dissolved Oxygen) are measured in mg/L. WHO indicates a drinking water standard of 500 mg/L for DO. Therefore, the normalized concentration difference index for DO is provided in Equation 15.

$$C_{DO} = \frac{X \frac{mg}{L} - 0 \frac{mg}{L}}{500 \frac{mg}{L} - 0 \frac{mg}{L}}$$

$$C_{DO} = \frac{X}{500}$$

Equation 15: Normalized Concentration Difference Index for Dissolved Oxygen

The readings provided for conductivity are in μs/cm. The EPA has a secondary standard for drinking water of 250 μs/cm. Therefore, the normalized concentration difference index for conductivity is provided in Equation 16.

$$C_{Conductivity} = \frac{X \frac{\mu s}{cm} - 0 \frac{\mu s}{cm}}{250 \frac{\mu s}{cm} - 0 \frac{\mu s}{cm}}$$

$$C_{Conductivity} = \frac{X}{250}$$

Equation 16: Normalized Concentration Difference Index for Conductivity

7.2 Gordon Weight Data for 2-Cluster Groundwater Quality Analysis (G2)

Table 14: G2-Cluster Mean - 01

Weight	Mean	STD
Conductivity	5.74	1.94
pH (H ion)	7.68	3.14
DO	0.000	0.000
Turbidity	9.68	1.23
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0250	0.156
Ca	1.37	1.42

Table 15: G2-Cluster Mean - 02

Weight	Mean	STD
Conductivity	5.32	1.86
pH (H ion)	5.66	3.59
DO	0.000	0.000
Turbidity	9.60	1.33
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0286	0.167
Ca	1.42	1.46

Table 16: G2-Cluster Mean - 03

Weight	Mean	STD
Conductivity	6.57	2.03
pH (H ion)	6.11	3.51
DO	0.000	0.000
Turbidity	9.67	1.29
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0300	0.171
Ca	1.43	1.47

Table 17: G2-Cluster Mean - 04

Weight	Mean	STD
Conductivity	6.17	1.63
pH (H ion)	5.79	3.01
DO	0.000	0.000
Turbidity	9.63	1.28
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0388	0.193
Ca	1.62	1.66

Table 18: G2-Cluster Mean - 05

Weight	Mean	STD
Conductivity	5.85	1.89
pH (H ion)	6.25	3.34
DO	0.000	0.000
Turbidity	9.59	1.31
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0244	0.154
Ca	1.37	1.39

Table 19: G2-Cluster Mean - 06

Weight	Mean	STD
Conductivity	6.16	1.86
pH (H ion)	6.60	3.36
DO	0.000	0.000
Turbidity	9.20	1.64
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0253	0.157
Ca	1.46	1.38

Table 20: G2-Cluster Mean - 07

Weight	Mean	STD
Conductivity	6.02	1.86
pH (H ion)	5.91	3.59
DO	0.000	0.000
Turbidity	9.46	1.42
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0241	0.154
Ca	1.41	1.37

Table 21: G2-Cluster Mean - 08

Weight	Mean	STD
Conductivity	5.80	2.00
pH (H ion)	6.86	3.41
DO	0.000	0.000
Turbidity	9.64	1.25
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.385	0.507

Table 22: G2-Cluster Mean - 09

Weight	Mean	STD
Conductivity	5.70	1.97
pH (H ion)	6.56	3.47
DO	0.000	0.000
Turbidity	9.67	1.21
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0233	0.151
Ca	1.28	1.41

Table 23: G2-Cluster Mean - 10

Weight	Mean	STD
Conductivity	6.12	1.84
pH (H ion)	6.14	3.30
DO	0.000	0.000
Turbidity	9.65	1.25
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0277	0.164
Ca	1.48	1.44

Table 24: G2-Cluster Mean - 11

Weight	Mean	STD
Conductivity	5.60	1.98
pH (H ion)	6.32	3.35
DO	0.000	0.000
Turbidity	9.54	1.32
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0345	0.487

Table 25: G2-Cluster Mean - 12

Weight	Mean	STD
Conductivity	6.08	2.07
pH (H ion)	7.71	3.18
DO	0.000	0.000
Turbidity	9.65	1.31
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0285	0.158
Ca	1.42	1.42

Table 26: G2-Cluster Mean - 13

Weight	Mean	STD
Conductivity	5.71	1.99
pH (H ion)	6.42	3.70
DO	0.000	0.000
Turbidity	9.67	1.21
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0233	0.151
Ca	1.29	1.42

Table 27: G2-Cluster Mean - 14

Weight	Mean	STD
Conductivity	4.63	0.917
pH (H ion)	7.07	2.97
DO	0.000	0.000
Turbidity	9.86	0.706
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0249	0.156
Ca	1.30	1.39

Table 28: G2-Cluster Mean - 15

Weight	Mean	STD
Conductivity	6.33	1.58
pH (H ion)	6.93	3.04
DO	0.000	0.000
Turbidity	9.57	1.35
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0378	0.191
Ca	1.75	1.63

Table 29: G2-Cluster Mean - 16

Weight	Mean	STD
Conductivity	4.70	0.906
pH (H ion)	6.89	2.87
DO	0.000	0.000
Turbidity	9.75	0.871
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0238	0.152
Ca	1.36	1.32

Table 30: G2-Cluster Mean - 17

Weight	Mean	STD
Conductivity	5.88	1.92
pH (H ion)	6.17	3.36
DO	0.000	0.000
Turbidity	9.47	1.41
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0239	0.153
Ca	1.39	1.36

Table 31: G2-Cluster Mean - 18

Weight	Mean	STD
Conductivity	5.73	1.97
pH (H ion)	7.48	3.24
DO	0.000	0.000
Turbidity	9.33	1.58
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0305	0.172
Ca	1.43	1.50

Table 32: G2-Cluster Mean - 19

Weight	Mean	STD
Conductivity	6.00	1.67
pH (H ion)	6.10	3.02
DO	0.000	0.000
Turbidity	9.73	1.14
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0358	0.186
Ca	1.65	1.63

Table 33: G2-Cluster Mean - 20

Weight	Mean	STD
Conductivity	5.60	1.96
pH (H ion)	6.71	3.39
DO	0.000	0.000
Turbidity	9.73	1.13
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0235	0.151
Ca	1.28	1.41

Table 34: G2-Cluster Mean - 21

Weight	Mean	STD
Conductivity	5.61	1.97
pH (H ion)	6.78	3.36
DO	0.000	0.000
Turbidity	9.63	1.27
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0249	0.156
Ca	1.25	1.41

Table 35: G2-Cluster Mean - 22

Weight	Mean	STD
Conductivity	5.92	1.96
pH (H ion)	6.98	3.39
DO	0.000	0.000
Turbidity	9.58	1.34
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0243	0.154
Ca	1.39	1.39

Table 36: G2-Cluster Mean - 23

Weight	Mean	STD
Conductivity	6.12	1.86
pH (H ion)	6.15	3.33
DO	0.000	0.000
Turbidity	9.60	1.33
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0312	0.174
Ca	1.44	1.50

Table 37: G2-Cluster Mean - 24

Weight	Mean	STD
Conductivity	4.65	0.976
pH (H ion)	6.75	3.18
DO	0.000	0.000
Turbidity	9.80	0.851
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0284	0.166
Ca	1.38	1.45

Table 38: G2-Cluster Mean - 25

Weight	Mean	STD
Conductivity	5.41	1.98
pH (H ion)	6.92	3.34
DO	0.000	0.000
Turbidity	9.63	1.29
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0291	0.168
Ca	1.28	1.52

Table 39: G2-Cluster Mean - 26

Weight	Mean	STD
Conductivity	5.47	2.01
pH (H ion)	6.62	3.41
DO	0.000	0.000
Turbidity	9.70	1.80
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.105	0.307

Table 40: G2-Cluster Mean - 27

Weight	Mean	STD
Conductivity	5.91	2.07
pH (H ion)	6.97	3.42
DO	0.000	0.000
Turbidity	9.72	1.18
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0238	0.153
Ca	1.33	1.039

Table 41: G2-Cluster Mean - 28

Weight	Mean	STD
Conductivity	4.53	0.956
pH (H ion)	6.99	3.05
DO	0.000	0.000
Turbidity	9.92	0.538
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0235	0.151
Ca	1.33	1.38

Table 42: G2-Cluster Mean - 29

Weight	Mean	STD
Conductivity	5.89	2.09
pH (H ion)	7.17	3.24
DO	0.000	0.000
Turbidity	9.69	1.24
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0263	0.160
Ca	1.27	1.45

Table 43: G2-Cluster Mean - 30

Weight	Mean	STD
Conductivity	5.92	1.96
pH (H ion)	6.98	3.39
DO	0.000	0.000
Turbidity	9.58	1.34
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0243	0.154
Ca	1.39	1.39

Table 44: G2-Cluster Mean - 31

Weight	Mean	STD
Conductivity	6.10	1.86
pH (H ion)	6.10	3.35
DO	0.000	0.000
Turbidity	9.68	1.23
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0289	0.168
Ca	1.39	1.46

Table 45: G2-Cluster Mean - 32

Weight	Mean	STD
Conductivity	5.91	1.94
pH (H ion)	5.94	3.34
DO	0.000	0.000
Turbidity	9.66	1.23
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.342	0.474

Table 46: G2-Cluster Mean - 33

Weight	Mean	STD
Conductivity	5.60	1.96
pH (H ion)	6.71	3.39
DO	0.000	0.000
Turbidity	9.73	1.13
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0235	0.151
Ca	1.28	1.41

Table 47: G2-Cluster Mean - 34

Weight	Mean	STD
Conductivity	5.65	1.99
pH (H ion)	6.25	3.70
DO	0.000	0.000
Turbidity	9.73	1.13
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.319	0.479

Table 48: G2-Cluster Mean - 35

Weight	Mean	STD
Conductivity	5.60	1.97
pH (H ion)	6.78	1.36
DO	0.000	0.000
Turbidity	9.63	1.27
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0249	0.156
Ca	1.25	1.42

Table 49: G2-Cluster Mean - 36

Weight	Mean	STD
Conductivity	5.99	1.89
pH (H ion)	5.98	3.39
DO	0.000	0.000
Turbidity	9.35	1.57
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0370	0.189
Ca	1.46	1.57

Table 50: G2-Cluster Mean - 37

Weight	Mean	STD
Conductivity	6.52	1.85
pH (H ion)	6.08	3.46
DO	0.000	0.000
Turbidity	9.52	1.41
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0304	0.172
Ca	1.57	1.49

Table 51: G2-Cluster Mean - 38

Weight	Mean	STD
Conductivity	6.10	2.06
pH (H ion)	6.53	3.42
DO	0.000	0.000
Turbidity	9.55	1.44
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0251	0.156
Ca	1.34	1.38

Table 52: G2-Cluster Mean - 39

Weight	Mean	STD
Conductivity	5.91	1.92
pH (H ion)	7.26	3.27
DO	0.000	0.000
Turbidity	9.49	1.43
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0265	0.161
Ca	1.34	1.44

Table 53: G2-Cluster Mean - 40

Weight	Mean	STD
Conductivity	4.42	0.914
pH (H ion)	7.21	2.92
DO	0.000	0.000
Turbidity	9.92	0.507
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.178	0.382

