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ANALYSIS OF CLANCY DRINKING WATER CONTAMINATION FROM ON–SITE SEPTIC SYSTEM EFFLUENT

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by
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Abstract

Clancy, a small unincorporated town in Montana, is situated 11 miles southwest of Helena at the confluence of Clancy and Prickly Pear Creeks. Currently Clancy residences have only on-site drinking water wells and septic systems. Drinking water testing in 2012 and 2017 found nitrate levels exceeded the Environmental Protection Agency's (EPA) maximum contaminant level (MCL) of 10 mg/L in some of the residential drinking water wells. Elevated nitrate levels can cause a significant health concern for infants due to methemoglobinemia (Blue Baby Syndrome).

Due to the continued detection of elevated nitrate levels in Clancy's on–site drinking water wells further research into the drinking water quality by the Jefferson County Health Department and Montana Tech Environmental Engineering Department was conducted from February to December 2017. Six water sampling events were conducted on thirty drinking water wells spread over the community of Clancy.

The investigative study objectives were to: 1) Determine if drinking water contaminants are associated with on-site-septic systems, 2) Determine Clancy's groundwater flow, 3) Determine if nutrient rich groundwater is contaminating Clancy and Prickly Pear Creeks, and 4) Assess the effectiveness of septic effluent identifiers. Drinking water wells were sampled and analyzed for nitrate, chloride, specific conductivity, ammonia, pH, total coliform, *Escherichia coli*, and radon-222, uranium, and $\delta\ ^{15}N/\ \delta^{8}O$ isotopes.

Results from the study found nitrate levels to exceed the Environmental Protection Agency's MCL of 10 mg/L in 18 % of drinking wells. Uranium levels were found to exceed the EPA's MCL of 30 µg/L in 37% of Clancy's drinking water wells analyzed in the study. With the information provided from the water quality study the Clancy Water and Sewer District is pursuing the development of a centralized water system for the community.

Many smaller rural communities with on-site septic systems and drinking water wells, over time could likely encounter contamination of drinking water by septic effluent. Methods used in analysis of Clancy's drinking water quality may be applied to economically identifying septic effluent contamination affecting drinking water wells in other rural communities.

Keywords: (Drinking Water Wells, On-Site Septic System, Nitrate, Uranium, EPA, Clancy)

Dedication

I would like to dedicate this work to my wonderful spouse, Nicole Strozewski for all her support and understanding throughout our lives together and during this educational opportunity.

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Clancy Private Landowners

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1. Introduction

In the United States approximately 30% of households use on-site septic systems for wastewater disposal rather than publicly maintained sewer systems (USEPA, 2003). Most of the households using private septic systems and individual ground water wells are located in rural areas of the United States. In Montana approximately 61% of the population is connected to public sewer systems, and 38% use private septic systems for sewage disposal (USEPA, 2002). Clancy, Montana a rural community located in Jefferson County, is situated approximately 11 miles southwest of Helena (Figure 1). The community has a population of 223 citizens and 89 households (USCB, 2010), and is an example of a rural community that has both on-site drinking water wells and septic systems.

Clancy was primarily founded by silver mining camps in the late 1800's. Silver ore from Clancy was hauled by bull teams to Fort Benton where it was shipped by boat to Wales in Europe for smelting. Many of the residences located in the central part of the town were built in the late 1800's during the town's original development.

Figure 1: Clancy Montana Location Map

In determining septic effluent contamination of drinking water, some common analytical practices include measuring the levels of nitrate and *Escherichia coli* (*E*.coli). In February 2012, nine individual water wells were sampled by the Jefferson County Health Department and analyzed by the Montana Department of Public Health and Human Services. These samples resulted in high concentrations of nitrate (NO_3-N) in several of the centrally located residential wells in Clancy.

The nitrate concentrations in the 2012 sampled wells ranged from 0.39 to 11.4 mg/L. Three of the nine wells showed elevated levels of nitrates ranging 9.64 to 11.4 mg/L (Bullock, 2016). High nitrate concentrations above 10 mg/L are a health concern for pregnant women and infants as elevated nitrate levels can cause fatalities in infants due to methemoglobinemia or commonly known as Blue Baby Syndrome (Klassen, 2016).

Drinking water samples obtained in 2017 were analyzed for nitrate concentrations by the Montana Tech Environmental Engineering Department. Analyzed well samples indicated again high levels of nitrates at some of Clancy's drinking wells. High nitrate levels were observed in six of the nineteen wells ranging from 4.96 to 10.5 mg/L.

Due to the continued detection of elevated nitrate levels in Clancy's drinking water wells, further investigative research into the drinking water quality by the Jefferson County Health Department and Montana Tech Environmental Engineering Department was conducted from February 2017 to December 2017.

2. Background

2.1 Clancy Project Objectives

To analyze the Clancy's drinking water quality and determine if contaminants were associated with septic effluent, the following objectives were applied in the study:

1) Determine if drinking water contaminants are associated with on-site septic systems.
2) Determine Clancy's groundwater flow direction.
3) Determine if groundwater is contaminating Clancy and Prickly Pear Creeks.
4) Assess the effectiveness of septic effluent identifiers.

To meet the objectives, Clancy's drinking water wells were sampled and analyzed for the following parameters: nitrate, chloride, specific conductivity, ammonia, pH, oxidation reduction potential, total coliform, *E. coli*, radon-222, uranium, and $\delta\ ^{15}N$ / $\delta^{18}O$ isotopes. Typical components and concentrations found in septic tank effluent are indicated the following table (Gross, 2004), (Salvato,1992, (TableI)):

Table I. Typical Septic Tank Effluent Characteristics

Total Nitrogen	60	mg/L
Nitrate (N-NO3)	0	mg/L
Ammonia (N-NH3)	40	mg/L
BOD	120	mg/L
Chloride	80	mg/L
Coliform-Bacteria	106	CFU/100ml

2.2 Nitrate

According to the United States Geological Service natural occurring Nitrate (NO_3^-) concentrations found in ground water in southwestern Montana are approximately 0.6 mg/L (USGS, 2002). Nitrate contamination of ground water typically occurs from two sources; human/animal waste or synthetic fertilizers. In the nitrogen cycle, ammonia (NH_4^+) in human/animal waste is converted to nitrite (NO_2^-) by nitrifying soil bacteria:

$$\mathbf{NH_3 + 1.5O_2 \Rightarrow NO_2^- + H^+ + H_2O}$$

Nitrite is then converted to nitrate (NO_3^-) by nitrifying bacteria in the soil an aerobic environment:

$$\mathbf{NO_2^- + .5O_2 \Rightarrow NO_3^-}$$

Nitrate is a good indicator of septic effluent in ground water (USEPA, 2012). Nitrate contamination of drinking water is a concern due to the medical condition called methemoglobinemia in the blood. Methemoglobinemia or more commonly called "Blue Baby Syndrome," is a dangerous condition that can cause death in infants below 3 months of age, but can affect children up to eight years of age (Klassen, 2016).

Babies are most vulnerable to nitrate contamination because their micro-bacterial flora in their digestive tract is not completely developed (Romitti, 2013). Methemoglobinemia occurs when nitrates oxidize ferrous iron (Fe^{2+}) altering the ferrous iron to ferric iron (Fe^{3+}) in the blood (Klassen, 2016). Ferric iron (Fe^{3+}) does not allow oxygen to bind to red blood cells.

Mild effects of methemoglobinemia can cause shortness of breath caused by an insufficient supply of oxygen to the blood. Blue lips on infants are a sign of more severe cases, and can lead to asphyxiation and death.

There is also a correlation between birth defects and high nitrate levels in the expecting mothers. Researchers at Texas A & M Health Science Center School of Public Health published a study that examined the relationship between prenatal exposure to drinking-water nitrates and various birth defects (Romitti, 2013). The study found that nitrate intake greater than 5 mg/L was associated with several birth defects in new-born infants including spina bifida and limb deficiencies (Romitti, 2013).

According to the United States Geological Service, naturally occurring nitrates in the south western region of Montana should be less than 0.6 m/L (USGS, 2017). Once a water supply becomes contaminated with nitrate, it is costly to treat. Technologies such as ion exchange, reverse osmosis (RO), or distillation can be used to remove nitrate from contaminated drinking water.

2.3 Uranium

Uranium is classified as a radionuclide and is regulated in drinking water by the United States Environmental Protection Agency (EPA). The EPA's maximum contaminant level for uranium (MCL) in drinking water is 30 µg/L (USEPA, 2017). Long-term exposure from elevated levels of uranium in drinking can result in kidney damage, and is also connected to a greater risk of cancer. Uranium is rapidly removed from the blood stream and subsequently is deposited in both the kidneys and skeletal bones. The skeleton is the primary site of uranium accumulation in the human body. Treatment technologies for uranium removal from drinking water can include reverse osmosis.

