Water Quality Alert System for Detection of Brine Spills Using Low-Cost Technology

A thesis presented to
the faculty of
the Voinovich School of Leadership and Public Affairs of Ohio University

In partial fulfillment
of the requirements for the degree
Master of Science

Siti R. Hj Abd Rahman

August 2017

© 2017 Siti R. Hj Abd Rahman. All Rights Reserved.
This thesis titled

Water Quality Alert System for Detection of Brine Spills Using Low-Cost Technology

by

SITI R. HJ ABD RAHMAN

has been approved for

the Program of Environmental Studies

and the Voinovich School of Leadership and Public Affairs by

Natalie A. Kruse Daniels

Associate Professor of Environmental Studies

Mark Weinberg

Dean, Voinovich School of Leadership and Public Affairs
Hydraulic fracturing is an industry that has expanded quickly in the United States and around the world. Over the past years, salt waste water from these operations has been injected to the ground. The salt water is not only containing a high amount of salt, it is also containing a mixture of proppants, and other harmful substances which have potential risks and are toxic to public health, wildlife, and the environment. Produced water or waste fluid that came from hydraulic fracturing should be properly handled and disposed to protect the environment and human health. This study is focused on a study of a water quality alert system able to detect brine spills by using a low-cost technology. The water quality alert system is being developed especially in remote areas where it is not always feasible to monitor the quality of the water. The brine spill alert system is based upon using Atlas Scientific temperature and conductivity sensors and deploying them downstream of Class II injection wells. The data collection from the probes is transmitted to the Ohio Voinovich campus server using a cellular network to upload the data bundles into the Mongolab cloud database. Testing has demonstrated accuracy within 5-10% of reading from the calibrated commercial meter in laboratory conditions. Calibration for the EC sensor is necessary for every 5 days; meanwhile, the temperature sensor required a weekly calibration based on field data; however, additional investigation is necessary. Modeling the mixing of fracking fluids with river water using
PHREEQCi software demonstrated that a brine spill mixing with a stream in a ratio of 1:99 trigger the alert threshold of 1500 µS/cm during summer and winter seasons.
DEDICATION

Dedicated to my mother, Hjh Rokiah Bte Jambol.
ACKNOWLEDGMENTS

My special gratitude to my advisor Dr. Natalie Kruse for giving me the opportunity to conduct this challenging project. Thank you for her never-ending support and continued belief in me towards completing this project. I would like to thank to my committee members, Dr. Dina Lopez and Dr. Hans Kruse for their pieces of advices and support all the way. I couldn’t have achieved without the assistance of Jen Bowman, Nora Sullivan, and Sarah Cornwell. My deepest thank you to my stream-to-cloud team, Bahast Saber, Grace Fuch, Nana Kwabena Boadum, Clovis Ngim Nkempu, and especially Sebastian Teas who was always helped me throughout the journey.

I would like to thank my family in Brunei for their love and prayers. Finally to my boyfriend, Michael Bayer for his tremendous love, support, and words of encouragement for facing challenges in staying thousand miles away from my home country.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Dedication</td>
<td>5</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>6</td>
</tr>
<tr>
<td>List of Tables</td>
<td>9</td>
</tr>
<tr>
<td>List of Figures</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>12</td>
</tr>
<tr>
<td>Chapter 2: Literature Review</td>
<td>16</td>
</tr>
<tr>
<td>2.1 Brine from Marcellus and Utica Shale</td>
<td>16</td>
</tr>
<tr>
<td>2.2 Water Quality and Fossil Fuels</td>
<td>17</td>
</tr>
<tr>
<td>2.3 Brine Production and Composition</td>
<td>19</td>
</tr>
<tr>
<td>2.4 Treatment and Disposal Options</td>
<td>22</td>
</tr>
<tr>
<td>2.5 Impact of Brine Spills</td>
<td>24</td>
</tr>
<tr>
<td>2.6 Alternative Monitoring Techniques</td>
<td>25</td>
</tr>
<tr>
<td>Chapter 3: Objectives</td>
<td>27</td>
</tr>
<tr>
<td>Chapter 4: Development of Alert System</td>
<td>28</td>
</tr>
<tr>
<td>4.1 Development and Construction of Alert System</td>
<td>28</td>
</tr>
<tr>
<td>4.2 Instruments</td>
<td>28</td>
</tr>
<tr>
<td>4.3 Solar Panel</td>
<td>29</td>
</tr>
<tr>
<td>4.4 Stand-Post</td>
<td>30</td>
</tr>
<tr>
<td>4.5 Components in Waterproof Box Container</td>
<td>32</td>
</tr>
<tr>
<td>4.6 Instruments Deployment</td>
<td>33</td>
</tr>
<tr>
<td>4.7 Software</td>
<td>35</td>
</tr>
<tr>
<td>4.8 Cloud Bundle Database</td>
<td>36</td>
</tr>
<tr>
<td>4.9 Simulated Brine Spill</td>
<td>38</td>
</tr>
<tr>
<td>Chapter 5: Methods and Study Areas</td>
<td>39</td>
</tr>
<tr>
<td>5.1 Field Sites</td>
<td>39</td>
</tr>
<tr>
<td>5.2 On-site Water Quality Monitoring</td>
<td>42</td>
</tr>
<tr>
<td>5.3 Phreeqci Software Simulation</td>
<td>43</td>
</tr>
<tr>
<td>5.4 Phreeqci Simulation in Summer</td>
<td>46</td>
</tr>
<tr>
<td>5.5 Phreeqci Simulation in Winter</td>
<td>57</td>
</tr>
</tbody>
</table>
Chapter 6: Results and Discussion ................................................................. 69
  6.1 Objective 2 ............................................................................................... 69
  6.2 Objective 3 ............................................................................................... 77
  6.3 Objective 4 ............................................................................................... 79
  6.4 Aquatic Life Criteria ................................................................................ 89
Chapter 7: Conclusion and Future Work ......................................................... 97
  7.1 Conclusion ............................................................................................... 97
  7.2 Future Work ........................................................................................... 97
References ....................................................................................................... 99
Appendix 1: Batch Experiment Results for Summer ...................................... 104
Appendix 2: Batch Experiment Results for Winter ........................................ 106
LIST OF TABLES

Table 1: U.S. Geological Survey (2015) of Produced Water Quality ......................... 21
Table 2: The Stock Solutions Target Anion/Cation Concentration by Cogan (2016) ..... 45
Table 3 Supersaturated Minerals of Brine Low IC of Mix 4 ........................................ 47
Table 4: Data Block for Brine High IC Simulation ....................................................... 48
Table 4: Continued ........................................................................................................ 49
Table 5: Data Block for Brine Medium IC Simulation .................................................. 51
Table 5: Continued ........................................................................................................ 52
Table 5: Continued ........................................................................................................ 53
Table 6: Data Block for Brine Low IC Simulation ....................................................... 54
Table 6: Continued ........................................................................................................ 55
Table 6: Continued ........................................................................................................ 56
Table 7: The Ohio LTAP Center .................................................................................. 59
Table 8: The Road Salt Data Input on Deicing Chemical ............................................. 60
Table 9: Data Block for Brine High IC and Road Salt ................................................ 61
Table 9: Continued ....................................................................................................... 62
Table 9: Continued ....................................................................................................... 63
Table 10: Data Block for Brine Medium IC and Road Salt ......................................... 64
Table 10: Continued ..................................................................................................... 65
Table 11: Data Block For Brine Low IC and Road Salt. .............................................. 66
Table 11: Continued ..................................................................................................... 67
Table 11: Continued ..................................................................................................... 68
Table 12: EC Results Before and After Calibration .................................................. 70
Table 13: Temperature Results Before and After Calibration .................................... 71
Table 14: EC Results with Two Point Calibration Solutions ..................................... 79
Table 15: Phreeqci Simulation of Brine High IC ......................................................... 81
Table 16: Phreeqci Simulation of Brine Medium IC. ................................................... 84
Table 17: Phreeqci Simulation of Brine Low IC. ......................................................... 87
Table 18: Aquatic Life Criteria by US EPA ............................................................... 90
Table 19: Aquatic Life Criteria of Brine High IC with Precipitation ......................... 91
Table 20: Aquatic Life Criteria of Brine High IC without Precipitation ......................... 92
Table 21: Aquatic Life Criteria of Brine Medium IC with Precipitation ........................ 93
Table 22: Aquatic Life Criteria of Brine Medium IC without Precipitation ................... 94
Table 23: Aquatic Life Criteria of Brine Low IC with Precipitation ............................... 95
Table 24: Aquatic Life Criteria of Brine Low IC without Precipitation .......................... 96
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Sensor Development Locations in Athens County, Ohio</td>
<td>15</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Solar Panel in Torch Rest Area</td>
<td>29</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Solar Power System</td>
<td>30</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Stand-Post Preparation</td>
<td>31</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Solar Panel Preparation</td>
<td>32</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Waterproof Box Container</td>
<td>33</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Extension Cable with 12 Volts Battery</td>
<td>33</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Communication Data Module</td>
<td>34</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Sensors with PVC Pipe</td>
<td>35</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Raspberry Pi</td>
<td>36</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Mongolab Cloud Database</td>
<td>37</td>
</tr>
<tr>
<td>Figure 12</td>
<td>DTN Bundle</td>
<td>37</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Site 1A and Site 1B Locations in Torch Rest Area</td>
<td>40</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Site 2 Location in Sams Rd</td>
<td>40</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Site 3 Location in Ohio University</td>
<td>41</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Field Tests from January 2017 to March 2017</td>
<td>42</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Myron Ultrameter, Atlas Scientific EC and Temperature Sensors</td>
<td>43</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Phreeqc Software in Summer</td>
<td>46</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Phreeqc Software in Winter</td>
<td>57</td>
</tr>
<tr>
<td>Figure 20</td>
<td>EC Results for Laboratory Test</td>
<td>73</td>
</tr>
<tr>
<td>Figure 21</td>
<td>EC Results for Field Test</td>
<td>74</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Temperature Results for Laboratory Test</td>
<td>75</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Temperature Results for Field Test</td>
<td>76</td>
</tr>
<tr>
<td>Figure 24</td>
<td>EC Readings after Calibration</td>
<td>77</td>
</tr>
<tr>
<td>Figure 25</td>
<td>The Calibration Steps</td>
<td>78</td>
</tr>
<tr>
<td>Figure 26</td>
<td>The EC Values after Calibration</td>
<td>78</td>
</tr>
<tr>
<td>Figure 27a and 27b</td>
<td>PHREEQCi Simulation using Brine High IC</td>
<td>82</td>
</tr>
<tr>
<td>Figure 28a and 28b</td>
<td>PHREEQCi Simulation using Brine Medium IC</td>
<td>85</td>
</tr>
<tr>
<td>Figure 29a and 29b</td>
<td>PHREEQCi Simulation using Brine Low IC</td>
<td>88</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

Unconventional means of gas production, such as hydraulic fracturing have the potential of leading to energy independence among many oil-importing countries. While hydraulic fracturing and horizontal drilling technologies have led to a surge in the number of companies engaging in oil production, there has been a rise of concerns about the environmental risks caused by the increased level of oil and gas development.

Injection wells are used for the underground injection of fluids into the subsurface through the well bore. There are three subclasses of Class II injection wells, salt-water disposal wells, enhanced oil recovery (EOR) wells, and hydrocarbon storage wells. In the production of oil, there is usually a need to separate hydrocarbons from the salt-water mixture. In fact, there is an average of 10 barrels of waste fluid for every barrel of crude oil (Ground Water Protection Council, 2016). Salt water disposal wells are the focus of this project.

The number of saltwater disposal wells has been simultaneously increasing as shale gas development grows (Aasand, 2014). Produced water from Pennsylvania is being transported to Ohio and West Virginia because the disposal infrastructure is not suitable for disposing (McCurdy, n.d.). McCurdy mentioned that the Class II underground injection control wells have been injecting two billion gallons of fluid per day since the 1930’s. Brine disposal in Class II wells is the most economic method of disposal. The average cost for disposing the saltwater is only less than $0.25 per barrel and it only costs $1.00 per barrel of brine per hour to pay the operator (McCurdy, n.d.). In Ohio or West Virginia, it costs about $4.00-$6.00 per barrel to dispose of saltwater. Since
1985, the EPA has been responsible or the work permits, inspections, and enforcement of the Underground Injection Control Program (UIC), while some states have primacy and run their own UIC programs under the authority of the EPA (Stateimpact.npr.org, n.d.). Furthermore, operators were allowed to dispose brine in the waterways in the mid-1980s.

There are two technologies used together in the oil and gas industry to extract oil and gas from shale formations: horizontal drilling and hydraulic fracturing (Ridlington et al., 2013). Waste fluid from shale gas stimulation is comprised of several of substances such as salt, heavy metals, radioactive materials, and organic chemicals. There are approximately 750 chemicals hydraulic fracturing waste fluids and that could be a risk to environmental and human health (U.S. House of Representatives, 2011). Moreover, U.S. House of Representatives reported that about 29 chemicals were known as human carcinogens, toxic, and hazardous air pollutants (2011). Class II Injection wells are supposed to be a permanent storage system designed to hold oil and gas waste fluid in a deep subsurface ground stratum. The underground Class II injection wells in Ohio accepted approximately 81.7 million barrels of waste fluid between third quarter of 2010 and first quarter of 2015 (Auch, 2015). Many communities and residents living near Class II injection wells are at risk of brine spills. Several spills have occurred in Athens County (personal communication, Teresa Mills). The growth in injection wells receiving waste from hydraulic fracturing operations has raised concerns about the potential impacts on the environment and human health. A study has been carried out in Pennsylvania indicates that radium has accumulated in the sediment and soils affected by discharge of fracking waste fluid from the Marcellus Shale (Warner et al., 2013a).
Accidental or intentional brine spill incidents occurring in Ohio have increased over recent years. There was a brine truck crashed occurred in Barnesville, Ohio in early 2016, and another brine truck struck by a train in Morrow County in May 2016 (The Columbus Dispatch, 2016). The majority of spills occur during transportation of oil and gas waste fluid to the disposal sites which can cause serious impacts to the ecosystem and local communities’ health. Pettyjohn (1971) stated that surface water resources in Morrow County were affected by disposing brine directly into the streams, draining the evaporation pit into streams, and the natural discharge of the contaminated groundwater into water courses.

The specific objectives are to design a brine spill alert system that can detect accidental or intentional brine spills in the water bodies draining injection well sites and to test its accuracy, precision, and sensitivity. The brine spill alert system in this project has the goal to help detect and monitor future brine spills. The system is using temperature and conductivity sensors in two locations. Prevention and quick emergency response benefit everyone including community members, the environment, regulators, and business interests. The sensor package should offer a robust mechanism for detecting spills and have the capability to distinguish brine spills from road salt that has been applied to nearby roadways.

The structure of this case study is to build a brine spill alert system, and determine the effectiveness of the water quality measurement by 1) comparing side by side with a calibrated Myron Ultrameter 6P handheld meter, 2) conducting weekly calibration checks, and 3) simulating a brine spill and observing the alert system response. The aim
is to use the systems downstream of the K&H and Ginsburg injection wells in Torch and Albany, Ohio, respectively, and on Ohio University’s campus (Figure 1).

The alert system would provide a data management and analysis system to continuously monitor the water parameters and transmit that data to the internet with the goal of detecting any brine spill events or abnormal water quality and alerting stakeholders via SMS or email.

Figure 1. Sensor development locations in Athens County, Ohio One alert system was deployed at Site 1 downstream of the K&H injection wells in Torch, Ohio. One system will be deployed at Site 2 downstream of the Ginsburg injection well in Albany, Ohio. One test system was deployed on Ohio University’s campus, Site 3, as a demonstration system.
CHAPTER 2: LITERATURE REVIEW

2.1 Brine from Marcellus and Utica Shale

Hydraulic fracturing is used to stimulate deep natural gas supplies using large amount of water and water pressure to inject the hydraulic fracturing fluid, a mixture of sand, water, and additives, at high pressure into underground, into the target formation. If the waste fluids are not disposed of or treated with care, components found in hydraulic fracturing fluids (flowback and produced waste fluid) could create bad impact to human health and the environment (New Brunswick Responsible Energy Development Alliance, 2015). Leaching to the drinking water supply is one of the impacts which could lead to environmental and health concerns. According to United States House of Representatives (2011), between 2005 and 2009; there were about 780 million gallons of hydraulic fracturing waste fluid excluding water were used by 14 different companies in the oil and gas industries. There are multiple possible environmental impacts from fracking activities including injected water returning to the ground surface when it exceeds the capacity of the target formation (Hause et al. 2012).

Oil and gas extraction can impact aquatic life and plants in streams, rivers, and farmland through accidental or intentional releases of heavy metal and chemicals. A study carried out in the Bakken Region of Western North Dakota by Tomlinson et al. claimed that brine contamination can reduce the productivity of the soil and plants until remedial actions were in place (2014). Tomlinson et al. (2014) added that even though there are recovery techniques, there are still challenges faced to tackle brine contamination problems. Brine spills may threaten streams and rivers, and drinking water
supplies because chemical constituents of brine can be toxic to many organisms, and some chemicals are known to cause cancer. For example, tetramethylammonium chloride which can be present in fracking waste fluid is a non-biodegradable element which can harm aquatic life and humans (Elsner & Hoelzer, 2016).

Vidic et al (2013) states that the Marcellus Shale is the saltiest and most radiogenic of the US sedimentary basins. Worse still, a study by Warner et al. (2012) posits that Marcellus formation brine is affecting shallow water quality, including shallow drinking water resources. In support of this conclusion, Howarth et al. (2011), notes that due to the low porosity of Marcellus shale, the source of brine should be considered in the extraction of shale gas in order to avoid contamination of aquifers. In fact, from 2010 to 2011 for example, Marcellus developments accounted for between 68% and 79% of the total oil and gas waste in Pennsylvania, much of which is transported to Ohio for disposal. In addition, it is becoming common to find contaminants associated with oil and gas waste present in produced water in surface water bodies, including inorganic (e.g. Ba, Sr) and radioactive components.