Table 54: Gordon 2-Cluster Quality Score

Weight	Mean	Weight	Mean
Original	81.0		
01	79.2	21	80.9
02	82.0	22	80.3
03	80.4	23	81.2
04	81.5	24	81.7
05	81.4	25	80.9
06	81.3	26	81.4
07	81.9	27	80.0
08	80.7	28	81.2
09	81.0	29	79.8
10	81.1	30	80.3
11	81.9	31	81.1
12	78.7	32	81.8
13	81.2	33	80.8
14	81.1	34	81.6
15	79.7	35	80.9
16	81.5	36	82.1
17	81.8	37	80.8
18	80.2	38	80.8
19	81.0	39	80.1
20	80.8	40	81.1

7.3 Gordon Weight Data for 3-Cluster Groundwater Quality Analysis (G3)

Table 55: G3-Cluster Mean - 01

Weight	Mean	STD
Conductivity	4.51	0.970
pH (H ion)	7.02	3.03
DO	0.000	0.000
Turbidity	9.93	0.481
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.364	0.494

Table 56: G3-Cluster Mean - 02

Weight	Mean	STD
Conductivity	5.06	0.721
pH (H ion)	6.56	2.69
DO	0.000	0.000
Turbidity	9.86	0.713
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.034	0.182
Ca	1.62	1.56

Table 57: G3-Cluster Mean - 03

Weight	Mean	STD
Conductivity	6.40	1.76

pH (H ion)	6.20	3.13
DO	0.000	0.000
Turbidity	9.72	1.19
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.038	0.191
Ca	1.72	1.56

Table 58: G3-Cluster Mean - 04

Weight	Mean	STD
Conductivity	6.05	2.06
pH (H ion)	6.57	3.68
DO	0.000	0.000
Turbidity	9.69	1.24
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.024	0.154
Ca	1.25	1.42

Table 59: G3-Cluster Mean - 05

Weight	Mean	STD
Conductivity	4.78	0.641
pH (H ion)	6.36	2.68
DO	0.000	0.000
Turbidity	6.92	0.508
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.287	0.452

Table 60: G3-Cluster Mean - 06

Weight	Mean	STD
Conductivity	5.86	1.91
pH (H ion)	7.40	3.15
DO	0.000	0.000
Turbidity	9.40	1.50
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.026	0.160
Ca	1.47	1.42

Table 61: G3-Cluster Mean - 07

Weight	Mean	STD
Conductivity	4.51	0.970
pH (H ion)	7.02	3.03
DO	0.000	0.000
Turbidity	9.93	0.481
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.364	0.494

Table 62: G3-Cluster Mean - 08

Weight	Mean	STD
Conductivity	5.20	0.780
pH (H ion)	6.30	2.81
DO	0.000	0.000
Turbidity	9.88	0.676
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.036	0.187
Ca	1.75	1.60

Table 63: G3-Cluster Mean - 09

Weight	Mean	STD
Conductivity	5.92	2.00
pH (H ion)	5.63	3.56
DO	0.000	0.000
Turbidity	9.53	1.39
N	0.000	0.000

SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.170	0.376

Table 64: G3-Cluster Mean - 10

Weight	Mean	STD
Conductivity	4.51	0.970
pH (H ion)	7.02	3.03
DO	0.000	0.000
Turbidity	9.93	0.481
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.364	0.494

Table 65: G3-Cluster Mean - 11

Weight	Mean	STD
Conductivity	6.03	1.91
pH (H ion)	6.53	3.40
DO	0.000	0.000
Turbidity	8.23	1.91
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.033	0.178
Ca	1.52	1.51

Table 66: G3-Cluster Mean - 12

Weight	Mean	STD
Conductivity	6.15	1.63
pH (H ion)	6.24	2.98
DO	0.000	0.000
Turbidity	9.67	1.22
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.035	0.184
Ca	1.69	1.61

Table 67: G3-Cluster Mean - 13

Weight	Mean	STD
Conductivity	4.52	0.942
pH (H ion)	7.49	2.90
DO	0.000	0.000
Turbidity	9.79	0.886
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.029	0.169
Ca	1.31	1.46

Table 68: G3-Cluster Mean - 14

Weight	Mean	STD
Conductivity	5.73	1.98
pH (H ion)	6.22	3.26
DO	0.000	0.000
Turbidity	9.74	1.13
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.211	0.408

Table 69: G3-Cluster Mean - 15

Weight	Mean	STD
Conductivity	4.61	0.952
pH (H ion)	7.63	2.92
DO	0.000	0.000
Turbidity	9.91	0.635
N	0.000	0.000
SO_4^{2-}	0.000	0.000

Na	0.000	0.000
Mg	0.024	0.153
Ca	1.30	1.37

Table 70: G3-Cluster Mean - 16

Weight	Mean	STD
Conductivity	5.80	2.00
pH (H ion)	6.86	3.41
DO	0.000	0.000
Turbidity	9.64	1.25
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.385	0.507

Table 71: G3-Cluster Mean - 17

Weight	Mean	STD
Conductivity	6.02	1.86
pH (H ion)	5.91	3.59
DO	0.000	0.000
Turbidity	9.46	1.42
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.024	0.154
Ca	1.41	1.37

Table 72: G3-Cluster Mean - 19

Weight	Mean	STD
Conductivity	5.00	0.989
pH (H ion)	6.25	3.14
DO	0.000	0.000
Turbidity	9.85	0.746
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.028	0.165
Ca	1.44	1.41

Table 73: G3-Cluster Mean - 18

Weight	Mean	STD
Conductivity	6.37	1.56
pH (H ion)	4.78	2.73
DO	0.000	0.000
Turbidity	9.50	1.41
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.040	0.195
Ca	1.70	1.67

Table 74: G3-Cluster Mean - 20

Weight	Mean	STD
Conductivity	4.53	0.956
pH (H ion)	6.99	3.05
DO	0.000	0.000
Turbidity	9.92	0.538
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.023	0.151
Ca	1.33	1.38

Table 75: G3-Cluster Mean - 21

Weight	Mean	STD
Conductivity	5.47	2.01
pH (H ion)	6.62	3.41
DO	0.000	0.000
Turbidity	9.70	1.18
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.105	0.307

Table 76: G3-Cluster Mean - 22

Weight	Mean	STD
Conductivity	4.68	0.928
pH (H ion)	6.71	2.95
DO	0.000	0.000
Turbidity	9.75	0.874
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.026	0.160
Ca	1.40	1.38

Table 77: G3-Cluster Mean - 23

Weight	Mean	STD
Conductivity	5.69	1.96
pH (H ion)	6.14	3.39
DO	0.000	0.000
Turbidity	9.25	1.58
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.031	0.173
Ca	1.41	1.51

Table 78: G3-Cluster Mean - 25

Weight	Mean	STD
Conductivity	6.51	1.49
pH (H ion)	4.55	2.70
DO	0.000	0.000
Turbidity	9.34	1.52
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.037	0.189
Ca	1.70	1.61

Table 79: G3-Cluster Mean - 24

Weight	Mean	STD
Conductivity	4.82	0.955
pH (H ion)	8.14	2.29
DO	0.000	0.000
Turbidity	9.52	1.10
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.026	0.158
Ca	1.43	1.35

Table 80: G3-Cluster Mean - 26

Weight	Mean	STD
Conductivity	4.78	0.641
pH (H ion)	6.36	2.68
DO	0.000	0.000
Turbidity	6.92	0.508
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.287	0.452

Table 81: G3-Cluster Mean - 27

Weight	Mean	STD
Conductivity	6.91	1.65
pH (H ion)	4.72	2.90
DO	0.000	0.000
Turbidity	9.62	1.36
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.043	0.202
Ca	1.92	1.69

Table 82: G3-Cluster Mean - 28

Weight	Mean	STD
Conductivity	5.89	2.09
pH (H ion)	6.87	3.40
DO	0.000	0.000
Turbidity	9.69	1.24
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.026	0.160
Ca	1.27	1.45

Table 83: G3-Cluster Mean - 29

Weight	Mean	STD
Conductivity	6.78	1.47
pH (H ion)	4.96	2.80
DO	0.000	0.000
Turbidity	9.59	1.34
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0600	0.237
Ca	1.91	1.84

Table 84: G3-Cluster Mean - 30

Weight	Mean	STD
Conductivity	4.34	1.03
pH (H ion)	6.66	3.24
DO	0.000	0.000
Turbidity	9.91	0.544
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.273	0.459

Table 85: G3-Cluster Mean - 31

Weight	Mean	STD
Conductivity	4.75	0.946
pH (H ion)	8.37	2.23
DO	0.000	0.000
Turbidity	9.81	0.820
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0240	0.154
Ca	1.35	1.36

Table 86: G3-Cluster Mean - 32

	Mean	STD
Conductivity	5.88	1.92
pH (H ion)	6.17	3.36
DO	0.000	0.000
Turbidity	9.47	1.41
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0240	0.153
Ca	1.39	1.36

Table 87: G3-Cluster Mean - 33

Weight	Mean	STD
Conductivity	5.49	2.00
pH (H ion)	6.53	3.45
DO	0.000	0.000
Turbidity	9.78	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.251	0.447

Table 88: G3-Cluster Mean - 34

Weight	Mean	STD
Conductivity	5.00	1.02
pH (H ion)	6.20	3.24
DO	0.000	0.000
Turbidity	9.85	0.748
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0320	0.176
Ca	1.45	1.54

Table 89: G3-Cluster Mean - 35

Weight	Mean	STD
Conductivity	5.86	1.68
pH (H ion)	6.49	3.25
DO	0.000	0.000
Turbidity	9.68	1.23
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0330	0.178
Ca	1.45	1.54

Table 90: G3-Cluster Mean - 36

Weight	Mean	STD
Conductivity	5.73	1.97
pH (H ion)	7.48	3.24
DO	0.000	0.000
Turbidity	9.33	1.58
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0310	0.172
Ca	1.43	1.50

Table 91: G3-Cluster Mean - 37

Weight	Mean	STD
Conductivity	6.55	1.50
pH (H ion)	7.48	3.24
DO	0.000	0.000
Turbidity	9.33	1.58
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0310	0.172
Ca	1.43	1.50

Table 92: G3-Cluster Mean - 38

Weight	Mean	STD
Conductivity	5.47	2.01
pH (H ion)	9.67	1.12
DO	0.000	0.000
Turbidity	9.70	1.12
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.105	.0307

Table 93: G3-Cluster Mean - 39

Weight	Mean	STD
Conductivity	5.41	1.98
pH (H ion)	6.92	3.34
DO	0.000	0.000
Turbidity	9.63	1.29
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0290	0.168
Ca	1.28	1.52

Table 94: G3-Cluster Mean - 40

Weight	Mean	STD
Conductivity	5.19	1.98
pH (H ion)	6.92	3.34
DO	0.000	0.000
Turbidity	9.63	1.29
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.0290	0.168
Ca	1.76	1.59