In a multiple year United States Geological Survey (USGS) study of radiochemical elements in groundwater across Jefferson County, Montana; it was determined 14% (18 of 128) of wells sampled in the county had uranium levels above the EPA's MCL of 30 µg/L (USGS, 2013).

2.4 Chloride

Chloride can be used as an indicator for human waste due to the fact humans consume large amounts of sodium chloride (NaCl) from such items as processed food (Hunt, 2002). The EPA has a 250 mg/L maximum contaminant level (MCL) for drinking water. This is due to a bad taste and odor that generally occurs above the 250 mg/L threshold. There are no health-based EPA guidelines for chloride.

2.5 Total Coliform and *Escherichia coli*

Coliforms are bacteria found in the digestive tracts of humans and other warm blooded animals. Most coliform bacteria do not cause disease. However, some strains of coliforms, mainly the strain *Escherichia coli* (*E. coli*), can cause serious illness. *E. coli* can be found in livestock and chickens. Of the five common groups of bacteria that comprise the total coliforms, only *E. coli* is not found naturally in groundwater. Consequently, *E. coli* is considered to be the species of coliform bacteria that is the foremost indicator of fecal pollution. Coliform lab analysis is normally given by a positive or negative result. Quantitative results for coliforms are reported in the "Most Probable Number" (MPN).

2.6 δ ^{15}N and δ^{18}O Isotopes

Nitrate contamination of ground water is increasing across North America due to a growth in fertilizers used in agricultural; animal wastes from large scale farming practices; and non-point source septic systems. Nitrate contamination is also a leading contributor in water quality degradation that results in eutrophication and hypoxia in surface waters.

To aid in identifying sources of nitrate contamination, ground water is analyzed using the nitrogen isotope ratio method, which is based on the level of the two stables isotopes found in nitrate (NO3), δ ^{15}N and δ^{18}O. Characteristic δ ^{15}N and δ^{18}O patterns of nitrates found during the denitrification process allow δ ^{15}N and δ^{18}O isotopes to be used as tracers in determining different nitrate levels and distinguishing sources of nitrates (Kendall, 2000).

Nitrogen isotope ratios are normally reported in per mil of a (‰). Generally δ ^{15}N results are used to distinguish NO_3-N derived from ammonium (NH_4^+) fertilizers and human/animal waste products. Animal wastes are high in δ ^{15}N due to their diet being enriched with plant material. δ^{18}O is used in detecting NO_3-N from naturally occurring atmospheric nitrates and nitrate (NO_3-N) based fertilizers.

Ranges of nitrogen isotope signatures δ ^{15}N for sources of ground water nitrates include levels measured in nitrogen per mil (‰) from $^{-}$10 to +22 (Table II). Ranges of stable oxygen isotope signatures δ^{18}O for sources of ground water nitrates include levels measured in per mil (‰) from +18 to +68 (Table II) (Kendall, 2000).

Table II. Isotope δ ^{15}N and δ^{18}O Signature Ranges/Nitrate Sources

δ ^{15}N / δ^{18}O Ranges mil(‰)	**Nitrate Sources**
δ ^{15}N **(-10 to +2)**	**Natural Rain Water**
δ ^{15}N **(- 5 to +2)**	**Ammonium Based Fertilizers**
δ ^{15}N **(+3 to +9)**	**Natural Denitrification Cycle**
δ ^{15}N **(+10 to +22)**	**Human/Animal Waste**
δ^{18}O **(+18 to +22)**	**Nitrate Based Fertilizers**
δ^{18}O **(+19 to +22)**	**Nitrates from Precipitation**

2.7 Ammonia

Ammonia is an indicator of fresh sewage contamination in water. In what is called the "nitrification cycle," ammonia found in fresh sewage is converted to nitrites by soil bacteria.

The EPA has no Maximum Concentration Level assigned to ammonia. Extremely high levels of ammonia are required to affect human's health. Naturally occurring ammonia levels in groundwater are normally below 0.20 mg/L (Wood, 2016).

Fish are highly susceptible to increased levels of ammonia. Ammonia levels greater than 2.0 mg/L can be toxic to fish. The toxicity of ammonia is highly dependent on pH and temperature (Floyd, 2012).

2.8 Specific Conductivity

Specific Conductance is a measure of how well an electrical current can travel through water. The conductivity in water increases as ions in the water increase. More conductive material, such as metals and salts in a solution, result in a higher conductivity. Therefore, specific conductance is a measure of the presence of inorganic total dissolved solids (TDS) in water; and can be used as a general indicator of contaminants in water.

Specific conductivity is a measured using a sensor that reads electrical resistance. It is measured in micro Siemens per cm (µS/cm) which is International System of Units. In the United States tap water can range 50 to 800 µS/cm (Rose, 2014).

2.9 Oxidation-Reduction Potential

ORP is measured in millivolts (mV) and ranges from -2,000 mV to +2,000 mV. ORP expresses the ability of a water solution to release and accept electrons from chemical reactions; or known as the measure of stored electrical potential (Wareham,1993). Most tap water ORP in North America is between +200 and+600 mV (Wareham, 1993).

2.10 Radon-222

Uranium-238 (^{238}U) is a naturally occurring radioactive element commonly found in different concentrations in soil. Uranium-238 decays into radium-226 (^{226}Ra) and then by alpha–particle emission decays into radon-222 (^{222}Rn) (DeWayne, 2000).

Radon-222 is an odorless and colorless radioactive noble gas that is naturally occurring in both soil and water. Radon 222's half-life (3.82 days) is long enough to be used as a natural tracer in hydrogeological processes (DeWayne, 2000). Radon-222 can be used to analyze the hydrogeological process of groundwater contributing to surface water.

Ground water contribution to surface water and location can generally be determined by radon-222 analysis in waterways. Determining the quantity of groundwater added to surface water through radon-222 analysis is based on radon-222 gas existing at higher concentrations in groundwater, then in surface water. The locations of groundwater contribution to surface water can be found by determining areas of elevated radon-222 in the surface water. After groundwater enters surface water, the radon-222 gas diffuses into the atmosphere (Shaw, 2018).

Radon-222 levels greater than 30 pCi/L general have shown a gain in surface water from groundwater, and levels less than 30 pCi/L indicate little to no gain in surface water (Shaw, 2018). As levels of radon-222 increase beyond 30 pCi/L so does the gain in surface water from groundwater.

2.11 pH

The pH of pure water is 7 at 25 degrees Celsius. A pH lower than 7 indicates acidic conditions. A pH higher than 7 specifies basic conditions. A normal pH range for surface and ground water is between 6.5 and 8.5. Levels of pH determine the water's ability to receive or gain protons.

3. Methodology

3.1 Overview

Approximately 30 Clancy drinking water wells were sampled over six sampling events during an eleven month period, beginning in the February 2017 and extending to December 2017. During these sampling periods surface water samples in both Clancy and Prickly Pear Creeks were obtained and analyzed. Water quality for all samples was assessed at Montana Tech Environmental Engineering Department and Montana Bureau of Mines and Geology laboratories (MBMG). Water samples analyzed in Montana Tech and (MBMG) laboratories followed EPA methods and references (Table III).

Table III. Reference and EPA Methods

Field and Lab Parameters	Analytical Instrumentation	Reference or Method
pH, Specific Conductivity, ORP	YSI EXO_2 Sonde	N.A.
Ammonia	HACH 600 DR Spectrophotometer	EPA 350.1
Chloride	Titration –Silver Nitrate	EPA 4500.0 CI
Nitrate	HACH 600 DR Spectrophotometer	EPA 353.2
Uranium	(ICP) Inductively Coupled Plasma Spectroscopy	EPA 200.8
Isotopes $\delta\ ^{15}N$ and $\delta^{18}O$	$\delta\ ^{15}N + \delta^{18}O$ Isotope N_2O Chemical Denitrifier	N.A.
Radon 222	Determination of Radon in Drinking Water by Liquid Scintillation Counting	EPA 913.0
E.coli and Total Coliforms	Idexx Colilert -18	EPA 9223.0 B

Clancy's groundwater flow directions were determined through the combination of Global Positioning System (GPS) surveying of well heads and obtaining static water depths in the residential wells during each sampling period.

3.2 Determination of Drinking Water and Surface Water Contaminants

Selected Clancy unfiltered residential drinking wells were sampled and analyzed for nutrients and radionuclides. Each residence's drinking water was sampled by running residential water outlets for a time period of two minutes before obtaining water samples in acid washed polyethylene bottles. Drinking water from each residence was collected in two separate 500 ml bottle(s).

One 500 ml sample was stored at 4 degrees Celsius and analyzed for nitrate, chloride, and ammonia. The analysis occurred within 48 hours to be in accordance with Environmental Protection Agency methods for chemical analysis of water (Table II). The second 500 ml sample was acidified with nitric acid (HNO_3) to lower the pH below 2 and preserve the sample. The sample was stored in a laboratory refrigerator at 4 degrees Celsius.