2.2 Water Quality and Fossil Fuels

The process of extracting oil and gas entails the use and production of large volumes of fluid. In fact, oil and gas fields themselves contain large volumes of brine, which may contain hydrocarbon residues, heavy metals, hydrogen sulfide, boron, as well as various radioactive materials. In addition, the amount of produced water increases as the oil well ages (Verbeek, 2003). Whereas evaporation pits were once the most popular manner of disposing of the produced water, the current process of using injection wells is
seen as more environmentally friendly. The use of evaporation pits had the risk of ground and surface water pollution by infiltration into local aquifers or discharge into streams and rivers in case the pit collapsed (Koplos, Kobelski, Karimjee, & Sham, 2006).

Haluszack, Rose, & Kunp (2012), notes that oil and gas waste fluid can contain total dissolved solids (TDS) and Cl at concentrations greater than 100,000 mg/L. TDS is a total measure of the inorganic salts and organic matter present in the water solution by measuring the electrical conductivity to determine the presence of ions in water (WHO, 1996). Similarly, leakage from oil and gas wells due to failed casings can lead to methane contamination of groundwater. Overall, some of the major problems posed in extraction and transportation of petroleum products and wastes are spills and leaks. To avoid this problem, a Class II injection well should be designed and constructed in a manner similar to a Class I well (Jung et al., 2010). A Class I well is used to dispose of hazardous and non-hazardous waste into deep rock underground (U.S. EPA, n.d) that include petroleum refining, chemical production, commercial disposal, food production, metal production, and municipal waste fluid treatment. However, well construction does not avoid accidental or intentional spills of waste fluid or leaks due to material corrosion.

In this research, a brine spill alert system has been created to notify relevant stakeholders of possible instances of brine spillage. While the general infrastructure of Ohio Class II Injection Wells appears to be safe, there is always a risk of spillage that may be a result of leaks in the facility’s pipes, truck accidents, spills, brine transfers, and corroded pipes and casings (The Columbus Dispatch, 2016). Generally, brine is composed of organic waste, salts, metals, and other chemicals. These brines contain high
concentrations of salts that may corrode sections of the tanks and pipes, which could lead to leaks. In turn, these leaks can lead to environmental pollution and degradation (Nogues et al., 2010).

2.3 Brine Production and Composition

Ziemkiewicz (2015) observed the primary composition of the waste fluid is from materials in the shale as opposed to the additives in the drilling fluid after examining the inorganic, organic, and radioactive components of flowback water. Furthermore, the salt content was composed primarily of sodium, chloride, calcium, barium, strontium, and magnesium. The study also found lead, aluminum, selenium, manganese, and iron from the flowback water which coming from four sites in West Virginia. Moreover, Ziemkiewicz (2015) added that the radioactive material radium was beyond the range of the EPA’s maximum contaminant level. Research by Warner (2014) identified new tracers for the hydraulic fracturing fluid, specifically boron to chloride ratio (B/Cl), lithium to chloride ratio (Li/Cl) and isotopes $\delta^{11}$B and $\delta^{7}$Li, in 39 samples from the conventional produced waters. Blauch (2011) investigated the early analysis of flowback water from Marcellus shale drilling; concentration of barium increases with time after drilling operations. Calcium content increases geographically from west to east; it was found that the mid-region of Pennsylvania has high content of brine (Blauch, 2011).

After hydraulic fracturing has taken place, the fluid that returns to the surface is called waste fluid or flowback and produced water (Haluszczak et al., 2012). Shramm (2011) referred flowback water as a water solution that travels back to the surface during the process of hydraulic fracturing and also after its completion. Flowback water consists
of chemical additives from the hydraulic fracturing fluid, clays, dissolved metal ions, and total dissolved solids (TDS) used to rupture the Marcellus shale (Shramm, 2011).

However, Shramm (2011) explained produced water as the water that naturally exists in shale formations which also flows to the surface from gas wells. Again, Shramm added that produced water has high TDS and leaches out minerals (iron, calcium, magnesium, barium, and radium) from the shale. Dissolved hydrocarbons: ethane, methane, and propane can be found in the produced water. Produced water typically consists of various heavy metals, greases and oils, salts, volatile, and semi-volatile organic compounds that have been extract from the shale zone (Hayes, 2015). A study has been carried out by Haluszczak et al. (2012) evaluated the composition of flowback and produced water from the Marcellus shale that came from Pennsylvania; Cl, Br, Na, Mn, Fe, Ba, Ra, Sr, Mg, Ca, and K were the key inorganic components present in the flowback waters. Kharaka and Hanor (2004) stated that brine from fracking has greater than 35,000 mg/L of total dissolved solids. Table 1 shows the summary of produced water quality prepared by U.S. Geological Survey that came from Pennsylvania, Ohio, and West Virginia (2015).
Table 1: U.S. Geological Survey (2015) summarized the produced water quality from Pennsylvania, Ohio, and West Virginia.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS (mg/L)</td>
<td>26</td>
<td>528,724</td>
<td>148,145</td>
<td>2,303</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>2</td>
<td>5,290</td>
<td>288</td>
<td>112</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>10</td>
<td>51,000</td>
<td>5,863</td>
<td>115</td>
</tr>
<tr>
<td>TOC (mg/L)</td>
<td>1.2</td>
<td>5,680</td>
<td>311</td>
<td>95</td>
</tr>
<tr>
<td>pH</td>
<td>1.2</td>
<td>11.8</td>
<td>6.26</td>
<td>1,028</td>
</tr>
<tr>
<td>SO4²⁻ (mg/L)</td>
<td>0.01</td>
<td>3,910</td>
<td>237</td>
<td>1,630</td>
</tr>
<tr>
<td>Cl⁻ (mg/L)</td>
<td>1</td>
<td>97,400</td>
<td>97,036</td>
<td>2,489</td>
</tr>
<tr>
<td>Alkalinity (mg/L as CoCO3)</td>
<td>13</td>
<td>1,235</td>
<td>189</td>
<td>8</td>
</tr>
<tr>
<td>Br⁻ (mg/L)</td>
<td>0.01</td>
<td>2,129,000</td>
<td>2,374</td>
<td>1,849</td>
</tr>
<tr>
<td>Na⁺ (mg/L)</td>
<td>0.2</td>
<td>434,403</td>
<td>36,965</td>
<td>2,448</td>
</tr>
<tr>
<td>Ca²⁺ (mg/L)</td>
<td>0.4</td>
<td>101,200</td>
<td>17,510</td>
<td>2,461</td>
</tr>
<tr>
<td>Mn²⁺ (mg/L)</td>
<td>0.002</td>
<td>138</td>
<td>26</td>
<td>941</td>
</tr>
<tr>
<td>Mg²⁺ (mg/L)</td>
<td>0.4</td>
<td>137,110</td>
<td>2,710</td>
<td>2,457</td>
</tr>
<tr>
<td>Ba²⁺ (mg/L)</td>
<td>0.01</td>
<td>13,600</td>
<td>377</td>
<td>978</td>
</tr>
<tr>
<td>Sr²⁺ (mg/L)</td>
<td>0.009</td>
<td>13,100</td>
<td>736</td>
<td>124</td>
</tr>
<tr>
<td>Fe²⁺ Total (mg/L)</td>
<td>0.01</td>
<td>5,800</td>
<td>154</td>
<td>1,460</td>
</tr>
<tr>
<td>Ra²²⁶ (pCi/L)</td>
<td>0.08</td>
<td>5,300</td>
<td>244</td>
<td>53</td>
</tr>
<tr>
<td>Ra²²⁸ (pCi/L)</td>
<td>0.05</td>
<td>9.27</td>
<td>0.52</td>
<td>43</td>
</tr>
</tbody>
</table>

A study conducted by Lauer et al. (2015) on surface water impacted from spills mentioned that the produced water from the Bakken formation had a TDS of 35,000-
330,000 mg/L. Meanwhile, Johnson et al. (2015) analyzed 27 samples that had been taken from the regional brine sources at the Salt Spring State Park in Susquehanna County, Pennsylvania; they had an average conductivity reading of 13,000 µS/cm and average TDS of 8,450 mg/L. In contrast, 15 samples were collected at homes in the same region showing an average conductivity of 1,970 µS/cm and TDS of 1,380 mg/L (Johnson et al., 2015). Based on the information from a study by Johnson et al. (2015) readings from 29 samples on road salt impacted locations suggest an average increase in conductivity of only 179 µS/cm.

According to the US EPA (1992), the electrical conductivity (EC) of rivers in the United States generally ranges from 50 to 1500 µS/cm or µmhos/cm. In addition, a healthy stream with EC between 150 and 500 µS/cm has the ability to support most fish species and macroinvertebrates (U.S. EPA, 1992). Fish or any macroinvertebrates can only tolerate a certain amount of salt in the water which could cause stress to aquatic organisms.

Based on the literature presented here and the range of healthy values for conductivity in streams, the initial alert level for the alert system being developed in this study is 1500 µS/cm. The EC values measured in the literature due to road salt were too low to trigger the alert system (Johnson et al., 2015).

2.4 Treatment and Disposal Options

The United States EPA has classified the underground injection control program into five classes of injection wells. Waste fluids that are associated with natural gas and oil are injected into the Class II injection well (U.S. EPA, n.d). While flowback water is
often reused for another hydraulic fracturing operation, produced water from the wells is not typically recycled and usually stored in tanks and pits before being transported to Class II injection wells (Coimbra, 2013). Blauch (2011) conducted a study on recycling flowback water and reuse of flowback water for further fracking. The study stated that the chloride and total dissolved solid levels increases as the amount of flowback water increased with time, however this is common practice in the Utica and Marcellus shale plays (Blauch, 2011). In addition, treatment to eliminating detrimental or toxic components may need to be implemented before flowback water is able to be reused in drilling.

The most common way to dispose of flowback and produced water is by injecting into Class II injection wells. There are several downsides of Class II injection wells, including earthquakes induced due to the high volumes of fluid injection underground (Chameides, 2013). Chameides (2013) added that an alternative way to dispose the flowback and produced water is by treating the contaminant on the waste fluid at brine treatment plants before releasing it into river or sewer. Brine treatment plants where the wastewater is treated by removing salts or any contaminants are uncommon and have inconsistent efficacy. Brine is normally disposed of in seven ways: surface water discharge, land application, evaporation pond, deep well injection, dust control spread, sewer discharge, and de-icing agent spread (www.desalitech.com, 2016).

EPA (2015) released an assessment report on the potential impacts to drinking water resources that may occur due to inadequate treatment of hydraulic fracturing waste fluid. Insufficient treatment of hydraulic fracturing waste fluid may increase the
concentration of chloride, bromide, chloride, iodide, and total dissolved solid (TDS) in streams (EPA, 2015). Moreover, EPA stated that bromide and iodide can transformed into disinfection byproducts (DBPs) which are toxic and cancer causing (2015).

2.5 Impact of Brine Spills

Athens County received the third highest amount of fracking waste fluid in Ohio in 2014. (Arenschild, 2015). Arenschild (2015) added that there were about 25 million barrels of brine waste fluid were injected into 200 injection wells in Ohio in 2014. About 2.9 million barrels were injected into the seven Class II injection wells in Athens County in the same year. Moreover, the K&H Class II injection wells near Torch, Ohio (Site 1, Figure 1), are located near to Hocking River and Ohio River, this could increase the risk of future water contamination. About 23 injection wells have been shut down due to claims that they may have polluted the drinking water and farm irrigation aquifers in California (www.rt.com, 2015). Once a spill enters to the drinking water, performing the cleanups can be complicated and costly. Brine spills can cause negative impacts to human health, animal health, environment, assets, and community reputation.

Brine is sometimes referred as produced water which may contain toxic organic compounds and salts that can pollute ground water and surface water. These chemicals may be harmful to human health and the environment. Carcinogens including naphthalene, benzene, and acrylamide are all present in fracking fluid (Food & Waterwatch, 2012). For example, EWG reported that crystalline silica (quartz) is the most common fracking chemical used nationwide can cause cancer and respiratory difficulty (2015). Meanwhile, glycol ethers and alcohols that usually found for household
cleaning products which can cause endocrine disruption to humans, and alcohol can harm aquatic life (EWG, 2015).

2.6 Alternative Monitoring Techniques

There are a variety of methods and monitoring devices that can be used to monitor water quality. A study by Warner (2015) investigated fracturing fluid by using elemental and isotopic ratios and signatures. Warner analyzed about 39 samples from conventional produced water in West Virginia. The research has been successfully distinguished the flowback fluid by using boron and lithium isotope compositions. Another study by Ziemkiewicz (2015) studied flowback water from four locations in West Virginia. The study showed that the salt content was influenced by sodium (Na, Mg, Cl, Ca, Ba, and Sr with a range of TDS of 8,840 mg/L – 154,000 mg/L. Furthermore, Ziemkiewicz (2015) confirmed that strontium and barium is a signature to detect the contaminants.

Researchers and scientists have been trying to formulate and identify ways to improve stream or river water quality. Monitoring water quality requires money, time, and results can be hard to interpret because often the more accurate, the more expensive they are.

There are several ways to monitor and control water quality which include manual water sampling from various locations by undergoing different laboratory techniques. Some analytical methods required a high cost equipment or need highly skilled personnel to handle the instrument. In this research, a low-cost brine alert system developed to monitor the watershed in a real-time monitoring system. This system consists of low-cost sensors that installed at several critical locations.
Water is naturally a poor conductor of electricity, if ions are added into it, the resistance reduces and there is more conduction. Accordingly, a conductivity sensor is able to detect presence of ions and salts such as sodium, chlorine, or acids. Since brine contains a high concentration of these salts, a contamination of the river with brine that can lead to an increase in the river’s ions and subsequently increase its conductivity. In this study, the EC and temperature measurements are the basic detection technique to use in the early warning monitoring system. In general, EC is a useful determinant in measuring the stream water quality in detecting any source of pollution that is likely to change the amount of dissolved ions in solution. Inductive conductivity sensors, like those used in this project, work by identifying the level of induced current transmitted by the electrolyte (e.g. water in the stream). The brine alert system provides informative data to monitor the water quality. An online or real-time water monitoring systems is the most feasible method to monitor any changes in water parameters because of the severe potential health hazards and consequences to the environment.
CHAPTER 3: OBJECTIVES

The main goal of this study is to build and test the wireless sensor networks to monitor the water quality downstream of Class II injection wells and enabled to transmit data through a wireless sensor network connected to 3G server. The objectives include:

i. Developing and building a low-cost alert system and deploy it downstream of injection wells in Athens County, Ohio, and test the alert system in the field.

ii. Testing the accuracy of the low-cost alert system by comparing the readings to a calibrated high accuracy commercial meter.

iii. Testing the precision of the low-cost alert system by performing weekly calibration checks using known standards.

iv. Determining the sensitivity of the alert system by simulating the conductivity of different mixing fraction of fracking brine and river water during brine spills.
CHAPTER 4: DEVELOPMENT OF ALERT SYSTEM

4.1 Development and Construction of the Alert System

In this section, Objective 1 is achieved by developing and constructing the alert system.

4.2 Instruments

The hardware components, including solar panels and the 3 ft. high stand-post were set up in the laboratory before setting it up at Site 1A, Site 1B, Site 2, and Site 3; to date sensor packages at Site 1A and 3 have been deployed. The solar panels were connected to the 12V battery for power supply and back up as shown in Figure 2. The low-cost sensors are connected to the Raspberry Pi and the micro-controllers from Atlas Scientific as shown in Figure 6. These electronic devices were stored inside a waterproof box container.
4.3 Solar Panel

The 1 - ½” x 1 - ½” – 3 ft. angle steel plate is attached onto the 1225 x 685 x 75mm solar panel as shown in Figure 3. The angle steel plate was secured to the four mounting holes with screws and nuts. Then, the adjustable solar panel mounting bracket were installed towards the center and fastened with bolts, nuts, and washers to reduce any loose contact of uneven surface.
Figure 3. The set up a solar power system.

4.4 Stand-Post

The team were cut 4” x 4” x 6 ft. of pressure treated lumber into half and clean and remove any debris from the bucket before mixing the concrete. Researchers filled a 5 gallon bucket with 1½ inches of concrete mix and inserted the 4” x 4” x 3 ft. pressure treated lumber into the bucket, then added about 1½ inches of concrete and mix with 3 quarts of water as shown in Figure 4. The bucket is then tapped with a metal rod to release any air bubbles.
The team attached the 1 ¼” x 12” of galvanized steel pipe nipple into the galvanized floor flange and secure it onto the 4” x 4” x 3 ft. of pressure treated lumber with the 1½” wood screws. The L-shaped angle brackets were installed on the side of the lumber to support the weight of the waterproof box. The solar panel was then fastened to the 1 ¼“ x 12” galvanized steel pipe nipple as shown on Figure 5.
4.5 Components inside the Waterproof Box Container

The Raspberry pi uses a multiplexer sync board to make multiple connections (Ogallo, 2015). Ogallo mentioned that the EC probe is connected to a micro-controller to convert data from analogue to digital. Meanwhile, the temperature sensor has its own built-in digitizer and attached it directly to the multiplexer board (Ogallo, 2015).

Four 9/16” holes were drilled out on the surface of the waterproof box container, and extension cables were inserted. The connections include: female and male of extension solar panel cables, EC probes, and temperature probes. Electrical wires were covered with cord protectors, and any gaps were sealed with the seal coax connectors with the intention to protect the instruments and cables from water damage and easy access.
4.6 Instruments Deployment

The temperature and EC sensor from Atlas Scientific installed and sealed outside the waterproof water container to prevent water leaks as shown in Figure 6. The 12V battery has extended to 2 ½ meter of solar panel extension cable. The solar panel extension cables are connected as shown in Figure 7.

Figure 6. The waterproof box container.