Table 95: Gordon 3-Cluster Quality Score

Weight	Mean	Weight	Mean
Original	81.0		
01	81.3	21	81.8
02	81.3	22	82.5
03	80.3	23	83.0
04	80.5	24	79.8
05	87.6	25	87.6
06	80.0	26	87.6
07	81.3	27	81.5
08	81.4	28	80.3
09	82.5	29	81.5
10	81.3	30	82.1
11	83.4	31	78.8
12	80.8	32	81.8
13	80.7	33	81.3
14	81.5	34	81.9
15	80.1	35	80.6
16	80.7	36	80.2
17	81.9	37	82.1
18	81.9	38	75.8
19	82.6	39	80.9
20	81.3	40	82.5

7.4 Upper Three Runs Weight for 2-Cluster Groundwater Quality Analysis (UTR2)

Table 96: UTR2-Cluster Mean - 01

Weight	Mean	STD
Conductivity	2.49	1.04
pH (H ion)	9.66	1.32
DO	0.000	0.000
Turbidity	9.99	0.234
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000

Mg	0.000	0.000
Ca	0.0132	0.114

Table 97: UTR2-Cluster Mean - 02

Weight	Mean	STD
Conductivity	2.47	0.869
pH (H ion)	9.80	1.10
DO	0.000	0.000
Turbidity	9.99	0.243
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00806	0.0984

Table 98: UTR2-Cluster Mean - 03

Weight	Mean	STD
Conductivity	2.61	0.938
pH (H ion)	9.66	1.32
DO	0.000	0.000
Turbidity	9.99	1.32
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0136	0.116

Table 99: UTR2-Cluster Mean - 04

Weight	Mean	STD
Conductivity	2.66	1.05
pH (H ion)	9.96	0.525
DO	0.000	0.000
Turbidity	9.98	0.262
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00969	0.0979

Table 100: UTR2-Cluster Mean - 05

Weight	Mean	STD
Conductivity	2.15	0.722
pH (H ion)	9.77	1.17
DO	0.000	0.000
Turbidity	9.99	0.236
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00799	0.0890

Table 101: UTR2-Cluster Mean - 06

Weight	Mean	STD
Conductivity	2.33	0.869
pH (H ion)	9.75	1.24
DO	0.000	0.000
Turbidity	9.98	0.273
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0100	0.0999

Table 102: UTR2-Cluster Mean - 07

Weight	Mean	STD
Conductivity	2.34	0.905
pH (H ion)	9.75	1.24
DO	0.000	0.000
Turbidity	9.98	0.274
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0102	0.101

Table 103: UTR2-Cluster Mean - 08

Weight	Mean	STD
Conductivity	2.25	0.966
pH (H ion)	10.0	0.0271
DO	0.000	0.000
Turbidity	9.98	0.0271
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 104: UTR2-Cluster Mean - 09

Weight	Mean	STD
Conductivity	2.25	1.03
pH (H ion)	9.78	1.17
DO	0.000	0.000
Turbidity	10.0	0.0928
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00808	0.0895

Table 105: UTR2-Cluster Mean - 10

Weight	Mean	STD
Conductivity	2.28	1.01
pH (H ion)	9.82	1.05
DO	0.000	0.000
Turbidity	9.99	0.241
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00841	0.0913

Table 106: UTR2-Cluster Mean - 11

Weight	Mean	STD
Conductivity	2.60	0.933
pH (H ion)	9.75	1.22
DO	0.000	0.000
Turbidity	9.97	0.334
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00888	0.0938

Table 107: UTR2-Cluster Mean - 12

Weight	Mean	STD
Conductivity	2.61	0.883
pH (H ion)	9.75	1.22
DO	0.000	0.000
Turbidity	9.97	0.334
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000888	0.0938

Table 108: UTR2-Cluster Mean - 13

Weight	Mean	STD
Conductivity	2.38	0.975
pH (H ion)	9.80	1.11
DO	0.000	0.000
Turbidity	9.99	2.43
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00836	0.0911

Table 109: UTR2-Cluster Mean - 14

Weight	Mean	STD
Conductivity	2.01	0.775
pH (H ion)	9.77	1.17
DO	0.000	0.000
Turbidity	9.99	0.250
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00799	0.0890

Table 110: UTR2-Cluster Mean - 15

Weight	Mean	STD
Conductivity	2.27	0.866
pH (H ion)	9.88	0.894
DO	0.000	0.000
Turbidity	9.99	0.228
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 111: UTR2-Cluster Mean - 16

Weight	Mean	STD
Conductivity	1.99	0.881
pH (H ion)	9.85	0.851
DO	0.000	0.000
Turbidity	9.99	0.244
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 112: UTR2-Cluster Mean - 17

Weight	Mean	STD
Conductivity	2.49	0.946
pH (H ion)	9.73	1.28
DO	0.000	0.000
Turbidity	9.99	0.240
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00863	0.0925

Table 113: UTR2-Cluster Mean - 18

Weight	Mean	STD
Conductivity	2.30	0.992
pH (H ion)	9.68	1.40
DO	0.000	0.000
Turbidity	9.95	0.437
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0113	0.106

Table 114: UTR2-Cluster Mean - 19

Weight	Mean	STD
Conductivity	2.24	1.04
pH (H ion)	9.82	1.05
DO	0.000	0.000
Turbidity	9.99	0.241
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00828	0.0906

Table 115: UTR2-Cluster Mean - 20

Weight	Mean	STD
Conductivity	1.85	0.886
pH (H ion)	9.87	0.928
DO	0.000	0.000
Turbidity	9.98	0.276
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 116: UTR2-Cluster Mean - 21

Weight	Mean	STD
Conductivity	2.34	0.972
pH (H ion)	9.80	1.10
DO	0.000	0.000
Turbidity	9.99	0.244
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00819	0.0901

Table 117: UTR2-Cluster Mean - 22

Weight	Mean	STD
Conductivity	2.37	0.934
pH (H ion)	9.80	1.10
DO	0.000	0.000
Turbidity	9.99	0.243
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00808	0.0895

Table 118: UTR2-Cluster Mean - 23

Weight	Mean	STD
Conductivity	2.57	0.934
pH (H ion)	9.56	0.532
DO	0.000	0.000
Turbidity	9.98	0.262
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00988	0.0989

Table 119: UTR2-Cluster Mean - 24

Weight	Mean	STD
Conductivity	1.98	0.880
pH (H ion)	9.86	0.950
DO	0.000	0.000
Turbidity	10.0	0.0947
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 120: UTR2-Cluster Mean - 25

Weight	Mean	STD
Conductivity	2.20	0.912
pH (H ion)	9.86	0.933
DO	0.000	0.000
Turbidity	9.99	0.237
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 121: UTR2-Cluster Mean - 26

Weight	Mean	STD
Conductivity	2.13	0.857
pH (H ion)	9.88	0.889
DO	0.000	0.000
Turbidity	9.99	0.244
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 122: UTR2-Cluster Mean - 27

Weight	Mean	STD
Conductivity	1.80	0.734
pH (H ion)	9.81	1.09
DO	0.000	0.000
Turbidity	9.99	0.251
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00828	0.0906

Table 123: UTR2-Cluster Mean - 28

Weight	Mean	STD
Conductivity	2.60	1.12
pH (H ion)	9.96	0.534
DO	0.000	0.000
Turbidity	9.98	0.262
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0102	0.100

Table 124: UTR2-Cluster Mean - 29

Weight	Mean	STD
Conductivity	2.64	0.976
pH (H ion)	9.75	1.23
DO	0.000	0.000
Turbidity	9.98	0.312
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00906	0.0948

Table 125: UTR2-Cluster Mean - 30

Weight	Mean	STD
Conductivity	2.38	0.975
pH (H ion)	9.80	1.11
DO	0.000	0.000
Turbidity	9.99	0.243
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00841	0.0913

Table 126: UTR2-Cluster Mean - 31

Weight	Mean	STD
Conductivity	2.45	0.934
pH (H ion)	9.77	1.18
DO	0.000	0.000
Turbidity	10.0	0.0929
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00822	0.0903

Table 127: UTR2-Cluster Mean - 32

Weight	Mean	STD
Conductivity	2.01	0.755
pH (H ion)	9.77	1.17
DO	0.000	0.000
Turbidity	9.99	0.250
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00810	0.0896

Table 128: UTR2-Cluster Mean - 33

Weight	Mean	STD
Conductivity	2.11	0.787
pH (H ion)	9.73	1.27
DO	0.000	0.000
Turbidity	9.97	0.361
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00885	0.0936

Table 129: UTR2-Cluster Mean - 34

Weight	Mean	STD
Conductivity	2.24	1.04
pH (H ion)	9.82	1.05
DO	0.000	0.000
Turbidity	9.99	0.241
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00828	0.0906

Table 130: UTR2-Cluster Mean - 35

Weight	Mean	STD
Conductivity	2.69	1.01
pH (H ion)	9.96	0.525
DO	0.000	0.000
Turbidity	9.98	0.262
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00969	0.0979

Table 131: UTR2-Cluster Mean - 36

Weight	Mean	STD
Conductivity	2.45	0.934
pH (H ion)	9.77	1.18
DO	0.000	0.000
Turbidity	2.91	1.37
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00802	0.0903

Table 132: UTR2-Cluster Mean - 37

Weight	Mean	STD
Conductivity	2.55	0.961
pH (H ion)	9.79	1.13
DO	0.000	0.000
Turbidity	9.99	0.227
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.00819	0.0901

Table 133: UTR2-Cluster Mean - 38

Weight	Mean	STD
Conductivity	2.29	1.05
pH (H ion)	9.54	1.56
DO	0.000	0.000
Turbidity	9.99	0.260
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0171	0.130

Table 134: UTR2-Cluster Mean - 39

Weight	Mean	STD
Conductivity	2.60	0.946
pH (H ion)	9.79	1.13
DO	0.000	0.000
Turbidity	9.99	.0227
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	1.01	0.913

Table 135: UTR2-Cluster Mean - 40

Weight	Mean	STD
Conductivity	2.19	0.988
pH (H ion)	9.75	1.24
DO	0.000	0.000
Turbidity	9.98	0.273
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.0102	0.101

Table 136: Upper Three Runs 2-Cluster Quality Score

Weight	Mean	Weight	Mean
Original	77.6		
01	77.9	21	77.6
02	77.6	22	77.6
03	77.8	23	77.6
04	77.1	24	77.7
05	77.8	25	77.6
06	77.8	26	77.6
07	77.8	27	77.9
08	77.3	28	77.2
09	77.7	29	77.6
10	77.6	30	77.6
11	77.6	31	77.6
12	77.6	32	77.9
13	77.6	33	77.9
14	77.9	34	77.6
15	77.5	35	77.1
16	77.7	36	87.8
17	77.7	37	77.5
18	78.0	38	78.2
19	77.6	39	77.4
20	77.7	40	77.8

7.5 McQueen Branch Weight for 2-Cluster Groundwater Quality Analysis (MB2)

Table 137: MB2-Cluster Mean - 01

Weight	Mean	STD
Conductivity	2.04	0.892
pH (H ion)	9.12	2.20
DO	0.000	0.000
Turbidity	9.73	1.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 138: MB2-Cluster Mean - 02

