Teton
Conservation
District
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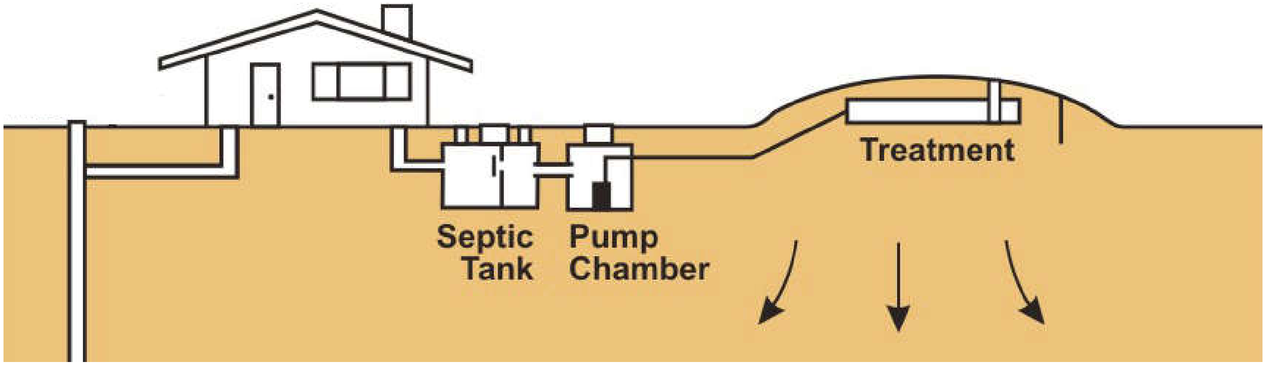
TETON COUNTY SEPTIC SYSTEM
EFFLUENT MONITORING
REPORT

Prepared for:

TETON CONSERVATION DISTRICT



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1. Introduction

The Teton County Septic System Effluent Monitoring Project is an investigation into septic system impact on groundwater given the relative uncertainty surrounding the treatment potential of commonly used residential leachfield designs. Septic tanks remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter. Septic tank effluent, which contains significant concentrations of pathogens, Ammonia, and other nutrients, has traditionally been discharged to soil media absorption fields (leachfields) for further treatment through biological processes (nitrification and denitrification), adsorption, filtration, and infiltration into underlying soils. These systems work well if they are installed in areas with appropriate soils and hydraulic capacities, are designed to treat the incoming waste load to meet public health, groundwater, and surface water performance standards, are installed properly, and are maintained to ensure long-term performance.

In Teton County many systems are located close to groundwater, four feet regulatory minimum, in coarse alluvial soils. These conditions, in combination with the cold climate, create a condition where onsite system installations might not be adequate for minimizing Nitrate contamination of groundwater, removing Phosphorus compounds, and attenuating pathogenic organisms (e.g., bacteria, viruses) in this four-foot vadose zone. Nitrates that leach into groundwater used as a drinking water source can cause methemoglobinemia, also known as “blue baby syndrome”. Nitrates and Phosphorus discharged into surface waters directly or through subsurface flows can spur algal growth and lead to eutrophication and low Dissolved Oxygen in creeks and rivers. In addition, pathogens reaching groundwater or surface waters can cause human disease through direct consumption or recreational contact.

The intent of the Septic System Effluent Monitoring Project is to determine the impact of typical septic tank soil absorption systems on groundwater in Teton County, WY. With this stated purpose in mind and the fact that residents have expressed concern about nutrient and pathogen contamination of drinking water supplies and the overall nutrient contribution to the groundwater and the subsequent impact on surface water, the Teton Conservation District and Teton County jointly funded this effort, the result of which is contained herein.

Project Timeline

In June of 2019, the Teton Conservation District issued a Request for Proposals (RFP) for the work. The Nelson Engineering Team, consisting of Nelson Engineering and Alder Environmental LLC, responded to the request in July of 2019, and after consideration was awarded the work in August of 2019 with an amended scope of service (described in detail later in this section). A kick off meeting was held in November of 2019 to discuss the scope of services, the sampling plan, and the selection of probable properties for installation of monitoring wells.

A solicitation for volunteers was drafted and released to the public in December of 2019. Only a handful of responses were received, so additional research and more pointed and direct requests were required in order to obtain a list of suitable candidates.

Four primary or preferred sites and four secondary sites were then chosen for site visits and detailed evaluation. The criteria for the selection of a site included the following:

- the system should have documented design records, installation inspections and regular maintenance to reduce the number of variables that could invalidate the statistical analysis of the monitoring program;
- the leachfield should be situated above relatively shallow groundwater (10 feet deep or less) to facilitate easier installation and sampling of the groundwater;
- the system should serve two or more full-time residents;
- the age of the system should be between 5 and 30 years, rather than brand new construction, ensuring a healthy and functioning biomat is in place; and
- ideal sites would have relatively open space downgradient from the leachfield for placement of monitoring wells.

Site visits were conducted from May through August of 2020, four sites with raised mound distribution systems in place were chosen, and temporary well and access easement and agreement documents were executed. Installation of the monitoring wells occurred in August and September of 2020. Sampling began in October of 2020. Five additional months of sampling were added by contract amendment, extending the sampling through March of 2022. Reclamation of the sites took place in late spring of 2022.

Amended Scope of Services

PARAMETERS TO BE SAMPLED

The initial project scope required that the parameters to be sampled would be as follows:

- Field parameters (Specific Conductivity, pH, temperature, and Dissolved Oxygen)
- Laboratory analysis (Nitrate, Nitrite, Ammonia, Orthophosphate, Phosphorus, Chloride, and E.coli)

The Team agreed with the listed field parameters but was of the opinion that the laboratory analysis included parameters that would not apply to all sampling points given the constituents of the typical wastewater and the biological process that occur in a septic system. The following is a table showing the typical composition of untreated domestic wastewater for the parameters listed in the RFP.

TABLE 1-1 Typical Composition of Untreated Domestic Wastewater

Parameter	Unit	Low (1) Strength	Medium (1) Strength	High (1) Strength	Typical Teton Village
Nitrogen, Total	mg/l	20	40	70	30-40
Ammonia	mg/l	12	25	45	25-30
Nitrates	mg/l	0	0	0	0-2
Nitrites	mg/l	0	0	0	0
Total Phosphorus	mg/l	4	7	12	7-12
Chlorides	mg/l	30	50	90	77

(1) Wastewater Engineering Treatment and Reuse, Metcalf & Eddy, Fourth Edition, Table 3-15

The Ammonia concentration in effluent from a septic tank is typically higher than raw wastewater, because the organic Nitrogen is broken down anaerobically to Ammonia resulting in average Ammonia levels of 40 mg/l. Some of the Phosphate will precipitate out in a septic tank thus reducing the Total Phosphorus concentration in the septic tank effluent. Literature and experience indicate that there would not be any measurable Nitrates or Nitrites in the septic tank effluent. The Team understood that the purpose of requesting sampling and testing for total coliform and E. coli was to determine if pathogens could be transmitted to groundwater from the wastewater but proposed to test only for E. coli in the groundwater, anticipating that there would be total coliform in the shallow groundwater from other natural sources regardless of the septic systems. The Team also anticipated that E. coli in a septic tank would be “too numerous to count”, and therefore the test results would not provide useful data.

PROPOSED SAMPLING

- Septic Tank Effluent- The Team proposed to sample and test the field parameter, with the exception of Dissolved Oxygen, which should not be present, and proposed to test for Ammonia, Total Phosphate, and Chlorides. The purpose of the lab tests was primarily to determine the concentration of the constituents being applied to the leachfield. The Team did not propose to sample and test for E. coli or total coliform, again, believing the colonies to be too numerous to count.
- Leachfield- The leachfield monitoring points were proposed as two lysimeters and one monitoring well. The lysimeters would be set at 1’± and 3’± below the bottom of the leachfield; the parameters tested would be all the field parameters plus Ammonia, Nitrate, Total Phosphate, Chlorides, and E. coli. The purpose of the lysimeter testing was to determine if the nitrification process in the upper section of the leachfield was converting the Ammonia to Nitrate and if the anoxic zone below was effectively converting Nitrates to Nitrogen gas during all seasons. The monitoring well in the leachfield allowed for sampling of groundwater directly below the leachfield prior to substantial dilution. Parameters tested in the leachfield monitoring well included all of the field parameters plus Ammonia, Nitrate, Orthophosphate, Total Phosphate, Chlorides, and E. coli.
- Monitoring Wells- The Team proposed one upgradient monitoring well to determine the background water quality prior to the septic system, three monitoring wells downgradient and about 10 feet from the leachfield, and two monitoring wells downgradient and about 50 feet from the leachfield. The Team initially did not believe that it would be necessary to sample each of the wells 10 feet downgradient of the leachfield every month of the year, and based on the gradient, proposed sampling just two of the three wells to reduce the overall number of samples. The Team anticipated that irrigation ditches and surface water ponds could affect the groundwater gradient and that the gradient would shift seasonally; once the direction of groundwater movement was determined, it was thought that it could be possible to strategically eliminate the sampling of one or more of the downgradient wells thus reducing field time and laboratory costs. Ultimately, all downgradient wells were sampled monthly. Parameters tested in the groundwater monitoring wells included all of the field parameters plus Ammonia, Nitrate, Orthophosphate, Total Phosphate, Chlorides, and E. coli.

TABLE 1-2 Summary of Proposed (Amended) Sampling Sites and Laboratory Analysis

Sampling Location	No. of Sampling Points	LABORATORY ANALYSIS PARAMETERS				
		Nitrogen, Ammonia as N	Phosphorus, Total	Chloride	Nitrogen, Nitrate as N	E. coli
SEPTIC TANK						
Effluent	1	1	1	1		
LEACHFIELD						
Lysimeters (-1' and -3')	2	2	2	2	2	2
Groundwater	1	1	1	1	1	1
GROUNDWATER						
Upgradient	1	1	1	1	1	1
Downgradient (10')	3	3	3	3	3	3
Downgradient (50')	2	2	2	2	2	2
TOTAL PER SITE	**10**	**10**	**10**	**10**	**9**	**9**
MAX PER FOUR SITES	**40**	**40**	**40**	**40**	**36**	**36**

SEPTIC SYSTEM SITES

The initial project scope required that six sites be sampled – three pressurized or raised systems and three traditional, gravity systems in locations with relatively shallow groundwater for a one-year period.

The Team was of the opinion that the number of septic systems to be monitored could be reduced, but the minimum number should be four to ensure statistically accurate results. From there the plan was to select two septic systems that were conventional gravity systems with a good distribution system, and two raised mound pressure distribution systems; however, since the focus was shallow groundwater applications (10 feet deep or less) to facilitate easier installation and sampling of the groundwater, a decision was made to choose raised mound systems instead. (Two systems consisted of leachfields constructed of pipe and gravel and two were constructed using drain tiles or standard infiltrator units to distribute the effluent.) All four systems would be required to have documented design records, installation inspections, and regular maintenance, as previously mentioned, to ensure that the systems to be monitored were properly designed and constructed and maintained on a regular basis. Monitoring a system that was not properly designed, installed or maintained, would insert additional variables that could invalidate the statistical analysis of the monitoring program.

2. Onsite Wastewater Treatment System

A conventional onsite wastewater treatment system consists of a septic tank and subsurface infiltration system, which discharges to groundwater and usually relies on the unsaturated or vadose zone for final polishing of the wastewater before it enters the saturated zone.

A septic system is a highly efficient, self-contained, underground wastewater treatment system. Because septic systems treat and dispose of household wastewater onsite, they are often more economical than centralized sewer systems in rural areas where lot sizes are larger and houses are spaced widely apart. Septic systems are also simple in design, which make them generally less expensive to install and maintain. And by using natural processes to treat the wastewater onsite, usually in a homeowner's backyard, septic systems don't require the installation of miles of sewer lines, making them less disruptive to the environment.

A septic system consists of two main parts: a septic tank and a drainfield. The septic tank is a watertight box, usually made of concrete, with an inlet and outlet pipe. Wastewater flows from the home to the septic tank through the sewer pipe. The septic tank treats the wastewater naturally by holding it in the tank long enough for solids and liquids to separate. The wastewater forms three layers inside the tank. Solids lighter than water (such as greases and oils) float to the top forming a layer of scum. Solids heavier than water settle at the bottom of the tank forming a layer of sludge. This leaves a middle layer of partially clarified wastewater.

The layers of sludge and scum remain in the septic tank where anaerobic bacteria found naturally in the wastewater work to break the solids down. The sludge and scum that cannot be broken down are retained in the tank until the tank is pumped. The layer of clarified liquid flows from the septic tank to the drainfield or to a distribution device, which helps to uniformly distribute the wastewater in the drainfield. A standard drainfield (also known as a leachfield, disposal field, or a soil absorption system) is a series of trenches or a bed lined with gravel or coarse sand and buried one to three feet below the ground surface. Perforated pipes or drain tiles run through the trenches to distribute the wastewater. The drainfield treats the wastewater by allowing it to slowly trickle from the pipes out into the gravel and down through the soil. The gravel and soil act as biological filters.

INFLUENT WASTEWATER CHARACTERISTICS

Potential groundwater pollutants from septic tank systems are primarily those associated with domestic wastewater. Contaminants originating from sewer system cleaning can also contribute to groundwater pollution potential of septic tank systems. Based on numerous studies, the volume of wastewater introduced to a septic tank system for a residential household may range from 26 to 85 gallons/person/day (gpcd). A study published in the "USEPA Onsite Wastewater Treatment Systems Manual"(2) of 1188 residential houses showed a mean per capita daily indoor use of 69.3 gpcd, a median of 60.5 gpcd, with a standard deviation of 39.6 gpcd. Leaks in household water fixtures discharging to the sewer system and infiltration/inflow in the sewer system may contribute to the influent flow to the septic tank.