Figure 7. The 12V battery is connected to the 2 ½ meter of solar panel extension cable.
The Atlas Scientific EC (K 1.0 Kit) and temperature sensors (ENV-TMP-D) were connected to the Raspberry pi, Analogue to digital converter (ADC) boards, the 12V battery, and circuit board that were placed inside the waterproof box (Atlas-Scientific, 2017). An ADC is needed by the EC sensor that can only read analogue signals as shown in Figure 8.

Figure 8. The communication data module was built to collect data from the EC and temperature sensors which based on a Wi-Fi technology and DTN platform before uploaded to the cloud database for water quality data access.

A hole was dug about 1 ¾ ft. deep in the ground to place the cement-filled bucket which contains the solar panel mount as shown on Figure 9. The sensors are anchored inside a PVC pipe to protect the sensors. The waterproof box containing the Raspberry pi, ADC boards, circuit boards, and the 12V battery were hung from the post by winding the wire around the box at the side of the stand post.
Bahast Saber, a member of the Stream to Cloud team, wrote the software controlling the sensors and the data storage and transfer in Python on the Raspberry pi (Figure 10). This software controls the data collection and storage on the Raspberry Pi and transmits that data from remote sites to the campus server by using a cellular network (not implemented in this project), or DTN using wireless network.
4.8 Cloud Bundle Database

Data bundles are units of data containing one or more measurements that are collected from the temperature and EC probes. The bundles are transmitted via the data mule and disruption tolerant networking (DTN) from sites with no cellular or wireless network coverage. DTN is a networking approach suitable when there is a disruption in data transmission (Nasa.gov, 2014). The data bundles were delivered to a server on the OU campus, unpacked, and uploaded to a Mongolab cloud database as shown in the Figure 11.
The Linux SSG command is used to manually read data from the sensors. A python script provides continuous data readings which are collected and stored on the Raspberry pi, and transferred via the DTN protocol using the data mule to an on-campus server for upload to the MongoLab cloud database. Figure 12 shows the content of one data bundle.
4.9 Simulated Brine Spill

The alert level that would indicate as a spill has been set at 1500 µS/cm. The sensors were immersed in the 450 µS/cm and 12,880 µS/cm of calibration solutions for 900 seconds each (15 minutes). If the alert level is operational, the high conductivity were detected, then transmitted to the alert signal database and flagged it as the trigger level. The Atlas Scientific electrical conductivity sensor was able to cover a wide range of solution; therefore, it had the capability to distinguished between the low and high conductivity solutions effectively (450 µS/cm and 12,880 µS/cm).
CHAPTER 5: METHODS AND STUDY AREAS

5.1 Field Sites

This study aims to design and test an alert system to detect a brine spill by using a low-cost water quality monitoring sensors. Four locations were selected as the study areas: Torch (Sensor Site 1A and 1B, Figure 13), Albany (Sensor Site 2, Figure 14), and Ohio University (Sensor Site 3, Figure 15). The Class II waste fluid injection wells are situated in Skunk Run watershed in Torch (Figure 13) and Biddle Creek watershed on Sams Rd, Albany (Figure 14). During this study, systems were deployed at sites 1A and 3; systems will be deployed at sites 1B and 2 in the near future. The on-campus location was chosen to test different network and data transfer methods and to allow more frequent access to the alert system for testing. The on-campus sampling location is located in Oxbow Creek near to the building of Life Science Research Facility as shown in Figure 16. The sampling point for Site 1A (Figure 13) is located ¼ miles downstream of the Class II injection wells; meanwhile Site 1B is located at 28464 Osborne Rd in Coolville. The sampling point for Site 2 as shown Figure 14 is located about one mile downstream from a Class II injection well. During the three-month deployment period, the Atlas Scientific sensors at Sensor Site 1A and Sensor Site 3 were able to collect and transfer water quality data from remote area to the Mongolab cloud bundle database, although there are reliability problems that must be addressed during future development.
Figure 13. Alert system locations, Site 1A and Site 1B, Skunk run in Torch Rest Area, downstream of the Class II injection wells. An alert system was deployed at site 1A during this study.

Figure 14. The third location where an alert system will be deployed, Site 2, Biddle Creek in Sams Rd, downstream of the Class II injection wells.
In this section, the methodology is structured into two sections:

1. Field Test

2. PHREEQC software (A Graphical User Interface for Geochemical Computer Program).

PHREEQC software is a multipurpose window-based geochemical program that has the capability to build data files, view text files that contained simulations outcomes, and run simulation in a single framework interface (pubs.usgs.gov, 1997).
5.2 On-site Water Quality Monitoring

Field tests as shown in Figure 16 were carried out with the alert system to test the system’s data collection and transmission, accuracy, precision, and sensitivity. Field testing was conducted from January to March 2017 at the Sites 1 and 3 as shown in Figure 1, 13, and 15. This section describes the methods used to achieve Objective 2 and Objective 3. Water quality was analyzed with the following parameters: electrical conductivity (EC), and temperature. The alert system is designed to send an alert at a conductivity threshold of 1500 µS/cm as discussed in Section 2.3.

Objective 2 was achieved by comparing EC and temperature readings that are collected every five minutes using the low cost sensor system with data collected using a calibrated Myron Ultrameter Model 6P on at least a weekly basis with the goal of data accuracy within 5-10%. Myron Ultrameter Model 6P and the low cost sensor system: Atlas Scientific EC sensor (K 1.0 Kit) and Atlas Scientific Temperature sensor Model ENV-TMP-Dare shown on Figure 17. While a goal of 5-10% agreement was set, the data
will also be reviewed to determine if the accuracy is sufficient to avoid false positive and false negative readings.

Objective 3 is to test the preciseness of the data measured by the low-cost alert system. This was achieved by conducting a calibration check of the sensors on weekly basis by using a known conductivity solution (e.g. solutions with a known conductivity of 450 µS/cm and 1500 µS/cm). Calibration was conducted by calibrating with known EC solutions following manufacturer guidelines and comparing temperature readings with a bulb thermometer. Deviation from calibration values were recorded, the goal is <5-10% deviation from standard values.

Figure 17. From left: Myron Ultrameter Model 6P, Atlas Scientific Electrical Conductivity sensor, and Atlas Scientific Temperature sensor.

5.3 PHREEQCi Software Simulation

Objective 4 was achieved by conducting a simulation model with PHREEQCi software (USGS, 2017). The conductivity of the mix binary artificial brine – river water, and tertiary mix artificial brine – river water – rock salt solutions at different mixing ratios was tested to determine what mixture of brine to surface water is necessary to
achieve the conductivity threshold of 1500 uS/cm. These simulations can show what volume of spilled brine with respect to surface water is required to set off the alert system in the summer and winter, respectively. The rock salt solution was added to simulate the runoff during winter time.

The first set of simulations was the mixing of the produced water and river water. The second simulation was the mixing of the produced water, river water, and road salt in simulated batch experiments. The river water composition was collected from watersheddata.com (Ohio Watershed Data, 2015) for a sample at the Hocking River. For the brine, the cation and anion concentrations previously reported by Cogan (2016) were used as shown in Table 2. One solution with high concentrations, one with a medium concentrations and one with relatively low concentrations were modeled for the fracking brine.

The model was used to show the impact on stream water chemistry due to brine spills of differing magnitudes. The first simulation was to quantify the effect on the electrical conductivity and temperature by increasing or decreasing the amount of the produced water spilled with respect to river water.
Table 2: The stock solutions target anion/cation concentration prepared by Cogan (2016). The amount of chemical used to achieve the concentrations which require making 1000 ml of solution listed in this table. The number in parenthesis that labelled next to the solution names is called the ionic strength of the solution.

<table>
<thead>
<tr>
<th>Solution Name</th>
<th>Na&lt;sup&gt;+&lt;/sup&gt; (mg/L)</th>
<th>Ca&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>Ba&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>Mg&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>Sr&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>Fe&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>Mn&lt;sup&gt;2+&lt;/sup&gt; (mg/L)</th>
<th>HCO&lt;sub&gt;3&lt;/sub&gt;− (mg/L)</th>
<th>Cl&lt;sup&gt;−&lt;/sup&gt; (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High IC (4)</td>
<td>64000</td>
<td>27500</td>
<td>5000</td>
<td>2000</td>
<td>2500</td>
<td>50</td>
<td>5</td>
<td>6000</td>
<td>182454</td>
</tr>
<tr>
<td>Medium IC (1)</td>
<td>16000</td>
<td>6500</td>
<td>1500</td>
<td>650</td>
<td>1000</td>
<td>10</td>
<td>1</td>
<td>3000</td>
<td>45838</td>
</tr>
<tr>
<td>Low IC (0.5)</td>
<td>8300</td>
<td>3300</td>
<td>750</td>
<td>350</td>
<td>500</td>
<td>5</td>
<td>0.5</td>
<td>1000</td>
<td>23246</td>
</tr>
</tbody>
</table>
5.4 PHREEQC\textit{i} Simulation in Summer Season

![Image](Figure 18. The set up for summer season simulation; mixture of produced water - river water which was simulated with PHREEQC\textit{i} software.)

In the first simulation experiment, the fraction of produced water was increased on every batch as shown in Figure 18. Solution 1 is the Brine High IC mixed with the river water called Solution 2 as shown on Table 4. Table 2 shows the compositions that were inserted to the data block as shown in Table 4 for Brine High IC, Table 5 for Brine Medium IC, and Table 6 for Brine Low IC. The simulated of EC and temperature of the produced water were calculated and graphs were constructed. The electrical conductivity values were measured by multiplying the ionic strength I reported in the output of the program by $6.2 \times 10^4$ (www.aqion.com, 2012). Electrical Conductivity ($\mu$S/cm) = $6.2 \times 10^4$ x Ionic Strength (mol/L).

To begin, a simulation of solution without minerals or precipitation is necessary to understand which mineral can be formed in the river water when mixed with the brine. Table 3 shows one example of the saturation indexes output under data block of mixing without precipitation. The minerals with SI greater than zero are the ones that could be forming in equilibrium conditions and without considering the kinetics of mineral formation. Not all the minerals with SI greater than zero can form because of kinetic
conditions. The paragenesis of the minerals was investigated and only those mineral likely to form were considered in the simulations with precipitation. When minerals interacted with an aqueous solution, they can either dissolve or precipitate in order achieve equilibrium. For example, Table 3 shows the list of supersaturated mineral highlighted in yellow that have the possibility to form when in contact with the river water. Barite, calcite, Fe(OH)₃, pyrolusite, and gibbsite were selected to be equilibrated in Solution 1 and Solution 2 due to the effects of the kinetic reaction factors on the mineral assemblage in water and rock/ground interactions (Tennisen, 1974). Note that the solutions were equilibrated with carbon dioxide and oxygen in the atmosphere.

Table 3: List of supersaturated minerals under simulation of Brine Low IC of Mix number 4 that describe which minerals phases are in equilibrium, supersaturated, or under saturated with respect to the solution.

<table>
<thead>
<tr>
<th>Phase</th>
<th>SI**</th>
<th>log I/H</th>
<th>log K₂(S₂ K₂, 1 atm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aelite</td>
<td>2.85</td>
<td>5.43</td>
<td>2.58 BaCa(CO₃)²</td>
</tr>
<tr>
<td>Apatite</td>
<td>1.40</td>
<td>3.46</td>
<td>2.06 CaCO₃</td>
</tr>
<tr>
<td>Baryte</td>
<td>2.53</td>
<td>-7.57</td>
<td>-10.10 BaSO₄</td>
</tr>
<tr>
<td>Baryocalcite</td>
<td>2.69</td>
<td>5.43</td>
<td>2.74 BaCa(CO₃)²</td>
</tr>
<tr>
<td>Birnessite</td>
<td>58.41 -27.14 -35.55 MnO14:SH₂O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bixbyite</td>
<td>11.43</td>
<td>11.12</td>
<td>-0.31 MnO2</td>
</tr>
<tr>
<td>Boehmite</td>
<td>0.65</td>
<td>8.59</td>
<td>7.94 Al₂O₃</td>
</tr>
<tr>
<td>Calcite</td>
<td>1.55</td>
<td>3.46</td>
<td>1.91 CaCO₃</td>
</tr>
<tr>
<td>Diaspore</td>
<td>1.06</td>
<td>8.59</td>
<td>7.52 Al₂O₃</td>
</tr>
<tr>
<td>Dolomite</td>
<td>3.74</td>
<td>6.42</td>
<td>2.65 CaMg(CO₃)²</td>
</tr>
<tr>
<td>Dolomite-dis</td>
<td>2.16</td>
<td>6.42</td>
<td>4.26 CaMg(CO₃)²</td>
</tr>
<tr>
<td>Dolomite-ord</td>
<td>3.75</td>
<td>6.42</td>
<td>2.67 CaMg(CO₃)²</td>
</tr>
<tr>
<td>Fe(OH)₃</td>
<td>0.51</td>
<td>6.44</td>
<td>5.92 Fe(OH)₃</td>
</tr>
<tr>
<td>Ferrite-Ca</td>
<td>5.49</td>
<td>27.89</td>
<td>22.41 CaFe₂O₄</td>
</tr>
<tr>
<td>Ferrite-Mg</td>
<td>5.41</td>
<td>27.39</td>
<td>21.98 MgFe₂O₄</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.49</td>
<td>8.59</td>
<td>8.09 Al(OH)₃</td>
</tr>
<tr>
<td>Goethite</td>
<td>5.70</td>
<td>6.44</td>
<td>0.74 FeOH</td>
</tr>
<tr>
<td>Hausmannite</td>
<td>10.24</td>
<td>21.41</td>
<td>11.07 MnO₄</td>
</tr>
<tr>
<td>Hematite</td>
<td>12.27</td>
<td>12.89</td>
<td>0.52 Fe₂O₃</td>
</tr>
<tr>
<td>Huntite</td>
<td>1.53</td>
<td>12.34</td>
<td>10.81 CaMg₂(CO₃)⁴</td>
</tr>
<tr>
<td>Magnesite</td>
<td>0.53</td>
<td>2.96</td>
<td>2.42 MgCO₃</td>
</tr>
<tr>
<td>Magnetite</td>
<td>0.23</td>
<td>11.39</td>
<td>11.16 Fe₂O₄</td>
</tr>
<tr>
<td>Manganite</td>
<td>5.72</td>
<td>5.56</td>
<td>-0.16 MnO(OH)</td>
</tr>
<tr>
<td>MnO₂ (gemma)</td>
<td>8.17</td>
<td>-7.95</td>
<td>-16.13 MnO₂</td>
</tr>
<tr>
<td>Monohydrocalcite</td>
<td>0.71</td>
<td>2.46</td>
<td>2.75 CaCO₃:SH₂O</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>9.99</td>
<td>-7.95</td>
<td>-17.94 MnO₂</td>
</tr>
<tr>
<td>Stromatolite</td>
<td>2.27</td>
<td>1.95</td>
<td>-0.32 SrCO₃</td>
</tr>
<tr>
<td>Todorokite</td>
<td>52.99</td>
<td>7.16</td>
<td>-45.82 MnO₁₂:3H₂O</td>
</tr>
<tr>
<td>Witherite</td>
<td>5.04</td>
<td>1.97</td>
<td>-3.07 BaCO₃</td>
</tr>
</tbody>
</table>
Table 4: Data block of the input file for Brine High IC solution.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp</td>
<td>25</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
</tr>
<tr>
<td>redox pe</td>
<td>Units mg/l</td>
</tr>
<tr>
<td>density</td>
<td>1</td>
</tr>
<tr>
<td>Alkalinety</td>
<td>6000 as HCO3</td>
</tr>
<tr>
<td>Ba</td>
<td>2500</td>
</tr>
<tr>
<td>Ca</td>
<td>13750</td>
</tr>
<tr>
<td>Cl</td>
<td>182454</td>
</tr>
<tr>
<td>Fe(2)</td>
<td>25</td>
</tr>
<tr>
<td>K</td>
<td>0.001 charge</td>
</tr>
<tr>
<td>Mg</td>
<td>1000</td>
</tr>
<tr>
<td>Mn(2)</td>
<td>2.5</td>
</tr>
<tr>
<td>Na</td>
<td>64000</td>
</tr>
<tr>
<td>Sr</td>
<td>1250</td>
</tr>
<tr>
<td>-water</td>
<td>1 # kg</td>
</tr>
</tbody>
</table>

**EQUILIBRIUM PHASES 1**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2(g)</td>
<td>-3.5 10</td>
</tr>
<tr>
<td>O2(g)</td>
<td>-0.67 10</td>
</tr>
</tbody>
</table>

**SELECTED_OUTPUT 1**

- file HIGH BRINE2.sel
- reset false
- simulation true
- state true
- solution true
- pH true
- pE true
- ionic_strength true
- water true
- totals Ca S(O) K Mg Na Cl Fe
- equilibrium_phases Calcite Pyroclisite Gibbsite Barite
- saturation_indices Barite Pyroclisite Gibbsite Calcite
- SAVE solution 1-1

END

**SOLUTION 2**

- file NO PPT HIGH BRINE2.sel
- reset false
- simulation true
- state true
- solution true
- pH true
- pE true
- ionic_strength true
- water true
- totals Ca S(O) K Mg Na Cl Fe
- equilibrium_phases Calcite Pyroclisite Gibbsite Barite
- saturation_indices Barite Pyroclisite Gibbsite Calcite
- SAVE solution 1-1

END

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp</td>
<td>19.2</td>
</tr>
<tr>
<td>pH</td>
<td>7.79</td>
</tr>
<tr>
<td>redox pe</td>
<td>Units mg/l</td>
</tr>
<tr>
<td>density</td>
<td>1</td>
</tr>
<tr>
<td>Al</td>
<td>0.03633</td>
</tr>
<tr>
<td>Alkalinety</td>
<td>172</td>
</tr>
<tr>
<td>Ca</td>
<td>57.5</td>
</tr>
<tr>
<td>Cl</td>
<td>24.5</td>
</tr>
<tr>
<td>Fe(2)</td>
<td>0.135</td>
</tr>
<tr>
<td>K</td>
<td>2.83 charge</td>
</tr>
<tr>
<td>Mg</td>
<td>13.9</td>
</tr>
<tr>
<td>Mn</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Table 4: continued.