Weight	Mean	STD
Conductivity	2.01	0.886
pH (H ion)	9.52	1.45
DO	0.000	0.000
Turbidity	9.93	0.572
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 139: MB2-Cluster Mean - 03

Weight	Mean	STD
Conductivity	1.82	0.807
pH (H ion)	9.98	.201
DO	0.000	0.000
Turbidity	9.73	1.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 140: MB2-Cluster Mean - 04

Weight	Mean	STD
Conductivity	1.88	0.859
pH (H ion)	9.61	1.47
DO	0.000	0.000
Turbidity	9.78	0.981
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 141: MB2-Cluster Mean - 05

Weight	Mean	STD
Conductivity	1.74	0.726
pH (H ion)	9.68	1.33
DO	0.000	0.000
Turbidity	9.78	0.990
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 142: MB2-Cluster Mean - 06

Weight	Mean	STD
Conductivity	1.92	0.887
pH (H ion)	9.04	2.32
DO	0.000	0.000
Turbidity	9.85	0.808
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 143: MB2-Cluster Mean - 07

Weight	Mean	STD
Conductivity	1.90	0.861
pH (H ion)	9.64	1.41
DO	0.000	0.000
Turbidity	9.73	1.08
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 144: MB2-Cluster Mean - 08

Weight	Mean	STD
Conductivity	1.74	0.726
pH (H ion)	9.68	1.33
DO	0.000	0.000
Turbidity	9.78	0.990
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 145: MB2-Cluster Mean - 09

Weight	Mean	STD
Conductivity	1.90	0.861
pH (H ion)	9.64	1.41
DO	0.000	0.000
Turbidity	9.73	1.08
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 146: MB2-Cluster Mean - 10

Weight	Mean	STD
Conductivity	1.92	0.861
pH (H ion)	9.57	1.43
DO	0.000	0.000
Turbidity	9.78	0.992
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 147: MB2-Cluster Mean - 11

Weight	Mean	STD
Conductivity	1.81	0.811
pH (H ion)	9.64	1.41
DO	0.000	0.000
Turbidity	9.76	1.02
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 148: MB2-Cluster Mean - 12

Weight	Mean	STD
Conductivity	1.92	0.873
pH (H ion)	9.62	1.41
DO	0.000	0.000
Turbidity	9.75	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 149: MB2-Cluster Mean - 13

Weight	Mean	STD
Conductivity	1.93	0.897
pH (H ion)	9.60	1.37
DO	0.000	0.000
Turbidity	9.78	1.04
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 150: MB2-Cluster Mean - 14

Weight	Mean	STD
Conductivity	1.93	0.897
pH (H ion)	9.60	1.37
DO	0.000	0.000
Turbidity	9.78	1.04
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 151: MB2-Cluster Mean - 15

Weight	Mean	STD
Conductivity	1.87	0.863
pH (H ion)	9.18	2.18
DO	0.000	0.000
Turbidity	9.76	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 152: MB2-Cluster Mean - 16

Weight	Mean	STD
Conductivity	1.90	0.870
pH (H ion)	9.61	1.44
DO	0.000	0.000
Turbidity	9.73	1.06
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 153: MB2-Cluster Mean - 17

Weight	Mean	STD
Conductivity	1.79	0.778
pH (H ion)	9.72	1.25
DO	0.000	0.000
Turbidity	9.75	1.04
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 154: MB2-Cluster Mean - 18

Weight	Mean	STD
Conductivity	1.93	0.836
pH (H ion)	9.61	1.46
DO	0.000	0.000
Turbidity	9.90	0.625
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 155: MB2-Cluster Mean - 19

Weight	Mean	STD
Conductivity	1.97	0.899
pH (H ion)	9.15	2.21
DO	0.000	0.000
Turbidity	9.75	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 156: MB2-Cluster Mean - 20

Weight	Mean	STD
Conductivity	1.90	0.861
pH (H ion)	9.63	1.43
DO	0.000	0.000
Turbidity	9.80	0.959
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 157: MB2-Cluster Mean - 21

Weight	Mean	STD
Conductivity	1.97	0.856
pH (H ion)	9.03	2.33
DO	0.000	0.000
Turbidity	8.92	0.596
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 158: MB2-Cluster Mean - 22

Weight	Mean	STD
Conductivity	1.95	0.839
pH (H ion)	9.69	1.30
DO	0.000	0.000
Turbidity	9.69	1.12
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 159: MB2-Cluster Mean - 23

Weight	Mean	STD
Conductivity	1.87	0.867
pH (H ion)	9.18	2.18
DO	0.000	0.000
Turbidity	9.72	1.08
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 160: MB2-Cluster Mean - 24

Weight	Mean	STD
Conductivity	1.89	0.862
pH (H ion)	9.55	1.50
DO	0.000	0.000
Turbidity	9.75	1.04
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 161: MB2-Cluster Mean - 25

Weight	Mean	STD
Conductivity	1.79	0.797
pH (H ion)	9.99	0.151
DO	0.000	0.000
Turbidity	9.70	1.11
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 162: MB2-Cluster Mean - 26

Weight	Mean	STD
Conductivity	1.83	0.833
pH (H ion)	9.05	2.32
DO	0.000	0.000
Turbidity	9.76	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 163: MB2-Cluster Mean - 27

Weight	Mean	STD
Conductivity	1.90	0.835
pH (H ion)	9.68	1.31
DO	0.000	0.000
Turbidity	9.71	1.10
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 164: MB2-Cluster Mean - 28

Weight	Mean	STD
Conductivity	1.83	0.773
pH (H ion)	9.99	0.151
DO	0.000	0.000
Turbidity	9.92	0.603
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 165: MB2-Cluster Mean - 29

Weight	Mean	STD
Conductivity	2.01	0.888
pH (H ion)	9.17	2.18
DO	0.000	0.000
Turbidity	9.84	0.821
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 166: MB2-Cluster Mean - 30

Weight	Mean	STD
Conductivity	1.97	0.908
pH (H ion)	9.12	2.20
DO	0.000	0.000
Turbidity	9.75	1.04
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 167: MB2-Cluster Mean - 31

Weight	Mean	STD
Conductivity	1.92	0.883
pH (H ion)	9.05	2.32
DO	0.000	0.000
Turbidity	9.72	1.08
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 168: MB2-Cluster Mean - 32

Weight	Mean	STD
Conductivity	1.97	0.914
pH (H ion)	9.29	1.95
DO	0.000	0.000
Turbidity	9.79	0.976
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 169: MB2-Cluster Mean - 33

Weight	Mean	STD
Conductivity	1.83	0.833
pH (H ion)	9.05	2.32
DO	0.000	0.000
Turbidity	9.76	1.03
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 170: MB2-Cluster Mean - 34

Weight	Mean	STD
Conductivity	1.89	0.848
pH (H ion)	9.68	1.31
DO	0.000	0.000
Turbidity	9.60	1.26
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 171: MB2-Cluster Mean - 35

Weight	Mean	STD
Conductivity	1.96	0.829
pH (H ion)	9.68	1.31
DO	0.000	0.000
Turbidity	9.66	1.19
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 172: MB2-Cluster Mean - 36

Weight	Mean	STD
Conductivity	1.87	0.867
pH (H ion)	9.18	2.18
DO	0.000	0.000
Turbidity	9.72	1.08
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 173: MB2-Cluster Mean - 37

Weight	Mean	STD
Conductivity	1.88	0.862
pH (H ion)	9.68	1.31
DO	0.000	0.000
Turbidity	9.71	1.10
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 174: MB2-Cluster Mean - 38

Weight	Mean	STD
Conductivity	1.88	0.861
pH (H ion)	9.63	1.44
DO	0.000	0.000
Turbidity	3.36	2.23
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 175: MB2-Cluster Mean - 39

Weight	Mean	STD
Conductivity	1.92	0.884
pH (H ion)	9.02	2.37
DO	0.000	0.000
Turbidity	9.72	1.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 176: MB2-Cluster Mean - 40

Weight	Mean	STD
Conductivity	1.84	0.838
pH (H ion)	9.05	2.32
DO	0.000	0.000
Turbidity	9.61	1.25
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 177: McQueen Branch 2-Cluster Quality Score

Weight	Mean	Weight	Mean
Original	79.6		
01	79.8	21	81.7
02	78.5	22	78.7
03	78.0	23	79.7
04	78.7	24	78.9
05	78.4	25	78.1
06	79.7	26	79.9
07	78.8	27	78.7
08	78.4	28	77.6
09	78.8	29	79.4
10	78.8	30	79.8
11	78.7	31	80.0
12	78.7	32	79.3
13	87.3	33	79.9
14	87.3	34	78.9
15	79.7	35	78.8
16	78.8	36	79.7
17	78.6	37	78.7
18	78.4	38	88.1
19	79.7	39	80.0
20	78.6	40	80.3

7.6 Crouch Branch Weight for 2-Cluster Groundwater Quality Analysis (CB2)

Table 178: CB2-Cluster Mean - 01

Weight	Mean	STD
Conductivity	2.40	1.12
pH (H ion)	5.32	0.615
DO	0.000	0.000
Turbidity	2.39	2.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 179: CB2-Cluster Mean - 02

Weight	Mean	STD
Conductivity	2.42	1.15
pH (H ion)	9.87	0.918
DO	0.000	0.000
Turbidity	9.87	0.604
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 180: CB2-Cluster Mean - 03

Weight	Mean	STD
Conductivity	2.49	1.11
pH (H ion)	9.87	0.907
DO	0.000	0.000
Turbidity	9.88	0.509
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 181: CB2-Cluster Mean - 04

Weight	Mean	STD
Conductivity	2.45	1.08
pH (H ion)	9.9	0.809
DO	0.000	0.000
Turbidity	9.92	0.456
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 182: CB2-Cluster Mean - 05

Weight	Mean	STD
Conductivity	2.17	0.996
pH (H ion)	10.0	0.00177
DO	0.000	0.000
Turbidity	9.92	0.431
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 183: CB2-Cluster Mean - 06

Weight	Mean	STD
Conductivity	2.28	1.10
pH (H ion)	10.0	0.00177
DO	0.0000	0.0000
Turbidity	9.93	0.391
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 184: CB2-Cluster Mean - 07

Weight	Mean	STD
Conductivity	2.42	1.13
pH (H ion)	9.89	0.841
DO	0.000	0.000
Turbidity	9.93	0.435
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 185: CB2-Cluster Mean - 08

Weight	Mean	STD
Conductivity	2.29	1.09
pH (H ion)	10.0	0.00177
DO	0.0000	0.0000
Turbidity	9.92	0.459
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 186: CB2-Cluster Mean - 09

Weight	Mean	STD
Conductivity	2.40	1.13
pH (H ion)	9.90	0.800
DO	0.0000	0.0000
Turbidity	9.92	0.445
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 187: CB2-Cluster Mean - 10

Weight	Mean	STD
Conductivity	2.42	1.13
pH (H ion)	9.89	0.841
DO	0.000	0.000
Turbidity	9.93	0.435
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 188: CB2-Cluster Mean - 11

Weight	Mean	STD
Conductivity	2.25	1.10
pH (H ion)	10.0	0.000177
DO	0.000	0.000
Turbidity	9.92	0.445
N	0.0000	0.0000
SO_4^{2-}	0.0000	0.0000
Na	0.0000	0.0000
Mg	0.0000	0.0000
Ca	0.0000	0.0000