Maximum and minimum flows and instantaneous peak flow variations are necessary factors in properly sizing and designing septic systems. The system should be capable of accepting and treating normal peak events without compromising performance. Peak flows for sizing sewer systems are typically determined by summation of fixture units in accordance with the International Plumbing Code. Septic tanks in Wyoming are sized to provide 40+ hours of detention time based on 150 gpd per bedroom with a minimum septic tank size of 1000 gallons. While this capacity may seem like much more than is necessary, given the average gallons per capita per day, the volume is calculated to provide room for solids build up on the bottom and scum accumulation on the surface, leaving sufficient capacity for anaerobic digestion of the wastewater without frequent pumping or cleaning of the tank.

The quality characteristics of wastewater entering septic tank systems are summarized in the following table taken from the USEPA Onsite Wastewater Treatment Systems Manual(2).

TABLE 2-1 Constituent Mass Loadings and Concentrations in Typical Residential Wastewater [a]

Constituent		**Mass Loading (grams/person/day)**	**Concentration [b] (mg/L)**
Total Solids (TS)		115-200	500-800
Volatile Solids (VS)		65-85	280-375
Total Suspended Solids (TSS)		35-75	155-330
Volatile Suspended Solids (VSS)		25-60	110-265
5-day Biochemical Oxygen Demand (BOD_5)		35-65	155-286
Chemical Oxygen Demand (COD)		115-150	500-660
Total Nitrogen (TN)		6-17	26-75
Ammonia (NH_4)		1-3	4-13
Nitrites and Nitrates (NO_2-N; NO_3-N)		<1	<1
Total Phosphorus (TP)[c]		1-2	6-12
Fats, Oils and Grease (FOG)		12-18	70-105
Volatile Organic Compounds (VOC)		0.02-0.07	0.1-0.3
Surfactants		2-4	9-18
Total Coliforms (TC)[d]		-	10^8-10^{10}
Fecal Coliforms (FC)[d]		-	10^6-10^8
[a] For typical residential dwellings equipped with standard water using fixtures and appliances			
[b] Milligrams per liter; assumed water use of 60 gpcd			
[c] The detergent industry has lowered the TP concentrations since early studies therefore Sedlak (1991) was used for TP data			
[d] Concentrations presented in Most Probable Number of organisms per 100 milliliters (MPN)			
Source: Adapted from Bauer et al., 1979; Bennett and Linstet, 1975; Laak, 1975, 1986; Sedlak, 1991; Tchobanoglous and Burton, 1991.			

The physical and chemical constituents in septic tank influents are reasonably comparable in their concentrations to medium strength community domestic wastewater. Bacteria counts in household wastewater tend to be lower than in community wastewater, with a possible cause being a shorter incubation time from the source to the septic tank in comparison with time from the source to the community treatment plant.

SEPTIC TANK TREATMENT EFFICIENCY

Numerous studies have been made of the treatment efficiencies and effluent qualities from septic tanks, with fewer reported studies related to soil absorption systems efficiencies.

The septic tank serves several important functions such as solid-liquid separation, storage of solids and floatable materials, and anaerobic treatment of both stored solids as well as non-settleable organic materials. Previous studies have shown that the treatment efficiency of the septic tanks is variable, probably due to the fact that most of the residential wastewater is discharged to the septic tank in a short period of time, four to eight hours, thus reducing the effective detention time in a tank sized for daily flow.

The treatment processes that contribute to the septic tank treatment efficiency is settling of the solids and anaerobic digestion of the settled biosolids. These processes remove up to 50% of the BOD_5 resulting in an effluent that is primarily soluble BOD_5.

The Total Nitrogen (organic plus Ammonia) in the septic tank influent averages 40 mg/l with 32% in the Ammonium form. Anaerobic digestion of the organic Nitrogen converts most of the Nitrogen to the Ammonium form. Therefore, the septic tank is ineffective in Nitrogen removal, but it does cause conversion of organic Nitrogen to Ammonium. The Nitrates concentration in septic tank effluents is low due to the lack of Oxygen in that environment.

The anaerobic digestion process occurring in the septic tank converts most of the influent phosphorous, both organic and condensed Phosphate forms, to soluble Orthophosphate. Septic tanks are not highly efficient in Phosphorus removal.

Based on the composite information from 41 tank systems the following table represents typical physical and chemical parameter effluent concentrations from septic tanks.

TABLE 2-2 Summary of Effluent Quality from Various Septic Tank Studies [a]

Parameter		**Sample-Weighted Average** [b]
Suspended Solids		77 mg/l
BOD_5		142 mg/l
COD		296 mg/l
Total Nitrogen		42 mg/l
Total Phosphorous		15 mg/l

[a] Septic Tank System Effects on Ground Water Quality, Canter and Knox, 1985(3)

[b] Calculated from 5 studies of 41 septic tanks

As temperature decreases, so does microbial activity. It has been found that microbes in wastewater become dormant from 35 to 39°F. Temperature also affect the flow and mixing characteristics in the septic tank. Very little research evaluating septic tank treatment at varying temperatures is available. However, on study of the anaerobic digestion of septic tanks and temperature effects at 41°F, 50°F, and 68°F found organic removal efficiency impact are minimal at higher hydraulic retention times. This is a positive outcome for cold climates with larger septic tank capacities. The septic tank at 68°F consistently achieves higher levels of performance compared to tanks a 41°F and 50°F. The septic tank operating at 41°F was the most affected by hydraulic retention time changes (Viraraghavan and Dickenson, 1991)(4).

SOIL ABSORPTION SYSTEM EFFICIENCY

Pretreated wastewater from the septic tank enters the subsurface infiltration system at the surface of the infiltration zone. A biological layer (biomat) forms in this zone, which usually is only a few centimeters thick. Most of the physical, chemical and biological treatment of the pretreated effluent occurs in this zone and in the vadose zone below the biomat. Particulate matter in the septic tank effluent accumulates on the infiltrative surface and within the pores of the soil matrix, providing a source of carbon and nutrients to the active biomass. New biomass and its metabolic by-products accumulate in this zone. The accumulated biomass, particulate matter, and metabolic by-products reduce the porosity and the infiltration rate through them. Thus, the infiltration zone is a transitional zone where fluid flow changes from saturated to unsaturated flow. The biomat controls the rate at which the pretreated wastewater moves through the infiltration zone in coarse to medium textured soils, but it is less likely to control the flow through fine textured silt and clay soils because they may be more restrictive to flow than the biomat.

Nitrogen

The transport and fate of Ammonium ions may involve adsorption, cation exchange, incorporation in microbial biomass, or release to the atmosphere in the gaseous form. The effluent from the septic tank is spread over a sand layer at the upper level of the drainfield. The suspended solids, organic material, and bacteria accumulate on the sand creating a thin layer (2-3 mm) of biomass. The aerobic bacteria in the biomass digest the organic material and convert the Ammonia to Nitrate.

Anaerobic conditions will normally prevail below the upper layers of soil beneath the soil absorption system but above the groundwater. Under these conditions, positively charged Ammonium ions (NH_4^+) are readily adsorbed onto negatively charged particles.

Nitrates can be formed by nitrification, the conversion of Ammonium ion to Nitrites and to Nitrates. Nitrification (NH_4^+ to NO_2^- to NO_3^-) is an aerobic reaction performed primarily by autotrophic organisms, and Nitrate is the predominant end product. Nitrification is dependent on the aeration of the soil which in turn is dependent on the soil characteristics, percolation rate, loading rate, and distance to groundwater. Effluent from septic systems located in sandy soils can be expected to undergo predominately aerobic reactions.

Denitrification is another important Nitrogen transformation in the subsurface environment underlying septic tank systems. It is the only mechanism by which the NO_3^- concentration in the percolating (and oxidized) effluent can be decreased. Denitrification, or the reduction of NO_3 to NO_2 or N_2, is a biological process performed primarily by ubiquitous facultative heterotrophs. In the absence of O_2, NO_3^- acts as an acceptor of electrons generated in the microbial decomposition of an energy source. However, in order for the denitrification to occur in soils beneath a home waste disposal system, the Nitrogen must usually be in the NO_3^- form and an energy source (organic carbon) must be available. Therefore nitrification, an aerobic reaction, must occur before denitrification. (Septic Tank System Effects on Ground Water Quality, Canter and Knox, 1985)(3).

Like other biochemical reactions, microbial nitrification and denitrification activity is affected by temperature. The activity increases with reaction temperature, and nitrification/denitrification is limited when wastewater temperature and soil temperature is below 10°C (Water Environment Federation, 1998)(5).

Nitrogen in the form of Nitrate will become very mobile if it reaches the groundwater because of its solubility and anionic form. Nitrates can move with groundwater with minimal transformation. They can migrate long distances from input areas if there are highly permeable subsurface materials which contain Dissolved Oxygen. (Septic Tank System Effects on Ground Water Quality, Canter and Knox, 1985)(3).

Chlorides

Chlorides are natural constituents in groundwater and household wastewater. Septic systems are ineffective for Chloride removal. Due to their anionic form (Cl^-) and mobility with the water, Chlorides can be useful as a tracer or indicator of septic tank system pollution.

Phosphorus

The anaerobic digestion process occurring in the septic tank converts most of the influent Phosphorus, both organic and condensed Phosphate forms, to soluble Orthophosphate. Septic tank portion of septic tank systems are not highly efficient in Phosphorus removals. (Septic Tank System Effects on Ground Water Quality, Canter and Knox, 1985)(3).

While Phosphorus can move through soils underlying soil absorption systems and reach groundwater, this has not been a major concern since Phosphorus can easily be retained in the underlying soils due to chemical changes and adsorption.

Biological Contaminants

The potential for biological contamination of groundwater by percolation from septic tank systems is high. Biological contaminates (pathogens) have a wide variety of physical and biological characteristics, including wide ranges in sizes, shape, surface properties, and die-away rates. There have been numerous studies of the transport and fate of bacteria and viruses in soils and groundwater associated with septic tank systems.

Several mechanisms combine to remove bacteria and viruses in soil. The physical process of straining (chance contact) and the chemical process of adsorption (bonding and chemical interaction) appear to be the most significant. The most important factors that may influence removal efficiency of bacteria and viruses is flow rate and soil type. Low flow rates (adsorption field loading rates) result in very efficient removal of bacteria and viruses. Sandy soils with low water holding capacity have a lower survival rate.

Trace Organic Constituents

Trace organic compounds can be present in septic tank effluent from oil and grease residues introduced during dish washing, clothes laundering, and other cleaning tasks. However, typically these compounds are not detected in the underlying groundwater plume, indicating relatively complete volatile organic compound (VOC) transformation in a sandy unsaturated zone.(6)

Overall, properly-functioning septic systems provide a high degree of removal of trace organic constituents, particularly in the drainfield unsaturated zones, although some recalcitrant compounds can persist. However, these same compounds also persist through conventional sewage treatment as well.(6)

FAILING SEPTIC SYSTEMS

The previous sections discuss the relatively high degree of treatment that a properly (designed, constructed and maintained) functioning septic system will provide for many wastewater constituents. However, studies have documented impacts from septic systems on surface water courses, and the data suggests that the surface water impacts are the result of seepage of untreated wastewater from ‘failing’ septic systems. Septic system failure is a term commonly used when wastewater discharged to a drainfield does not percolate into the subsurface, but breaks out onto the surface and drains into a nearby surface water course. This can result from inadequate percolation through the drainfield, from soil clogging, high groundwater, or mechanical failure.(6)

3. Site Selection and Characteristics

As previously mentioned, four monitoring sites were chosen for sampling, two of the pipe and gravel construction and two of the infiltrator construction. To protect the privacy of the volunteers, the sites will be referred to by number only. Study Site Location Maps can be found in Appendix A. The record Teton County Small Wastewater Facility permits for all four sites are included in Appendix B.

Sites were chosen based on design/installation records and proper maintenance, groundwater depth, the number of full-time residents, the age of the system, and the available land for placement of downgradient monitoring wells.

Site 1

The system located at Site 1 was built on or around 9/15/1994 and sized at 600gpd to accept wastewater from a 3-bedroom, 3-bathroom house and a 1-bedroom, 1-bathroom apartment above the garage. The septic tank is a dual chamber 1500-gallon capacity vault, and the lift station is a single compartment 1000-gallon capacity vault. The type of leachfield construction is a gravel bed mound system, with a site percolation rate of 3 min/inch, but fill was used with a percolation rate of 10 min/inch. The leachfield area is 1000sf (25’ wide by 40’ long) and consists of a 2-inch diameter manifold to 1-inch diameter perforated pipe, 5-feet on center, with pressure discharge, 12 inches of one to two-inch washed rock, and 24 inches of pit run. Estimated depth to seasonal groundwater, as given in the permit documentation, is 3.33 feet. Occupancy is typically two adults in the main home.

Design and calculated flow rate data is given in the table below.

TABLE 3-1 Site 1 Flows

Design Application Rate	0.6	gpd/sf
Average Application Rate	0.09	gpd/sf
Peak Month Rate	0.32	gpd/sf
Pump	18.46	gpm
Vol Cycle	143	gal

Monitoring wells for Site 1 were installed on 7/23/20, 8/6/20, and 9/25/20.

Site 2

The system located at Site 2 was built on or around 7/2/1993 and sized at 600gpd to accept wastewater from a 3-bedroom, 2-bathroom house and a 1-bedroom, 1-bathroom apartment above the garage. The septic tank is a dual chamber 1000-gallon capacity vault, and the lift station is a single compartment 1000-gallon capacity vault. The type of leachfield construction is a gravel bed mound system, with a site percolation rate of 15 min/inch. The leachfield area is 1152sf (24’ wide by 48’ long) and consists of a 2-inch diameter manifold to 4-inch diameter perforated pipe, 6-feet on center, with gravity discharge from perforated pipe, and 12 inches of gravel. Measured depth to seasonal groundwater, as given in the permit documentation, is 4.5 feet. Occupancy is typically two adults, one in the main home and one in the garage apartment.

Design and calculated flow rate data is given in the table below.