Nitrate (NO_3-N) and ammonia (NH_{3-} N) concentrations were measured through EPA approved methods 353.2 and 350.1, respectively. Hach 600 DR spectrophotometer analysis results were reported in mg/L. Spectrometer acceptable calibration range shall be within 15% of the standard solution. Chloride (Cl^-) concentrations were determined by the EPA approved Hach silver-nitrate titration method (4500 CI); which includes titrating a 100 ml sample to an orange-brown color. Chloride was reported in mg/L.

The 200 ml radionuclide sample was collected from each residential drinking well and filtered with a .45 μm filter. A separate 200 ml radionuclide samples from both Prickly Pear and Clancy Creeks was obtained for laboratory analysis. Nitric acid (HNO_3) was added to each 200 ml filtered sample as a preservative. The samples were then submitted to the Montana Bureau of Mines and Geology (MBMG) for analysis of uranium levels in an inductively coupled plasma spectroscopy (ICP-MS). Uranium levels were reported in µg/L.

A 100 ml sample of drinking water from each residence was obtained for testing of total coliforms and *E. coli* bacteria. Idexx reagents were added to the sample immediately before incubating the 100 ml sample for 24 hours at 68^{o} F to be in compliance with the United States Environmental Protection Agency Total Coliform Rule (Idexx, 2018). The analytical method used was EPA 9223 B (Table II).

After the 24 hour incubation period the sample was observed for yellow and blue color indicators. A yellow color indicated total coliforms were present; and a blue color in a 300 nm UV light showed the presence of *E. coli*. Samples testing positive for total coliforms were then quantitatively measured using the Most Probable Number Index (MPN).

Four drinking wells in the Clancy study area were analyzed for $\delta\ ^{15}N$ and $\delta^{18}O$ isotopes. Three wells were selected with high nitrate concentrations and one with a low nitrate concentration. The three drinking wells with high nitrate concentrations were selected within the region of highest elevation to the lowest elevation in the Clancy study area.
All selected isotope samples contained at least 0.5 mg/L of nitrate (NO_3-N); less than 2% nitrite of nitrate; and less than 30,000 mg/L chloride. The four residential drinking water samples were filtered with .45 µm filter; placed in 50 ml polyethylene conical tubes; and then frozen.

Frozen drinking water samples were sent to the University of Waterloo in Ontario, Canada for $\delta\ ^{15}N$ and $\delta^{18}O$ isotope analysis using the $\delta\ ^{15}N + \delta^{18}O$ isotope N_2O chemical denitrifier method (Table II). In the chemical denitrifier method nitrate (NO_3^-) is converted to nitrite (NO_2^-); and then chemically converted to nitrous oxide (N_2O) (Heemskirik, 2018). The nitrous oxide gas is then analyzed for $\delta^{15}N$ and $\delta\ ^{18}O$ light spectrum signatures in an isotope mass ratio spectrometer.

To evaluate pH, specific conductivity, and oxidation-reduction potential (ORP) levels in well samples, 300 ml of water were placed in the calibration cup of an YSI EXO 2 sonde logger and measurement values were recorded in the field. The sonde logger was pre-calibrated and programed to record for pH, specific conductivity, and ORP.

3.3 Determination of Clancy's Groundwater Flow Direction

Clancy groundwater flow directions were calculated using static water and well head elevations. Static water levels in the residential wells were measured with a Solinist water level meter during each sampling period. Individual well heads in the Clancy study area were surveyed using a Trimble Geographic Positioning System (GPS) unit.

The difference between static water levels and well head elevations was subtracted from the well head elevation to determine static water elevations for each well. Geographic Information System (GIS) maps were created showing the study wells in the Clancy area with associated nitrate, ammonia, uranium, and static water elevations.

The Trimble GPS surveying equipment was checked for accuracy at the nearest "base station" to Clancy. The "base station" used for the calibration test was located at the Helena Department of Transportation.

3.4 Determination of Groundwater is Contaminating Clancy Area Creeks

Surface water contaminant level determination in Clancy and Prickly Pear Creeks was determined through grab samples collected in 500 ml bottles. Grab samples were analyzed for nitrate (NO_3-N) and ammonia (NH_3-N) levels with the HACH 600 DR spectrophotometer.

Surface water grab samples in both Prickly Pear and Clancy creeks were obtained within the community of Clancy and approximately 1.5 miles above and below the community of Clancy. The samples were used to compare nitrate levels from within the community to levels outside the community.

Radon-222 analysis was used to aid in determining if Clancy's contaminated groundwater was contributing to Clancy and Prickly Pear Creeks. Grab samples were obtained in 125 ml glass bottles from drinking water wells and both area creeks.

Drinking well water was slowly added to a plastic bucket, and a 125 ml bottle was placed at the bottom of the bucket and allowed to fill up. The bottle was then capped after visible air bubbles were removed.

Creek samples were obtained by placing a 125 ml glass bottle at the bottom of the creek and allowed the bottle to fill with creek water. All visible air bubbles were removed from the containers before sealing. All bottles were labeled with the time and date of sampling.

The samples were submitted to the Montana Bureau of Mines and Geology for radon-222 analysis using the EPA Method 913 (Table II). This method is referred to as the, "Determination of radon in drinking water by Liquid Scintillation Counting" (Hahn, 1991). The process is based on an atom's desire to have a stable nucleus. Radioactivity is the result of an unstable arrangement of neutrons and protons. An arrangement to attain a stable nucleus is achieved by the emission of alpha or beta particles. In the liquid scintillation process for radon-222 particle analysis, energy from the radioactive alpha particle is converted to light waves and detected by the scintillation counter. (NLD, 2004).

3.5 Assessing the Effectiveness of Septic Effluent Identifiers.

In order to determine the effectiveness of various septic effluent identifiers, laboratory results for nitrate (NO_3-N) and chloride (Cl^-) were compared. Drinking water sample data and graphs were employed to compare the correlations between the two identifiers in drinking wells with nitrate (NO_3-N) levels below 1 mg/L and above 5 mg/L. Clancy well water samples were also used to compare nitrate (NO_3-N) and specific conductivity in detecting septic effluent.

4. Results

4.1 Determination of Contaminants Associated with Septic Systems

In determining if Clancy's drinking water was contaminated with septic effluent, various methods were used to analyze the drinking water. The research focused on septic effluent identifiers such as nitrate, chloride, *E.coli,* ammonia, and $\delta^{15}N$ and $\delta^{18}O$ isotopes. Clancy's drinking well locations used in the research project were not disclosed in the thesis paper in order to protect the privacy rights of homeowners.

4.1.1. Ground Water Nitrate Levels

During the study in Clancy it was determined that elevated nitrate levels above 2 mg/L existed in approximately 47% of Clancy's drinking water wells. Clancy's residential drinking water wells exceeded the EPA's Maximum Contaminant Level (MCL) for nitrate in 18 % of the wells tested during the study period. The highest concentrations of nitrates found in Clancy's drinking wells are located in the oldest parts of the community (Figure 2). Nitrate (NO_3-N) in the Clancy wells averaged data range of 3.28 mg/L over the study period (Table IV).

Table IV. Clancy Average Nitrate Concentrations in Drinking Wells

Nitrate(mg/L)	Nitrate(mg/L)
8.74	0.85
9.61	1.22
0.74	0.39
0.13	0.37
1.59	0.65
5.68	4.92
10.44	3.99
9.04	1.41
4.90	0.96
0.31	6.89
2.24	0.14
2.40	4.29
5.98	0.00
0.67	Average 3.28

Figure 2: Approximate Areas of Nitrate Concentration in Clancy

4.1.2. Groundwater Uranium Analysis

Sampling analysis for uranium in Clancy's drinking water wells occurred in May, 2017. Nineteen wells were sampled from the study area. In 37% of wells, uranium concentrations exceeded the EPA’s MCL of 30 μg/L. The highest concentrations of uranium in the Clancy drinking water wells are north of Clancy Creek (Figure 3). Drinking water in the Clancy study data range averaged 25.1 μg/L.