Table 189: CB2-Cluster Mean - 12

Weight	Mean	STD
Conductivity	2.42	1.12
pH (H ion)	9.89	0.843
DO	0.000	0.000
Turbidity	9.93	0.424
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 190: CB2-Cluster Mean - 13

Weight	Mean	STD
Conductivity	2.26	1.10
pH (H ion)	10.0	0.000177
DO	0.000	0.000
Turbidity	9.91	0.465
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 191: CB2-Cluster Mean - 14

Weight	Mean	STD
Conductivity	2.53	1.10
pH (H ion)	9.85	0.962
DO	0.000	0.000
Turbidity	9.93	0.426
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 192: CB2-Cluster Mean - 15

Weight	Mean	STD
Conductivity	2.49	1.11
pH (H ion)	9.87	0.907
DO	0.000	0.000
Turbidity	9.88	0.509
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 193: CB2-Cluster Mean - 16

Weight	Mean	STD
Conductivity	2.38	1.12
pH (H ion)	9.90	0.807
DO	0.000	0.000
Turbidity	9.92	0.420
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 194: CB2-Cluster Mean - 17

Weight	Mean	STD
Conductivity	2.32	1.05
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.91	0.441
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 195: CB2-Cluster Mean - 18

Weight	Mean	STD
Conductivity	2.45	1.09
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.92	0.441
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 196: CB2-Cluster Mean - 19

Weight	Mean	STD
Conductivity	2.50	1.08
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.93	0.380
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 197: CB2-Cluster Mean - 20

Weight	Mean	STD
Conductivity	2.38	1.15
pH (H ion)	9.89	0.836
DO	0.000	0.000
Turbidity	9.95	0.395
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 198: CB2-Cluster Mean - 21

Weight	Mean	STD
Conductivity	2.52	1.11
pH (H ion)	9.87	0.883
DO	0.000	0.000
Turbidity	9.92	0.416
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 199: CB2-Cluster Mean - 22

Weight	Mean	STD
Conductivity	2.46	1.08
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.94	0.421
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 200: CB2-Cluster Mean - 23

Weight	Mean	STD
Conductivity	2.44	1.12
pH (H ion)	9.90	0.807
DO	0.000	0.000
Turbidity	9.91	0.485
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 201: CB2-Cluster Mean - 24

Weight	Mean	STD
Conductivity	2.44	1.10
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.91	0.474
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 202: CB2-Cluster Mean - 25

Weight	Mean	STD
Conductivity	2.31	1.03
pH (H ion)	9.90	0.800
DO	0.000	0.000
Turbidity	9.91	0.445
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 203: CB2-Cluster Mean - 26

Weight	Mean	STD
Conductivity	2.40	1.14
pH (H ion)	9.90	0.807
DO	0.000	0.000
Turbidity	9.90	0.485
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 204: CB2-Cluster Mean - 27

Weight	Mean	STD
Conductivity	2.31	1.03
pH (H ion)	9.90	0.800
DO	0.000	0.000
Turbidity	9.91	0.445
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 205: CB2-Cluster Mean - 28

Weight	Mean	STD
Conductivity	2.40	1.16
pH (H ion)	9.88	0.879
DO	0.000	0.000
Turbidity	9.94	0.411
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 206: CB2-Cluster Mean - 29

Weight	Mean	STD
Conductivity	2.40	1.12
pH (H ion)	5.32	0.615
DO	0.000	0.000
Turbidity	2.39	2.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 207: CB2-Cluster Mean - 30

Weight	Mean	STD
Conductivity	2.50	1.08
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.93	0.380
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 208: CB2-Cluster Mean - 31

Weight	Mean	STD
Conductivity	2.40	1.12
pH (H ion)	5.32	0.615
DO	0.000	0.000
Turbidity	2.39	2.07
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 209: CB2-Cluster Mean - 32

Weight	Mean	STD
Conductivity	2.46	1.09
pH (H ion)	9.90	0.807
DO	0.000	0.000
Turbidity	9.92	0.468
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 210: CB2-Cluster Mean - 33

Weight	Mean	STD
Conductivity	2.42	1.15
pH (H ion)	9.89	0.846
DO	0.000	0.000
Turbidity	9.96	0.334
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 211: CB2-Cluster Mean - 34

Weight	Mean	STD
Conductivity	2.46	1.08
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.93	0.447
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 212: CB2-Cluster Mean - 35

Weight	Mean	STD
Conductivity	2.35	1.04
pH (H ion)	9.90	0.809
DO	0.000	0.000
Turbidity	9.93	0.362
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 213: CB2-Cluster Mean - 36

Weight	Mean	STD
Conductivity	2.29	1.09
pH (H ion)	10.0	0.00177
DO	0.000	0.000
Turbidity	9.92	0.458
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 214: CB2-Cluster Mean - 37

Weight	Mean	STD
Conductivity	2.46	1.13
pH (H ion)	9.86	0.936
DO	0.000	0.000
Turbidity	9.94	0.424
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 215: CB2-Cluster Mean - 38

Weight	Mean	STD
Conductivity	2.53	1.10
pH (H ion)	9.85	0.962
DO	0.000	0.000
Turbidity	9.93	0.426
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 216: CB2-Cluster Mean - 39

Weight	Mean	STD
Conductivity	2.44	1.10
pH (H ion)	9.90	0.804
DO	0.000	0.000
Turbidity	9.91	0.474
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 217: CB2-Cluster Mean - 40

Weight	Mean	STD
Conductivity	2.42	1.14
pH (H ion)	9.90	0.822
DO	0.000	0.000
Turbidity	9.87	0.504
N	0.000	0.000
SO_4^{2-}	0.000	0.000
Na	0.000	0.000
Mg	0.000	0.000
Ca	0.000	0.000

Table 218: Crouch Branch 2-Cluster Quality Score

Weight	Mean	Weight	Mean
Original	77.6		
01	95.6	21	77.5
02	77.7	22	77.5
03	77.6	23	77.5
04	77.5	24	77.5
05	77.4	25	77.6
06	77.4	26	77.6
07	77.5	27	77.6
08	77.4	28	77.5
09	77.5	29	95.6
10	77.5	30	77.5
11	77.4	31	77.4
12	77.5	32	77.5
13	77.4	33	77.5
14	77.6	34	77.5
15	77.6	35	77.5
16	77.5	36	77.4
17	77.6	37	77.5
18	77.5	38	77.6
19	77.5	39	77.5
20	77.5	40	77.6

7.7 Gordon 2-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives				
			Statistic	Std. Error
VAR00001	Mean		80.9300	.12027
	95% Confidence Interval for Mean	Lower Bound	80.6867	
		Upper Bound	81.1733	
	5% Trimmed Mean		80.9778	
	Median		81.0500	
	Variance		.579	
	Std. Deviation		.76063	
	Minimum		78.70	
	Maximum		82.10	
	Range		3.40	
	Interquartile Range		1.00	
	Skewness		-.894	.374
	Kurtosis		.910	.733

Figure 27: Descriptive Statistics for Gordon 2-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00001	.157	40	.014	.945	40	.052

(a. Lilliefors Significance Correction)

Figure 28: Test for Normality for Gordon 2-Cluster Perturbation

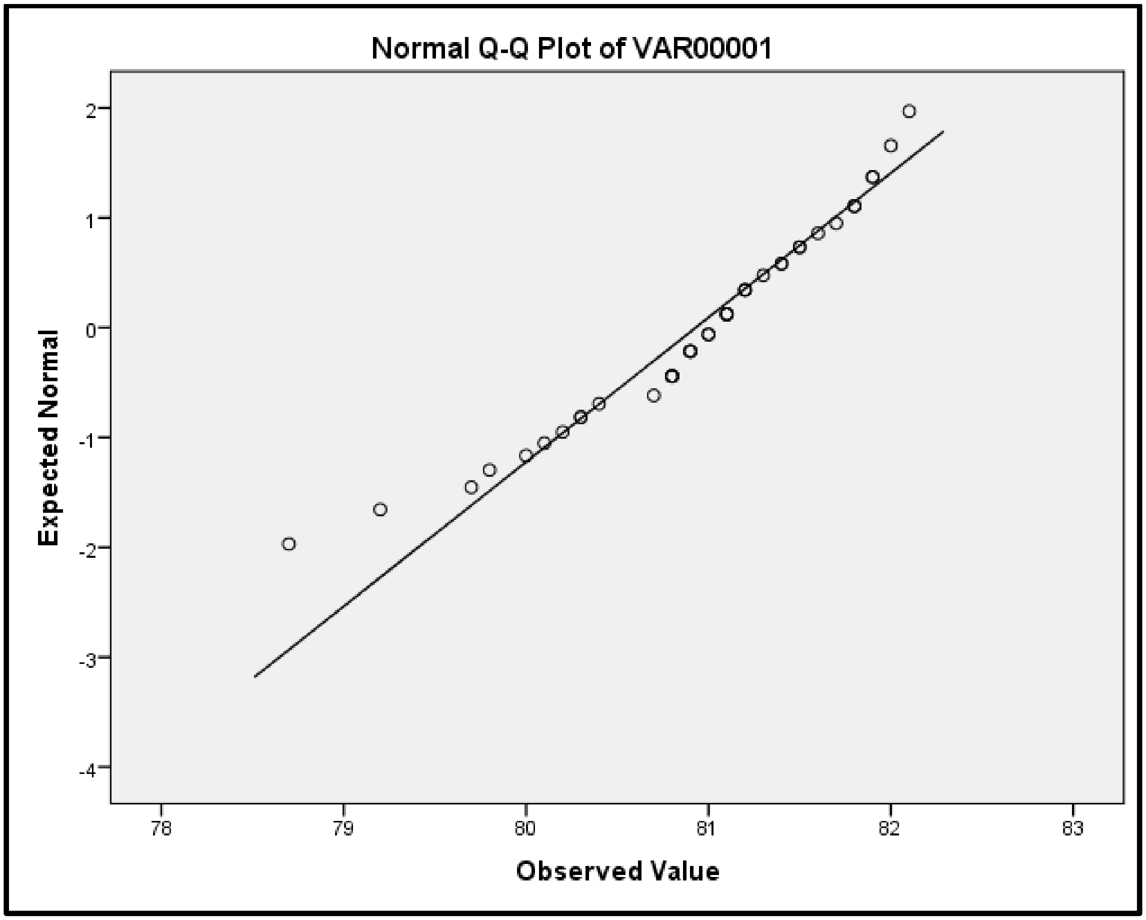


Figure 29: Normal Q-Q Plot for Gordon 2-Cluster Perturbation

One-Sample Test						
	Test Value = 81.0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
VAR00001	-.582	39	.564	-.07000	-.3133	.1733

Figure 30: One-Sample, Two-Tailed t-Test for Gordon 2-Cluster Perturbation

The statistical proof regarding the centrality of the 2-cluster perturbation of Gordon aquifer:

a. H_0: $\mu = 81.0$

   H_1: $\mu \neq 81.0$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.945 with a p-value of 0.052. This suggests that the data comes from a population with a normal probability distribution because the p-value is greater than $\alpha = 0.05$. The standard deviation is unknown and therefore a t-test is utilized to test if the mean of the Gordon groundwater quality calculation changes when cluster quantities change.

c. The t-test in SPSS gave test statistic of -0.582 and a p-value of 0.564.

d. Fail to Reject the H_0 because the p-value is greater than the $\alpha = 0.05$.

e. There is not sufficient evidence to support that the mean Gordon groundwater quality calculation value changes with 2-cluster perturbation changes.