TABLE 3-2 Site 2 Flows

Design Application Rate	0.52	gpd/sf
Average Application Rate	0.13	gpd/sf
Peak Month Rate	0.16	gpd/sf
Pump	97.54	gpm
Vol Cycle	178.8	gal

Monitoring wells for Site 2 were installed on 7/22/20 and 9/16/20.

Site 3

The system located at Site 3 was built on or around 10/18/2013 and sized at 900gpd (the equivalent of six bedrooms) to accept wastewater from a 4-bedroom, 3-full-bathroom and 3-half-bathroom house, barn, and greenhouse/workshop/garage. The septic tank is a dual chamber 1500-gallon capacity vault, and the lift station is a single compartment 1000-gallon capacity vault. The type of leachfield construction is an infiltrator chamber bed (64 chambers) mound system, with a percolation rate of 10 min/inch (lower soil) and an average of 54 min/inch (upper soil). The leachfield area is 864sf (12’ wide by 72’ long) and consists of a 2-inch diameter line from the pump to a 1.5-inch diameter manifold to eight 1-inch diameter laterals strung through the infiltrator units. Each lateral is perforated with eight 3/16-inch diameter holes facing upward at 4-feet on center. The mound itself is composed of five feet of pit run fill over silty loam. Measured depth to seasonal groundwater as given in the permit documentation is 3.43 feet. Occupancy is typically two adults and two children in the main home.

Design and calculated flow rate data is given in the table below.

TABLE 3-3 Site 3 Flows

Design Application Rate	1.04	gpd/sf
Average Application Rate	0.56	gpd/sf
Peak Month Rate	0.66	gpd/sf
Pump	85.83	gpm
Vol cycle	178.8	gal

Monitoring wells for Site 3 were installed on 7/21/20, 8/6/20, and 9/16/20.

Site 4

The system located at Site 4 was built on or around 8/19/1999 and sized at 750gpd to accept wastewater from a 3-bedroom, 3-bathroom main house and a 2-bedroom, 2-bathroom guest house. The septic tank is a dual chamber 1500-gallon capacity vault, and the lift station is a single compartment 1000-gallon capacity vault. The type of leachfield construction is an infiltrator chamber bed (42 chambers) mound system, with a percolation rate of 10 min/inch. The leachfield area is 788sf (18’ wide by 43.75’ long) and consists of pressure discharge through a 2-inch diameter line from the pump to a 3-inch diameter manifold to six 1.5-inch diameter laterals strung through the infiltrator units. Each lateral is perforated with seven 1/4-inch diameter holes facing upward at 6.25-feet on center. The mound itself is composed of six inches of pea rock and 24 to 30 inches of 3-inch minus pit run. Estimated depth to seasonal groundwater as given in the permit documentation is 2 feet. Occupancy is typically two adults and two children in the main home and an assumed average of two adults in the guest house.

Design and calculated flow rate data is given in the table below.

TABLE 3-4 Site 4 Flows

Design Application Rate	0.952	gpd/sf
Average Application Rate	0.481	gpd/sf
Peak Month Rate	0.702	gpd/sf
Pump	59.98	gpm
Vol Cycle	107.96	gal

Monitoring wells for Site 4 were installed on 9/9/20.

4. Sampling Procedures

A Septic System Effluent Monitoring Sampling and Analysis Plan (SAP), prepared by Alder Environmental LLC can be found in Appendix C. Following are excerpts from the SAP that summarize the sampling procedures that were utilized during the project. The SAP describes the methodology that was chosen to provide reliable and repeatable monitoring of the typical septic systems found in Teton County. Sites were selected based on the criteria identified in the previous section. Raw Field Data Forms can be found in Appendix D, and Laboratory Data can be found in Appendix E.

Sampling Frequency and Timeframe

The septic tank effluent and each well and lysimeter were sampled at all locations monthly, for a period of 17 months. The sampling regime included sampling over a duration of one year at minimum in order to capture seasonal fluctuations in the groundwater table, as well as to capture seasonal climatic changes.

Well Array Design and Purpose

A well array design was prepared and installed to successfully and accurately assess impacts to groundwater while being cost effective and minimally invasive and damaging to landowners' properties and leachfield. The well array included one upgradient well, one well within the leachfield, and five downgradient monitoring wells. Additionally, two lysimeters were installed directly below the adsorption field at a depth of one and three feet below the infiltrators. The effluent from the septic tank was sampled directly from the lift stations.

Seven groundwater monitoring points were installed. The monitoring points included one upgradient monitoring well installed to determine the background water quality prior to the septic system, one monitoring well installed in the leachfield, three monitoring wells installed downgradient and about 10 feet from the leachfield, and two monitoring wells installed downgradient and about 50 feet from the leachfield.

The purpose of the monitoring well upgradient of the adsorption field was to obtain a background water sample to adequately quantify the dilution of Nitrates discharged from the adsorption field. The purpose of the monitoring well in the leachfield was to allow for groundwater sampling directly below the leachfield prior to substantial dilution. The purpose of installing and collecting samples from the two lysimeters at different depths was to determine if the nitrification process in the upper section of the leachfield is converting the Ammonia to Nitrate and if the anoxic zone below is effectively converting Nitrates to Nitrogen gas during all seasons. The lysimeter testing was intended to determine the amount of nitrification and denitrification that occurs prior to the wastewater comingling with the groundwater, and to determine the bacterial (E. coli coliform) removal in this zone. The lysimeters allowed for moisture to be pulled from the vadose zone into a ceramic pot through the use of a vacuum pump, to retrieve the sample for laboratory analysis.

WASTEWATER METHODS

Pump run time meters were installed in the pump controllers. The purpose was to quantify the amount of wastewater that is applied to the adsorption field on a monthly basis between sampling.

The method used depended on the septic tank/adsorption field configuration, but each method allowed for the determination of monthly flows. Since all sampling sites were pumped, a counter was installed to monitor pump starts, and draw down was measured between the pump ON and OFF, to determine how much effluent was pumped.

LYSIMETER DESIGN AND INSTALLATION METHODS

At each site, two lysimeters were installed directly below the adsorption field at depths of 1'+/- and 3'+/- below the bottom of the leachfield. Lysimeters installed were Soilmoisture's Model 1920F1 Pressure-Vacuum Soil Water Samplers, which came fully assembled. The operating instructions state that "the unit is constructed of a 1.9-inch O.D. PVC tube (made of FDA-approved material) with a 2-bar porous ceramic cup bonded to one end. The serviceable end of the Sampler was completely sealed, and two 1/4-inch tube connectors protrude from the top. The white tube connector indicates the "Pressure/Vacuum" side and is used exclusively for pressurizing and evacuating the Sampler. The green tube connector is used to recover the collected sample. Two 1/4-inch O.D. polyethylene access tubes were used for pressurizing and recovering samples which terminated in neoprene tubing. Clamping rings were used to clamp the neoprene to keep the Sampler under negative pressure." An extraction kit was required for sample retrieval and a vacuum pump is required to evacuate the sampler. A Model 2006G2 Pressure-Vacuum Hand Pump and Model 1900K3 1,000 ml Extraction Kit was used. A 2-1/2" well bore pipe with a drive point was used for lysimeter installation and bedded with sand and a silica slurry. Lysimeters were covered with an irrigation valve box (labeled with site identification) to contain all tubing.

WELL DESIGN AND INSTALLATION METHODS

At each site, monitoring wells were installed at the seven locations identified above in an array that takes into account the site's localized groundwater gradient. As previously stated, an upgradient monitoring well was installed, along with a monitoring well within the adsorption field and five monitoring wells downgradient of the adsorption field. Three of the downgradient monitoring wells were approximately 10 feet downgradient of the adsorption field and two were approximately 50 feet downgradient of the adsorption field. It was anticipated that at some sites, because of seasonal surface flow, the groundwater gradient may shift thus requiring that the monitoring wells be located to allow accurate sampling during all seasons.

Shallow (about 8-10 feet below ground surface), small diameter 1.0-inch PVC monitoring wells were installed at each site. The monitoring wells were installed at a depth where groundwater sampling could occur through the full range of seasonal groundwater depths. Typically, the seasonal groundwater elevation on the west bank of the Snake River varies 2-3 feet; however, there are locations where the variation is 6-7 feet.

1. The PVC well casings were perforated by the manufacturer. Therefore, monitoring wells had perforations approximately 2 feet below and 2 feet above the average groundwater level. Anticipated depth below ground level was 6 to 10 feet.
2. Two 5-foot perforated sections were put together, and the top portion (approximately 2 feet) of the perforation was duct taped.
3. The wells were installed using a vibratory hammer to drive a 2.5" steel pipe with steel well point to the desired depth. The perforated PVC pipe was then installed, installing silica sand in the annulus between the steel pipe and PVC pipe and withdrawing the steel pipe. The well casing

and ground surface interface was plugged with bentonite clay. A cap was placed on the top of the PVC well pipe. (In some instances, if requested by the landowner, an irrigation valve box was installed to cover the well at the ground surface and no bentonite clay was added).

4. At the completion of the monitoring and sampling, all equipment (including the monitoring wells) was removed, and the tubing to the buried lysimeters was cut.

Following installation of monitoring wells, a survey of well locations and well elevations was completed in order to be able to calculate groundwater elevations at each well, once future groundwater depth readings were measured during sampling events.

Sampling Parameters, Collection Methods and Laboratory Analysis

The following section describes the chemical and physical parameters that were collected in the field and analyzed in the laboratory.

SAMPLING PARAMETERS OVERVIEW

The methods presented below for sampling and measuring chemical water quality parameters generally followed the techniques described in the USGS' *National Field Manual for the Collection of Water-Quality Data* (Book 9), various dates(7). Table 4-1 describes the lab parameters that were sampled for, as well as other information about the laboratory requirements and analyses. For the lab analyses, Energy Laboratories performed the nutrient parameter analysis; however, any similar USEPA-certified labs would be acceptable when attempting to reproduce this study.

TABLE 4-1 Laboratory Analytical Method Details

Parameter	Lab Method	Container/ Volume	Preservative	Storage	Holding Time	Reporting Units	Practical Quantitation Limit
Chloride	EPA 300.0	250mL Plastic	n/a	2°C to 6°C	28 days	mg/L	1
Bacteria, E. coli Coliform	A9223 B	100mL plastic sterile	n/a	2°C to 6°C	6 hours	MPN/100 mL	1
Nitrogen, Ammonia	EPA 350.1	250mL plastic	Sulfuric acid	2°C to 6°C	28 days	mg/L	0.05
Nitrogen, Nitrate + Nitrite	EPA 353.2	250mL plastic	Sulfuric acid	2°C to 6°C	28 days	mg/L	0.01
Phosphorus, Total	EPA 365.1	250mL plastic	Sulfuric acid	2°C to 6°C	28 days	mg/L	0.005
Phosphate, Total	Calculation	n/a	n/a	n/a	n/a	mg/L	0.03

Laboratory analysis parameters included nutrients (Ammonia, Nitrate plus Nitrite, Total Phosphorus, and Total Phosphate), major ions (Chloride), and biological (E. coli coliform bacteria).

Field parameters (Dissolved Oxygen, pH, Specific Conductance, and water temperature) were measured during all sampling events at all sites, except Dissolved Oxygen was not measured at the septic tank effluent monitoring site or from the lysimeters. The physical parameter of depth of water for groundwater monitoring wells was measured during all sampling events at all sites. Table 4-2 indicates which parameters were sampled and analyzed for, at which sites and at what frequency.

TABLE 4-2 Summary of Sampling Sites and Laboratory Analysis

Sampling Location		**SEPTIC TANK**	**LEACHFIELD**		**GROUNDWATER**		
Sampling Sites		**Effluent**	**Lysimeters (-1' & -3')**	**Groundwater**	**Upgradient**	**Downgradient (10' distance)**	**Downgradient (50' distance)**
# of Sampling Points		1	2	1	1	3	2
FIELD PARAMETERS	Dissolved Oxygen			1	1	3	2
	pH	1	2	1	1	3	2
	Specific Conductance	1	2	1	1	3	2
	Temperature	1	2	1	1	3	2
LABORATORY ANALYSIS PARAMETERS	Nitrogen, Ammonia as N	1	2	1	1	3	2
	Nitrogen, Nitrate + Nitrate as N		2	1	1	3	2
	Chloride	1	2	1	1	3	2
	Phosphorus, Total	1	2	1	1	3	2
	Phosphate, Total	1	2	1	1	3	2
	E. coli		2	1	1	3	2

At the septic tank effluent monitoring point, field parameters, except for Dissolved Oxygen which should not be present, was sampled and tested. Ammonia, Total Phosphorus, Total Phosphate, and Chlorides were also tested. The purpose of these lab tests is primarily to determine the concentration of the constituents being applied to the leachfield. E. coli was not tested for, as the colonies would likely be too numerous to count.

The parameters to be tested in the leachfield lysimeters include all the field parameters plus Ammonia, Nitrate plus Nitrite, Total Phosphorus, Total Phosphate, Chlorides, and E. coli. The parameters to be tested in the leachfield monitoring well and the groundwater monitoring wells include all the field parameters plus Ammonia, Nitrate plus Nitrite, Total Phosphorus, Total Phosphate, Chlorides, and E. coli.

INSTRUMENTATION AND CALIBRATION

Field water quality parameters were measured using a handheld multiparameter instrument, the YSI 556 Multiprobe System, or equivalent device. This multiprobe provides high resolution, accuracy, appropriate range, and field calibrations. Field instrumentation information for sampling can be found in Table 4-3.