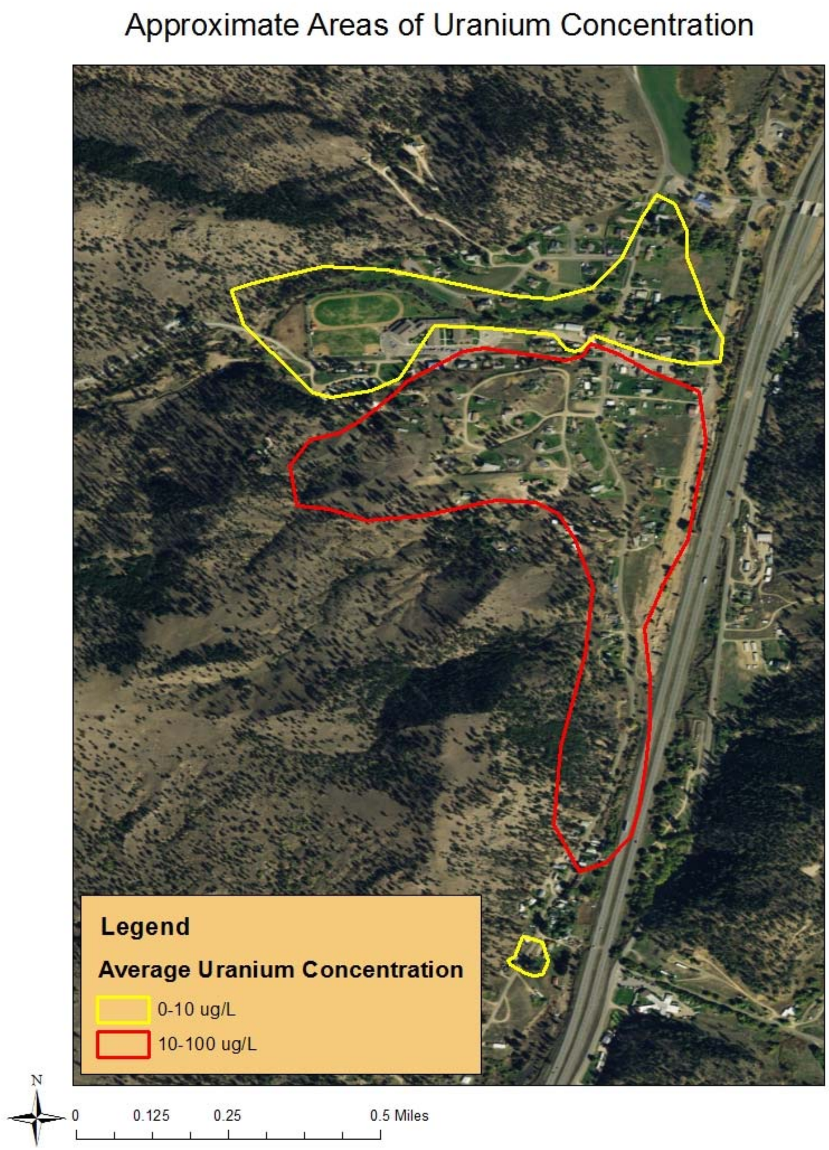

Figure 3: Approximate Areas of Uranium Concentration in Clancy

4.1.3. Groundwater Chloride Analysis

Chloride concentrations in the drinking water wells ranged from 8 to 209 mg/L. The average cholride reading from Clancy's drinking wells was 45.7 mg/L (Table V).

4.1.4. Total Coliforms- *E. coli* Analysis

Clancy had ten drinking wells test positive for total coliforms during four separate sampling periods. The total coliform results ranged from a Most Probable Number (MPN) of 1 to 792 MPN. No drinking wells tested positive for *E.coli.*

4.1.5. Ground Water δ ^{15}N and O18 Isotope Analysis

Isotope samples from four selected Clancy drinking water wells were submitted to the University of Waterloo, Canada for δ ^{15}N and δ^{18}O analysis. Three wells had elevated concentrations of nitrates, and one well had a low level of nitrate. Isotope analysis was used to aid in distinguishing between nitrate contaminations due to human/animal waste, industrial fertilizers, or naturally occurring nitrate.

Isotope results indicated 4 out of the 4 samples were categorized in the mixture of human/animal waste (DEQ, 2017). Clancy is a residential community with no stockyards or animal farms, so it was reasoned that nitrates originated from human waste.

Three out of 4 of the samples included naturally occurring nitrates in the soil. Isotope samples δ ^{15}N ranged from 5.51 to 9.20 (‰); and δ ^{15}N samples ranged from -4.81 to -10.34 (‰) (Table V),(Figure 4).

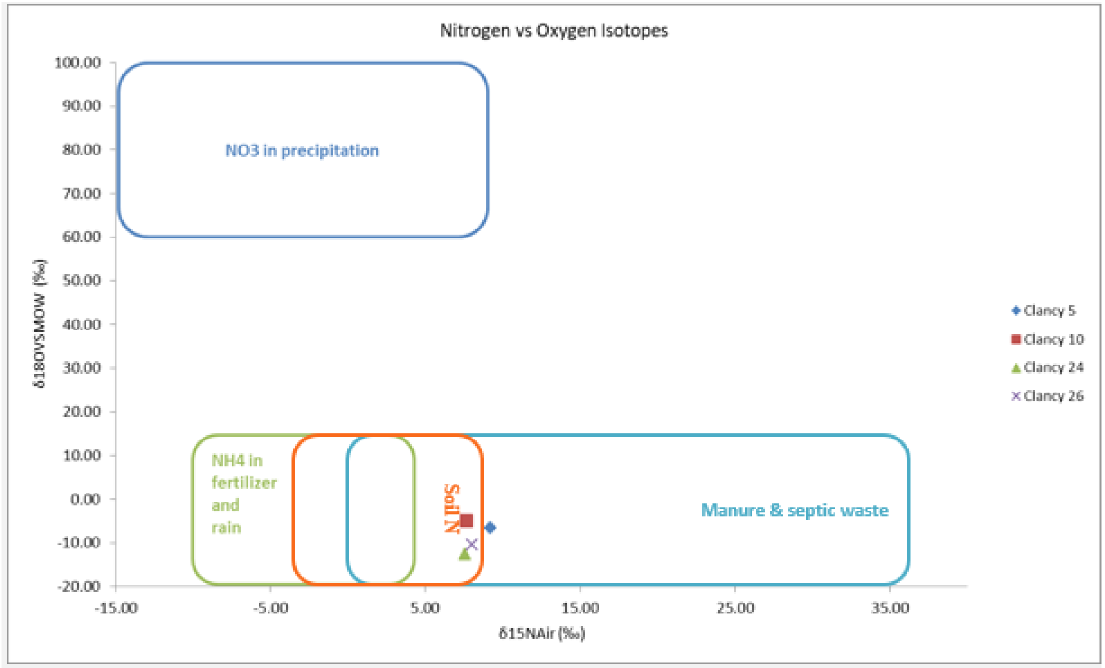

Figure 4: δ ^{15}N vs δ^{18}O Isotope Analysis of Clancy Drinking Wells (Kroon, 2017)

4.1.6. Groundwater Ammonia Analysis

Ammonia concentrations in Clancy's drinking water from on-site wells indicated minimal concentrations ranging from 0.006 to 0.022 mg/L (Table V). This indicated no fresh sewage was contaminating any of the drinking wells.

4.1.7. Groundwater Specific Conductivity Analysis

Specific conductivity in the Clancy drinking water wells ranged from 377 to 2805 µS/cm. The average specific conductivity from the study is 1008.8 µS/cm (Table V). This indicates there is a general increased level of contaminants in Clancy's drinking wells.

4.1.8. Groundwater Oxidation-Reduction Potential Analysis

Oxidation-Reduction Potential (ORP) values ranged from 107.4 mV to 355.2 mV, with an average value of 238.7 mV (Table IV). These ORP values indicate that conditions in the groundwater are favorable for the nitrification. The ORP results suggest that the conditions are not favorable for de-nitrification or the continuation of the nitrification process from nitrate to nitrogen gas.

4.1.9. Groundwater Radon-222 Analysis

Radon-222 analysis of three Clancy drinking water wells shows concentrations of radon-222 were higher than surface water. The concentrations of the three wells were 1083, 4554, and 5329 pCi/L.

4.1.10. Groundwater pH Analysis

Levels of pH in Clancy drinking water wells ranged from 6.35 to 8.89 (Table IV).

4.2 Determination of Clancy's Groundwater Flow Directions

4.2.1. Static Ground Water Level Elevations

Static water elevations in Clancy ranged from 4203 to 4290 feet and averaged 4240 feet (Table IV). During the study the Trimble GPS (R2 GNSS Receiver) surveying equipment was checked for accuracy by taking a GPS point at the Helena Montana Department of Transportation "Base Station". The average vertical precision for the study was 4.25 cm and for the horizontal precision 3.05 cm. It was determined that the Clancy's Water and Sewer District area ground water flow is generally in a northeast direction (Figure 5).