7.8 Gordon 3-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives				
			Statistic	Std. Error
VAR00004	Mean		81.6500	.33762
	95% Confidence Interval for Mean	Lower Bound	80.9671	
		Upper Bound	82.3329	
	5% Trimmed Mean		81.5611	
	Median		81.3500	
	Variance		4.559	
	Std. Deviation		2.13530	
	Minimum		75.80	
	Maximum		87.60	
	Range		11.80	
	Interquartile Range		1.48	
	Skewness		1.084	.374
	Kurtosis		4.025	.733

Figure 31: Descriptive Statistics for Gordon 3-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00004	.203	40	.000	.817	40	.000

(a. Lilliefors Significance Correction)

Figure 32: Test for Normality for Gordon 3-Cluster Perturbation

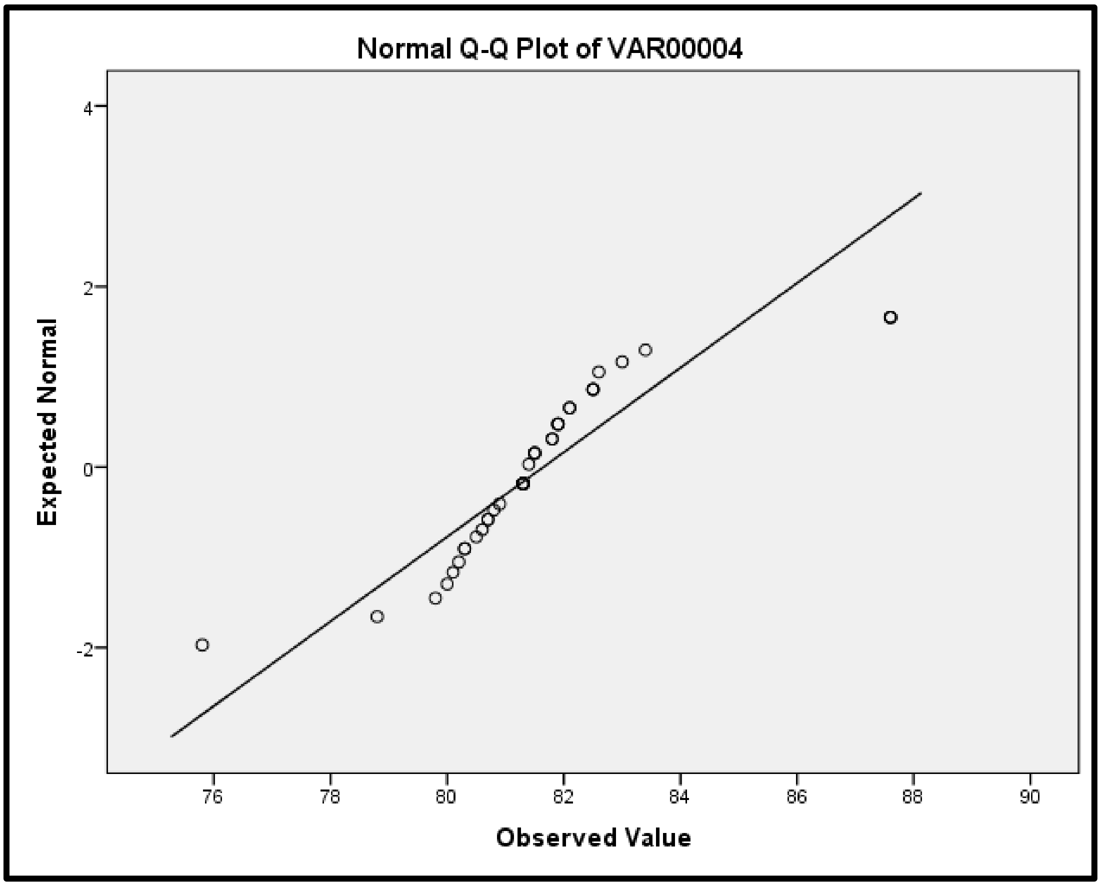


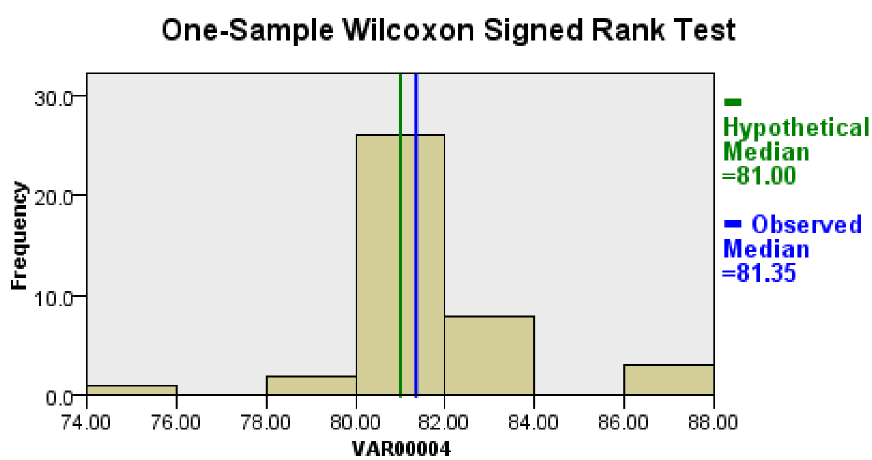
Figure 33: Normal Q-Q Plot for Gordon 3-Cluster Perturbation

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00004 equals 81.00.	One-Sample Wilcoxon Signed Rank Test	.029	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 34: One-Sample Wilcoxon Signed Rank Test for Gordon 3-Cluster Perturbation



Total N	40
Test Statistic	572.500
Standard Error	74.298
Standardized Test Statistic	2.187
Asymptotic Sig. (2-sided test)	.029

Figure 35: Wilcoxon Signed Rank Test Statistic for Gordon 3-Cluster Perturbation

The statistical proof regarding the centrality of the 3-cluster perturbation of Gordon aquifer:

a. H_0: $M_{population} = 81.0$

   H_1: $M_{population} \neq 81.0$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.817 with a p-value of <0.0001. This does not support that the data comes from a population with a normal probability distribution because the p-value is less than $\alpha = 0.05$. The standard deviation is unknown and therefore the sign test is used to test if the Median of the Gordon groundwater quality calculation changes when cluster quantities change.

c. The sign test in SPSS gave a test statistic of 572.500 and a p-value of 0.029.

d. Reject the H_0 because the p-value is less than the $\alpha = 0.05$.

e. There is sufficient evidence to support that the Gordon groundwater quality calculation median value changes when 3-cluster quantities change.

7.9 Gordon 3-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives				
			Statistic	Std. Error
VAR00004	Mean		81.6500	.33762
	95% Confidence Interval for Mean	Lower Bound	80.9671	
		Upper Bound	82.3329	
	5% Trimmed Mean		81.5611	
	Median		81.3500	
	Variance		4.559	
	Std. Deviation		2.13530	
	Minimum		75.80	
	Maximum		87.60	
	Range		11.80	
	Interquartile Range		1.48	
	Skewness		1.084	.374
	Kurtosis		4.025	.733

Figure 36: Descriptive Statistics for Gordon 3-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00004	.203	40	.000	.817	40	.000

(a. Lilliefors Significance Correction)

Figure 37: Test for Normality for Gordon 3-Cluster Perturbation

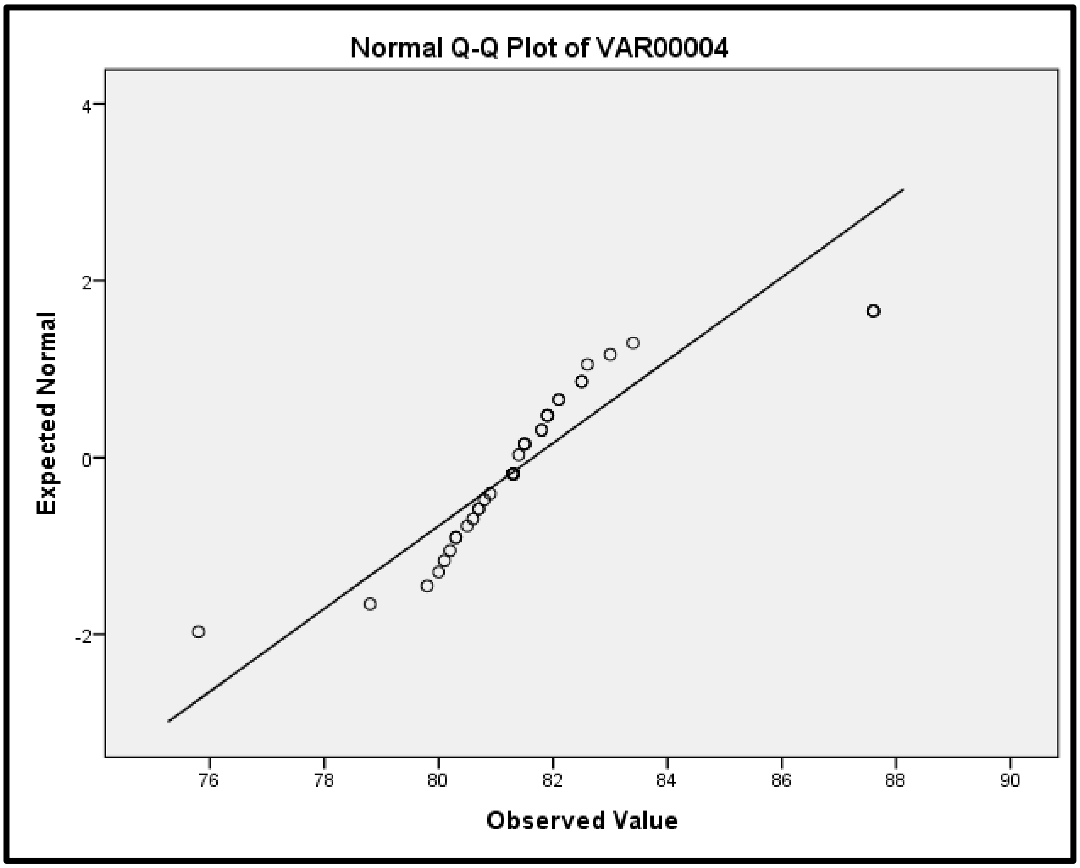


Figure 38: Normal Q-Q Plot for Gordon 3-Cluster Perturbation

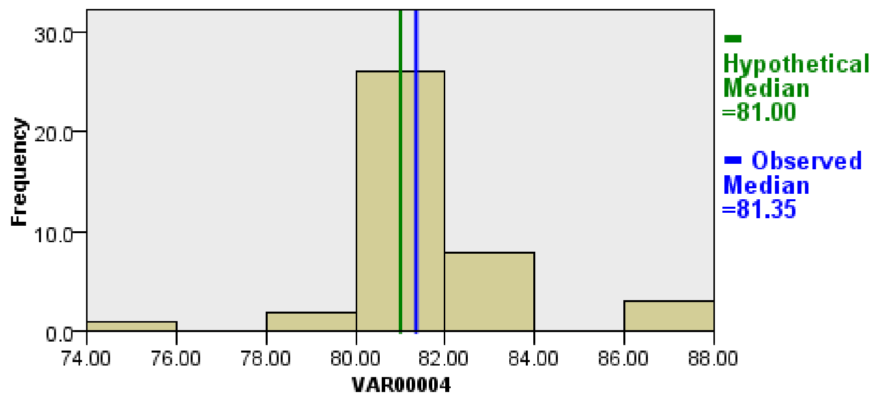
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00004 equals 81.00.	One-Sample Wilcoxon Signed Rank Test	.029	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 39: One-Sample Wilcoxon Signed Rank Test for Gordon 3-Cluster Perturbation