Calibrations of the water quality field parameter probes were performed as recommended by the manufacturer. Calibration of the probes was done twice annually for temperature and at the beginning of each monthly sampling event for pH, Specific Conductance, and Dissolved Oxygen. The following calibration solutions were recommended for this project since their values cover the general range found in groundwater in the Fish Creek and Snake River watersheds:

- pH – a two-point calibration using 7.00 and 10.00 pH buffer solutions
- Specific Conductance – a solution concentration of 447 µS/cm
- Dissolved Oxygen – 100% air saturation method

TABLE 4-3 Field Instrumentation

Make	Meter Name	Parameters Measured	Model #	Serial #	Manual Link
Eutech Instruments/ Oakton	PCSTestr35	pH, conductivity, TDS, Salinity, Temperature	NA	1607981	http://www.4oakton.com/SellSheets/35425-00,-05,-10.pdf
YSI	Pro Plus Multiparameter Meter	pH, DO, conductivity ORP, Temperature	605596	16M101916	https://www.ysi.com/File%20Library/Documents/Manuals/605596-YSI-ProPlus-User-Manual-RevD.pdf
Geotech	Geopump peristaltic pump-Series 1	Water Samples	51350031	3328	http://www.geotechenv.com/Manuals/Geotech_Geopump_Peristaltic_Pump.pdf
Geotech	Geopump easy load II pump head	Water Samples	900-1280	L14004504	http://www.geotechenv.com/Manuals/Geotech_Geopump_Peristaltic_Pump.pdf
Soilmoisture	Pressure Vacuum Hand Pump	Soil Water Samples	2006G2		https://www.soilmoisture.com/pdfs/Resource_Instructions_0898-2006_2006G%20Pressure%20Vacuum%20Hand%20Pump.pdf

SEPTIC TANK SAMPLING

At each of the four septic pump vaults, unfiltered samples of effluent were collected directly from the vault. Samples were analyzed at the laboratory for Ammonia, Total Phosphorus, Total Phosphate, and Chlorides. Field parameters, except for Dissolved Oxygen which should not be present, (Specific Conductivity, pH, and temperature) were measured in the field.

Pre-Sampling Preparation

Pre-sampling preparation included:

- preparing appropriate data sheets
- checking and gathering of field and processing supplies and equipment
- ordering the proper bottle sets from the laboratory 2-3 weeks in advance of sampling date
- inventorying and ordering (if necessary) processing supplies

Energy Laboratories (Casper, WY) was employed for analysis of nutrients. Energy Labs bottles arrived with labels on and preservatives separate to be added to samples in the field.

The laboratory's instructions for preparing the bottles were followed and preservatives were added when needed. Protective nitrile gloves were worn when handling bottles to protect against contamination and protect samplers against acids and other preservatives. Safety goggles were used for sampling from the septic tanks.

Sample Collection

The septic tank effluent was collected using a low-flow peristaltic sampling pump.

The Septic Tank and Lysimeter Field Data Form was used to record sampling data.

Sampling Technique:

1. The port at the pump vault was inspected for signs of damage.
2. Water quality probes were rinsed with distilled water before and after use at each site.
3. Effluent water was extracted from the vault using a low-flow peristaltic pump and dedicated, site specific tubing. The intake end of the tubing was inserted into the septic tank. The outlet end of the tubing was placed into a dedicated flask or bottle. Effluent was sufficiently purged to ensure that the tubing was cleaned prior to sample collection. The purged effluent was collected into a flask or bottle, and field parameters (Specific Conductivity, pH, and temperature) were measured once with the Multi-Parameter Tester 35 (PCSTestr 35) from the flask or bottle. Field parameters were recorded on the Field Data Form. A Nitrate/Nitrite test strip was dipped into this purged water, read, and recorded. Purged water was disposed of back into the vault after sampling was complete.
4. Samples were collected. Preservatives were added to any bottles requiring them.
5. Sample bottles were labelled in the field with permanent/ waterproof markers. Site name, date and times were double-checked in the field.
6. After samples were collected, deionized water was flushed through the tubing and tubing was dried. The dry tubing was stored in a plastic bag for the next sampling event at each site. [Note: Some sites had dedicated tubing installed at the septic tank vault.]
7. The pump run time meter was checked and recorded on the Field Data Form.

Sample Preparation

Sample bottle caps were firmly placed on bottles and immediately placed in a plastic bag in a cooler containing ice. Samples were cooled to between 2-6° C until arrival at the laboratories. If different laboratories had been used, the laboratory's procedures would have been followed for storing samples until shipment. Table 4-1 provides the holding times and preservatives required for each parameter.

LYSIMETER SAMPLE COLLECTION

At the four leachfield sites, unfiltered samples were collected from the two lysimeters at each site. Samples were analyzed at the laboratory for Ammonia, Nitrate plus Nitrite, Total Phosphorus, Total Phosphate, Chlorides, and E. coli. Field parameters, except for Dissolved Oxygen which would not have been accurate as read from the lysimeters, (Specific Conductivity, pH, and temperature) were measured in the field.

Pre-Sampling Preparation

Pre-sampling preparation included:
- preparing appropriate data sheets
- checking and gathering of field and processing supplies and equipment
- ordering the proper bottle sets from the laboratory 2-3 weeks in advance of sampling date
- inventorying and ordering (if necessary) processing supplies

Energy Laboratories (Casper, WY) was employed for analysis of nutrients. Energy Labs bottles arrived with labels on and preservatives separate to be added to samples in the field.

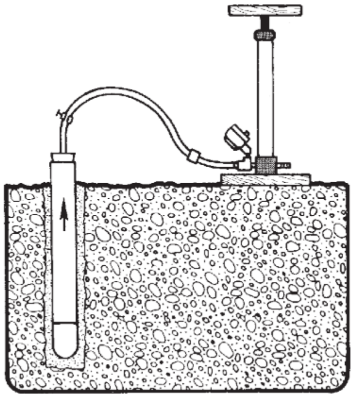
The laboratory's instructions for preparing the bottles were followed and preservatives were added when needed. Protective nitrile gloves were worn when handling bottles to protect against contamination and protect samplers against acids and other preservatives.

Sample Collection

The Septic Tank and Lysimeter Field Data Form was used to record sampling data.

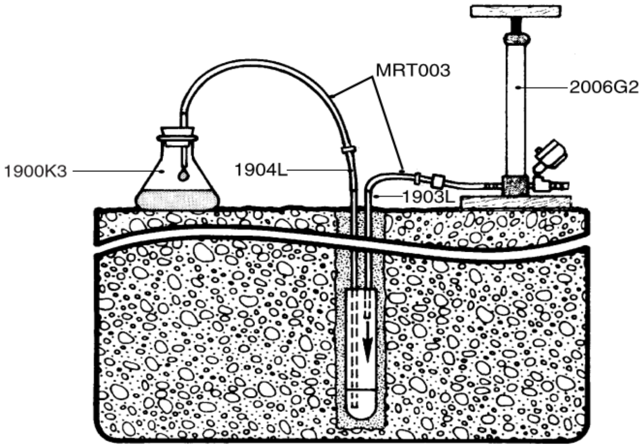
Sampling Technique (according to Soilmoisture's Operation Manual for 1920F1 Pressure-Vacuum Soil Water Samplers):

1. The area around the lysimeter was inspected for signs of damage.
2. To collect a sample, the discharge access tube was closed using a clamping ring, and the vacuum port of the hand pump was connected to the Pressure-Vacuum access tube. Using the pump, a vacuum of about 60 cb was created inside the Sampler, as indicated on the gauge connected to the pump and shown below.



NOTE: The vacuum within the sampler causes the moisture to move from the soil, through the porous ceramic cup, and into the sampler. The rate at which the soil solution collects within the sampler depends on the hydraulic conductivity of the soil, the soil suction value within the soil (as measured in tensiometers), and the amount of vacuum that has been created within the sampler. In moist soils of good conductivity, at field capacity (10 to 30 centibars of soil suction as read on a tensiometer), substantial soil water samples can be collected within a few hours. Under more difficult conditions, it may require several days to collect an adequate sample. In general, a vacuum of 50 to 85 cb is normally applied to the Soil Water Sampler. In very sandy soils, however, it has been noted that very high vacuums applied to the Soil Water Sampler seem to result in a lower rate of collection of the sample than a lower vacuum. In these coarse, sandy soils, the high vacuum within the Sampler may deplete the moisture in the immediate vicinity of the porous ceramic cup reducing the hydraulic conductivity, which creates a barrier to the flow of water to the cup. In loams and gravelly clay loams, users have reported collection of 300 to 500 ml of solution over a period of a day with an applied vacuum of 50 cb, when soils are at field capacity. At wastewater disposal sites, users have obtained 1500 ml of sample solution in 24 hours following cessation of irrigation with 1 to 2 inches of wastewater on sandy or clay loam soil.

3. To recover a soil water sample, the Pressure-Vacuum tube was removed from the vacuum port of the pump, and the tube was attached to the pressure port. The discharge access tube was placed in a small collection bottle and both clamping rings were removed. A few strokes were applied to the hand pump to develop enough pressure within the Sampler to force the collected water out of the Sampler and into the collection bottle, as shown below.



4. Subsequent samples were collected by again creating a vacuum within the sampler and following the steps as outlined above.
5. The soil water was collected from the lysimeter in a flask and poured into sample bottles. Preservatives were added to any bottles requiring them.
6. Sample bottles were labelled in the field with permanent/ waterproof markers. Site name, date and times were double-checked in the field.
7. Field parameters were measured from the remaining collected water in the flask using the Multi-Parameter Tester 35 (PCSTestr 35) instrument. Field parameters were recorded on the Field Data Form.
8. The multiprobe instrument was rinsed with distilled water prior to and after each use.
9. After sampling completion, the tube ends were covered or plugged to prevent debris from entering the tubes and later contaminating the Sampler.
10. All water was removed from the sample line before clamping it for the next sample.

Sample Preparation

Sample bottle caps were firmly placed on bottles and immediately placed in a plastic bag in a cooler containing ice. Samples were cooled to between 2-6° C until arrival at the laboratories. If different laboratories would have been used, the laboratory's procedures would have been followed for storing samples until shipment. Table 4-1 provides the holding times and preservatives required for each parameter.

WELL SAMPLE COLLECTION

At each of the four sites, unfiltered samples were collected from the seven groundwater monitoring wells at each site. These seven monitoring wells include the following: one upgradient monitoring well, one monitoring well in the leachfield, three monitoring wells downgradient and about 10 feet from the leachfield, and two monitoring wells downgradient and about 50 feet from the leachfield.

For all monitoring wells, samples were analyzed at the laboratory for Ammonia, Nitrate plus Nitrite, Total Phosphorus, Total Phosphate, Chlorides, and E. coli. Field parameters (Dissolved Oxygen, Specific Conductivity, pH, and temperature) were measured in the field.

Pre-Sampling Preparation

Pre-sampling preparation included:

- preparing appropriate data sheets
- checking and gathering of field and processing supplies and equipment
- ordering the proper bottle sets from the laboratory 2-3 weeks in advance of sampling date
- inventorying and ordering (if necessary) processing supplies

Energy Laboratories (Casper, WY) was employed for analysis of nutrients. Energy Labs bottles arrived with labels on and preservatives separate to be added to samples in the field.

The laboratory's instructions for preparing the bottles were followed and preservatives were added when needed. Protective nitrile gloves were worn when handling bottles to protect against contamination and protect samplers against acids and other preservatives.

Sample Collection

The monitoring wells were purged using a low-flow peristaltic sampling pump, and all field parameters were measured continuously in a flow cell during the purging process until the water characteristics were consistent of groundwater. The key constituents for this determination were temperature and Dissolved Oxygen (DO) concentration in the purged water. Water sample collection began once field parameters stabilized, and samples were collected from the monitoring wells at the top six inches of the groundwater.

The Groundwater Well Field Data Form was used to record sampling data.

Sampling Technique:

1. The area around the wellhead and casing was inspected for signs of damage.
2. Water quality probes were rinsed with distilled water before and after use at each site.

3. The groundwater level was measured using a clean water level meter. Both the depth to water below the top of casing and the depth to the bottom of the well were measured to the hundredths of a foot.
4. The water volume was calculated using the formula provided in the Field Data Sheet.
5. Water was purged from the well using a low-flow peristaltic pump and dedicated, site-specific tubing (one dedicated tube was used for all groundwater wells at each site – starting at the upgradient well, distilled water was flushed through the tubing between leachfield well and all downgradient wells). The intake end of the tubing was inserted into the well to a depth of approximately 6” below the water’s surface. The outlet end of the tubing was connected to the flow cell containing the multiprobe instrument. The purge volume for each well was at least 3 well volumes or when field water quality parameters stabilized, in order to assure that fresh formation groundwater was sampled. Purged water was discharged into a bucket and disposed of downgradient of the well and far enough away to prevent recharging the well.
6. Final, stabilized temperature, pH, Specific Conductance, and Dissolved Oxygen were recorded on the Field Data Form.
7. Samples were not collected until field parameter measurements had stabilized. The flow cell was disconnected before samples were collected.
8. Sampling followed low flow sampling techniques, requiring a flow rate between 100-500 mL/minute.
9. Samples were collected. Preservatives were added to any bottles requiring them.
10. Sample bottles were labelled in the field with permanent/ waterproof markers. Site name, date and times were double-checked in the field.
11. After samples were collected, distilled water was flushed through the tubing and tubing was dried. The dry tubing was stored in a plastic bag for the next sampling event at each site.

Sample Preparation

Sample bottle caps were firmly placed on bottles and immediately placed in a plastic bag in a cooler containing ice. Samples were cooled to between 2-6° C until arrival at the laboratories. If different laboratories would have been used, the laboratory’s procedures would have been followed for storing samples until shipment. Table 4-1 provides the holding times and preservatives required for each parameter.

DEPTH TO GROUNDWATER

Methods for measuring water levels in wells are described in Garber and Koopman (1978)(8).

The groundwater level was measured using a clean water level meter. Both the depth to water below the top of casing and the depth to the bottom of the well were measured to the hundredths of a foot.

Pre-Sampling Preparation

Pre-sampling preparation included:

- preparing appropriate data sheets
- checking and gathering of field equipment
    - a vice grip for removing the well caps
    - a Solinst model 102 or equivalent water level meter

Depth Measurements

Methods from USGS' *National Field Manual for the Collection of Water-Quality Data* (Book 9) were used.