<table>
<thead>
<tr>
<th>Na</th>
<th>45.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>5(0)</td>
<td>161</td>
</tr>
<tr>
<td>-water 1 # kg</td>
<td></td>
</tr>
</tbody>
</table>

EQUILIBRIUM PHASES 2
- CO₂(g) -3.5 10
- O₂(g) -0.67 10

SAVE solution 2-2
END

USE solution 1
USE solution 2

MIX 4
- 1 0.0016
- 2 0.9984

EQUILIBRIUM PHASES 4
- Barite 0 10 precipitate_only
- Calcite 0 10 precipitate_only
- Fe(OH)₃ 0 10 precipitate_only
- Pyrolusite 0 10 precipitate_only
- Gibbsite 0 10 precipitate_only

SAVE solution 4-4
END

MIX 5
- 1 0.00157
- 2 0.99843

EQUILIBRIUM PHASES 5
- Barite 0 10 precipitate_only
- Calcite 0 10 precipitate_only
- Fe(OH)₃ 0 10 precipitate_only
- Pyrolusite 0 10 precipitate_only
- Gibbsite 0 10 precipitate_only

SAVE solution 5-5
END

USE solution 1
USE solution 2

MIX 6
- 1 0.002338
- 2 0.997662

EQUILIBRIUM PHASES 6
- Barite 0 10 precipitate_only
- Calcite 0 10 precipitate_only
- Fe(OH)₃ 0 10 precipitate_only
- Pyrolusite 0 10 precipitate_only
- Gibbsite 0 10 precipitate_only

SAVE solution 6-6
END

USE solution 1
USE solution 2

MIX 7
- 1 0.0121
- 2 0.9879

EQUILIBRIUM PHASES 7
- Barite 0 10 precipitate_only
- Calcite 0 10 precipitate_only
- Fe(OH)₃ 0 10 precipitate_only
- Pyrolusite 0 10 precipitate_only
- Gibbsite 0 10 precipitate_only

SAVE solution 7-7
END

USE solution 1
USE solution 2

MIX 8
- 1 0.014
- 2 0.986

EQUILIBRIUM PHASES 8
- Barite 0 10 precipitate_only
- Calcite 0 10 precipitate_only
- Fe(OH)₃ 0 10 precipitate_only
- Pyrolusite 0 10 precipitate_only
- Gibbsite 0 10 precipitate_only

SAVE solution 8-8
END

USE solution 1
USE solution 2

MIX 9
- 1 0.019
- 2 0.981

SAVE solution 9-9
END
Table 4: continued.

<table>
<thead>
<tr>
<th>SAVE solution 7-7</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE solution 1</td>
<td>USE solution 2</td>
</tr>
<tr>
<td>MIX 8</td>
<td></td>
</tr>
<tr>
<td>1 0.014</td>
<td>2 0.986</td>
</tr>
</tbody>
</table>

**EQUILIBRIUM_PHASES 8**
- Barite 0.10 precipitate_only
- Calcite 0.10 precipitate_only
- Fe(OH)3 0.10 precipitate_only
- Pyrohaisite 0.10 precipitate_only
- Gibbsite 0.10 precipitate_only

<table>
<thead>
<tr>
<th>SAVE solution 8-8</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE solution 1</td>
<td>USE solution 2</td>
</tr>
<tr>
<td>MIX 9</td>
<td></td>
</tr>
<tr>
<td>1 0.019</td>
<td>2 0.981</td>
</tr>
</tbody>
</table>

**EQUILIBRIUM_PHASES 9**
- Barite 0.10 precipitate_only
- Calcite 0.10 precipitate_only
- Fe(OH)3 0.10 precipitate_only
- Pyrohaisite 0.10 precipitate_only
- Gibbsite 0.10 precipitate_only

| SAVE solution 9-9 | END |
Table 5: Data block of the input file for Brine Medium IC simulation.

<table>
<thead>
<tr>
<th>SOLUTION I Brine Med IC</th>
<th>SOLUTION I Brine Med IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp 25</td>
<td>temp 25</td>
</tr>
<tr>
<td>pH 7</td>
<td>pH 7</td>
</tr>
<tr>
<td>pe 4</td>
<td>pe 4</td>
</tr>
<tr>
<td>redox pe</td>
<td>redox pe</td>
</tr>
<tr>
<td>units mg/l</td>
<td>units mg/l</td>
</tr>
<tr>
<td>density 1</td>
<td>density 1</td>
</tr>
<tr>
<td>Alkalinity 3000</td>
<td>Alkalinity 3000</td>
</tr>
<tr>
<td>Ba 750</td>
<td>Ba 750</td>
</tr>
<tr>
<td>Ca 3250</td>
<td>Ca 3250</td>
</tr>
<tr>
<td>Cl 45838</td>
<td>Cl 45838</td>
</tr>
<tr>
<td>Fe(2) 5</td>
<td>Fe(2) 5</td>
</tr>
<tr>
<td>K 0.001 charge</td>
<td>K 0.001 charge</td>
</tr>
<tr>
<td>Mg 325</td>
<td>Mg 325</td>
</tr>
<tr>
<td>Mn(2) 0.5</td>
<td>Mn(2) 0.5</td>
</tr>
<tr>
<td>Na 16000</td>
<td>Na 16000</td>
</tr>
<tr>
<td>Sr 500</td>
<td>Sr 500</td>
</tr>
<tr>
<td>-water 1 kg</td>
<td>-water 1 kg</td>
</tr>
</tbody>
</table>

EQUILIBRIUM_PHASES 1

| CO2(g) -3.5 x 10        | CO2(g) -3.5 x 10        |
| O2(g) -0.67 x 10        | O2(g) -0.67 x 10        |

SELECTED_OUTPUT 1

- file MED BRINE2.sel
- reset false
- simulation true
- state true
- solution true
- pH true
- pe true
- ionic_strength true
- water true
- totals Ca S(6) K Mg Na Cl Fe
- equilibrium phases Calcite Pyrohustite

Gibbsite Barite

- saturation_indices Barite Pyrohustite Gibbsite
Calcite Fe(OH)3

SAVE solution 1-1
END

SOLUTION 2

temp 19.2
pH 7.79
pe 4
redox pe
units mg/l
density 1
Al 0.03633
Alkalinity 172
Ca 57.5
Cl 24.5
Fe(2) 0.135
K 2.83 charge
Mg 13.9
Mn 0.09

Fe(OH)3

SAVE solution 1-1
END

SOLUTION 2

temp 19.2
pH 7.79
pe 4
redox pe
units mg/l
density 1
Al 0.03633
Alkalinity 172
Ca 57.5
Cl 24.5
Fe(2) 0.135
K 2.83 charge
Mg 13.9
Mn 0.09

Fe(OH)3
Table 5: continued.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>45.8</td>
<td>Na</td>
</tr>
<tr>
<td>5O(5)</td>
<td>161</td>
<td>5O(5)</td>
</tr>
<tr>
<td>wwater 1 # kg</td>
<td>water 1 # kg</td>
<td></td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 2</strong></td>
<td><strong>EQUILIBRIUM PHASES 2</strong></td>
<td></td>
</tr>
<tr>
<td>CO(2)</td>
<td>-3.5</td>
<td>CO(2)</td>
</tr>
<tr>
<td>O2(2)</td>
<td>-0.67</td>
<td>O2(2)</td>
</tr>
<tr>
<td><strong>SAVE solution 2-2</strong></td>
<td><strong>SAVE solution 2-2</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 4</td>
<td>MIX 4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.91</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.89</td>
<td>2</td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 5</strong></td>
<td><strong>EQUILIBRIUM PHASES 5</strong></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Pyrohrosis</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Fe(OH)3</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td><strong>SAVE solution 4-4</strong></td>
<td><strong>SAVE solution 4-4</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 5</td>
<td>MIX 5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.011</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.889</td>
<td>2</td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 6</strong></td>
<td><strong>EQUILIBRIUM PHASES 6</strong></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Pyrohrosis</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Fe(OH)3</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td><strong>SAVE solution 5-5</strong></td>
<td><strong>SAVE solution 5-5</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 6</td>
<td>MIX 6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.011</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.889</td>
<td>2</td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 7</strong></td>
<td><strong>EQUILIBRIUM PHASES 7</strong></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td><strong>SAVE solution 6-6</strong></td>
<td><strong>SAVE solution 6-6</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 8</td>
<td>MIX 8</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.014</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.986</td>
<td>2</td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 9</strong></td>
<td><strong>EQUILIBRIUM PHASES 9</strong></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td><strong>SAVE solution 7-7</strong></td>
<td><strong>SAVE solution 7-7</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 9</td>
<td>MIX 9</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.010</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.991</td>
<td>2</td>
</tr>
<tr>
<td><strong>EQUILIBRIUM PHASES 10</strong></td>
<td><strong>EQUILIBRIUM PHASES 10</strong></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0</td>
<td>0 precipitate only</td>
</tr>
<tr>
<td><strong>SAVE solution 8-8</strong></td>
<td><strong>SAVE solution 8-8</strong></td>
<td></td>
</tr>
<tr>
<td><strong>END</strong></td>
<td><strong>END</strong></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 10</td>
<td>MIX 10</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.024</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0.976</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 5: continued.

<table>
<thead>
<tr>
<th>Phases</th>
<th>Components</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrohiste 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVE solution 7.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 0.986</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrohiste 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVE solution 8-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0.019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 0.981</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrohiste 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVE solution 9-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0.0243</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 0.9757</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrohiste 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVE solution 10-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0.02434</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 0.97566</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrohiste 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAVE solution 11-11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6: Data block of the input file for Brine Low IC simulation

<table>
<thead>
<tr>
<th>Mixing with Precipitation</th>
<th>Mixing without Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOLUTION Brine LOW IC</strong></td>
<td><strong>SOLUTION Brine LOW IC</strong></td>
</tr>
<tr>
<td>temp 25</td>
<td>temp 25</td>
</tr>
<tr>
<td>pH 7</td>
<td>pH 7</td>
</tr>
<tr>
<td>pe 4</td>
<td>pe 4</td>
</tr>
<tr>
<td>redox pe</td>
<td>redox pe</td>
</tr>
<tr>
<td>units mg/l</td>
<td>units mg/l</td>
</tr>
<tr>
<td>density 1</td>
<td>density 1</td>
</tr>
<tr>
<td>Alkalinity 1000 as HCO3</td>
<td>Alkalinity 1000 as HCO3</td>
</tr>
<tr>
<td>Ba 375</td>
<td>Ba 375</td>
</tr>
<tr>
<td>Ca 1650</td>
<td>Ca 1650</td>
</tr>
<tr>
<td>Cl 23246</td>
<td>Cl 23246</td>
</tr>
<tr>
<td>Fe(2) 2.5</td>
<td>Fe(2) 2.5</td>
</tr>
<tr>
<td>K 0.001 charge</td>
<td>K 0.001 charge</td>
</tr>
<tr>
<td>Mg 175</td>
<td>Mg 175</td>
</tr>
<tr>
<td>Mn(2) 0.25</td>
<td>Mn(2) 0.25</td>
</tr>
<tr>
<td>Na 8300</td>
<td>Na 8300</td>
</tr>
<tr>
<td>Sr 250</td>
<td>Sr 250</td>
</tr>
<tr>
<td>-water 1 # kg</td>
<td>-water 1 # kg</td>
</tr>
</tbody>
</table>

**EQUILIBRIUM_PHASES 1**

| CO2(g) -3.5 10            | CO2(g) -3.5 10              |
| O2(g) -0.67 10            | O2(g) -0.67 10              |

**SELECTED_OUTPUT 1**

- file LOW_BRINE with ppt2.sel
- reset false
- simulation true
- solution true
- pH true
- pe true
- ionic_strength true
- water true
- totals Ca S(6) K Mg Na Cl Fe
- equilibrium_phases Calcite Pyro-halite

Gibbsite Barite Fe(OH)3
- saturation_indices Barite Pyro-halite Gibbsite
Calcite Fe(OH)3

SAVE solution 1-1
END

**SOLUTION 2**

| temp 19.2               | temp 19.2                  |
| pH 7.79                 | pH 7.79                    |
| pe 4                    | pe 4                       |
| redox pe                | redox pe                   |
| units mg/l              | units mg/l                 |
| density 1               | density 1                  |
| Al 0.03633              | Al 0.03633                 |
| Alkalinity 172          | Alkalinity 172             |
| Ca 57.5                 | Ca 57.5                    |
| Cl 24.5                 | Cl 24.5                    |
| Fe(2) 0.135             | Fe(2) 0.135                |
| K 2.83 charge           | K 2.83 charge              |
| Mg 13.9                 | Mg 13.9                    |
| Mn 0.09                 | Mn 0.09                    |
| Na 45.9                 | Na 45.9                    |

SAVE solution 1-1
END

**SOLUTION 2**

| temp 19.2               | temp 19.2                  |
| pH 7.79                 | pH 7.79                    |
| pe 4                    | pe 4                       |
| redox pe                | redox pe                   |
| units mg/l              | units mg/l                 |
| density 1               | density 1                  |
| Al 0.03633              | Al 0.03633                 |
| Alkalinity 172          | Alkalinity 172             |
| Ca 57.5                 | Ca 57.5                    |
| Cl 24.5                 | Cl 24.5                    |
| Fe(2) 0.135             | Fe(2) 0.135                |
| K 2.83 charge           | K 2.83 charge              |
| Mg 13.9                 | Mg 13.9                    |
Table 6: continued.

<table>
<thead>
<tr>
<th>S(l)</th>
<th>1.01</th>
<th>Mn</th>
<th>0.09</th>
</tr>
</thead>
<tbody>
<tr>
<td>-water</td>
<td>1 # kg</td>
<td>Na</td>
<td>45.9</td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 2</td>
<td>S(l)</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td>CO2(g)</td>
<td>-3.5 10</td>
<td>P(l)</td>
<td></td>
</tr>
<tr>
<td>O2(g)</td>
<td>-0.67 10</td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 2-2</td>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 4</td>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.01</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.99</td>
<td>MIX 4</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 4</td>
<td>1</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>2</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
<td>SAVE solution 4-4</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>Pyrohuite 0.10 precipitate_only</td>
<td></td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 4-4</td>
<td></td>
<td>MIX 5</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td>1</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>2</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
<td>SAVE solution 5-5</td>
<td></td>
</tr>
<tr>
<td>MIX 5</td>
<td></td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.02</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.98</td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 5</td>
<td>MIX 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>1</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td>2</td>
<td>0.979</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td></td>
<td>SAVE solution 6-6</td>
<td></td>
</tr>
<tr>
<td>Pyrohuite 0.10 precipitate_only</td>
<td></td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 5-5</td>
<td></td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td>MIX 7</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>1</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>2</td>
<td>0.978</td>
<td></td>
</tr>
<tr>
<td>MIX 6</td>
<td></td>
<td>SAVE solution 7-7</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.021</td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.979</td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 6</td>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>MIX 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td>1</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td>2</td>
<td>0.976</td>
<td></td>
</tr>
<tr>
<td>Pyrohuite 0.10 precipitate_only</td>
<td></td>
<td>SAVE solution 8-8</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 6-6</td>
<td></td>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td>MIX 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td>1</td>
<td>0.0242</td>
<td></td>
</tr>
<tr>
<td>MIX 7</td>
<td>2</td>
<td>0.9758</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.022</td>
<td>SAVE solution 9-9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.978</td>
<td>END</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 7</td>
<td>USE solution 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>USE solution 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td>MIX 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td>1</td>
<td>0.0243</td>
<td></td>
</tr>
<tr>
<td>Pyrohuite 0.10 precipitate_only</td>
<td>2</td>
<td>0.9757</td>
<td></td>
</tr>
</tbody>
</table>
Table 6: continued.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibbsite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 7-7</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 8</td>
<td></td>
</tr>
<tr>
<td>1 0.024</td>
<td></td>
</tr>
<tr>
<td>2 0.076</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 8</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Calcite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Fe(III) 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Pyrochlore 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Gibbsite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 8-8</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 9</td>
<td></td>
</tr>
<tr>
<td>1 0.0242</td>
<td></td>
</tr>
<tr>
<td>2 0.9758</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 9</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Calcite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Fe(III) 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Pyrochlore 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Gibbsite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 9-9</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 10</td>
<td></td>
</tr>
<tr>
<td>1 0.0243</td>
<td></td>
</tr>
<tr>
<td>2 0.9757</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 10</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Calcite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Fe(III) 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Pyrochlore 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Gibbsite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 10-10</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>USE solution 1</td>
<td></td>
</tr>
<tr>
<td>USE solution 2</td>
<td></td>
</tr>
<tr>
<td>MIX 11</td>
<td></td>
</tr>
<tr>
<td>1 0.02434</td>
<td></td>
</tr>
<tr>
<td>2 0.97566</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 11</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Calcite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Fe(III) 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Pyrochlore 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>Gibbsite 0.10</td>
<td>precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 11-11</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
</tbody>
</table>
5.5 PHREEQCi Simulation in Winter Season

Figure 19. The set up simulation for winter season; mixture of produced water - river water - rock salt mixture which was simulated with PHREEQCi software.

The readings of the conductivity detected by the alert system were impacted during the winter season because of road salt application. Salt brine is commonly applied during the anti-icing operating and pre-wetting solid rock salt (ODOT, 2016). The Ohio Local Technical Assistance Program (LTAP) recommended to apply about 30-33% of calcium chloride solution with temperature below 25°F (2016) to achieve the effective concentration to treat snow and ice on the road surface. According to Ohio Department of Transportation (ODOT)’s road salt specification, rock salt can be prepared in various forms. In this research, a solution of 23% salt and 77% water were used to represent a typical road salt solution mixture (ODOT, 2016).