One-Sample Wilcoxon Signed Rank Test



Total N	40
Test Statistic	572.500
Standard Error	74.298
Standardized Test Statistic	2.187
Asymptotic Sig. (2-sided test)	.029

Figure 40: Wilcoxon Signed Rank Test Statistic for Gordon 3-Cluster Perturbation

The statistical proof regarding the centrality of the 3-cluster perturbation of Gordon aquifer:

a. H_0: $M_{population} = 81.0$

   H_1: $M_{population} \neq 81.0$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.817 with a p-value of <0.0001. This does not support that the data comes from a population with a normal probability distribution because the p-value is less than $\alpha = 0.05$. The standard deviation is unknown and therefore the sign test is used to test if the Median of the Gordon groundwater quality calculation changes when cluster quantities change.

c. The sign test in SPSS gave a test statistic of 572.500 and a p-value of 0.029.

d. Reject the H_0 because the p-value is less than the $\alpha = 0.05$.

e. There is sufficient evidence to support that the Gordon groundwater quality calculation median value changes when 3-cluster quantities change.

7.10 Upper Three Runs 2-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives				
			Statistic	Std. Error
VAR00002	Mean		77.9150	.25552
	95% Confidence Interval for Mean	Lower Bound	77.3982	
		Upper Bound	78.4318	
	5% Trimmed Mean		77.6750	
	Median		77.6000	
	Variance		2.612	
	Std. Deviation		1.61603	
	Minimum		77.10	
	Maximum		87.80	
	Range		10.70	
	Interquartile Range		.20	
	Skewness		6.165	.374
	Kurtosis		38.629	.733

Figure 41: Descriptive Statistics for Upper Three Runs 2-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00002	.429	40	.000	.242	40	.000

(a. Lilliefors Significance Correction)

Figure 42: Test for Normality for Upper Three Runs 2-Cluster Perturbation

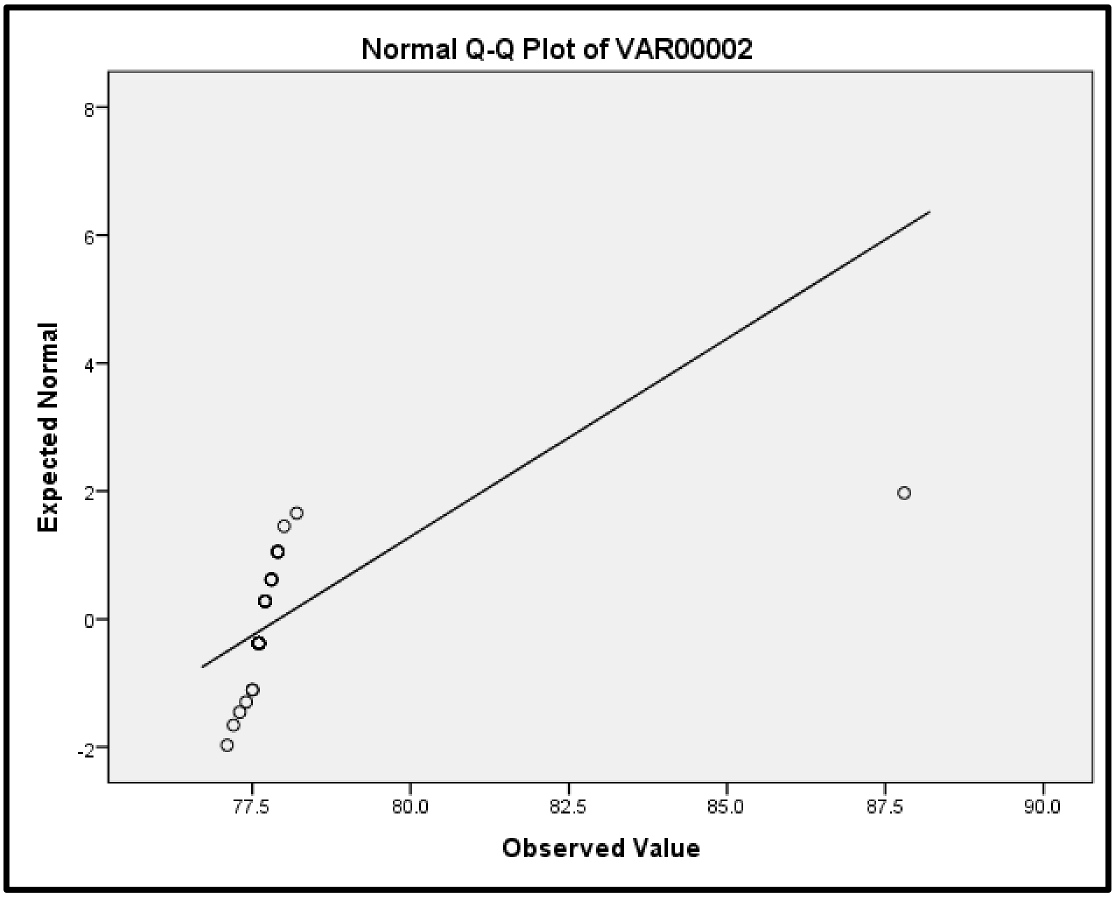


Figure 43: Normal Q-Q Plot for Upper Three Runs 2-Cluster Perturbation

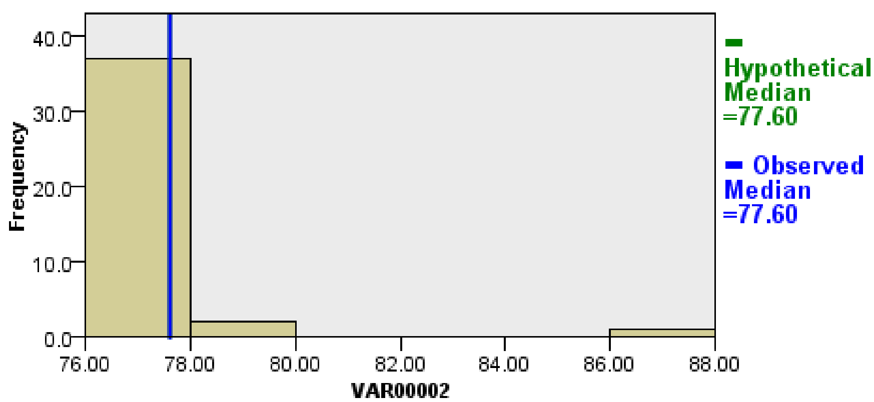
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00002 equals 77.60.	One-Sample Wilcoxon Signed Rank Test	.017	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 44: One-Sample Wilcoxon Signed Rank Test for Upper Three Runs 2-Cluster Perturbation

One-Sample Wilcoxon Signed Rank Test



Total N	40
Test Statistic	233.000
Standard Error	34.891
Standardized Test Statistic	2.379
Asymptotic Sig. (2-sided test)	.017

Figure 45: Wilcoxon Signed Rank Test Statistic for Upper Three Runs 2-Cluster Perturbation

The statistical proof regarding the centrality of the 2-cluster perturbation of Upper Three Runs aquifer:

a. H_0: $M_{population} = 77.6$

   H_1: $M_{population} \neq 77.6$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.242 with a p-value of <0.0001. This does not support that the data comes from a population with a normal probability distribution because the p-value is less than $\alpha = 0.05$. The standard deviation is unknown and therefore the sign test is used to test if the Median of the Upper Three Runs groundwater quality calculation changes when cluster quantities change.

c. The sign test in SPSS gave test statistic of 233.000 and a p-value of 0.017.

d. Reject the H_0 because the p-value is less than the $\alpha = 0.05$.

e. There is sufficient evidence to support that the Upper Three Runs groundwater quality calculation median value changes when cluster quantities change.

7.11 McQueen Branch 2-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives				
			Statistic	Std. Error
VAR00004	Mean		79.7475	.37639
	95% Confidence Interval for Mean	Lower Bound	78.9862	
		Upper Bound	80.5088	
	5% Trimmed Mean		79.4139	
	Median		78.8500	
	Variance		5.667	
	Std. Deviation		2.38047	
	Minimum		77.60	
	Maximum		88.10	
	Range		10.50	
	Interquartile Range		1.10	
	Skewness		2.816	.374
	Kurtosis		7.424	.733

Figure 46: Descriptive Statistics for McQueen Branch 2-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00004	.333	40	.000	.581	40	.000

(a. Lilliefors Significance Correction)