1. The well was checked for any damage and potential for contamination.
2. The diameter of the well was measured and well construction material was recorded.
3. The water level meter probe and line were cleaned with nonphosphate laboratory soap, like Liquinox, and rinsed with distilled water prior to depth measurements.
4. The depth to groundwater surface was measured from the top of the pipe (north side) and recorded on the Field Data Form.
5. The probe was then lowered until reaching the bottom of the well. This distance was recorded as the depth to the well bottom from the top of the pipe.
6. The well cap was replaced securely after measurements were completed.

Quality Assurance/Quality Control (QA/QC)

Quality Assurance (QA) may be defined as an integrated system of management procedures designed to evaluate the quality of data and to verify that the quality control system is operating within acceptable limits (Friedman and Erdmann, 1982; Eaton et al., 1995)(9,10). Quality Control (QC) may be defined as the system of technical procedures designed to ensure the integrity of data by adhering to proper field sample collection methods, operation and maintenance of equipment and instruments. Together, QA/QC functions to ensure that all data generated is consistent, valid, and of known quality (U.S. Environmental Protection Agency, 1983; 1990)(11). QA/QC should not be viewed as an obscure notion to be tolerated by monitoring and assessment personnel, but as a critical, deeply integrated concept within each step of the monitoring process.

Standardized field procedures were followed to prevent contamination of the samples, and these guidelines are stated below. QC included both internal and external measures. It is the duty of the sampler to ensure internal QA/QC in all stages of the monitoring. External QC involved the contract laboratories.

EQUIPMENT MAINTENANCE

All equipment and instrumentation were properly maintained according to the manufacturer's instructions, as previously described.

FIELD QUALITY CONTROL SAMPLES

Quality Control sampling sites were selected using random numbers generated by www.random.org or another random table generator. Sampling sites were numbered 1-4 and groundwater wells were numbered 1-7 at each site. Therefore, a random number between 1-28 was selected for each sampling event, corresponding to one well at a particular site (i.e., MW1 at Site 2 would be used for the QA/QC site if 8 was the random number generated).

Field Duplicates

Duplicate samples are defined as: two or more samples taken consecutively at the same site or two or more measurements made consecutively with a field instrument. Procedures for each duplicate sample were documented on field data sheets. Sites that had duplicate samples were randomly determined prior to sampling. If samples are representative and the sampling methods are consistent, differences between samples and duplicates should be within acceptable ranges for the selected parameter (within 20%).

Sample duplication was completed at least once per sampling event for all chemistry parameters. Duplicate samples of laboratory analyzed parameters consisted of two sample bottles filled sequentially at the same site by the same person.

Field Blanks

As part of Quality Control, field blanks for water chemistry samples were required for each water quality laboratory sampling activity. Field blanks are sterilized laboratory bottles filled with de-ionized or distilled water while in the field and treated as a sample. Blanks are used to identify errors or contamination in sample collection while in the field. If samplers have any reason to suspect that sampling bottles may contribute contamination, they should be discarded. Sterilized and empty chemistry field blank bottles were provided by the contract laboratory. Field blanks were delivered to the contract laboratory for analysis with the water quality samples. After the field blank was filled with de-ionized or distilled water, it remained closed and with the samples until delivery to the laboratory. The parameter(s) to be analyzed for each type of blank were rotated among sample events.

SAMPLE PRESERVATION AND HOLDING TIME

Field samplers were responsible for adding the appropriate preservative, immediately placing samples which require cooling in an insulated container with wet ice (or blue ice packs if preferred by the laboratory) and ensuring that the samples were kept at the required temperature when the sampler gave up custody. Table 4-1 provides a list of parameters, preservatives and holding times.

For nutrient samples sent to Energy Labs, the cooler included one sample bottle containing a minimum of 200 mL de-ionized or distilled water. This bottle was labeled “Temperature Check”. In the absence of a temperature check, a regular sample may be used. The temperature of this water was measured and recorded when the samples arrived at the office or commercial laboratory before the samples were tested. This temperature was an audit to verify that the samples arrived at the laboratory at the required temperature and indicated that the samples were maintained at that temperature after collection.

Water chemistry samples requiring laboratory analysis were immediately preserved (preservatives supplied by Energy Laboratories), placed on ice and kept at 2-6° C throughout the next business day shipping delivery to the laboratory. Samples with 48 hour holding times were shipped no later in the week than Thursday for a Friday delivery.

DOCUMENTATION AND RECORDS

Field Sampling Documentation

Equipment Checklists were reviewed prior to leaving the office for a sampling event to ensure all necessary supplies were available. Samplers carried field data forms, and complete entries for each site during each sampling event. Hard copies of the data forms used in the field and COC forms from the laboratories were maintained, but data forms and other information were scanned and maintained digitally.

Sample Labeling

Water quality samples were labeled with a permanent, waterproof marking pen on plastic or synthetic type labels. Labels are provided on the bottles from both Energy Labs and were filled out accordingly. Sample identification information was recorded on the sample, on the chain of custody forms, on the laboratory's analytical reports, and on the field data forms.

Chain of Custody Forms

Chain of custody documents how and when samples were collected, preserved (if required), stored, transported to the laboratory, treated, and tracked during the analytical processes. Chain of Custody (COC) forms were completed by samplers prior to delivery to the laboratory or shipment center. Copies of completed original forms were maintained with the data forms.

The COC form was prepared and signed by the sampler before samples were shipped, and a carbon copy or scan of the COC form was retained. The COC form was sealed in a zip lock bag inside a cooler with the samples and shipped to the contract analytical laboratory. After samples changed custody, laboratory internal COC procedures were implemented according to their Quality Assurance Plan. The completed original COC form was returned by the analytical laboratory after completion of analyses.

Data Review and Validation

Data generated by the contract laboratories is subject to the internal contract laboratory QA/QC process before it is released. This data is assumed valid because the laboratory should adhere to internal QA/QC procedures. Field data generated by samplers is considered valid and usable only after the QA/QC procedures and process have been applied, evaluated, and deemed acceptable. Data determined to be invalid was rejected and not used in any reports.

Sampling Plan Modifications

Some suggestions for sampling plan modifications are as follows:

1. For the leachfield wells (MW2), possibly make those wells deeper than 10 foot, if installation allows for this. (The study was originally designed for sites with very shallow groundwater. Due to difficulties finding appropriate sites, some of the sites ended up having slightly deeper groundwater. If sites with deeper groundwater (like Sites 3 and 4) are to be used in the future, deeper (15-20 foot) wells, including the upgradient and downgradient wells, should be used. However, this may require a different method of installation.)

2. For the leachfield wells (MW2), it could be helpful to have only the lower two-foot section of the PVC well within groundwater be perforated and the top portion solid PVC, to help reduce the likelihood of leachate getting in the well. Also, it would be advantageous to place bentonite in the annular space between the steel well pipe and the PVC monitoring pipe for at least 4 feet below the bottom of the leachfield to provide a monitoring well surface seal.
3. Take onsite air temperature readings during sampling events.
4. Re-evaluate vacuum lysimeters, due to difficulties collecting samples. Pulling samples from gravel leachfield versus fine soils presented issues collecting enough sample volume.

5. Summary of Primary Findings

The following section contains a summary of primary findings.

In general, the data supports the fact that the septic systems—in specific the leachfields—work well during the summer months; the onsite treatment systems are removing nitrogen, phosphorus, phosphate and E.coli from the wastewater effluent. It seems that leachfield sites are achieving a good level of dilution as well, based on the sample results at the 10-foot monitoring wells and the 50-foot monitoring wells. The winter data set indicates that nitrification and denitrification are, however, reduced in the colder months. We observed that the last two winters were particularly cold and dry. We were able to add “blue board” to insulate the sample ports at the center of the leachfield and warm them enough to keep the lysimeters from freezing but were not always able to get enough sample volume to perform a laboratory test.

Site 1

The data set for Site 1 was fairly complete. There were times when a complete set of samples was not possible to obtain.

SITE 1 NITRATE, TEMPERATURE AND DISSOLVED OXYGEN OBSERVATIONS

The Nitrate, temperature and Dissolved Oxygen (DO) data from all of the collective sampling points at Site 1 demonstrates that the groundwater Nitrate levels decrease with an increase in temperature, and the Dissolved Oxygen levels decrease with an increase in temperature in sync with the DO saturation, but there is still DO available for biological activity, Chart 5-1. This indicates that aerobic biological activity, including denitrification, decreases as temperature decreases and increases as temperature increases. We surmise that as groundwater temperature decreases, aerobic biological activity decreases, thus bacteria are not utilizing Oxygen from O_2 or NO_3, and therefore, Nitrate levels will increase at lower temperatures.