The goal for this second batch simulations was to determine the amount of produced water that must be mixed with river water with road salt to reach the EC alert level of 1500 uS/cm. Based on the expected EC values for healthy streams and those caused by road salt runoff, the EC ‘alert’ level for the low-cost alert system has been set at 1500 µS/cm to avoid false alarms due to other runoff types. The varying amounts of produced water were mixed with river water and varied amounts of road salt depending
on the condition of the pavement temperature. Figure 19 is the setup of simulation for
winter season. There are six types of rock-salt application depending on the condition of
the pavement temperature prepared by The Ohio LTAP Center (2016) as shown on Table
7:

In the winter simulation experiment were simulated by mixing the mixture of
produced water and river water as Solution 4 (for every one of the 3 fracking brines
simulated) to the road salt composition on every batch. Solution 3 is the road salt
composition as shown in Table 8 by applying the wet pavement heavy snow more than
2”/hour from Table 7. This solution was inserted into the data block of the simulation as
shown in Table 9 for Brine High IC, Table 10 for Brine Medium IC, and Table 11 for
Brine Low IC. The simulated of EC and temperature of the produced water were
calculated and graphs were constructed. Note that solution 4 is the most diluted of the
river water-brine mixings and should reflect the lower environmental effect.
Table 7: The Ohio LTAP Center (2016) summarized the rock salt application rate depending on the condition of the pavement temperature.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dry Pavement Light Snow Less Than 2&quot;/Hour</th>
<th>Wet Pavement Light Snow Less Than 2&quot;/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 32°F (Rising)</td>
<td>Above 32°F (Rising)</td>
<td>25°F to 32°F</td>
</tr>
<tr>
<td>Bridges and icy Spots</td>
<td>Acceptable</td>
<td>Recommended</td>
</tr>
<tr>
<td>Plow and treat @ 50 to 100 lb./mile</td>
<td>Plow and treat @ 50 to 100 lb./mile</td>
<td>Plow and treat @ 100 to 200 lb./mile</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dry Pavement Light Snow Less Than 2&quot;/Hour</th>
<th>Wet Pavement Light Snow More Than 2&quot;/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 32°F (Rising)</td>
<td>Above 32°F (Rising)</td>
<td>25°F to 32°F</td>
</tr>
<tr>
<td>Bridges and icy Spots</td>
<td>Acceptable</td>
<td>Recommended</td>
</tr>
<tr>
<td>Plow and treat @ 50 to 100 lb./mile</td>
<td>Plow and treat @ 50 to 100 lb./mile</td>
<td>Plow and treat @ 100 to 200 lb./mile</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Freezing Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 32°F (Rising)</td>
<td>Above 32°F (Rising)</td>
</tr>
<tr>
<td>Bridges and icy Spots</td>
<td>Recommended</td>
</tr>
<tr>
<td>Plow and treat @ 100 lb./mile</td>
<td>Plow and treat @ 100 to 200 lb./mile</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Black Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 32°F (Rising)</td>
<td>Above 32°F (Rising)</td>
</tr>
<tr>
<td>Bridges and icy Spots</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Applying anti-icing material prior to the formation of black ice</td>
<td>Applying anti-icing material prior to the formation of black ice</td>
</tr>
</tbody>
</table>
Table 8: The road salt data input taken from a research on Deicing Chemical as source of constituents for highway runoff by Gregory E. Granato (1996).

<table>
<thead>
<tr>
<th>Constituent of Deicing Material</th>
<th>Estimated Concentration in mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>17000</td>
</tr>
<tr>
<td>Calcium</td>
<td>100</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.2</td>
</tr>
<tr>
<td>Sodium</td>
<td>11000</td>
</tr>
<tr>
<td>Potassium</td>
<td>5.1</td>
</tr>
<tr>
<td>Sulfate</td>
<td>22</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2</td>
</tr>
<tr>
<td>Silica</td>
<td>0.06</td>
</tr>
<tr>
<td>Boron</td>
<td>0.13</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.0075</td>
</tr>
<tr>
<td>Copper</td>
<td>0.027</td>
</tr>
<tr>
<td>Iron</td>
<td>0.22</td>
</tr>
<tr>
<td>Lead</td>
<td>0.015</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.0082</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.78</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.29</td>
</tr>
<tr>
<td>Bromide</td>
<td>0.29</td>
</tr>
<tr>
<td>Nitrate</td>
<td>0.17</td>
</tr>
</tbody>
</table>
Table 9: Data block of the input file for Simulation 4 for Brine High IC and mixing with Road Salt during winter.

<table>
<thead>
<tr>
<th></th>
<th>Mixing with Precipitation</th>
<th>Mixing without Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOLUTION 3 Road salt</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temp</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>pe</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>redox</td>
<td></td>
<td></td>
</tr>
<tr>
<td>units</td>
<td>mg/l</td>
<td></td>
</tr>
<tr>
<td>density</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Br(-1)</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Ca</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Cl</td>
<td>17000</td>
<td>17000</td>
</tr>
<tr>
<td>Cr(2)</td>
<td>0.0025</td>
<td>0.0025</td>
</tr>
<tr>
<td>Cu(2)</td>
<td>0.0135</td>
<td>0.0135</td>
</tr>
<tr>
<td>Fe(2)</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>K</td>
<td>5.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Mg</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>N(5)</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Na</td>
<td>11000</td>
<td>11000</td>
</tr>
<tr>
<td>Ni</td>
<td>0.002733</td>
<td>0.002733</td>
</tr>
<tr>
<td>Pb(2)</td>
<td>0.0075</td>
<td>0.0075</td>
</tr>
<tr>
<td>Si</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Sr</td>
<td>0.78</td>
<td>0.78</td>
</tr>
<tr>
<td>V(3)</td>
<td>0.09667</td>
<td>0.09667</td>
</tr>
<tr>
<td>-water</td>
<td>1 # kg</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2(g)</td>
<td>-3.5 10</td>
<td></td>
</tr>
<tr>
<td>O2(g)</td>
<td>-0.67 10</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 3-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIX 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Calcite</td>
<td>0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)3</td>
<td>0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 12-12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9: continued.

<table>
<thead>
<tr>
<th>MIX 10</th>
<th>USE solution 4</th>
<th>USE solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 0.985</td>
<td>USE solution 3</td>
<td>MIX 12</td>
</tr>
<tr>
<td>3 0.015</td>
<td></td>
<td>4 0.99</td>
</tr>
</tbody>
</table>

**EQUILIBRIUM_PHASES 10**
- Barite 0.10 precipitate_only
- Calcite 0.10 precipitate_only
- Fe(OH)3 0.10 precipitate_only
- Pyrolusite 0.10 precipitate_only
- Gibbsite 0.10 precipitate_only

**SAVE solution 10-10**

**END**

**USE solution 4**

**USE solution 3**

**MIX 11**
- 4 0.98
- 3 0.02

**EQUILIBRIUM_PHASES 11**
- Barite 0.10 precipitate_only
- Calcite 0.10 precipitate_only
- Fe(OH)3 0.10 precipitate_only
- Pyrolusite 0.10 precipitate_only
- Gibbsite 0.10 precipitate_only

**SAVE solution 11-11**

**END**

**USE solution 4**

**USE solution 3**

**MIX 12**
- 4 0.99
- 3 0.01

**EQUILIBRIUM_PHASES 12**
- Barite 0.10 precipitate_only
- Calcite 0.10 precipitate_only
- Fe(OH)3 0.10 precipitate_only
- Pyrolusite 0.10 precipitate_only
- Gibbsite 0.10 precipitate_only

**SAVE solution 12-12**

**END**

**USE solution 4**

**USE solution 3**

**MIX 13**
- 4 0.995
- 3 0.0045

**SAVE solution 13-13**

**END**

**USE solution 4**

**USE solution 3**

**MIX 14**
- 4 0.999
- 3 0.001

**SAVE solution 14-14**

**END**

**USE solution 4**

**USE solution 3**

**MIX 15**
- 4 0.0001
- 3 0.9999

**SAVE solution 15-15**

**END**
Table 9: continued.

<table>
<thead>
<tr>
<th>SAVE solution 13-13</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE solution 4</td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
</tr>
<tr>
<td>MIX 14</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.999</td>
</tr>
<tr>
<td>3</td>
<td>0.001</td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 14</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Fe(OH)3</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 14-14</td>
<td>END</td>
</tr>
<tr>
<td>USE solution 4</td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
</tr>
<tr>
<td>MIX 15</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0001</td>
</tr>
<tr>
<td>3</td>
<td>0.9999</td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 15</td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Calcite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Fe(OH)3</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0 10 precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 15-15</td>
<td>END</td>
</tr>
</tbody>
</table>
Table 10: Data block of the Input file for Simulation 5 for Brine Medium IC and mixing with Road Salt during winter.

<table>
<thead>
<tr>
<th>Mixing with Precipitation</th>
<th>Mixing without Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLUTION 3 Road salt</td>
<td>SOLUTION 3 Road salt</td>
</tr>
<tr>
<td>temp 25</td>
<td>temp 25</td>
</tr>
<tr>
<td>pH 7</td>
<td>pH 7</td>
</tr>
<tr>
<td>pe 5</td>
<td>pe 5</td>
</tr>
<tr>
<td>redox pe</td>
<td>redox pe</td>
</tr>
<tr>
<td>units mg/l</td>
<td>units mg/l</td>
</tr>
<tr>
<td>density 1</td>
<td>density 1</td>
</tr>
<tr>
<td>B 0.13</td>
<td>B 0.13</td>
</tr>
<tr>
<td>Br(-1) 0.29</td>
<td>Br(-1) 0.29</td>
</tr>
<tr>
<td>Ca 50</td>
<td>Ca 50</td>
</tr>
<tr>
<td>Cl 17000</td>
<td>Cl 17000</td>
</tr>
<tr>
<td>Cr(2) 0.0025</td>
<td>Cr(2) 0.0025</td>
</tr>
<tr>
<td>Cu(2) 0.0135</td>
<td>Cu(2) 0.0135</td>
</tr>
<tr>
<td>Fe(2) 0.11</td>
<td>Fe(2) 0.11</td>
</tr>
<tr>
<td>K 5.1</td>
<td>K 5.1</td>
</tr>
<tr>
<td>Mg 1.1</td>
<td>Mg 1.1</td>
</tr>
<tr>
<td>N(5) 0.17</td>
<td>N(5) 0.17</td>
</tr>
<tr>
<td>Na 11000</td>
<td>Na 11000</td>
</tr>
<tr>
<td>Ni 0.002733</td>
<td>Ni 0.002733</td>
</tr>
<tr>
<td>Pb(2) 0.0075</td>
<td>Pb(2) 0.0075</td>
</tr>
<tr>
<td>S(6) 11</td>
<td>S(6) 11</td>
</tr>
<tr>
<td>Si 0.06</td>
<td>Si 0.06</td>
</tr>
<tr>
<td>Sr 0.78</td>
<td>Sr 0.78</td>
</tr>
<tr>
<td>V(3) 0.09667</td>
<td>V(3) 0.09667</td>
</tr>
<tr>
<td>-water 1 # kg</td>
<td>-water 1 # kg</td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 3</td>
<td>EQUILIBRIUM_PHASES 3</td>
</tr>
<tr>
<td>CO2(g) -3.5 10</td>
<td>CO2(g) -3.5 10</td>
</tr>
<tr>
<td>O2(g) -0.67 10</td>
<td>O2(g) -0.67 10</td>
</tr>
<tr>
<td>SAVE solution 3-3</td>
<td>SAVE solution 3-3</td>
</tr>
<tr>
<td>END</td>
<td>END</td>
</tr>
<tr>
<td>USE solution 4</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>USE solution 3</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>MIX 12</td>
<td>MIX 12</td>
</tr>
<tr>
<td>4 0.985</td>
<td>4 0.985</td>
</tr>
<tr>
<td>3 0.015</td>
<td>3 0.015</td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 12</td>
<td>SAVE solution 12-12</td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>END</td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td>MIX 13</td>
</tr>
<tr>
<td>Fe(OH)3 0.10 precipitate_only</td>
<td>4 0.98</td>
</tr>
<tr>
<td>SAVE solution 12-12</td>
<td>3 0.02</td>
</tr>
<tr>
<td>END</td>
<td>SAVE solution 13-13</td>
</tr>
<tr>
<td>USE solution 4</td>
<td>END</td>
</tr>
<tr>
<td>USE solution 3</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>MIX 13</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>4 0.98</td>
<td>MIX 14</td>
</tr>
</tbody>
</table>
Table 10: continued.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Concentration</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barite</td>
<td>0.02</td>
<td>SAVE solution 13-13</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.10</td>
<td>END</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.10</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0.10</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>Fe(OH)₃</td>
<td>0.10</td>
<td>MIX 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0.10</td>
<td>SAVE solution 14-14</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.10</td>
<td>END</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.10</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0.10</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>Fe(OH)₃</td>
<td>0.10</td>
<td>MIX 15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0.10</td>
<td>SAVE solution 15-15</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.10</td>
<td>END</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.10</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0.10</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>Fe(OH)₃</td>
<td>0.10</td>
<td>MIX 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barite</td>
<td>0.10</td>
<td>SAVE solution 16-16</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.10</td>
<td>END</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)₃</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

Note: The table continues with similar entries for additional phases and solutions.
Table 11: Data block of the Input file for Simulation 6 for Brine Low IC and mixing with Road Salt during winter.

<table>
<thead>
<tr>
<th>Mixing with Precipitation</th>
<th>Mixing without Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLUTION 3 Road salt</td>
<td>SOLUTION 3 Road salt</td>
</tr>
<tr>
<td>temp 25</td>
<td>temp 25</td>
</tr>
<tr>
<td>pH 7</td>
<td>pH 7</td>
</tr>
<tr>
<td>pe 5</td>
<td>pe 5</td>
</tr>
<tr>
<td>redox pe</td>
<td>redox pe</td>
</tr>
<tr>
<td>units mg/l</td>
<td>units mg/l</td>
</tr>
<tr>
<td>density 1</td>
<td>density 1</td>
</tr>
<tr>
<td>B 0.13</td>
<td>B 0.13</td>
</tr>
<tr>
<td>Br (-1) 0.29</td>
<td>Br (-1) 0.29</td>
</tr>
<tr>
<td>Ca 50</td>
<td>Ca 50</td>
</tr>
<tr>
<td>Cl 17000</td>
<td>Cl 17000</td>
</tr>
<tr>
<td>Cr (2) 0.0025</td>
<td>Cr (2) 0.0025</td>
</tr>
<tr>
<td>Cu (2) 0.0135</td>
<td>Cu (2) 0.0135</td>
</tr>
<tr>
<td>Fe (2) 0.11</td>
<td>Fe (2) 0.11</td>
</tr>
<tr>
<td>K 5.1</td>
<td>K 5.1</td>
</tr>
<tr>
<td>Mg 1.1</td>
<td>Mg 1.1</td>
</tr>
<tr>
<td>N(S) 0.17</td>
<td>N(S) 0.17</td>
</tr>
<tr>
<td>Na 11000</td>
<td>Na 11000</td>
</tr>
<tr>
<td>Ni 0.002733</td>
<td>Ni 0.002733</td>
</tr>
<tr>
<td>Pb(2) 0.0075</td>
<td>Pb(2) 0.0075</td>
</tr>
<tr>
<td>S(6) 11</td>
<td>S(6) 11</td>
</tr>
<tr>
<td>Si 0.06</td>
<td>Si 0.06</td>
</tr>
<tr>
<td>Sr 0.78</td>
<td>Sr 0.78</td>
</tr>
<tr>
<td>V(3) 0.09667</td>
<td>V(3) 0.09667</td>
</tr>
<tr>
<td>-water 1 # kg</td>
<td>-water 1 # kg</td>
</tr>
</tbody>
</table>

EQUILIBRIUM_PHASES 3

CO2(g) -3.5 10
O2(g) -0.67 10
SAVE solution 3-3
END

USE solution 4
USE solution 3
MIX 12
4 0.97
3 0.03

EQUILIBRIUM_PHASES 12

Barite 0 10 precipitate_only
Calcite 0 10 precipitate_only
Fe(OH)3 0 10 precipitate_only
Pyrolusite 0 10 precipitate_only
Gibbsite 0 10 precipitate_only
SAVE solution 12-12
END

USE solution 4
USE solution 3
MIX 13
4 0.975
3 0.025

EQUILIBRIUM_PHASES 13

Barite 0 10 precipitate_only
Calcite 0 10 precipitate_only
SAVE solution 14-14
END
Table 11: continued.

<table>
<thead>
<tr>
<th>Solution Details</th>
<th>Solution Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe(OH)₃ 0.10 precipitate_only</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td>MIX 15</td>
</tr>
<tr>
<td>SAVE solution 13-13</td>
<td>4 0.978</td>
</tr>
<tr>
<td>END</td>
<td>3 0.022</td>
</tr>
<tr>
<td>USE solution 4</td>
<td>SAVE solution 15-15</td>
</tr>
<tr>
<td>USE solution 3</td>
<td>END</td>
</tr>
<tr>
<td>MIX 14</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>4 0.98</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>3 0.02</td>
<td>MIX 16</td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 14</td>
<td>4 0.965</td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td>3 0.028</td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td>SAVE solution 16-16</td>
</tr>
<tr>
<td>Fe(OH)₃ 0.10 precipitate_only</td>
<td>END</td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td>USE solution 4</td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td>USE solution 3</td>
</tr>
<tr>
<td>SAVE solution 14-14</td>
<td>MIX 17</td>
</tr>
<tr>
<td>END</td>
<td>4 0.92</td>
</tr>
<tr>
<td>USE solution 4</td>
<td>3 0.08</td>
</tr>
<tr>
<td>USE solution 3</td>
<td>SAVE solution 17-17</td>
</tr>
<tr>
<td>MIX 15</td>
<td>END</td>
</tr>
<tr>
<td>4 0.985</td>
<td></td>
</tr>
<tr>
<td>3 0.015</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 15</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)₃ 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 15-15</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>USE solution 4</td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
</tr>
<tr>
<td>MIX 16</td>
<td></td>
</tr>
<tr>
<td>4 0.9</td>
<td></td>
</tr>
<tr>
<td>3 0.1</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 16</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)₃ 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>SAVE solution 16-16</td>
<td></td>
</tr>
<tr>
<td>END</td>
<td></td>
</tr>
<tr>
<td>MIX 17</td>
<td></td>
</tr>
<tr>
<td>4 0.999</td>
<td></td>
</tr>
<tr>
<td>3 0.001</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM PHASES 17</td>
<td></td>
</tr>
<tr>
<td>Barite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Calcite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Fe(OH)₃ 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Pyrolusite 0.10 precipitate_only</td>
<td></td>
</tr>
<tr>
<td>Gibbsite 0.10 precipitate_only</td>
<td></td>
</tr>
</tbody>
</table>
Table 11: continued.