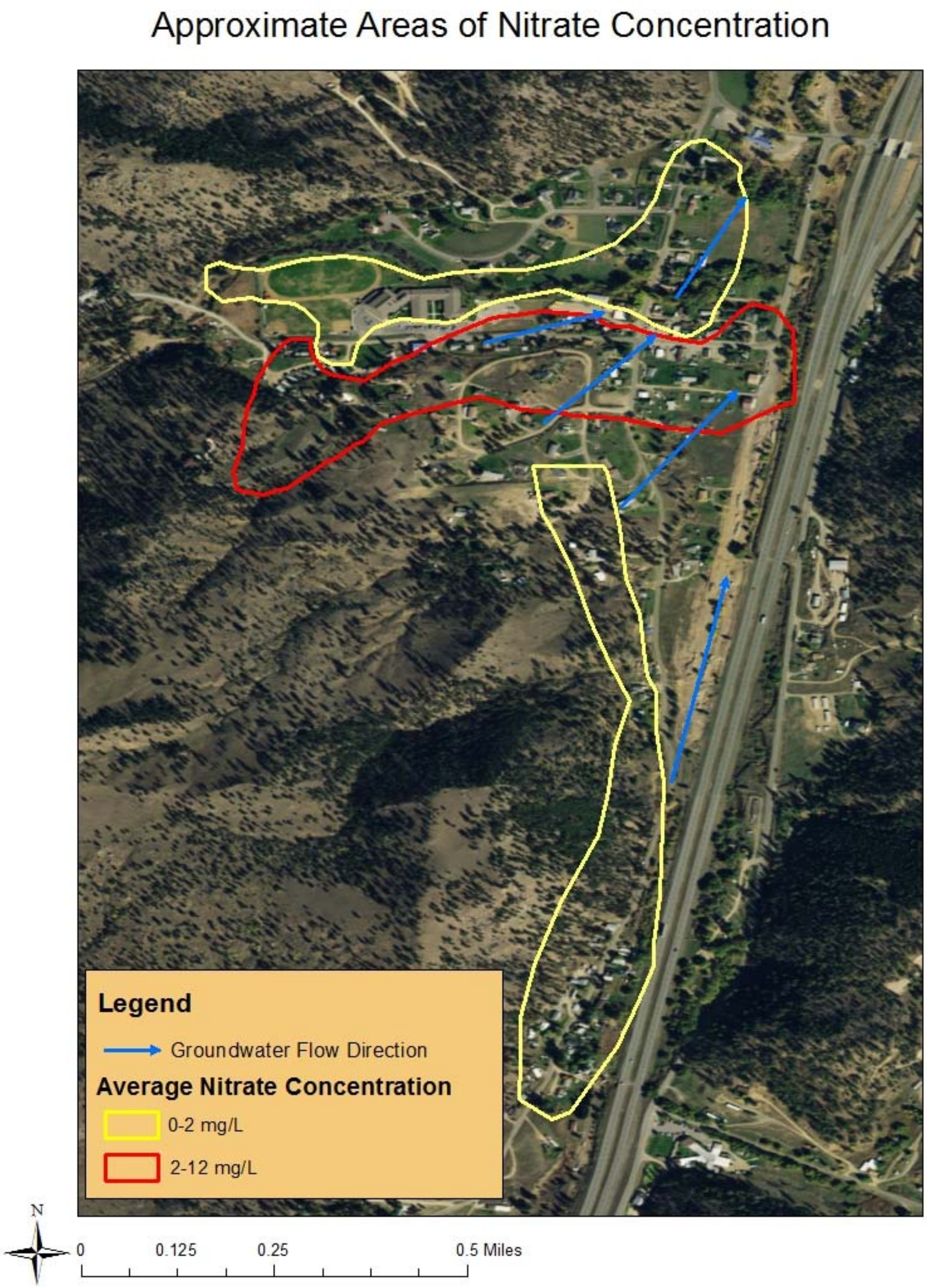

Figure 5: Ground Water Flow and Approximate Areas of Nitrate Concentration in Clancy

4.2.2. Surface Water Nitrate Levels

Average nitrate levels in Prickly Pear Creek ranged from 0.021 mg/L 1.5 miles upstream of confluence; to 0.168 mg/L 1.5 miles downstream of confluence at Clancy (Figure 6 and 7). Average Clancy Creek nitrate values range from 0.111 mg/L upstream 1.5 miles from the confluence; to 0.313 mg/L near the confluence at Clancy (Figure 6 and 8).

The Montana Department of Environmental Quality recommended total nitrogen standard for Prickly Pear Creek downstream of Clancy is 0.330 mg/L (DEQ, 2006). Total nitrogen includes organic nitrogen and inorganic nitrogen (ammonia, nitrate, and nitrite), average nitrate value alone at the confluence of Clancy and Prickly Pear Creeks is 0.313 mg/L.