CHART 5-1 Site 1

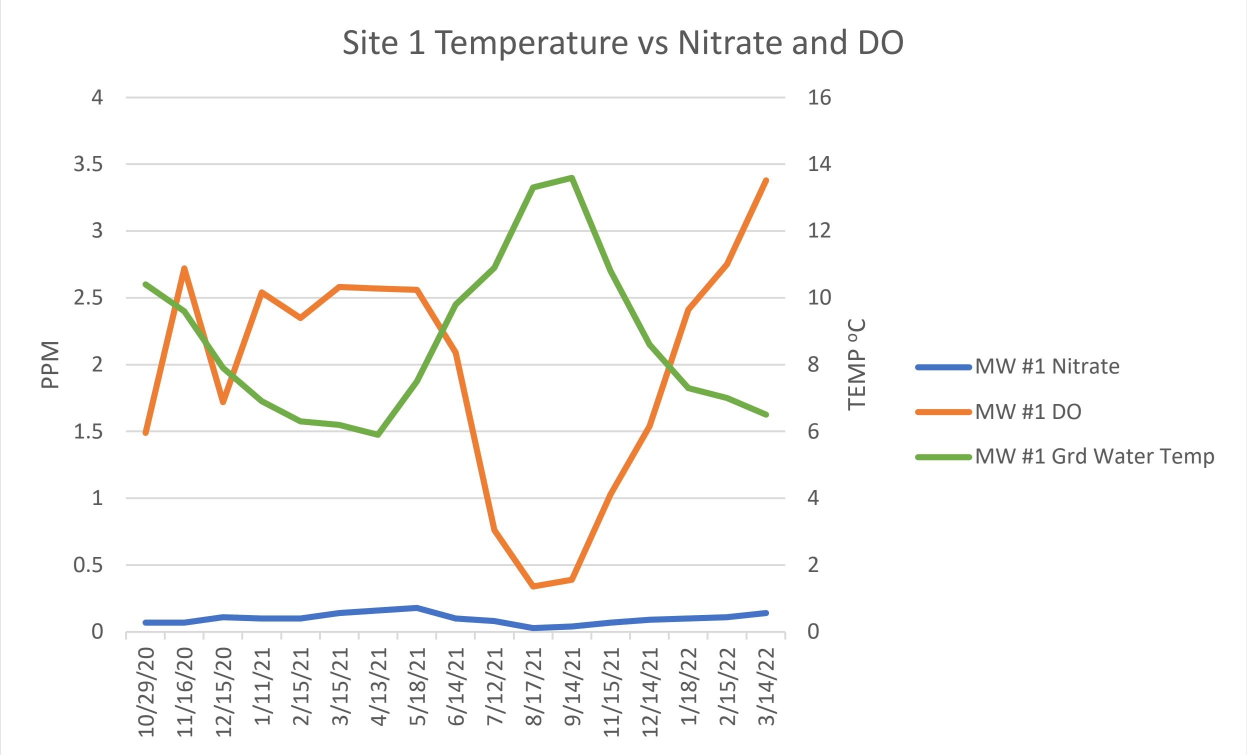


CHART 5-2 Site 1

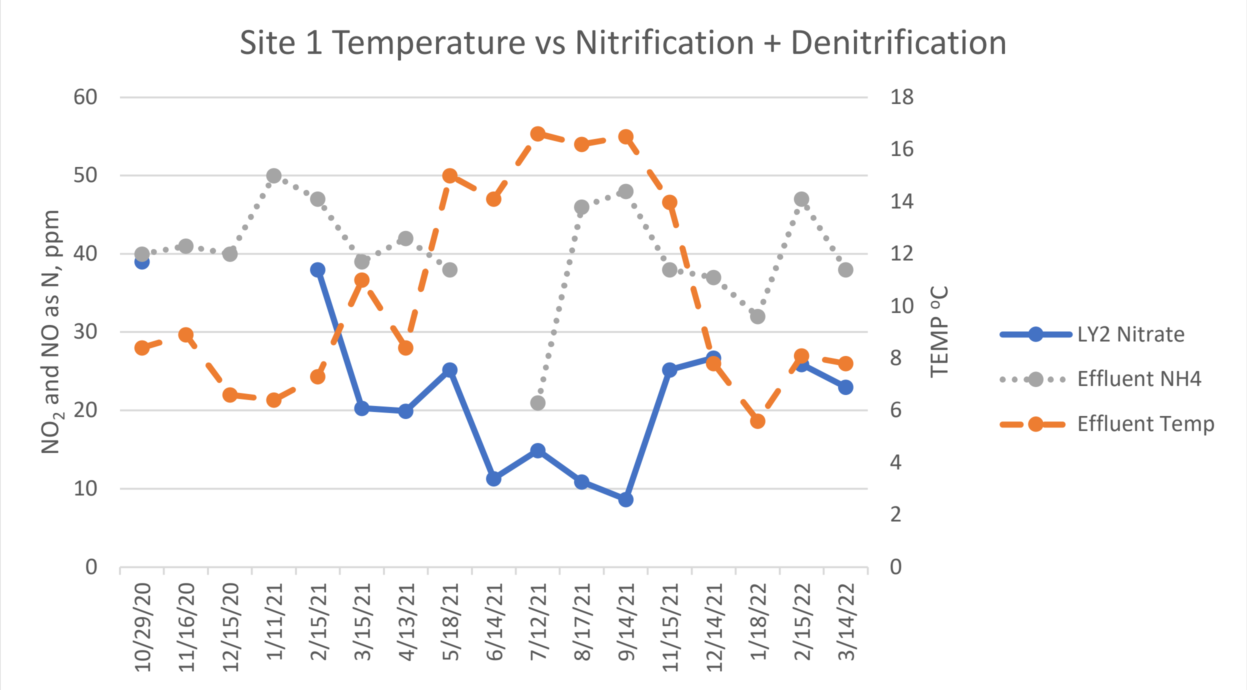
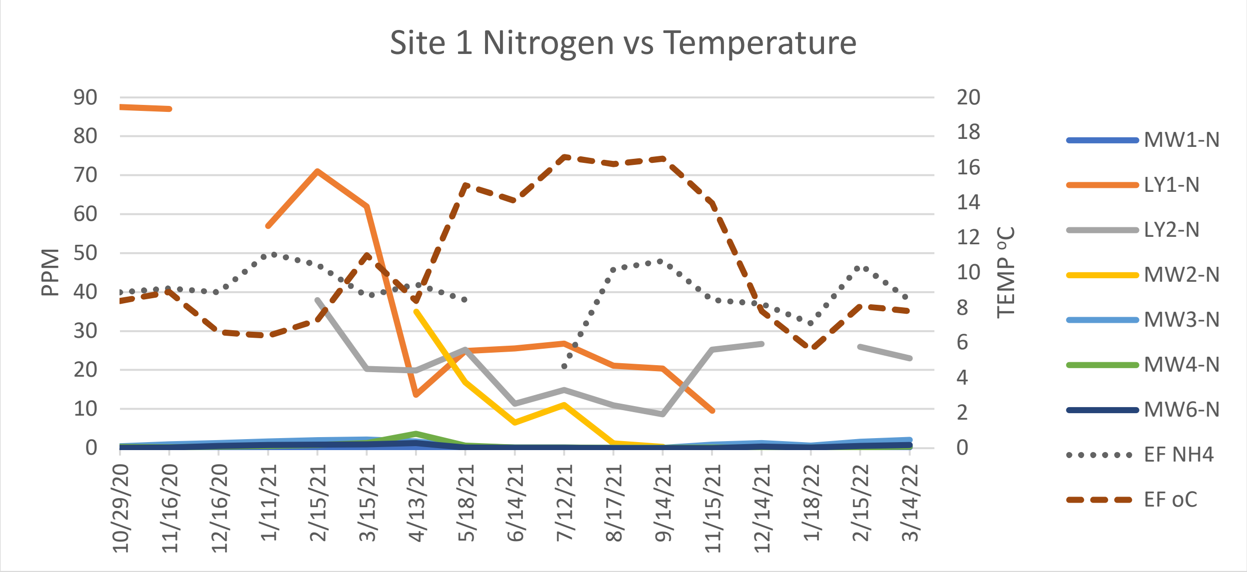


CHART 5-3 Site 1

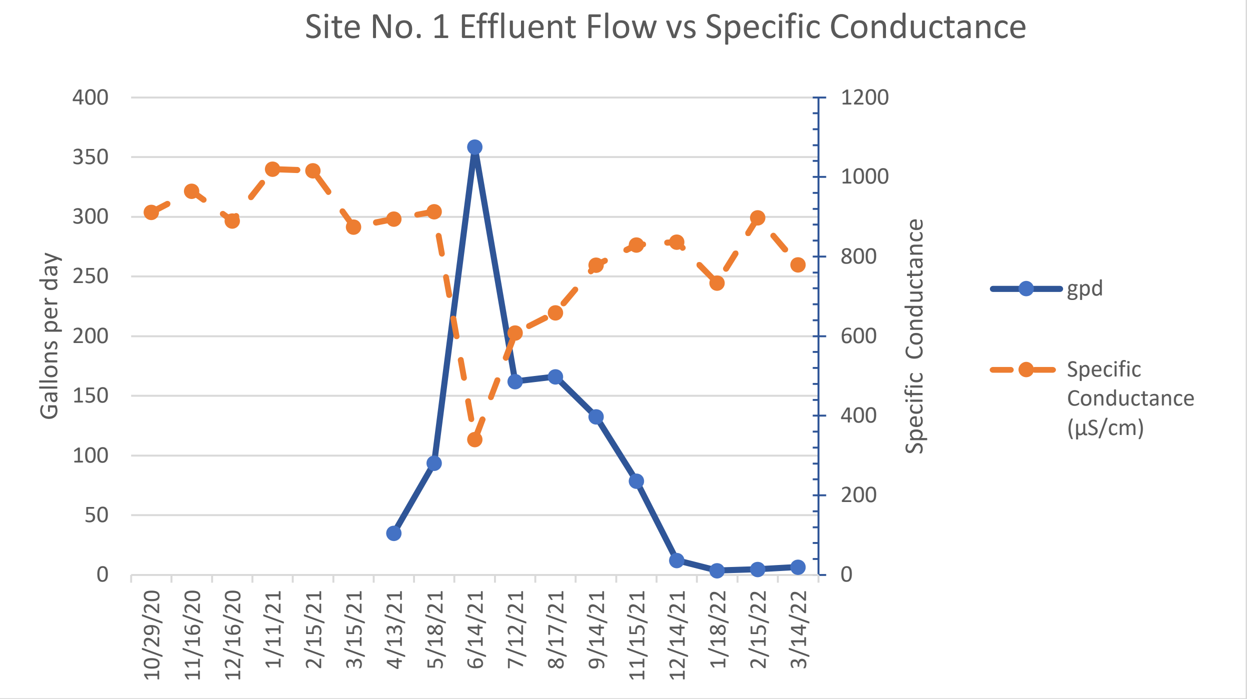


SITE 1 PUMP CHAMBER EFFLUENT OBSERVATIONS

Following are some observations from studying the data from the effluent samples taken from the pump chamber prior to discharge to the leachfield.

1. The effluent temperature varies based on the time of year, and more specifically, the climatic temperatures. A low of 5.8°C was observed in January, and a high of 16.6°C was observed in July. Effluent temperatures have a direct effect on the temperature of the leachfield. There could be a benefit to insulating the septic and pump tanks from the frost in the ground.
2. The effluent pH is fairly constant throughout the year, averaging 7.65, with a standard deviation of 0.2.
3. The effluent Ammonia, NH_4, is fairly consistent, averaging 40.3 mg/l, with a standard deviation of 7.1.
4. The effluent Nitrate is essentially nonexistent due to anaerobic digestion of organic Nitrate to Ammonia.
5. The effluent Chloride averages 34.6 mg/l, with a standard deviation of 9.8, resulting from one low test of 10 mg/l on 6/14/21, which could indicate possible infiltration, and one high test of 56 mg/l, principally due to grab samples.
6. The effluent Phosphorus and Phosphate are variable, probably due to laundry cycles and timing of grab samples.
7. Specific Conductance decreases when average daily flow increases indicating possible inflow or infiltration. The Specific Conductance was at its lowest in June. This could be due to infiltration of groundwater into the pump chamber diluting the septic tank effluent.

CHART 5-4 Site 1



SITE 1 LYSIMETER SAMPLE OBSERVATIONS

Following are some observations from studying the data from the lysimeter samples taken from the leachfield. Lysimeter 1 (LY1) pulled samples from approximately 8 inches below the top of the gravel bed. Lysimeter 2 (LY2) pulled samples from approximately 36 inches below the top of the gravel bed.

1. The lysimeter water temperatures vary with time of year, and more specifically, the ground temperature. Lysimeter temperatures are affected by the temperature of the applied effluent and ground temperature/frost. LY1 temperatures are slightly higher than the LY2 temperatures.
2. LY1 pH is generally similar to the effluent pH. LY2 pH was lower due to nitrification that occurs in the aerobic zone of the leachfield. Nitrification reduces the alkalinity (pH buffer) 7 ppm for each NH_4 ppm that is reduced to Nitrate.
3. LY1 Ammonia was not measurable, probably due to the time that it takes the vacuum pump to collect a sample and the continuing nitrification during that time. LY2 sample tests showed that the Ammonia was reduced to Nitrate by nitrification. Nitrification is affected by available Oxygen, temperature, and pH. The reduction in nitrification efficiency in the winter months (2.8 to 6.5 ppm) versus the summer months (0.07 to 0.18 ppm) is due to the lower temperatures.
4. LY1 and LY2 Nitrogen (NO_2 plus NO_3) levels were highest in the winter and lowest in the summer months. Denitrification, the conversion of NO_3 to Nitrite and Nitrogen gas, occurs in an anoxic condition where there is insufficient Dissolved Oxygen for the biological activity, resulting in the bacteria using the Oxygen in the NO_3 for metabolism. Denitrification is dependent upon Dissolved Oxygen, temperature, and a carbon source for the biological degradation. The lower denitrification levels observed in the winter are probably due to temperature.
5. Chloride concentration in the samples from the lysimeters is variable but generally similar to the Chloride levels in the effluent.

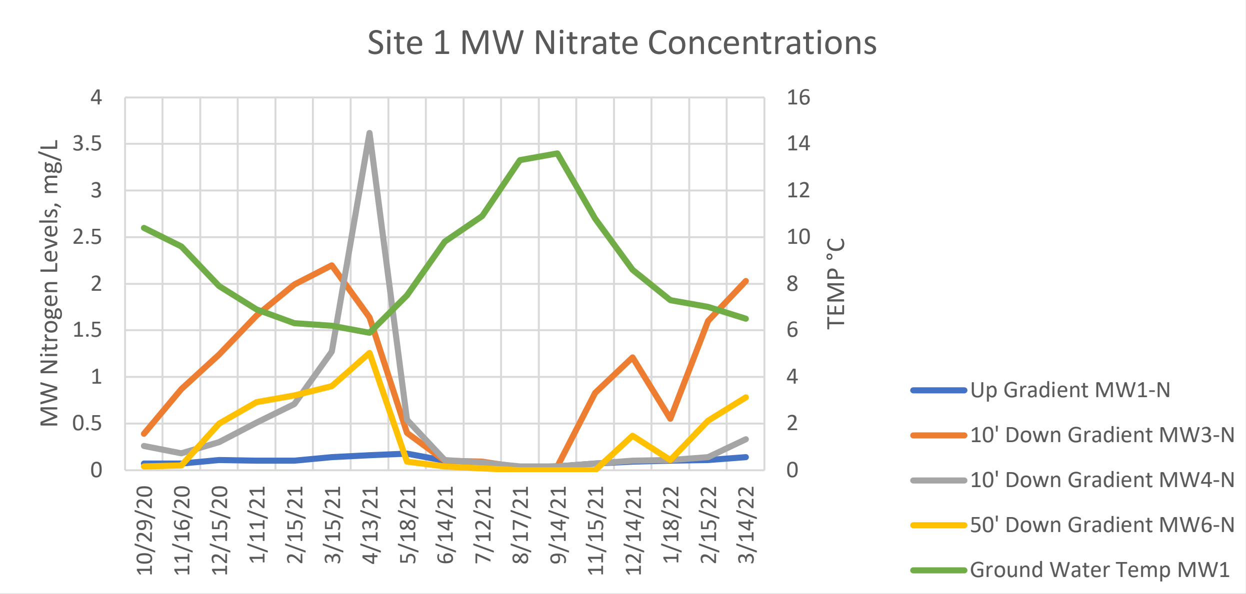
6. Phosphorus and Phosphate concentration in the lysimeters is variable and slightly lower than the effluent concentrations, probably due to adsorption to the soil particles.

SITE 1 MONITORING WELL SAMPLE OBSERVATIONS

Following are some observations from studying the data from the monitoring well samples taken from Site 1. Monitoring Well 1 (MW1) is the upgradient monitoring well. Monitoring Well 2 (MW2) is located in the center of the leachfield. Monitoring Wells 3 through 5 (MW3, MW4 and MW5) are located approximately 10 feet downgradient of the leachfield. Monitoring Wells 6 and 7 (MW6 and MW7) are approximately 50 feet downgradient of the leachfield.

1. Monitoring well sample temperatures are indicative of the groundwater temperature. Monitoring well water temperatures vary seasonally and are generally the same for MW1 and MW3 through MW7. Temperature of water in MW2 is generally a few tenths of a degree higher than the other monitoring wells, probably due to the influence of the leachfield.
2. Monitoring well water pH was very consistent and generally the same for MW1 and MW3 through MW7. The water in MW2 had a lower pH than the other monitoring wells, probably due to the nitrification process that was occurring in the leachfield.
3. Monitoring well Dissolved Oxygen (DO) varied seasonally probably due to temperature. The saturation level of Dissolved Oxygen is highest at low temperatures and lowest at high temperatures. The DO in MW1 was on average 7 mg/l below the DO saturation level for the measured temperature, with a standard deviation of 0.5 mg/l.
4. Ammonia concentrations in the monitoring wells were not measurable.
5. Nitrate nitrogen concentrations in MW1 (upgradient) and MW5 and MW7 (downgradient) ranged from 0.02 to 0.18 ppm. The Nitrogen concentrations in MW2 were highest in the winter (35 ppm) indicating reduced denitrification and possible short circuiting of effluent into MW2. The Nitrate concentrations in MW3, MW4, and MW6 were considerably lower than MW2 due to additional Nitrate removal and dilution with groundwater. The higher concentrations of Nitrate in MW1, MW6, and MW7 in April (generally March-May) could be due to snow melt and the atmospheric Nitrate captured in the snow.
6. Chloride concentrations in the monitoring wells show the effect of the groundwater diluting the Chloride from the effluent.
7. The reduced Phosphorus and Phosphate concentrations in the monitoring wells show the effect of the groundwater diluting the effluent leachate and the adsorption in the soil. MW2 did show some measurable Phosphorus and Phosphate concentration, but the concentration was at background levels in the downgradient monitoring wells.
8. Monitoring well MW1 and MW3 through MW7 water samples did not have any total coliform or E. coli bacteria. MW2 did show high concentrations of bacteria in July; this could be due to short circuiting of leachate into MW2 or sampling contamination.