Figure 47: Test for Normality for McQueen Branch 2-Cluster Perturbation

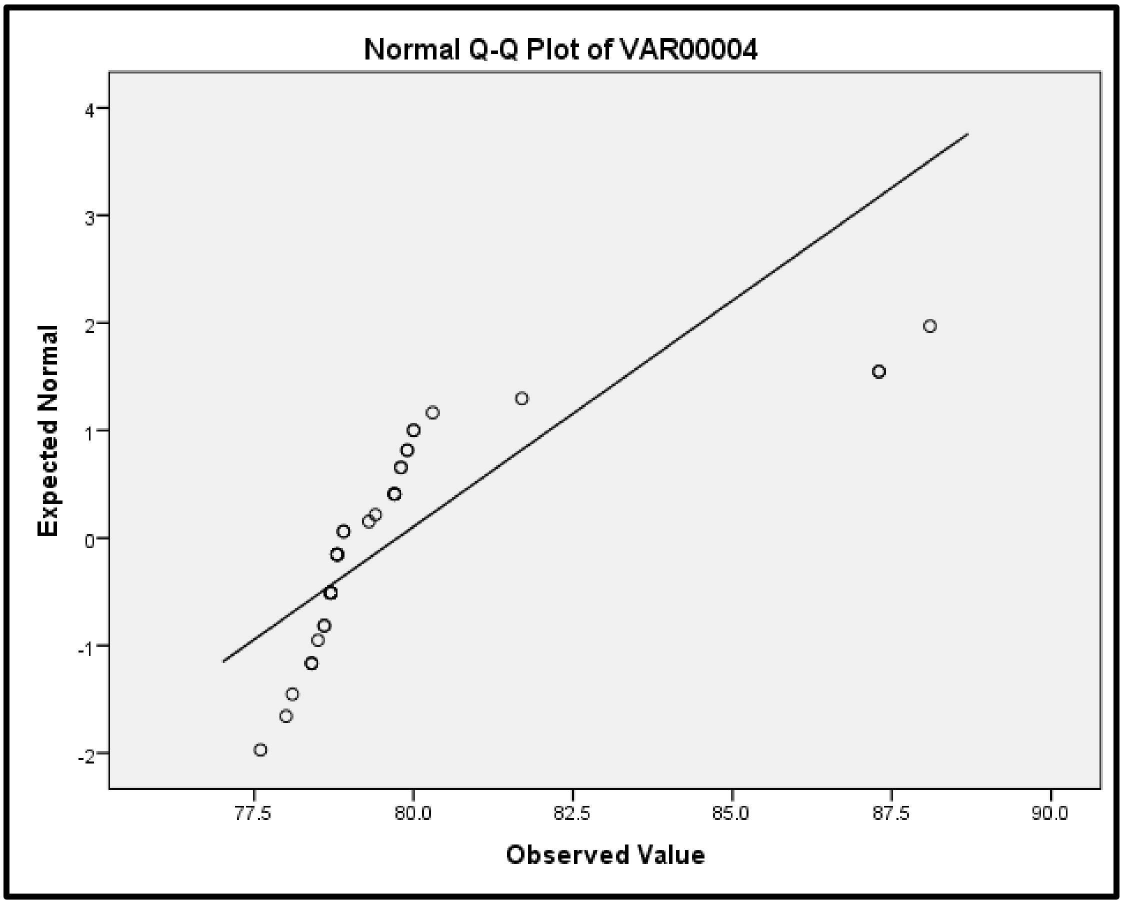


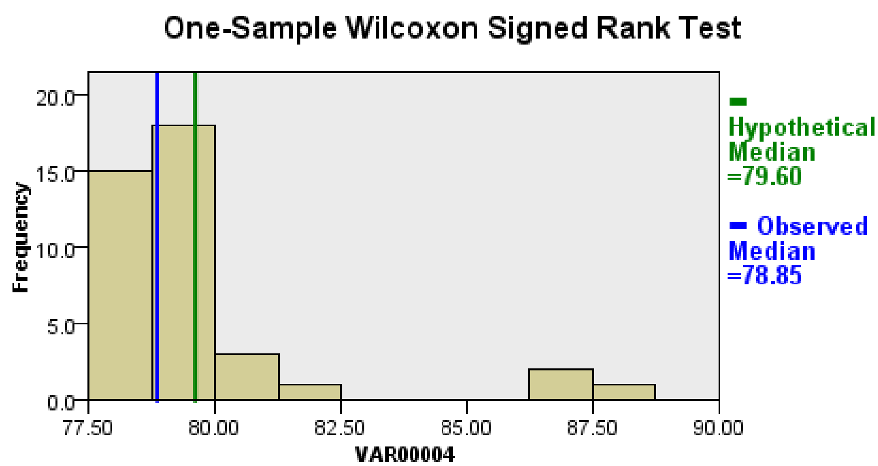
Figure 48: Normal Q-Q Plot for McQueen Branch 2-Cluster Perturbation

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00004 equals 79.60.	One-Sample Wilcoxon Signed Rank Test	.027	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 49: One-Sample Wilcoxon Signed Rank Test for McQueen Branch 2-Cluster Perturbation



Total N	40
Test Statistic	246.000
Standard Error	74.326
Standardized Test Statistic	-2.206
Asymptotic Sig. (2-sided test)	.027

Figure 50: Wilcoxon Signed Rank Test Statistic for McQueen Branch 2-Cluster Perturbation

The statistical proof regarding the centrality of the 2-cluster perturbation of McQueen Branch aquifer:

a. H_0: $M_{population} = 79.6$

   H_1: $M_{population} \neq 79.6$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.581 with a p-value of <0.0001. This does not support that the data comes from a population with a normal probability distribution because the p-value is less than $\alpha = 0.05$. The standard deviation is unknown and therefore the sign test is used to test if the Median of the McQueen Branch GQ changes when cluster quantities change.

c. The sign test in SPSS gave test statistic of 246.000 and a p-value of 0.027.

d. Reject the H_0 because the p-value is less than the $\alpha = 0.05$.

e. There is sufficient evidence to support that the McQueen Branch GQ median value changes when cluster quantities change.

7.12 Crouch Branch 2-Cluster IBM SPSS Statistics 24 Statistical Analysis

The following tables provide data from IBM SPSS Statistics 24 statistical software. This data is used to prove that the random perturbations come from a normal distribution and to prove the significance of the centrality.

Descriptives

			Statistic	Std. Error
VAR00003	Mean		78.4150	.63141
	95% Confidence Interval for Mean	Lower Bound	77.1379	
		Upper Bound	79.6921	
	5% Trimmed Mean		77.5167	
	Median		77.5000	
	Variance		15.947	
	Std. Deviation		3.99336	
	Minimum		77.40	
	Maximum		95.60	
	Range		18.20	
	Interquartile Range		.10	
	Skewness		4.290	.374
	Kurtosis		17.273	.733

Figure 51: Descriptive Statistics for Crouch Branch 2-Cluster Perturbation

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00003	.521	40	.000	.243	40	.000

(a. Lilliefors Significance Correction)

Figure 52: Test for Normality for Crouch Branch 2-Cluster Perturbation

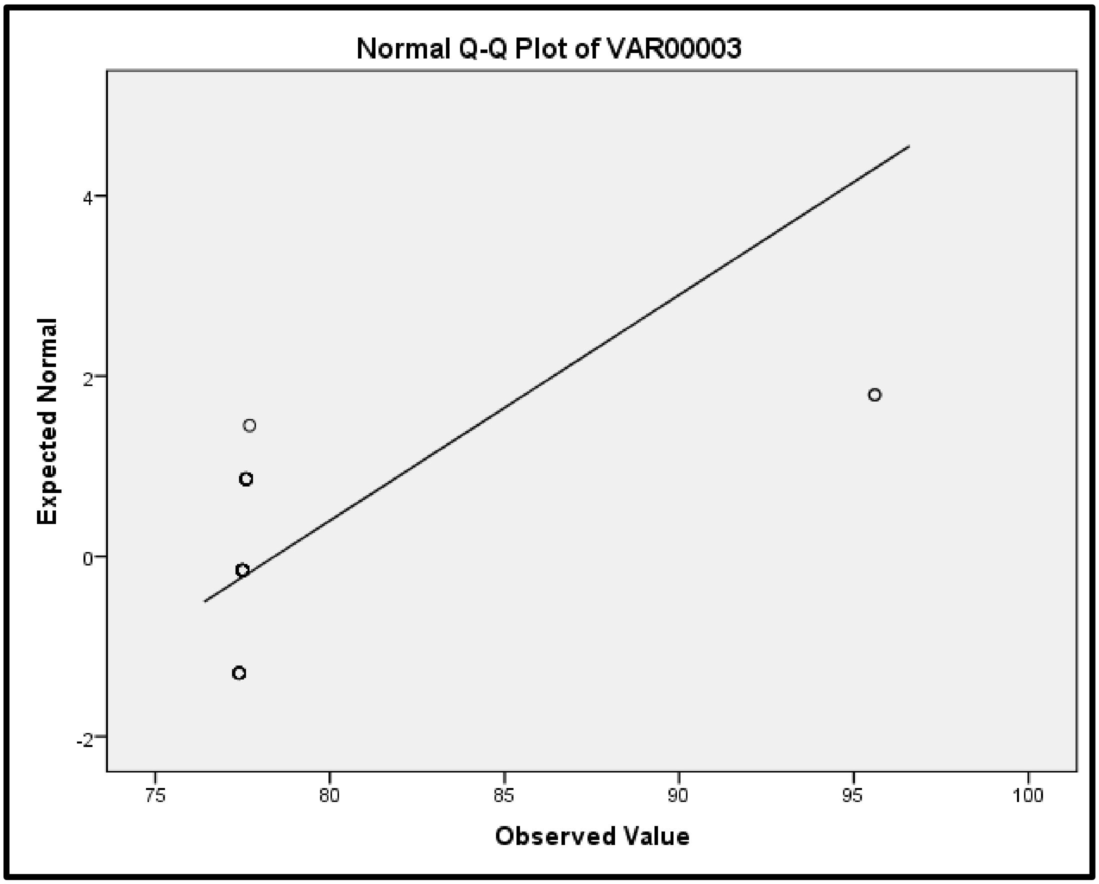


Figure 53: Normal Q-Q Plot for Crouch Branch 2-Cluster Perturbation

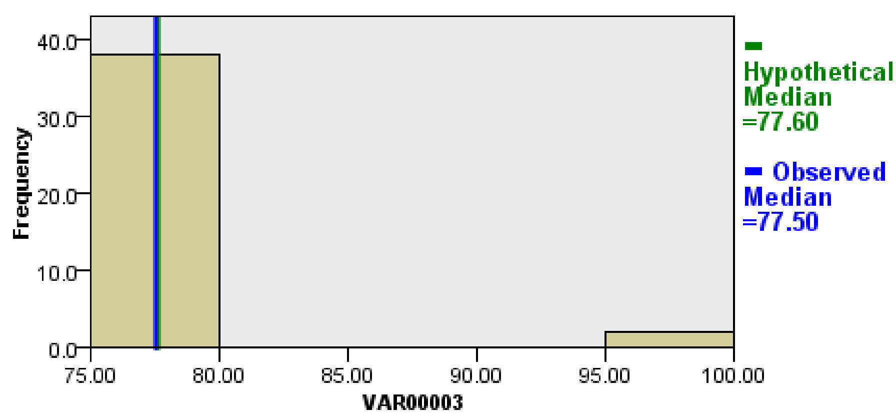
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of VAR00003 equals 77.60.	One-Sample Wilcoxon Signed Rank Test	.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 54: One-Sample Wilcoxon Signed Rank Test for Crouch Branch 2-Cluster Perturbation

One-Sample Wilcoxon Signed Rank Test



Total N	40
Test Statistic	83.000
Standard Error	49.034
Standardized Test Statistic	-3.365
Asymptotic Sig. (2-sided test)	.001

Figure 55: Wilcoxon Signed Rank Test Statistic for Crouch Branch 2-Cluster Perturbation

The statistical proof regarding the centrality of the 2-cluster perturbation of Crouch Branch aquifer:

a. H_0: $M_{population} = 77.6$

   H_1: $M_{population} \neq 77.6$

b. From the statistical software SPSS, the Shapiro-Wilk normality test gave a test statistic value of 0.243 with a p-value of <0.0001. This does not support that the data comes from a population with a normal probability distribution because the p-value is less than $\alpha = 0.05$. The standard deviation is unknown and therefore the sign test is used to test if the Median of the Crouch Branch groundwater quality calculation changes when cluster quantities change.

c. The sign test in SPSS gave test statistic of 83.000 and a p-value of 0.001.

d. Reject the H_0 because the p-value is less than the $\alpha = 0.05$.

e. There is sufficient evidence to support that the Crouch Branch groundwater quality calculation median value changes when cluster quantities change.