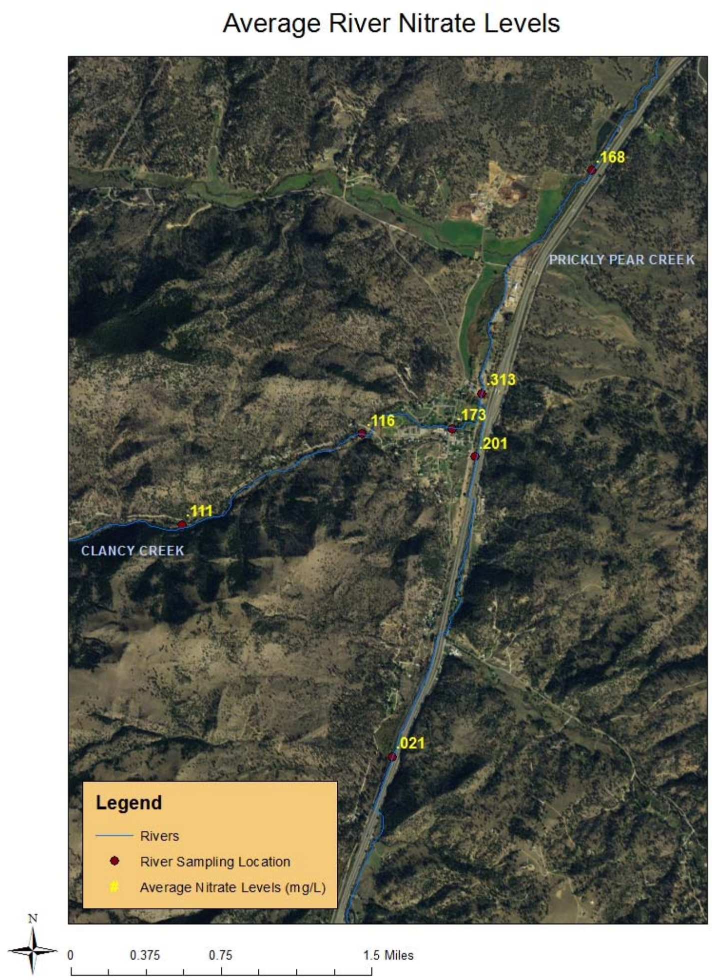

Figure 6: Prickly Pear and Clancy Creek Nitrate Average Levels

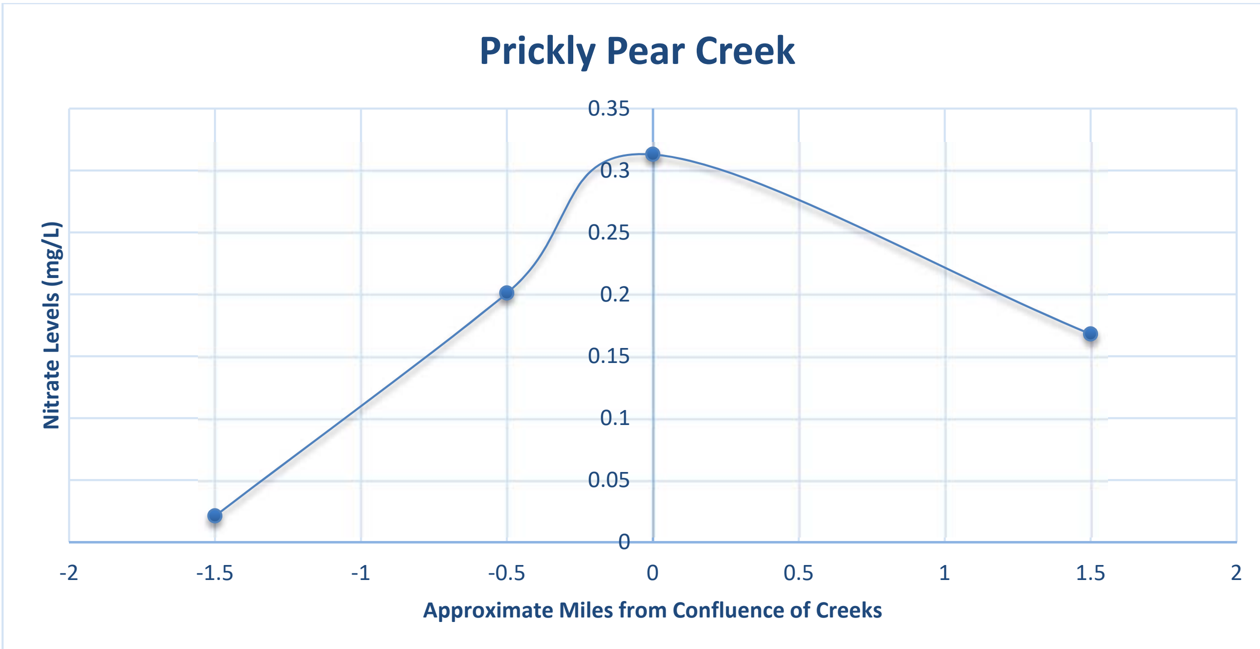

Figure 7: Prickly Pear Creek Nitrate Levels vs Distance from Confluence

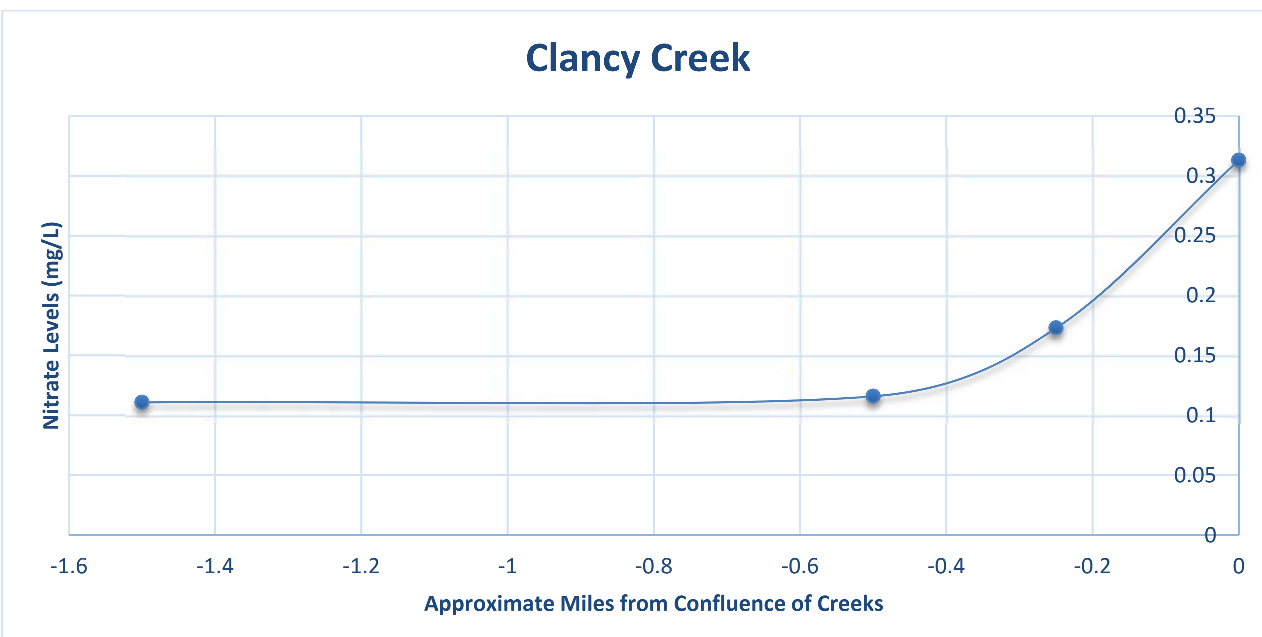

Figure 8: Clancy Creek Nitrate Levels vs Distance from Confluence

4.2.3. Radon 222 Analysis

Radon-222 analysis of Clancy and Prickly Pear Creeks provided additional support for determining if Clancy's contaminated ground water was contributing to surface water gain in both creeks. Radon-222 of 30 pCi/L and above indicates a contribution of ground water to surface water (Shaw, 2017). The radon-222 concentration results ranged from 28 to 128 pCi/L in Prickly Pear Creek with an average of 100 pCi/L. Clancy Creek concentrations ranged from 30 to 62 pCi/L with an average of 46 pCi/L (Figure 9). The results show both creeks are gaining from groundwater contribution, with the main tributary Prickly Pear Creek, having considerable more gain than Clancy Creek.

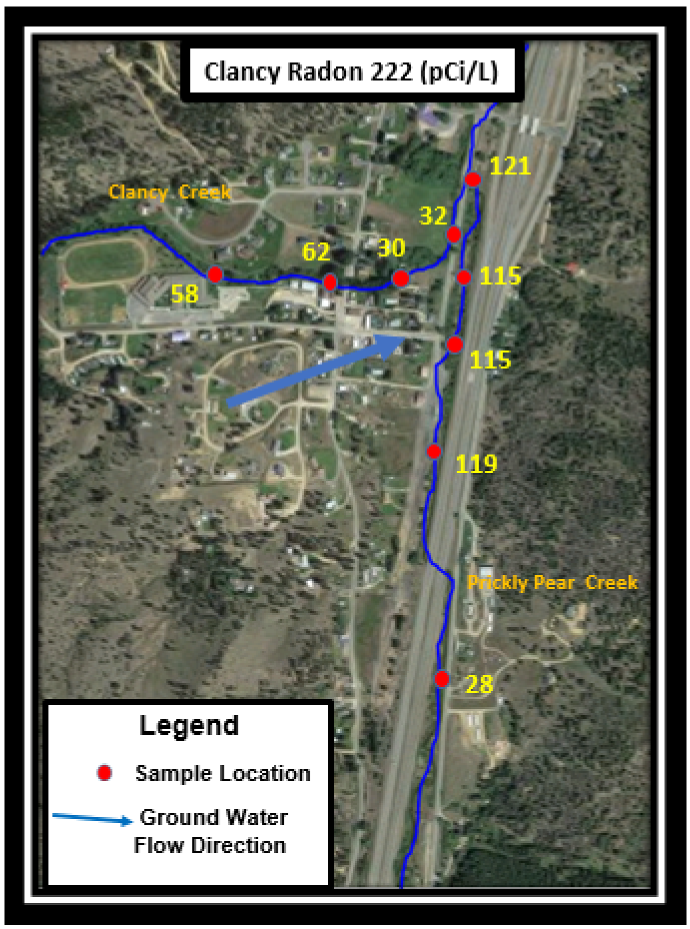

Figure 9: Radon 222 (pCi/L) Levels in Prickly Pear and Clancy Creeks

4.3 Compare the Effectiveness of Effluent Identifiers

4.3.1. Nitrate Vs Chloride

Chloride can be used as a finger print of septic effluent. (McQuillan, 2004). In comparing chloride to nitrate as a septic effluent identifier, it was found that nitrate levels less than 1 mg/L, had a slight correlation to chloride values.(Figure 10). In the comparison of chloride to nitrate values above 5 mg/L there is no correlation.(Figure 11). The correlation of chloride to nitrate occurs below 60 mg/L of chloride (Figure 10). Overall drinking water chloride has a very limited correlation with nitrate as a septic effluent identifier.