CHART 5-5 Site 1



Site 2

The data set for Site 2 was the most comprehensive of the sites. There were times when a complete set of samples was not possible to obtain.

SITE 2 NITRATE, TEMPERATURE AND DISSOLVED OXYGEN OBSERVATIONS

The Nitrate, temperature and Dissolved Oxygen (DO) data from all of the collective sampling points at Site 2 demonstrates that the groundwater Nitrate levels decrease with an increase in temperature, and the Dissolved Oxygen levels decrease with an increase in temperature in sync with the DO saturation, but there is still DO available for biological activity, Chart 5-6. This indicates that aerobic biological activity, including denitrification, decreases as temperature decreases and increases at temperature increases. We surmise that as groundwater temperature decreases, aerobic biological activity decreases, thus bacteria are not utilizing Oxygen from O_2 or NO_3, and therefore, Nitrate levels will increase at lower temperatures.

CHART 5-6 Site 2

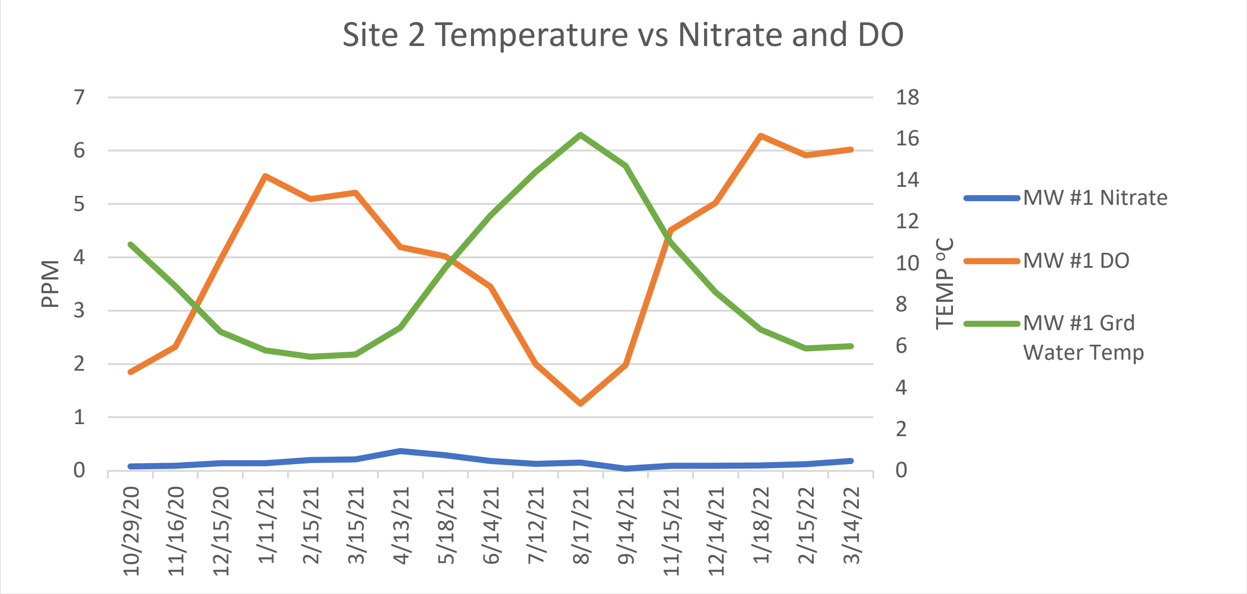


CHART 5-7 Site 2

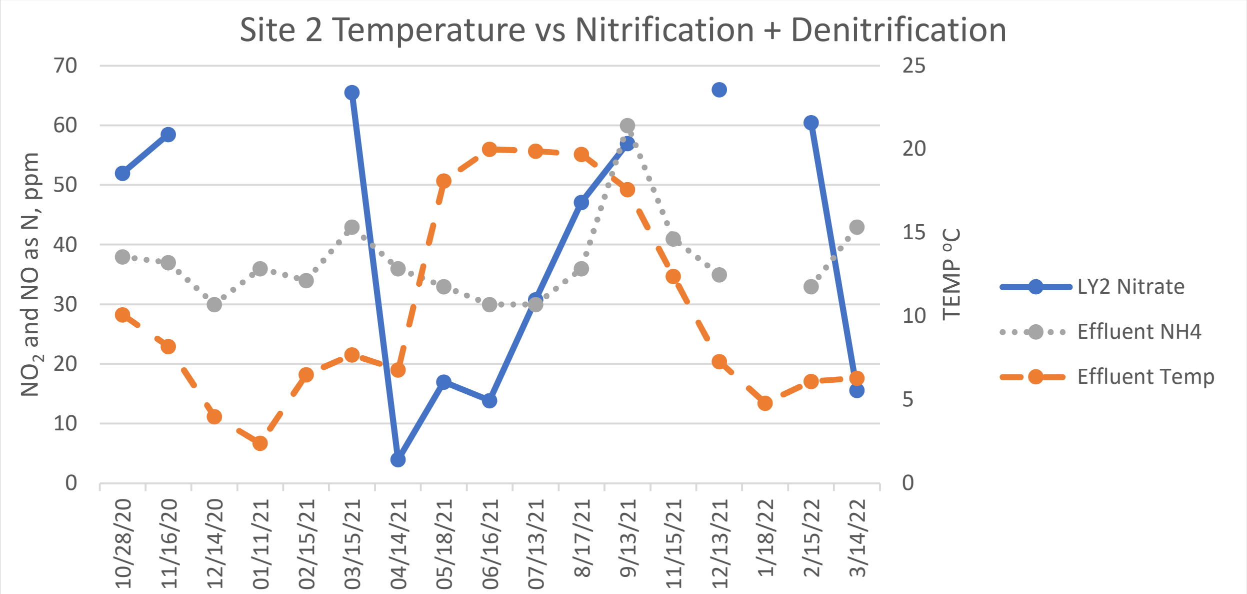


CHART 5-8 Site 2

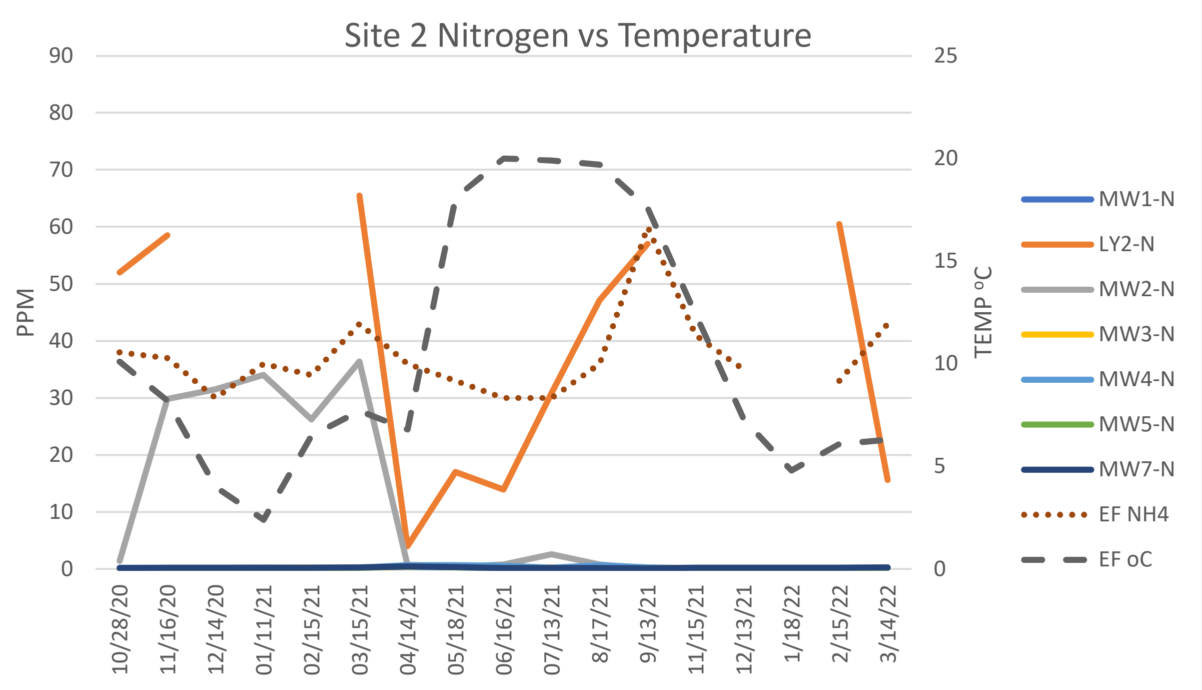
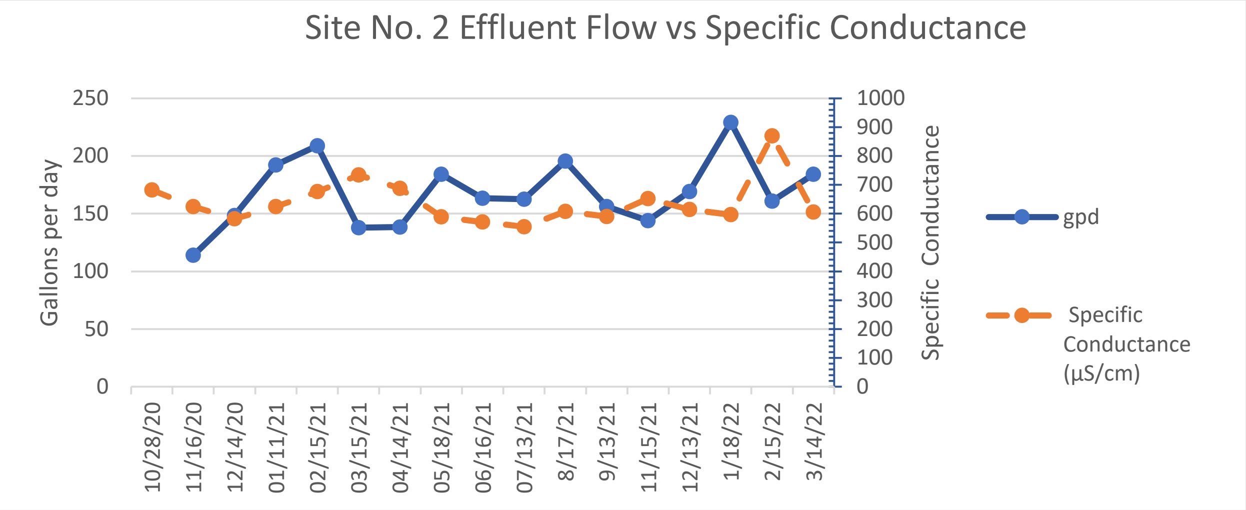


CHART 5-9 Site 2



SITE 2 PUMP CHAMBER EFFLUENT OBSERVATIONS

Following are some observations from studying the data from the effluent samples taken from the pump chamber prior to discharge to the leachfield.

1. The effluent temperature varies based on the time of year, and more specifically, the climatic temperatures. A low of 2.4°C was observed in January, and a high of 20°C was observed in June and July. Effluent temperatures have a direct effect on the temperature of the leachfield. There could be a benefit to insulating the septic and pump tanks from the frost in the ground.
2. The effluent pH is fairly constant throughout the year, averaging 7.52, with a standard deviation of 0.3.
3. The effluent Ammonia, NH_4, is fairly consistent, averaging 37.2 mg/l, with a standard deviation of 7.4.
4. The effluent Nitrate is essentially nonexistent due to anaerobic digestion of organic Nitrate to Ammonia.
5. The effluent Chloride averages 25.4 mg/l, with a standard deviation of 2.6.
6. The effluent Phosphorus averages 4.18 mg/l, with a standard deviation of 1.2, and Phosphate averages 12.61 mg/l, with a standard deviation of 4.1.

SITE 2 LYSIMETER SAMPLE OBSERVATIONS

Following are some observations from studying the data from the lysimeter samples taken from the leachfield. Lysimeter 1 (LY1) was intended to pull samples from approximately 12 inches below the top of the gravel bed, however no water was found in LY1. It is possible that because the leachfield is a gravel bed type that LY1 was not installed below the perforated pipe distributing the effluent. Lysimeter 2 (LY2) was intended to pull samples from approximately 36 inches below the top of the gravel bed, however it is possible that LY2 was not as deep as anticipated.