<table>
<thead>
<tr>
<th>SAVE solution 17-17</th>
<th>END</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE solution 4</td>
<td></td>
</tr>
<tr>
<td>USE solution 3</td>
<td></td>
</tr>
<tr>
<td>MIX 18</td>
<td></td>
</tr>
<tr>
<td>4 0.01</td>
<td></td>
</tr>
<tr>
<td>3 0.99</td>
<td></td>
</tr>
<tr>
<td>EQUILIBRIUM_PHASES 18</td>
<td>Barite 0.1 precipitate_only</td>
</tr>
<tr>
<td></td>
<td>Calcite 0.1 precipitate_only</td>
</tr>
<tr>
<td></td>
<td>Fe(OH)3 0.1 precipitate_only</td>
</tr>
<tr>
<td></td>
<td>Pyrolusite 0.1 precipitate_only</td>
</tr>
<tr>
<td></td>
<td>Gibbsite 0.1 precipitate_only</td>
</tr>
<tr>
<td>SAVE solution 18-18</td>
<td>END</td>
</tr>
</tbody>
</table>

In this Brine spill simulation, we were able to determine the percentage of produced water with respect to the river water, and rock-salt composition that would trigger an alert that reaches the reading of EC of 1500 µS/cm. This helps to determine the sensitivity of the low-cost alert system.
CHAPTER 6: RESULTS AND DISCUSSION

6.1 Objective 2

The aim for the second objective is to demonstrate and test the accuracy of taking readings by using the low-cost alert system (Atlas Scientific conductivity and temperature sensor). Performing a data comparison to a calibrated commercial meter, Myron Ultrameter Model 6P handheld meter, to test the effectiveness and ensure the low-cost alert system gives a consistent and reliable results every time. Results of the electrical conductivity have been collected from January 2017 to February 2017 as shown in Figure 20 and March 2017 as shown in Figure 21. Temperature results have been collected and compared between the laboratory testing from January 2017 to February 2017 as shown in Figure 22 and field testing that took place in March 2017 as shown in Figure 23. Calibration measurements were performed on each side by side field measurement in each study site. In this research point of view, the data measurement is seems to be reliable and within the ranged of 5-10% deviation from standard values which has been taken from the calibrated commercial meter for both electrical conductivity and temperature readings.

The first calibration was made on the first day of deployment where the result was recorded as 0 µS/cm and after calibration was 890.2 µS/cm as shown Table 12. This result was compared with the electrical conductivity reading of 875.4 µS/cm with a difference of data accuracy of 1.69% from the calibrated commercial meter. From the first day of deployment, the electrical conductivity probe was able to hold its calibration within three days which the readings were within 0.21% of data accuracy. The third
calibration was made on the 8th day of deployment where the calibration can hold up to five days that the results were still within the allowable range of 8.36%.

Meanwhile, Table 13 explained about the temperature readings from Atlas Scientific sensor were within the allowable range of 5-10%. On the first day of the sensor deployment, the temperature sensor was recorded as 0.19°C and the reading after the calibration was about 20.19°C. This result was compared with Myron meter reading that recorded as 20.8°C which was within the allowable of 2.93% of data accuracy. The second calibration was held on the second day of deployment where the can only hold about two days that had the accuracy of 2.27%. The readings of temperature from the Atlas Scientific sensor began to hold its calibration for about 7 days from the first day of deployment with the data accuracy of 9.6% from the calibrated commercial meter.

Table 12: Results from electrical conductivity reading by using Atlas Scientific sensors that have been taken before and after calibrating it with the 450 µS/cm and 12880 µS/cm standard calibration solutions. Accuracy test took place by comparing the results from Atlas Scientific and Myron meter which within the allowable range of 5-10% of data accuracy.

<table>
<thead>
<tr>
<th>Day</th>
<th>Atlas Scientific Reading (µS/cm)</th>
<th>Myron Reading (µS/cm)</th>
<th>% Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Calibration</td>
<td>After Calibration</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7.21</td>
<td>890.2</td>
<td>875.4</td>
</tr>
<tr>
<td>3</td>
<td>305.80</td>
<td>751.2</td>
<td>752.8</td>
</tr>
<tr>
<td>5</td>
<td>498.90</td>
<td>859</td>
<td>792.7</td>
</tr>
</tbody>
</table>
Table 13: Results from temperature readings by using Atlas Scientific sensors that have been taken before and after calibrating it with the reference reading from Myron meter. Accuracy test took place by comparing the results from Atlas Scientific and Myron meter which within the allowable range of 5-10% of data accuracy.

<table>
<thead>
<tr>
<th>Day</th>
<th>Atlas Scientific Before Calibration (°C)</th>
<th>Atlas Scientific After Calibration (°C)</th>
<th>Myron Reading (°C)</th>
<th>% Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19</td>
<td>20.19</td>
<td>20.8</td>
<td>2.93</td>
</tr>
<tr>
<td>3</td>
<td>8.43</td>
<td>13.5</td>
<td>13.2</td>
<td>2.27</td>
</tr>
<tr>
<td>7</td>
<td>7.64</td>
<td>13.6</td>
<td>12.4</td>
<td>9.6</td>
</tr>
</tbody>
</table>

From this study, it was determined that the reading from electrical conductivity of Atlas Scientific sensor was able to stay calibrated for up to 5-days period of time that within the ranged of 8.36% of data accuracy. Concurrently, the reading from the temperature of Atlas Scientific sensor can hold the calibration to 7-days period of time which within 9.6% of data accuracy.

The comparison between the laboratory results shown in Figure 20 and Figure 22 and the field results shown in Figure 21 and Figure 23 for both electrical conductivity and temperature shown a significant differences. The EC and temperature results from the laboratory were consistent throughout January until February due to the water that has been used in the laboratory was a distilled water which only contained relatively small dissolved salt or ions concentration in the water. The temperature in the laboratory was constantly in room temperature. Meanwhile, the EC and temperature results from the field were showing fluctuations. Rapid changes in temperature during the winter season could interrupt the sensor measurement due to the current flowing in the water. Since electrical conductivity is usually consist of metal electrodes which allow electrical current flowing in the water. The higher the dissolved salt or ion concentration in the
water, the more conductive the sample and the higher the conductivity reading will be. The snow or any sediment present in the water can affect the water flow and hence measurements were fluctuating.
Figure 20. Comparison of electrical conductivity results from the Scheduled Atlas Scientific low cost sensor meter, the Myron Meter 6P Model, and Ad hoc Atlas Scientific Measurements from the sensor deployment on Ohio University’s campus, Site 3. The electrical conductivity measurements were collected from January 2017 to February 2017 during the laboratory testing. The Scheduled Atlas Scientific Measurements were taken automatically at scheduled, while the Ad Hoc Atlas Scientific Measurements were taken between scheduled readings for field checks of the equipment.
Figure 21. Comparison of electrical conductivity results from the Scheduled Atlas Scientific low cost sensor meter, the Myron Meter 6P Model, and Ad hoc readings from the sensor deployment on Ohio University’s campus, Site 3. The electrical conductivity sensor was deployed and tested in the field in March 2017. The Scheduled Atlas Scientific Measurements were taken automatically as scheduled, while the Ad Hoc Atlas Scientific Measurements were taken between scheduled readings for field checks of the equipment.
Figure 22. Comparison of temperature results from the Scheduled Atlas Scientific low cost sensor meter, the Myron Meter 6P Model, and Ad hoc Atlas Scientific Measurements from the sensor deployment on Ohio University’s campus, Site 3. The temperature measurements were collected from January 2017 to February 2017 during the laboratory testing. The Scheduled Atlas Scientific Measurements were taken automatically as scheduled, while the Ad Hoc Atlas Scientific Measurements were taken between scheduled readings for field checks of the equipment.
Figure 23. Comparison of temperature results from the low cost sensor meter, the Myron Meter 6P Model, and Ad hoc readings from the sensor deployment on Ohio University’s campus, Site 3. The temperature sensor was deployed and tested in the field in March 2017. The Scheduled Atlas Scientific Measurements were taken automatically as scheduled, while the Ad Hoc Atlas Scientific Measurements were taken between scheduled readings for field checks of the equipment.
6.2 Objective 3

The third objective of this research was to evaluate and demonstrate the precision test that required to perform a weekly calibration checks using the known calibrated standards. Before the accuracy test was performed, the sensor was undergoing a calibration procedure by submerging the Atlas Scientific conductivity probe (K=1) into the two point calibrated standard solutions: 450 µS/cm and 12880 µS/cm. This calibration procedure is to improve data precision as shown in Figure 24 where the reading of the electrical conductivity at this point a calibration is needed. Figure 24 showed on how EC calibration is taking place; it takes about twelve seconds to stabilize the temperature sensor. Secondly, the electrical conductivity probe was immersed into the 450 µS/cm solution for 120 seconds. Finally, the electrical conductivity was immersed into the 12880 µS/cm solution for another 120 seconds towards the final step as shown on Figure 25.

![Figure 24](image.png)

Figure 24. The example of the electrical conductivity reading from Atlas Scientific that calibration is required with the two point calibrated solutions of 450 µS/cm and 12880 µS/cm.
Figure 25. The calibration steps for the electrical conductivity probe with the two point calibrated solutions of 450 µS/cm and 12880 µS/cm.

Figure 26. The results showing the electrical conductivity values when the Atlas Scientific EC probe immersed in a 450 µS/cm and 12880 µS/cm calibrated solutions after calibration.
Table 14: The tabulated results show the electrical conductivity value after doing the two point calibration solutions of 450 µS/cm and 12880 µS/cm.

<table>
<thead>
<tr>
<th>Before Calibration in 450 µS/cm solution</th>
<th>Calibrated Solution</th>
<th>After Calibration</th>
<th>% Difference</th>
<th>Calibrated Solution</th>
<th>After Calibration</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(µS/cm)</td>
<td>(µS/cm)</td>
<td>(µS/cm)</td>
<td>(%)</td>
<td>(µS/cm)</td>
<td>(µS/cm)</td>
<td>(%)</td>
</tr>
<tr>
<td>0</td>
<td>450</td>
<td>450.5</td>
<td>0.11</td>
<td>12880</td>
<td>12550</td>
<td>2.56</td>
</tr>
<tr>
<td>305.8</td>
<td>450</td>
<td>451.2</td>
<td>0.27</td>
<td>12880</td>
<td>12450</td>
<td>3.34</td>
</tr>
<tr>
<td>498.9</td>
<td>450</td>
<td>452.1</td>
<td>0.47</td>
<td>12880</td>
<td>12880</td>
<td>0.00</td>
</tr>
<tr>
<td>604.8</td>
<td>450</td>
<td>448</td>
<td>0.44</td>
<td>12880</td>
<td>12800</td>
<td>0.62</td>
</tr>
</tbody>
</table>

The results shown a much closed reading to the two calibrated solution values where as in Figure 26. For example the first calibration was made with the 450 µS/cm solution where the result was 450.5 µS/cm, which is a 0.11% difference. The second procedure was to calibrate it with 12880 µS/cm where the result after the calibration was about 12550 µS/cm with a difference of 2.56% as shown in Table 14. The results of calibrations were within 5-10% of data precision.

6.3 Objective 4

The fourth objective in this study was to determine the sensitivity of the low-cost alert system by simulating different mixing fractions of hydraulic fracturing brine and river water during brine spills in PHREEQCi software simulation. The scenarios are based on two seasons: winter and summer and simulating in three type of brines: High,
Medium, and Low. The model scenarios were used to demonstrate the capability of PHREEQC to perform a prediction on how much fraction of the stream water were impacted with the occurrence of the brine spill of different magnitudes by setting the conductivity threshold of 1500 µS/cm. Rivers in the United States are generally ranges up to 1500 µS/cm (US EPA, 1992).

The first brine spill simulation was for the Brine High IC interacting with river water which is presented on Table 15. The purpose was to estimate how the Brine High IC has the high capacity react with the stream water during summer, and in winter with additional road salt. During summer, the simulation started with Mix 4 with a fraction of brine of 0.0001 and a fraction of river water of 0.9999 as shown in Figure 27a. The electrical conductivity without any precipitation was about 670 µS/cm when it was simulated without mineral precipitation. Meanwhile, the reading of the electrical conductivity was 630 µS/cm when Mix 4 equilibrated with barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite producing precipitation of these minerals. The EC difference was about 40 µS/cm for this mixing ratio. The electrical conductivity threshold of 1500 µS/cm was reached when a fraction of brine was 0.00188 and a fraction river water was 0.99812 when the mixing was precipitated with barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite. Meanwhile, the fraction of brine and river water were 0.00188 and 0.99812 when there was no precipitation taking place.

During winter, road salt will be applied to nearby roadways. The addition of road salt in this simulation was to predict if the road salt application will produce a great impact and will trigger the alert system when there is a spill. The results shown on Table
15 shows a fraction of road salt was 0.0065 and a fraction solution 4 was 0.9935 to reach the conductivity threshold of 1500 µS/cm when barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite precipitated. Solution 4 in this mixing was contributed from a fraction of 0.00009935 from brine high IC and a fraction of 0.9934 from river water. A fraction of 0.9955 of Solution 4 mixed with 0.0045 of road salt has the capability to reach the conductivity threshold value when there was no precipitation of minerals during winter season as shown in Figure 27b. Solution 4 was consist of 0.00009955 of brine and 0.9954 of river water when there was no precipitation in mixing with road salt. The reason why the graph in Figure 27b has a decreasing trend is because as we increase the fraction of solution 4, we decrease the fraction of rock salt solution and rock salt solution is more concentrated than solution 4.

Table 15: The results of PHREEQC simulation of Brine High IC during summer and winter.

<table>
<thead>
<tr>
<th>Season</th>
<th>Mix</th>
<th>Fraction of Solution 4</th>
<th>Fraction of Brine</th>
<th>Fraction of River water</th>
<th>Road salt</th>
<th>EC (No Precipitation)</th>
<th>EC (Precipitation)</th>
<th>EC difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>4</td>
<td>0.0001000</td>
<td>0.9999000</td>
<td>0.0021570</td>
<td>1070</td>
<td>650</td>
<td>620</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.001000</td>
<td>0.9989000</td>
<td>0.0021570</td>
<td>873</td>
<td>1312</td>
<td>1312</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.0021570</td>
<td>0.9978430</td>
<td>0.0021570</td>
<td>1633</td>
<td>1566</td>
<td>1566</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.0021580</td>
<td>0.9970500</td>
<td>0.0021580</td>
<td>1718</td>
<td>1548</td>
<td>1548</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.0121000</td>
<td>0.9879000</td>
<td>0.0021580</td>
<td>6280</td>
<td>6107</td>
<td>6107</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.0140000</td>
<td>0.9860000</td>
<td>0.0021580</td>
<td>7166</td>
<td>6975</td>
<td>6975</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.0190000</td>
<td>0.9810000</td>
<td>0.0021580</td>
<td>9491</td>
<td>9254</td>
<td>9254</td>
<td>257</td>
</tr>
<tr>
<td>Winter</td>
<td>11</td>
<td>0.985</td>
<td>0.9834240</td>
<td>0.0015680</td>
<td>1814</td>
<td>1752</td>
<td>1752</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>0.98</td>
<td>0.9784320</td>
<td>0.0215680</td>
<td>1961</td>
<td>1899</td>
<td>1899</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.99</td>
<td>0.9884150</td>
<td>0.0115680</td>
<td>1667</td>
<td>1506</td>
<td>1506</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0.995</td>
<td>0.9834200</td>
<td>0.004515680</td>
<td>1505</td>
<td>1444</td>
<td>1444</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.999</td>
<td>0.9974016</td>
<td>0.00115680</td>
<td>1402</td>
<td>1342</td>
<td>1342</td>
<td>60</td>
</tr>
</tbody>
</table>
Figure 27a and 27b. The results from PHREEQC simulation using the Brine High IC that mixed with different mixing fractions of hydraulic fracturing brine, river water, and road-salt during brine spills in summer and winter. The EC threshold of 1500 µS/cm is shown.

The second brine spill simulation was for the Brine Medium IC interacting with river water as shown in Table 16. The purpose was to estimate how the Brine that has the
medium concentrations would react with the stream water during summer, and in winter with the addition of road salt. During summer, the simulation started with Mix 4 for the medium concentration brine with a fraction of brine of 0.01 and a fraction of river water of 0.99 as shown in Figure 28a. The electrical conductivity without any precipitation of minerals was about 716 µS/cm. Meanwhile, the reading of the electrical conductivity was 674 µS/cm when Mix 4 equilibrated with barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite producing the precipitation of these minerals. The EC difference was about 42 µS/cm. In this study, the electrical conductivity threshold of 1500 µS/cm was reached when the fraction of brine was 0.0109 and a fraction river water was 0.9891 when the mixing precipitated barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite. Meanwhile, a fraction of brine was 0.009 and a fraction of river water was 0.991 when no precipitation occurred during mixing. A fraction of brine between 0.9% and 1.1% is enough to trigger the alarm.