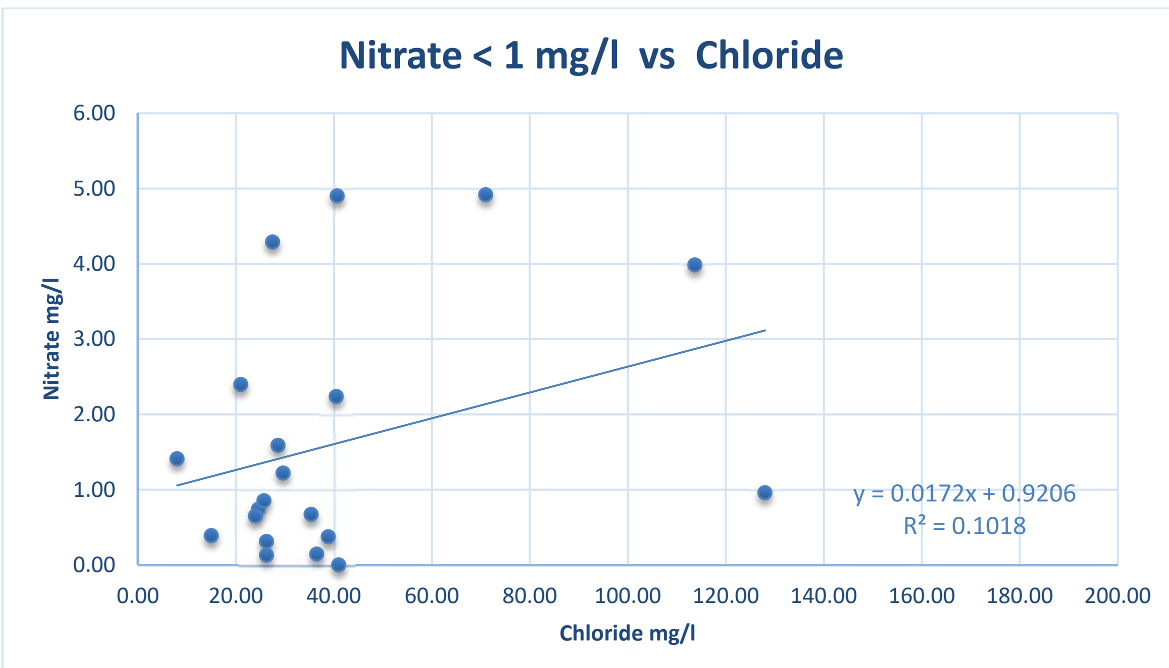

Figure 10: Nitrate < 1 mg/L Vs Chloride in Clancy Drinking Water Wells

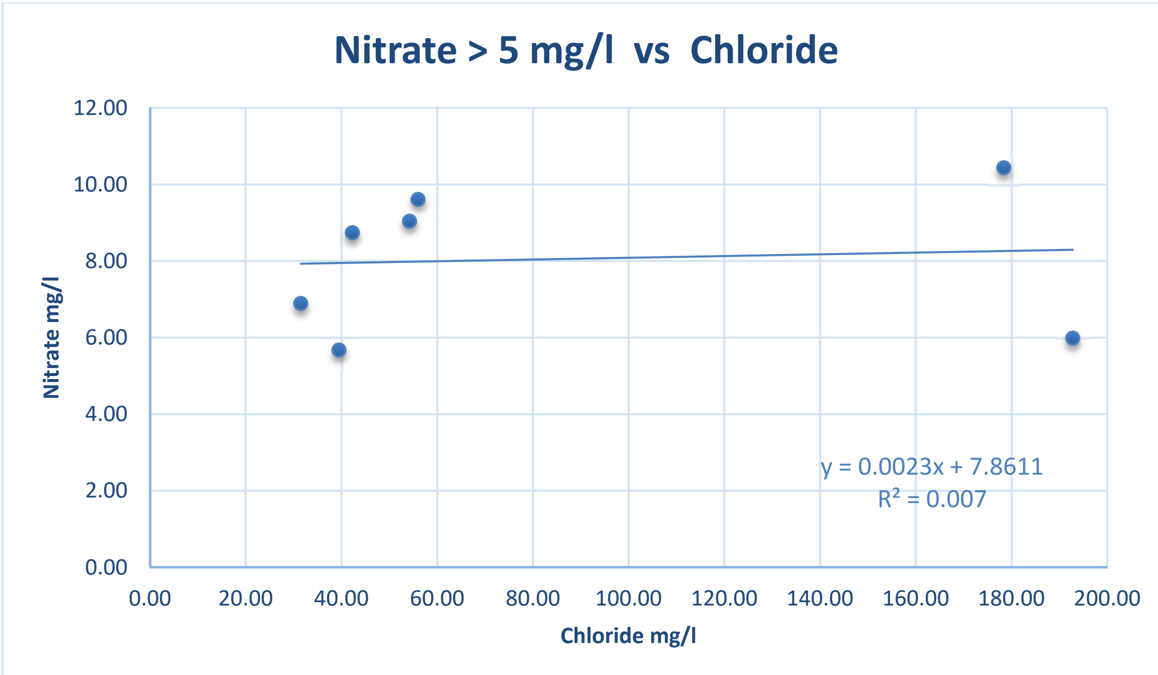

Figure 11: Nitrate > 5mg/L Vs Chloride in Clancy Drinking Water Wells

4.3.2. Nitrate Vs Specific Conductivity

Specific conductivity has little to no ability to be an indicator of septic effluent in water similar to nitrate. What minimal correlation occurs is below 1000 µs/cm of chloride. Beyond 1000 µs/cm, the comparison of nitrate to specific conductivity has no correlation (Figure 12).

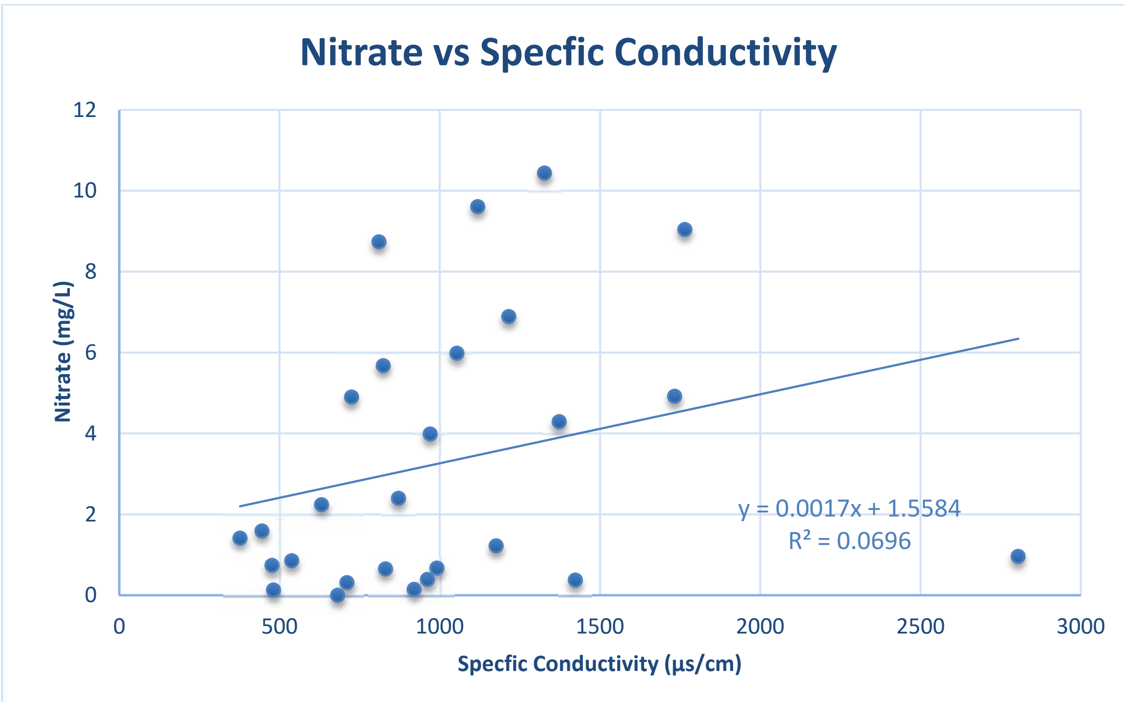

Figure 12: Nitrate vs Specific Conductivity in Clancy Drinking Water

5. Discussion of Additional Environmental Health Concerns

5.1 Water Quality Associated with Pharmaceuticals

This thesis evaluates the environmental health concerns of septic effluent contamination in drinking water wells. While focusing on the health concerns from elevated nitrate and uranium concentrations, it should also be noted that there is a growing concern of surface and groundwater contamination from pharmaceuticals.

When found in drinking water, chemicals in over-the-counter medications, personal skin care products, and prescription drugs are good indicators that septic effluent may be affecting water quality. Many ingredients found in medications and personal care products are not naturally occurring in ground water. Previous studies have confirmed the presence of pharmaceuticals in municipal wastewater effluents and residential on-site septic systems (Bhandri, 2015).

A study conducted by the U.S. Geological Survey (USGS) from 1999 to 2000 detected measurable amounts of one or more medications in 80% of the water samples drawn from a network of 139 streams in 30 states. (Buxton, 2002) Currently, the United States Environmental Protection Agency has set no maximum contamination limits on pharmaceuticals in drinking or surface waters. Some studies show adverse effects on aquatic life from pharmaceutical exposure.

Additionally the USGS and University of Missouri determined through a scientific study that birth-control hormones found in surface water can impact fish fertility for generations (Bhandri, 2015). In the study, the impact of synthetic hormone 17α-ethinylestradiol, an ingredient of most contraceptive pills, was determined to affect Japanese Medaka fish during the first week of development. While mature Medaka fish and their immediate offspring appeared unaffected, the second generation of fish struggled to fertilize eggs, while the third generation of fish had a 20% impaired fertility and survival rates (Bhandri, 2015).

In a research study conducted by the University of Boulder, Colorado, it was found that in three Colorado rivers female white suckers unnaturally outnumbered males five to one; and was also determined that 50 percent of the male white suckers had female sex tissues (Woodling, 2006). The researchers determined the effects on the fish were due to high estrogen concentrations found downstream of sewage plants. Estrogen compound was determined to be the cause of the sex alterations in the white suckers.

A study conducted by Clemson University observed fish and amphibian's exposed to waste water over long periods of time (Sowers, 2009). Fathead minnows and northern leopard frogs, both commonly found across North America were used in the research. These aquatic species were exposed to with endocrine disruptors found within the waste water. The results indicated that long-term exposure to wastewater effluent containing endocrine disruptors, can interfere with the sexual development of the fathead minnow and leopard frogs.