During winter, the results shown on Table 16 showed that a fraction of road salt of 0.0015 and a fraction solution 4 of 0.9985 reached the conductivity threshold of 1500 µS/cm when barite, calcite, Fe(OH)$_3$, pyrolusite, and gibbsite precipitated. Solution 4 in this mixing was contributed from a fraction of 0.0009985 from brine low IC and a fraction of 0.9975015 from river water. A fraction of 0.9999 of Solution 4 mixed with 0.0001 of road salt has the capability to reach the conductivity threshold value when there was no precipitation of minerals during the winter season as shown in Figure 28b. Solution 4 consisted of 0.0009999 of brine and 0.9989001 of river water when there was no precipitation in the mixing with road salt. A fraction of 0.1% of brine is enough to trigger the alarm in this case.
Table 16: The results of PHREEQCi simulation of Brine Medium IC during summer and winter.

<table>
<thead>
<tr>
<th>Season</th>
<th>Mix</th>
<th>Fraction of Solution 4</th>
<th>Fraction of Brine</th>
<th>Fraction of River water</th>
<th>Road salt</th>
<th>EC (No Precipitation)</th>
<th>EC (Precipitation)</th>
<th>EC difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>4</td>
<td>0.0010000</td>
<td>0.9990000</td>
<td></td>
<td>716</td>
<td>674</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.0100000</td>
<td>0.9900000</td>
<td></td>
<td>1556</td>
<td>1476</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.0110000</td>
<td>0.9890000</td>
<td></td>
<td>1649</td>
<td>1555</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.0119200</td>
<td>0.9880800</td>
<td></td>
<td>1734</td>
<td>1647</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.0121000</td>
<td>0.9879000</td>
<td></td>
<td>1751</td>
<td>1663</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.0140000</td>
<td>0.9860000</td>
<td></td>
<td>1928</td>
<td>1832</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.0190000</td>
<td>0.9810000</td>
<td></td>
<td>2393</td>
<td>2278</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0.0243000</td>
<td>0.9757000</td>
<td></td>
<td>2855</td>
<td>2750</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>0.0243400</td>
<td>0.9756000</td>
<td></td>
<td>2889</td>
<td>2754</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>13</td>
<td>0.985</td>
<td>0.0098500</td>
<td>0.9751500</td>
<td>0.015</td>
<td>1994</td>
<td>1913</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0.98</td>
<td>0.0098000</td>
<td>0.9702000</td>
<td>0.02</td>
<td>2140</td>
<td>2058</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.999</td>
<td>0.0099900</td>
<td>0.9890100</td>
<td>0.001</td>
<td>1585</td>
<td>1505</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.9999</td>
<td>0.0099990</td>
<td>0.9899010</td>
<td>0.0001</td>
<td>1558</td>
<td>1478</td>
<td>80</td>
</tr>
</tbody>
</table>
Figure 28a and 28b. The results from PHREEQC simulation using the Brine Medium IC that mixed with different mixing fractions of hydraulic fracturing brine, river water, and road-salt during brine spills in summer and winter by achieving the EC threshold of 1500 µS/cm.

The third brine spill simulation was for the Brine Low IC interacting with river water and the results are presented in Figure 29a. These figures show how the Brine that
has the lowest capacity would react to the stream water during summer, and winter with additional of road salt (Figure 29b). During summer, the simulation started with Mix 4 with a fraction of brine of 0.01 and a fraction of river water of 0.99 as shown in Table 17. The electrical conductivity without any precipitation was about 1072 µS/cm when it was simulated to forecast what would happen if barite, calcite, Fe(OH)_3, pyrolusite, and gibbsite did not precipitate. That conductivity should be the highest possible conductivity expected with this mix. Meanwhile, the reading of the electrical conductivity was 1020 µS/cm when Mix 4 was equilibrated with barite, calcite, Fe(OH)_3, pyrolusite, and gibbsite making them to precipitate. That conductivity represents the highest conductivity expected from this mix. The range of conductivities is then between 1020 and 1072 µS/cm. The EC difference was about 52 µS/cm. In this study, the electrical conductivity threshold of 1500 µS/cm was reached when a fraction of brine was 0.0211 and a fraction river water was 0.9789 when the mixing was precipitated with barite, calcite, Fe(OH)_3, pyrolusite, and gibbsite. Meanwhile, a fraction of brine was 0.0197 and a fraction of river water was 0.9803 when there was no precipitation occurred during mixing. In general we can see that only 2% of brine mixed with river water is capable of reaching the conductivity threshold.

The results shown on Table 17 showed a fraction of road salt was 0.0165 and a fraction solution 4 was 0.9835 to reach the conductivity threshold of 1500 µS/cm when barite, calcite, Fe(OH)_3, pyrolusite, and gibbsite were precipitated with the mixing of solution 4 and road salt. Solution 4 in this mixing contributes a fraction of 0.009835 from brine low IC and a fraction of 0.973665 from river water. A fraction of 0.9855 of
Solution 4 mixed with 0.0145 of road salt has the capability to reach the conductivity threshold value when did not precipitate during winter season as shown in Figure 29b. Solution 4 contributed 0.009855 of brine and 0.975645 of river water when there was no precipitation in mixing with road salt.

Table 17: The results of PHREEQCi simulation of Brine Low IC during summer and winter.

<table>
<thead>
<tr>
<th>Season</th>
<th>Mix</th>
<th>Fraction of Solution 4</th>
<th>Fraction of Brine</th>
<th>Fraction of River water</th>
<th>Road salt</th>
<th>EC (No Precipitation)</th>
<th>EC (Precipitation)</th>
<th>EC difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>4</td>
<td>0.0100000</td>
<td>0.9500000</td>
<td>0.0000000</td>
<td>1072</td>
<td>1020</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.0200000</td>
<td>0.9800000</td>
<td>0.0000000</td>
<td>1521</td>
<td>1455</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.0210000</td>
<td>0.9790000</td>
<td>0.0010000</td>
<td>1565</td>
<td>1499</td>
<td></td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.0220000</td>
<td>0.9780000</td>
<td>0.0030000</td>
<td>1610</td>
<td>1543</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.0240000</td>
<td>0.9760000</td>
<td>0.0080000</td>
<td>1700</td>
<td>1650</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.0242000</td>
<td>0.9758000</td>
<td>0.0082000</td>
<td>1709</td>
<td>1639</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.0243000</td>
<td>0.9757000</td>
<td>0.0083000</td>
<td>1714</td>
<td>1643</td>
<td></td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0.0243400</td>
<td>0.9756600</td>
<td>0.0083500</td>
<td>1715</td>
<td>1645</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Winter</td>
<td>12</td>
<td>0.97</td>
<td>0.0097000</td>
<td>0.9603000</td>
<td>1908</td>
<td></td>
<td>1908</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.973</td>
<td>0.0097500</td>
<td>0.9562500</td>
<td>1815</td>
<td></td>
<td>1761</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0.98</td>
<td>0.0098000</td>
<td>0.9702000</td>
<td>1666</td>
<td></td>
<td>1613</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.985</td>
<td>0.0098500</td>
<td>0.9751500</td>
<td>1518</td>
<td></td>
<td>1465</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>0.9</td>
<td>0.0099000</td>
<td>0.8910000</td>
<td>4021</td>
<td></td>
<td>3966</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>0.999</td>
<td>0.0099900</td>
<td>0.9890100</td>
<td>1102</td>
<td></td>
<td>1049</td>
<td>53</td>
</tr>
</tbody>
</table>
Figure 29a and 29b. The results from PHREEQCi simulation using the Brine Low IC that mixed with different mixing fractions of hydraulic fracturing brine, river water, and road-salt during brine spills in summer and winter by achieving the EC threshold of 1500 µS/cm.
6.4 Aquatic Life Criteria

Aquatic life criteria is an important evaluation and approach to monitor any potential impact of pollutant in the stream to protect the aquatic organism. EPA designed and recommended the aquatic life criteria to use a guideline as shown in Table 18 to protect a water body from any toxic contaminants that expected to risk majority of the species in both freshwater and saltwater organism either in short-term and long-term exposure (US EPA, 2004). Results were compiled after running the simulations for the three types of brine for summer and winter seasons as shown in Table 19a – Table 24c. The final results from the three simulations show that hardness was contributed by calcium, the concentration for potassium and sodium were above the standard guideline, and chloride concentrations were above the criteria of protection of aquatic life level which can be toxic for a long-term (chronic) exposure and short-term (acute) exposure.
Table 18: The recommended aquatic life criteria as a guideline prepared by US EPA (2004).

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Concentration Range</th>
<th>Hardness Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride</td>
<td>860 mg/L (Acute); 230 mg/L (Chronic)</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>1 mg/L (Chronic)</td>
<td></td>
</tr>
<tr>
<td>Sulfate</td>
<td>250 mg/L</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>&lt; 61 mg/L (Hardness: Soft)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61-120 mg/L (Hardness: Moderately Hard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>121-180 mg/L (Hardness: Hard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 180 mg/L (Hardness: Very Hard)</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>&lt; 61 mg/L (Hardness: Soft)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61-120 mg/L (Hardness: Moderately Hard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>121-180 mg/L (Hardness: Hard)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 180 mg/L (Hardness: Very Hard)</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>57.4 mg/L</td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>2.1 mg/L</td>
<td></td>
</tr>
</tbody>
</table>
Table 19: The results of Aquatic Life Criteria investigated under the composition of Brine High IC with precipitation

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4</th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>Na</th>
<th>Cl</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>4</td>
<td>157</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>196</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>155</td>
<td>Acceptable</td>
<td>83</td>
<td>Moderately Hard</td>
<td>245</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>155</td>
<td>Acceptable</td>
<td>86</td>
<td>Moderately Hard</td>
<td>260</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>130</td>
<td>Acceptable</td>
<td>258</td>
<td>Very Hard</td>
<td>1110</td>
<td>Unacceptable</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>125</td>
<td>Acceptable</td>
<td>291</td>
<td>Very Hard</td>
<td>1275</td>
<td>Unacceptable</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>112</td>
<td>Acceptable</td>
<td>379</td>
<td>Very Hard</td>
<td>1711</td>
<td>Unacceptable</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>155</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>193</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>154</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>192</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>155</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>194</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>156</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>195</td>
<td>Acceptable</td>
<td>16</td>
</tr>
</tbody>
</table>
Table 20: The results of Aquatic Life Criteria investigated under the composition of Brine High IC without precipitation.

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4 (mg/L)</th>
<th>Ca (mg/L)</th>
<th>K (mg/L)</th>
<th>Mg (mg/L)</th>
<th>Na (mg/L)</th>
<th>Cl (mg/L)</th>
<th>Fe (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
</tr>
<tr>
<td>4</td>
<td>161</td>
<td>Acceptable</td>
<td>87</td>
<td>Moderately Hard</td>
<td>196</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>160</td>
<td>Acceptable</td>
<td>98</td>
<td>Moderately Hard</td>
<td>245</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>160</td>
<td>Acceptable</td>
<td>101</td>
<td>Moderately Hard</td>
<td>260</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>159</td>
<td>Acceptable</td>
<td>285</td>
<td>Very Hard</td>
<td>1110</td>
<td>Unacceptable</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>159</td>
<td>Acceptable</td>
<td>320</td>
<td>Very Hard</td>
<td>1276</td>
<td>Unacceptable</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>158</td>
<td>Acceptable</td>
<td>414</td>
<td>Very Hard</td>
<td>1711</td>
<td>Unacceptable</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>158</td>
<td>Acceptable</td>
<td>87</td>
<td>Moderately Hard</td>
<td>193</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>158</td>
<td>Acceptable</td>
<td>87</td>
<td>Moderately Hard</td>
<td>192</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>159</td>
<td>Acceptable</td>
<td>87</td>
<td>Moderately Hard</td>
<td>194</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>160</td>
<td>Acceptable</td>
<td>87</td>
<td>Moderately Hard</td>
<td>195</td>
<td>Acceptable</td>
<td>16</td>
</tr>
</tbody>
</table>
### Table 21: The results of Aquatic Life Criteria investigated under the composition of Brine Medium IC with precipitation.

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4 mg/L</th>
<th>Ca mg/L</th>
<th>K mg/L</th>
<th>Mg mg/L</th>
<th>Na mg/L</th>
<th>Cl mg/L</th>
<th>Fe mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
</tr>
<tr>
<td>4</td>
<td>154 Acceptable</td>
<td>69 Moderately Hard</td>
<td>243 Unacceptable</td>
<td>17 Soft</td>
<td>217 Acceptable</td>
<td>517 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>5</td>
<td>153 Acceptable</td>
<td>71 Moderately Hard</td>
<td>262 Unacceptable</td>
<td>18 Soft</td>
<td>234 Acceptable</td>
<td>566 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>6</td>
<td>152 Acceptable</td>
<td>74 Moderately Hard</td>
<td>279 Unacceptable</td>
<td>18 Soft</td>
<td>250 Unacceptable</td>
<td>611 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>7</td>
<td>152 Acceptable</td>
<td>74 Moderately Hard</td>
<td>282 Unacceptable</td>
<td>18 Soft</td>
<td>253 Unacceptable</td>
<td>620 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>8</td>
<td>151 Acceptable</td>
<td>79 Moderately Hard</td>
<td>318 Unacceptable</td>
<td>19 Soft</td>
<td>286 Unacceptable</td>
<td>714 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>9</td>
<td>147 Acceptable</td>
<td>90 Moderately Hard</td>
<td>411 Unacceptable</td>
<td>20 Soft</td>
<td>371 Unacceptable</td>
<td>960 Acute</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>10</td>
<td>143 Acceptable</td>
<td>103 Moderately Hard</td>
<td>510 Unacceptable</td>
<td>22 Soft</td>
<td>462 Unacceptable</td>
<td>1221 Acute</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>11</td>
<td>143 Acceptable</td>
<td>103 Moderately Hard</td>
<td>511 Unacceptable</td>
<td>22 Soft</td>
<td>463 Unacceptable</td>
<td>1223 Acute</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>12</td>
<td>151 Acceptable</td>
<td>69 Moderately Hard</td>
<td>240 Unacceptable</td>
<td>17 Soft</td>
<td>383 Unacceptable</td>
<td>771 Chronic</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>13</td>
<td>151 Acceptable</td>
<td>69 Moderately Hard</td>
<td>239 Unacceptable</td>
<td>17 Soft</td>
<td>439 Unacceptable</td>
<td>856 Acute</td>
<td>0 Acceptable</td>
</tr>
<tr>
<td>14</td>
<td>153 Acceptable</td>
<td>69 Moderately Hard</td>
<td>243 Unacceptable</td>
<td>17 Soft</td>
<td>228 Unacceptable</td>
<td>534 Chronic</td>
<td>0 Acceptable</td>
</tr>
</tbody>
</table>
Table 22: The results of Aquatic Life Criteria investigated under the composition of Brine Medium IC without precipitation.

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4 mg/L</th>
<th>Ca Aquatic Life Criteria mg/L</th>
<th>K Aquatic Life Criteria mg/L</th>
<th>Mg Aquatic Life Criteria mg/L</th>
<th>Na Aquatic Life Criteria mg/L</th>
<th>Cl Aquatic Life Criteria mg/L</th>
<th>Fe Aquatic Life Criteria mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>159</td>
<td>Acceptable</td>
<td>92 Moderately Hard</td>
<td>243 Unacceptable</td>
<td>17 Soft</td>
<td>217 Acceptable</td>
<td>517 Chronic</td>
</tr>
<tr>
<td>5</td>
<td>159</td>
<td>Acceptable</td>
<td>95 Moderately Hard</td>
<td>262 Unacceptable</td>
<td>18 Soft</td>
<td>234 Acceptable</td>
<td>566 Chronic</td>
</tr>
<tr>
<td>6</td>
<td>159</td>
<td>Acceptable</td>
<td>98 Moderately Hard</td>
<td>279 Unacceptable</td>
<td>18 Soft</td>
<td>250 Unacceptable</td>
<td>611 Chronic</td>
</tr>
<tr>
<td>7</td>
<td>159</td>
<td>Acceptable</td>
<td>99 Moderately Hard</td>
<td>282 Unacceptable</td>
<td>18 Soft</td>
<td>253 Unacceptable</td>
<td>620 Chronic</td>
</tr>
<tr>
<td>8</td>
<td>159</td>
<td>Acceptable</td>
<td>105 Moderately Hard</td>
<td>318 Unacceptable</td>
<td>19 Soft</td>
<td>286 Unacceptable</td>
<td>714 Chronic</td>
</tr>
<tr>
<td>9</td>
<td>158</td>
<td>Acceptable</td>
<td>123 Hard</td>
<td>411 Unacceptable</td>
<td>20 Soft</td>
<td>371 Unacceptable</td>
<td>960 Acute</td>
</tr>
<tr>
<td>10</td>
<td>157</td>
<td>Acceptable</td>
<td>141 Hard</td>
<td>510 Unacceptable</td>
<td>22 Soft</td>
<td>462 Unacceptable</td>
<td>1221 Acute</td>
</tr>
<tr>
<td>11</td>
<td>157</td>
<td>Acceptable</td>
<td>141 Hard</td>
<td>511 Unacceptable</td>
<td>22 Soft</td>
<td>463 Unacceptable</td>
<td>1223 Acute</td>
</tr>
<tr>
<td>12</td>
<td>157</td>
<td>Acceptable</td>
<td>91 Moderately Hard</td>
<td>240 Unacceptable</td>
<td>17 Soft</td>
<td>383 Unacceptable</td>
<td>771 Chronic</td>
</tr>
<tr>
<td>13</td>
<td>156</td>
<td>Acceptable</td>
<td>91 Moderately Hard</td>
<td>239 Unacceptable</td>
<td>17 Soft</td>
<td>439 Unacceptable</td>
<td>856 Acute</td>
</tr>
<tr>
<td>14</td>
<td>159</td>
<td>Acceptable</td>
<td>92 Moderately Hard</td>
<td>243 Unacceptable</td>
<td>17 Soft</td>
<td>228 Acceptable</td>
<td>534 Chronic</td>
</tr>
</tbody>
</table>
Table 23: The results of Aquatic Life Criteria investigated under the composition of Brine Low IC with precipitation.

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4</th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>Na</th>
<th>Cl</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/L</td>
<td>Aquatic Life Criteria</td>
<td>mg/L</td>
<td>Aquatic Life Criteria</td>
<td>mg/L</td>
<td>Aquatic Life Criteria</td>
<td>mg/L</td>
</tr>
<tr>
<td>4</td>
<td>157</td>
<td>Acceptable</td>
<td>59</td>
<td>Soft</td>
<td>139</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>152</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>220</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>152</td>
<td>Acceptable</td>
<td>75</td>
<td>Moderately Hard</td>
<td>228</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>151</td>
<td>Acceptable</td>
<td>76</td>
<td>Moderately Hard</td>
<td>236</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>150</td>
<td>Acceptable</td>
<td>79</td>
<td>Moderately Hard</td>
<td>253</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>150</td>
<td>Acceptable</td>
<td>79</td>
<td>Moderately Hard</td>
<td>254</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>150</td>
<td>Acceptable</td>
<td>79</td>
<td>Moderately Hard</td>
<td>255</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>150</td>
<td>Acceptable</td>
<td>79</td>
<td>Moderately Hard</td>
<td>256</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>152</td>
<td>Acceptable</td>
<td>59</td>
<td>Soft</td>
<td>135</td>
<td>Acceptable</td>
<td>15</td>
</tr>
<tr>
<td>13</td>
<td>153</td>
<td>Acceptable</td>
<td>59</td>
<td>Soft</td>
<td>135</td>
<td>Acceptable</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>154</td>
<td>Acceptable</td>
<td>59</td>
<td>Soft</td>
<td>136</td>
<td>Acceptable</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>154</td>
<td>Acceptable</td>
<td>59</td>
<td>Soft</td>
<td>137</td>
<td>Acceptable</td>
<td>15</td>
</tr>
</tbody>
</table>
Table 24: The results of Aquatic Life Criteria investigated under the composition of Brine Low IC without precipitation.

<table>
<thead>
<tr>
<th>Mix</th>
<th>SO4 mg/L</th>
<th>Ca mg/L</th>
<th>K mg/L</th>
<th>Mg mg/L</th>
<th>Na mg/L</th>
<th>Cl mg/L</th>
<th>Fe mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
<td>Aquatic Life Criteria</td>
</tr>
<tr>
<td>4</td>
<td>159</td>
<td>Acceptable</td>
<td>74</td>
<td>Moderately Hard</td>
<td>139</td>
<td>Acceptable</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>158</td>
<td>Acceptable</td>
<td>90</td>
<td>Moderately Hard</td>
<td>220</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>157</td>
<td>Acceptable</td>
<td>92</td>
<td>Moderately Hard</td>
<td>228</td>
<td>Unacceptable</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>157</td>
<td>Acceptable</td>
<td>94</td>
<td>Moderately Hard</td>
<td>236</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>157</td>
<td>Acceptable</td>
<td>97</td>
<td>Moderately Hard</td>
<td>253</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>157</td>
<td>Acceptable</td>
<td>97</td>
<td>Moderately Hard</td>
<td>254</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>157</td>
<td>Acceptable</td>
<td>98</td>
<td>Moderately Hard</td>
<td>255</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>157</td>
<td>Acceptable</td>
<td>98</td>
<td>Moderately Hard</td>
<td>255</td>
<td>Unacceptable</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>155</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>256</td>
<td>Unacceptable</td>
<td>15</td>
</tr>
<tr>
<td>13</td>
<td>156</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>135</td>
<td>Acceptable</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>156</td>
<td>Acceptable</td>
<td>73</td>
<td>Moderately Hard</td>
<td>135</td>
<td>Acceptable</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>157</td>
<td>Acceptable</td>
<td>74</td>
<td>Moderately Hard</td>
<td>136</td>
<td>Acceptable</td>
<td>15</td>
</tr>
</tbody>
</table>
CHAPTER 7: CONCLUSION AND FUTURE WORK

7.1 Conclusion

In this thesis research, this low-cost alert monitoring system was developed to monitor the watershed in a real-time monitoring system. The low-cost monitoring system has the basic water quality related parameters: electrical conductivity and temperature that were measured with two types of sensors. The quality of the water is being monitored to provide an early warning of water contamination. Wi-Fi technology and DTN platform are applied in the development system which is suitable for remote places where it has a poor communication environment, and helps to achieve data transmission to the cloud database. In laboratory tests, the system performed reliably; however, in the field, the system was too unreliable to be fit for purpose and requires continued development. PHREEQC software has the ability to simulate and predict how much toxic chemicals from hydraulic fracturing can contaminate our water resources and threaten environment and aquatic life.

7.2 Future Work

Even though the electrical conductivity sensor has the ability to hold its calibration for five days and temperature sensor can hold about a week in the field, this is insufficient for an alert system. The future research is necessary to conduct a study to make the sensors that can hold a longer calibration period in order to make this alert system as more functional alert system.

Due to some unavoidable limitation such as the equipment malfunction and the sensors reading values that are not reasonable, there is likely to be an electrical fault or
limitations in reading in the field during cold weather. The temperature readings could affect the electrical conductivity readings. To remove side effects of temperature on, the specific conductivity values could be converted to raw conductivity values to examine data accuracy and reliability on a probe-by-probe basis. Future research is necessary to conduct a research on the rapid changes in temperature that could interrupt the sensors where measurements during cold weather have been affected due snow or presence of sediment that can affect the water flow that leads to differences and inconsistency in taking measurements.
REFERENCES


APPENDIX 1: BATCH EXPERIMENTS RESULTS FOR SUMMER

Appendix 1.1 Myron Results

<table>
<thead>
<tr>
<th>Date</th>
<th>µS/cm Avg EC</th>
<th>°C Temp</th>
<th>Date</th>
<th>µS/cm Avg EC</th>
<th>°C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2017</td>
<td>751.3</td>
<td>21.90</td>
<td>2/6/2017</td>
<td>740.1</td>
<td>23.50</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>758.7</td>
<td>21.20</td>
<td>2/7/2017</td>
<td>758.6</td>
<td>20.60</td>
</tr>
<tr>
<td>1/7/2017</td>
<td>770.4</td>
<td>20.90</td>
<td>2/7/2017</td>
<td>761.2</td>
<td>20.80</td>
</tr>
<tr>
<td>1/9/2017</td>
<td>800.2</td>
<td>22.60</td>
<td>2/10/2017</td>
<td>754</td>
<td>19.80</td>
</tr>
<tr>
<td>1/11/2017</td>
<td>764.2</td>
<td>23.30</td>
<td>2/10/2017</td>
<td>763.8</td>
<td>19.40</td>
</tr>
<tr>
<td>1/13/2017</td>
<td>751.3</td>
<td>22.90</td>
<td>2/13/2017</td>
<td>730.9</td>
<td>20.60</td>
</tr>
<tr>
<td>1/16/2017</td>
<td>760.2</td>
<td>23.40</td>
<td>2/13/2017</td>
<td>731.5</td>
<td>21.90</td>
</tr>
<tr>
<td>1/18/2017</td>
<td>760.3</td>
<td>22.40</td>
<td>2/14/2017</td>
<td>761.9</td>
<td>19.60</td>
</tr>
<tr>
<td>1/20/2017</td>
<td>748.1</td>
<td>22.30</td>
<td>2/14/2017</td>
<td>764.8</td>
<td>20.10</td>
</tr>
<tr>
<td>1/23/2017</td>
<td>751.7</td>
<td>22.90</td>
<td>2/15/2017</td>
<td>761.4</td>
<td>20.50</td>
</tr>
<tr>
<td>1/25/2017</td>
<td>743.9</td>
<td>20.10</td>
<td>2/16/2017</td>
<td>740.9</td>
<td>21.00</td>
</tr>
<tr>
<td>1/27/2017</td>
<td>772.6</td>
<td>22.30</td>
<td>2/17/2017</td>
<td>751.2</td>
<td>21.80</td>
</tr>
<tr>
<td>1/27/2017</td>
<td>958.5</td>
<td>20.90</td>
<td>2/20/2017</td>
<td>742.9</td>
<td>20.70</td>
</tr>
<tr>
<td>1/27/2017</td>
<td>962.6</td>
<td>21.50</td>
<td>2/21/2017</td>
<td>750.1</td>
<td>21.10</td>
</tr>
<tr>
<td>1/31/2017</td>
<td>768.2</td>
<td>21.30</td>
<td>2/22/2017</td>
<td>758.1</td>
<td>22.50</td>
</tr>
<tr>
<td>1/31/2017</td>
<td>772.3</td>
<td>22.50</td>
<td>2/22/2017</td>
<td>761.2</td>
<td>22.60</td>
</tr>
<tr>
<td>2/1/2017</td>
<td>740.3</td>
<td>21.80</td>
<td>2/24/2017</td>
<td>750.2</td>
<td>22.10</td>
</tr>
<tr>
<td>2/2/2017</td>
<td>751.6</td>
<td>22.40</td>
<td>2/24/2017</td>
<td>751.5</td>
<td>22.40</td>
</tr>
<tr>
<td>2/3/2017</td>
<td>694.7</td>
<td>20.80</td>
<td>2/27/2017</td>
<td>784.6</td>
<td>20.10</td>
</tr>
<tr>
<td>2/3/2017</td>
<td>715.6</td>
<td>21.40</td>
<td>2/28/2017</td>
<td>761.2</td>
<td>21.50</td>
</tr>
</tbody>
</table>

Appendix 1.2 Ad Hoc Atlas Scientific Results

<table>
<thead>
<tr>
<th>Date</th>
<th>µS/cm Avg EC</th>
<th>°C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2017</td>
<td>767.1</td>
<td>22.52</td>
</tr>
<tr>
<td>2/13/2017</td>
<td>765.2</td>
<td>21.23</td>
</tr>
<tr>
<td>2/20/2017</td>
<td>802.1</td>
<td>22.15</td>
</tr>
<tr>
<td>2/23/2017</td>
<td>760.3</td>
<td>21.45</td>
</tr>
<tr>
<td>2/27/2017</td>
<td>756.2</td>
<td>21.65</td>
</tr>
</tbody>
</table>
Appendix 1.3 Low Cost Sensor Results

<table>
<thead>
<tr>
<th>Date</th>
<th>μS/cm Avg EC</th>
<th>°C Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2017</td>
<td>766.5</td>
<td>22.73</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>762.1</td>
<td>22.83</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>765.0</td>
<td>22.91</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>765.4</td>
<td>22.81</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>766.8</td>
<td>22.69</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>780.8</td>
<td>21.75</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>847.6</td>
<td>22.64</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>845.7</td>
<td>22.80</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>849.2</td>
<td>22.92</td>
</tr>
<tr>
<td>1/5/2017</td>
<td>847.6</td>
<td>22.64</td>
</tr>
<tr>
<td>1/5/2017</td>
<td>845.7</td>
<td>22.80</td>
</tr>
<tr>
<td>1/5/2017</td>
<td>849.2</td>
<td>22.92</td>
</tr>
<tr>
<td>2/8/2017</td>
<td>780.2</td>
<td>22.60</td>
</tr>
<tr>
<td>2/13/2017</td>
<td>765.2</td>
<td>21.23</td>
</tr>
<tr>
<td>2/20/2017</td>
<td>802.1</td>
<td>22.15</td>
</tr>
<tr>
<td>2/23/2017</td>
<td>760.3</td>
<td>21.45</td>
</tr>
<tr>
<td>2/27/2017</td>
<td>756.2</td>
<td>21.65</td>
</tr>
</tbody>
</table>
Appendix 2.1 Myron Results

<table>
<thead>
<tr>
<th>Date</th>
<th>μS/cm</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg EC</td>
<td>Temp</td>
</tr>
<tr>
<td>3/6/2017</td>
<td>450.1</td>
<td>20.20</td>
</tr>
<tr>
<td>3/6/2017</td>
<td>870.7</td>
<td>20.60</td>
</tr>
<tr>
<td>3/7/2017</td>
<td>878.7</td>
<td>21.00</td>
</tr>
<tr>
<td>3/8/2017</td>
<td>644.1</td>
<td>15.20</td>
</tr>
<tr>
<td>3/9/2017</td>
<td>674.4</td>
<td>14.44</td>
</tr>
<tr>
<td>3/10/2017</td>
<td>414.9</td>
<td>13.48</td>
</tr>
<tr>
<td>3/11/2017</td>
<td>690.8</td>
<td>4.42</td>
</tr>
<tr>
<td>3/12/2017</td>
<td>692.1</td>
<td>5.35</td>
</tr>
<tr>
<td>3/13/2017</td>
<td>805.4</td>
<td>12.03</td>
</tr>
<tr>
<td>3/14/2017</td>
<td>807.5</td>
<td>5.32</td>
</tr>
<tr>
<td>3/15/2017</td>
<td>778.7</td>
<td>7.03</td>
</tr>
<tr>
<td>3/16/2017</td>
<td>653.0</td>
<td>80.06</td>
</tr>
<tr>
<td>3/17/2017</td>
<td>803.9</td>
<td>4.40</td>
</tr>
<tr>
<td>3/19/2017</td>
<td>682.8</td>
<td>8.03</td>
</tr>
<tr>
<td>3/20/2017</td>
<td>451.3</td>
<td>5.37</td>
</tr>
<tr>
<td>3/21/2017</td>
<td>655.9</td>
<td>11.23</td>
</tr>
<tr>
<td>3/22/2017</td>
<td>698.3</td>
<td>12.60</td>
</tr>
</tbody>
</table>
Appendix 2.2 Ad Hoc Atlas Scientific Results

<table>
<thead>
<tr>
<th>Date</th>
<th>µS/cm</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/6/2017</td>
<td>6.0</td>
<td>20.60</td>
</tr>
<tr>
<td>3/7/2017</td>
<td>890.6</td>
<td>21.55</td>
</tr>
<tr>
<td>3/8/2017</td>
<td>874.6</td>
<td>20.80</td>
</tr>
<tr>
<td>3/8/2017</td>
<td>620.2</td>
<td>15.10</td>
</tr>
<tr>
<td>3/9/2017</td>
<td>476.0</td>
<td>15.72</td>
</tr>
<tr>
<td>3/14/2017</td>
<td>986.4</td>
<td>2.76</td>
</tr>
<tr>
<td>3/15/2017</td>
<td>572.1</td>
<td>5.55</td>
</tr>
<tr>
<td>3/16/2017</td>
<td>1300.5</td>
<td>6.51</td>
</tr>
<tr>
<td>3/17/2017</td>
<td>861.1</td>
<td>3.96</td>
</tr>
<tr>
<td>3/19/2017</td>
<td>469.1</td>
<td>5.82</td>
</tr>
<tr>
<td>3/19/2017</td>
<td>659.5</td>
<td>7.80</td>
</tr>
<tr>
<td>3/20/2017</td>
<td>440.6</td>
<td>6.94</td>
</tr>
</tbody>
</table>
### Appendix 2.3 Low Cost Sensor Results

<table>
<thead>
<tr>
<th>Date</th>
<th>EC</th>
<th>Temp</th>
<th>Avg Temp</th>
<th>EC</th>
<th>Temp</th>
<th>SC</th>
<th>AC</th>
<th>AVG SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/6/17</td>
<td>6.00</td>
<td>20.60</td>
<td>20.60</td>
<td>6.55</td>
<td>7.21</td>
<td>7.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8/17</td>
<td>350.40</td>
<td>6.06</td>
<td>8.43</td>
<td>549.00</td>
<td>674.71</td>
<td>719.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8/17</td>
<td>452.70</td>
<td>10.80</td>
<td></td>
<td>621.18</td>
<td>763.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>479.30</td>
<td>15.80</td>
<td></td>
<td>581.48</td>
<td>728.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>474.50</td>
<td>15.77</td>
<td></td>
<td>576.05</td>
<td>721.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>475.80</td>
<td>15.67</td>
<td></td>
<td>578.98</td>
<td>725.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>474.20</td>
<td>15.64</td>
<td></td>
<td>577.43</td>
<td>723.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>476.10</td>
<td>15.55</td>
<td></td>
<td>580.96</td>
<td>727.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>468.60</td>
<td>15.61</td>
<td>14.13</td>
<td>571.01</td>
<td>715.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>266.00</td>
<td>13.78</td>
<td></td>
<td>338.55</td>
<td>424.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>498.90</td>
<td>15.75</td>
<td></td>
<td>605.96</td>
<td>758.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>498.90</td>
<td>15.75</td>
<td></td>
<td>605.96</td>
<td>758.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>481.70</td>
<td>16.06</td>
<td></td>
<td>580.89</td>
<td>727.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/9/17</td>
<td>230.70</td>
<td>0.09</td>
<td></td>
<td>440.08</td>
<td>551.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/14/17</td>
<td>512.00</td>
<td>0.69</td>
<td>4.17</td>
<td>955.80</td>
<td>1531.31</td>
<td>827.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/14/17</td>
<td>51.75</td>
<td>7.64</td>
<td></td>
<td>77.42</td>
<td>124.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/15/17</td>
<td>399.40</td>
<td>4.90</td>
<td>6.37</td>
<td>648.28</td>
<td>987.04</td>
<td>797.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/15/17</td>
<td>268.20</td>
<td>7.83</td>
<td></td>
<td>399.08</td>
<td>607.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/16/17</td>
<td>264.40</td>
<td>7.30</td>
<td>7.30</td>
<td>399.44</td>
<td>590.43</td>
<td>590.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/19/17</td>
<td>604.80</td>
<td>0.14</td>
<td></td>
<td>1151.62</td>
<td>1703.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/19/17</td>
<td>11.56</td>
<td>7.53</td>
<td></td>
<td>17.35</td>
<td>25.67</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/19/17</td>
<td>431.80</td>
<td>8.4</td>
<td></td>
<td>632.27</td>
<td>935.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/19/17</td>
<td>64.80</td>
<td>0.22</td>
<td></td>
<td>123.03</td>
<td>182.03</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>