In a study conducted on the bioaccumulation of pharmaceuticals and personal care product chemicals (PPCPs) in the Great Lakes Cootes Paradise Marsh, an urban wetland that receives treated municipal waste waters as well as urban storm runoff. Gold fish and carp were found to have detectable levels of pharmaceuticals and PPCP's in the fish's circulatory system, some of these included ibuprofen and caffeine (Muir, 2017).

As pharmaceutical and personal care product use increases across the United States and the world, the human health effects from these chemicals will likely have to be addressed. It has been shown in the previously mentioned research projects that pharmaceutical products such as estrogen and synthetic hormones can cause reproductive disorders of lower vertebrates such as fish and amphibians. It is yet unknown the long term effects that pharmaceuticals in drinking water will have on human health and reproduction.

6. Conclusions

Clancy's residential drinking water quality research indicates that drinking wells are contaminated by both nitrate and uranium. Nitrate and uranium concentrations both exceeded the Environmental Protection Agency Maximum Contaminant Limits (EPAMCL). In 18% of Clancy's drinking water wells, nitrate exceeded the EPAMCL, and uranium concentrations exceeded the EPAMCL in 37 % of Clancy's drinking wells.

Groundwater flow determination is important in understanding Clancy's septic effluent transport in groundwater, and the potential in affecting area surface water. Clancy's groundwater flows were determined to be in a northeast direction. The northeast direction of ground water travel is toward the confluence of Prickly Pear and Clancy Creeks.

Nitrate concentrations were found to increase substantially in Prickly Pear and Clancy Creek as the creeks flow through the community of Clancy. The nitrate concentrations at the confluence of the creeks approach the Montana Department of Environmental Quality standard for total nitrogen. Radon-222 analysis determined groundwater flowing through Clancy was contributing to both Prickly Pear and Clancy Creeks. It is concluded from the elevated nitrate concentrations and groundwater contribution, that the creeks are likely experiencing elevated nitrate concentrations from Clancy's septic effluent.

Chloride shows a slight association to nitrate as a septic effluent identifier; below 60 mg/L of chloride. Specific Conductivity shows a minor relationship to nitrate below 1000µs/cm of specific conductivity. Overall the correlation between specific conductivity and chloride to nitrate as a septic effluent indictor is very limited.

In the Clancy project, specific conductivity had an elevated average value of 1008.8 µs/cm, when compared to the national average range of 50 to 800 µs/cm. Nitrate concentrations exceeded the EPAMCL in particular areas within Clancy. The average Clancy drinking water nitrate concentration of 3.28 mg/L is significantly higher than the natural (or back ground) nitrate concentrations of 0.6 mg/L found in southwestern Montana.

Isotope $\delta\ ^{15}N$ and $\delta^{18}O$ analysis of four of Clancy's drinking wells, gave a reasonable indication that one source of nitrates was from human and animal waste. Clancy is a residential community with no large scale livestock operations to contribute to the elevated nitrate concentrations in the groundwater. Human septic waste rather than animal waste was then determined to be a source of nitrate contamination through the isotope $\delta\ ^{15}N$ and $\delta^{18}O$ analysis.

Through the data obtained in the research project it was determined Clancy's on-site drinking water quality was affected by septic system effluent. Elevated specific conductivity and nitrate concentrations, along with isotope $\delta\ ^{15}N$ and $\delta^{18}O$ analysis supported this assessment of Clancy's drinking water quality.

7. Recommendations

Many rural communities in Montana and across the United States are in need of quality drinking water, but smaller communities are unable to afford water or sewer treatment facilities. Drinking water quality concerns are often related to contamination from on-site septic systems, especially in communities that have been established for some time. Being able to provide smaller municipalities with affordable means to accurately assess drinking water quality can be achieved through selected methods applied in the Clancy research project.

Recommendations for efficiently analyzing drinking water quality affected by septic effluent would be to use the following methods:

1) Initially conduct a wide spatial residential drinking water sampling and analyze for nitrate (NO_3-N). This should preferably be conducted in the spring (April, May) when nitrate levels tend to be the highest in water wells due to runoff from winter snow melt, as determined in the Clancy water project.
2) Spatially apply Isotope $\delta\ ^{15}N$ and $\delta^{18}O$ analysis to areas with elevated levels of nitrate concentrations in drinking wells. This will aid in determining if nitrates are derived from human/animal waste, fertilizer, or naturally occurring.
3) If isotope $\delta\ ^{15}N$ and $\delta^{18}O$ analysis indicates the presence of nitrates from human/animal waste; then analyze drinking water samples for pharmaceuticals in water wells with the highest nitrate concentrations. The pharmaceutical analysis should focus on common household compounds that are not found naturally in groundwater, such as salicylic acid, estrogen, and caffeine.

4) Combine all the above data to evaluate the health risks, and distribute the data to the community. If surface water such as streams, rivers, and lakes become in question of being contaminated from septic effluent, it would be suggested to conduct spatial nitrate analysis of the waterways within and outside the community boundaries to compare nitrate concentrations.
5) Along with nitrate testing in the surface waters adjacent to the community, radon-222 analysis should be conducted to assist in determining if contaminated groundwater is contributing to surface water and affecting the surface water quality.

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9. Appendix: Clancy's Groundwater and Surface Water Analysis

Table V: Clancy Monthly Average Drinking Water Analysis (Feb-July 2017)

Water Elevation ft	Nitrate	Chloride	Specific Conductivity	Uranium
4249.7	8.74	42.30	810.68	15.8
4234.8	9.61	56.00	1118.80	9.38
4222.5	0.74	24.63	476.70	5.13
4226.6	0.13	26.25	481.28	2.56
4223.8	1.59	28.60	445.40	2.64
4224.5	5.68	39.50	824.06	6.45
4239.5	10.44	178.40	1327.04	34.2
	9.04	54.25	1764.66	18
	4.90	40.70	725.02	3.72
4255.9	0.31	26.25	710.85	3.21
	2.24	40.50	631.10	
4203.2	2.40	21.00	871.60	39.7
	5.98	192.81	1053.66	11.1
	0.67	25.75	991.37	43.7
4246.3	0.85	35.38	538.38	40.9
4262.6	1.22	29.67	1175.87	10.7
	0.39	15.00	961.65	
4267.1	0.37	38.88	1423.33	7.68
	0.65	24.00	831.05	
4227.8	4.92	71.00	1733.05	42.8
4218.8	3.99	113.70	970.50	77.3
4252.2	1.41	8.00	377.00	
4290.1	0.96	128.00	2804.70	102
	6.89	31.50	1215.60	10.4
4231.9	0.14	36.50	920.50	2.28
	4.29	27.50	1372.90	
	0.00	41.00	681.70	

Table VI: Clancy Monthly Average Nitrate Levels in Drinking Water

Clancy Monthly Average	
Drinking Well Water Nitrate Levels	
Month	**Nitrate Levels (mg/L)**
February	**2.89**
April*	**6.29**
May*	**4.37**
June	**3.64**
July	**3.76**

***Highest Nitrate Concentrations**

Table VII: Clancy Drinking Water δ ^{15}N / δ^{18}O Isotope Values

Sample	ID	δ ^{15}N (‰)	δ^{18}O $_{VSMOW}$ (‰)
1	Clancy 5	9.20	-6.44
2	Clancy 10	7.61	-4.81
3	Clancy 24	7.51	-12.54
4	Clancy 26	7.98	-10.34

Table VIII: Prickly Pear Creek Nitrate Levels Vs Approximate Distance from Confluence

Approx. Miles from Confluence	Nitrate Levels - Prickly Pear Creek (mg/L)
-1.5	0.021
-0.5	0.201
0.0	0.313
1.5	0.168

Table IX: Clancy Creek Nitrate Levels Vs Approximate Distance from Confluence

Approx. Miles from Confluence	Nitrate Levels - Clancy Creek (mg/L)
-1.50	0.111
-0.50	0.116
-0.25	0.173
0.00	0.313

Table X: Prickly Pear Creek Radon 222 Levels Vs Approximate Distance from Confluence

Approx. Miles from Confluence	Radon 222 Levels - Prickly Pear Creek (pCi/L)
1.00	28.0
0.50	119.0
0.40	115.0
0.25	115.0
0.00	12.01

Table XI: Clancy Creek Radon 222 Levels Vs Approximate Distance from Confluence

Approx. Miles from Confluence	Radon 222 Levels - Clancy Creek (pCi/L)
0.50	58.0
0.40	62.0
0.35	30.0
0.25	32.0

SIGNATURE PAGE

This is to certify that the thesis prepared by Matt Strozewski entitled

"ANALYSIS of CLANCY DRINKING WATER CONTAMINATION from ON–SITE SEPTIC SYSTEM EFFLUENT"

has been examined and approved for acceptance by the Department of Environmental Engineering, Montana Tech of The University of Montana, on this 19th day of April, 2018.

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