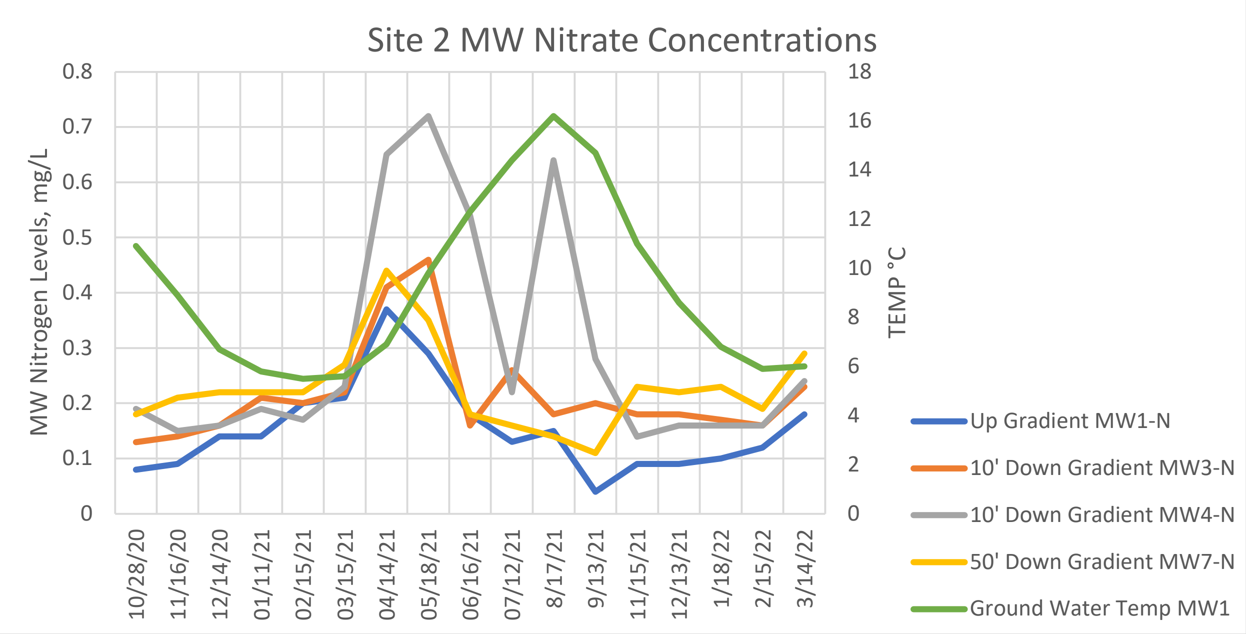
1. The lysimeter water temperatures vary with time of year, and more specifically, the ground temperature/frost. Lysimeter temperatures are affected by the temperature of the applied effluent and ground temperature/frost. LY1 temperatures were not measured.
2. LY1 pH was not measured. LY2 pH was generally higher than the effluent pH, indicating that nitrification in the aerobic zone of the leachfield was not lowering the pH. Nitrification reduces the alkalinity (pH buffer) 7 ppm for each NH_4 ppm that is reduced to Nitrate.
3. LY1 Ammonia was not measured. LY2 sample tests showed that the Ammonia was reduced to Nitrate by nitrification. Nitrification is affected by available Oxygen, temperature, and pH. The reduction in nitrification efficiency in the winter months was not substantially different than in the summer months.
4. LY1 Nitrogen levels were not measured. LY2 Nitrogen levels were variable but generally highest in the winter and lowest in the summer months. Denitrification, the conversion of NO_3 to Nitrite and Nitrogen gas, occurs in an anoxic condition where there is insufficient Dissolved Oxygen for the biological activity, resulting in the bacteria using the Oxygen in the NO_3 for metabolism. Denitrification is dependent upon Dissolved Oxygen, temperature, and a carbon source for the biological degradation. The low denitrification rates could be due to temperature and shallow installation of LY2 not giving sufficient time for complete denitrification.
5. Chloride concentration in the samples from the lysimeters is variable but lower than the Chloride levels in the effluent.
6. Phosphorus and Phosphate concentration in the lysimeters is variable and lower than the effluent concentrations, probably due to adsorption to the soil particles.

SITE 2 MONITORING WELL SAMPLE OBSERVATIONS

Following are some observations from studying the data from the monitoring well samples taken from Site 2. Monitoring Well 1 (MW1) is the upgradient monitoring well. Monitoring Well 2 (MW2) is located in the center of the leachfield. Monitoring Wells 3 through 5 (MW3, MW4 and MW5) are located approximately 10 feet downgradient of the leachfield. Monitoring Wells 6 and 7 (MW6 and MW7) are approximately 50 feet downgradient of the leachfield.

1. Monitoring well sample temperatures are indicative of the groundwater temperature. Monitoring well water temperatures vary seasonally and are generally the same for MW1 and MW3 through MW7. Temperature of water in MW2 is generally a few tenths of a degree lower than the other monitoring wells, probably due to the influence of the leachfield.
2. Monitoring well water pH was very consistent and generally the same for MW1 and MW3 through MW7. The water in MW2 had a lower pH than the other monitoring wells, probably due to the nitrification process that was occurring in the leachfield.
3. Monitoring well Dissolved Oxygen (DO) showed a general pattern of reduction from MW1 to MW3 through MW7, indicating that there could be some Oxygen demand imposed on the groundwater by the effluent from the leachfield. The DO varied seasonally, probably due to temperature. The saturation level of DO is highest at low temperatures and lowest at high temperatures.
4. Ammonia concentrations in the monitoring wells were not measurable.
5. Nitrate nitrogen concentrations in MW1 (upgradient) and MW5, MW6 and MW7 (downgradient) ranged from 0.14 to 0.46 ppm, being the highest in April. The Nitrogen concentrations in MW2 were highest in the winter (36.4 ppm) indicating reduced denitrification. The Nitrate concentrations in MW3 through MW7 were considerably lower than MW2 due to additional denitrification and dilution with groundwater.
6. Chloride concentrations in the monitoring wells show the effect of the groundwater diluting the Chloride from the effluent. MW2 had high Chloride concentrations November through March indicating less groundwater dilution during this period.
7. The reduced Phosphorus and Phosphate concentrations in the monitoring wells show the effect of the groundwater diluting the effluent leachate and the adsorption in the soil. MW2 did show some measurable Phosphorus and Phosphate concentration, but the concentration was at background levels in the downgradient monitoring wells.
8. The monitoring wells did occasionally show some coliform bacteria, however there did not seem to be a pattern.

CHART 5-10 Site 2



Site 3

The monitoring wells constructed 10 feet below the surface were not deep enough to sample groundwater except in June, July, August, and September. As a result, samples were not obtainable in the fall, winter, and spring months, and therefore no data was available to draw conclusions regarding the treatment efficiency of the Site 3 leachfield.

No further study was done for Site 3.

Site 4

The data set for Site 4 was fairly complete. There were times when a complete set of samples was not possible to obtain. Due to low groundwater elevation, samples were not taken in January, February, and March of 2022.

SITE 4 NITRATE, TEMPERATURE AND DISSOLVED OXYGEN OBSERVATIONS

The Nitrate, temperature, and Dissolved Oxygen (DO) data from all of the collective sampling points at Site 4 demonstrates that the groundwater Nitrate levels decrease with an increase in temperature, and the Dissolved Oxygen levels decrease with an increase in temperature in sync with the DO saturation, but there is still DO available for biological activity, Chart 5-11. This indicates that aerobic biological activity, including denitrification, decreases as temperature decreases and increases at temperature increase. We surmise that as groundwater temperature decreases aerobic biological activity decreases thus bacteria are not utilizing Oxygen from O_2 or NO_3, and therefore Nitrate levels will increase at lower temperatures.

CHART 5-11 Site 4

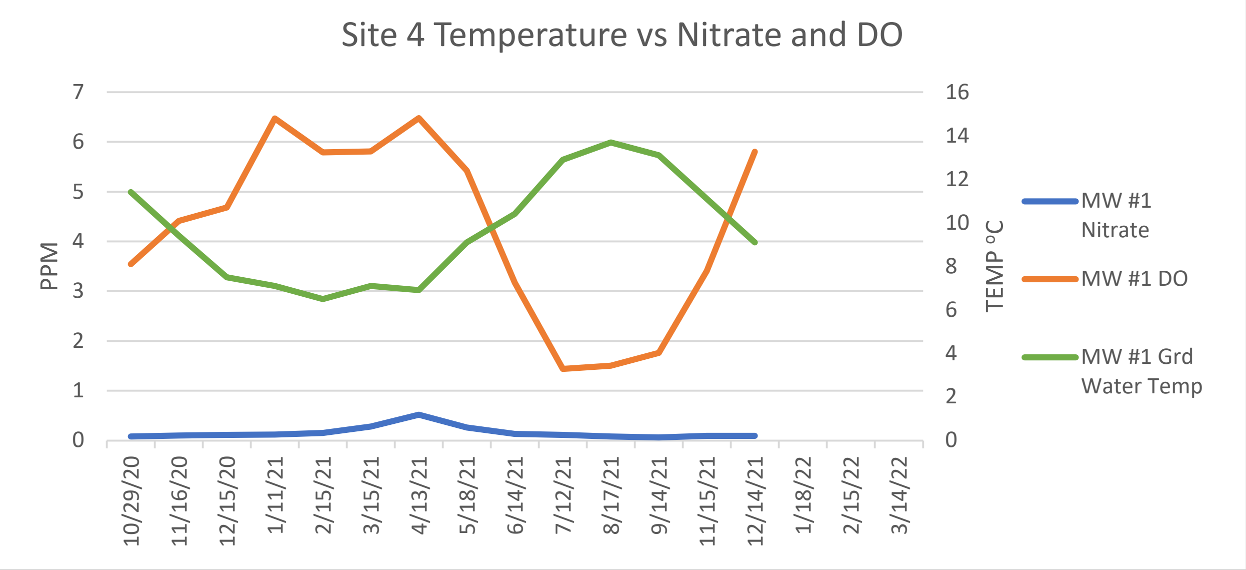


CHART 5-12 Site 4

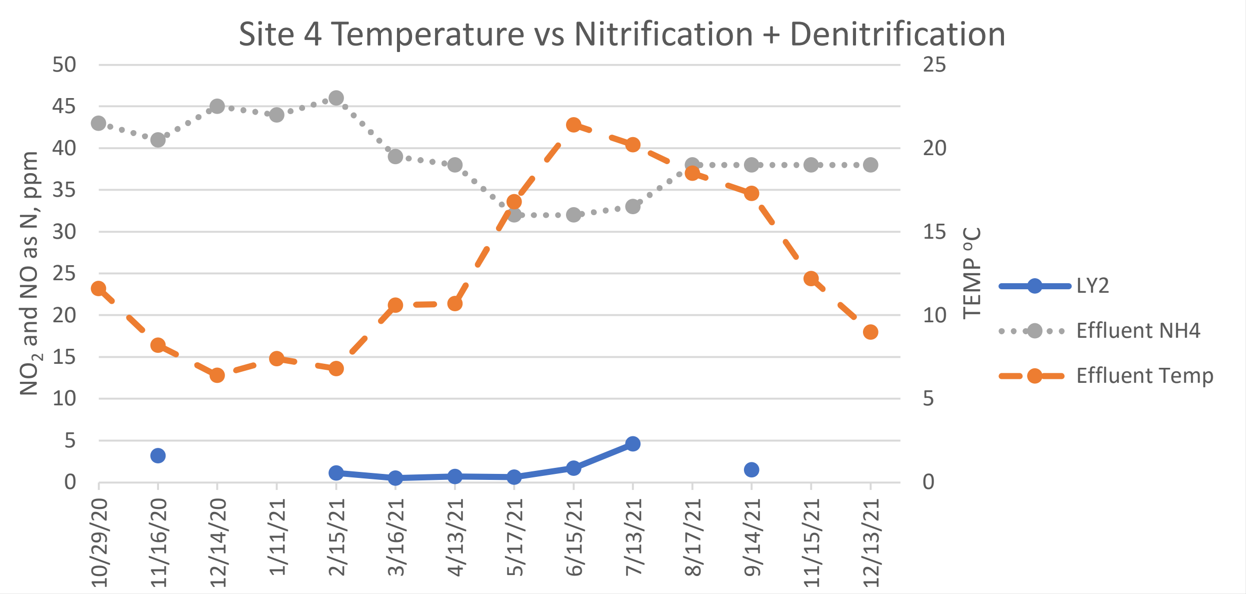


CHART 5-13 Site 4

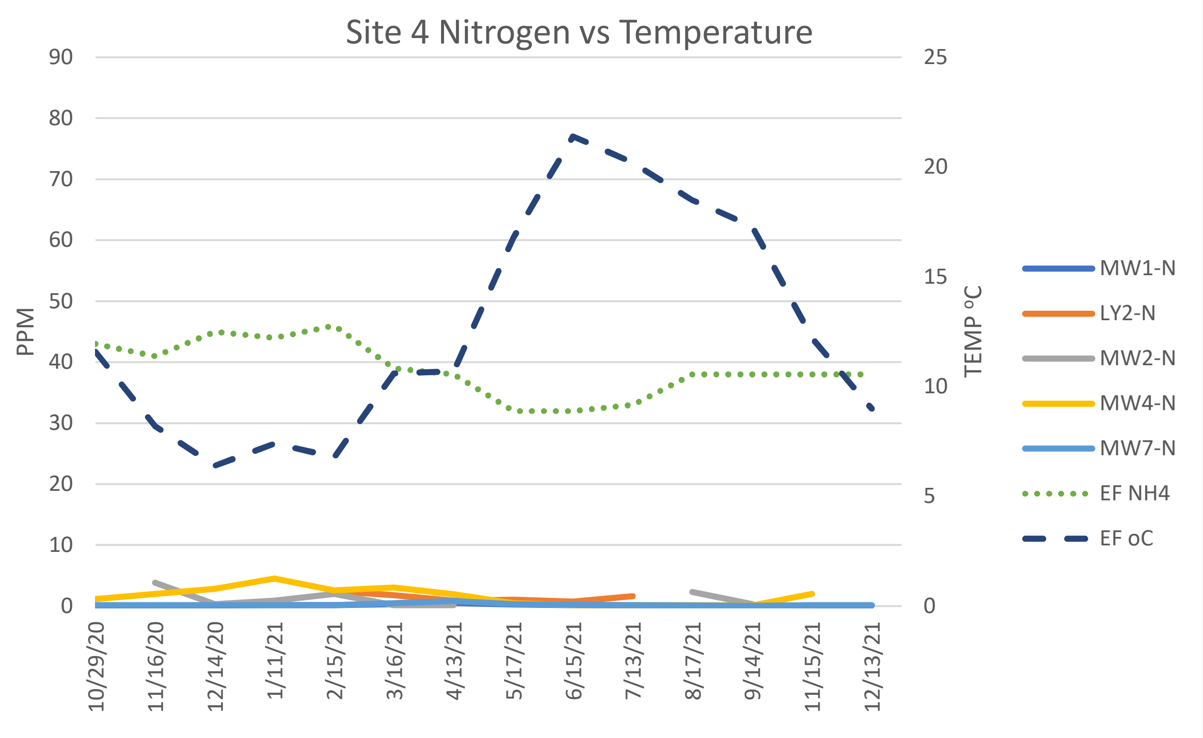
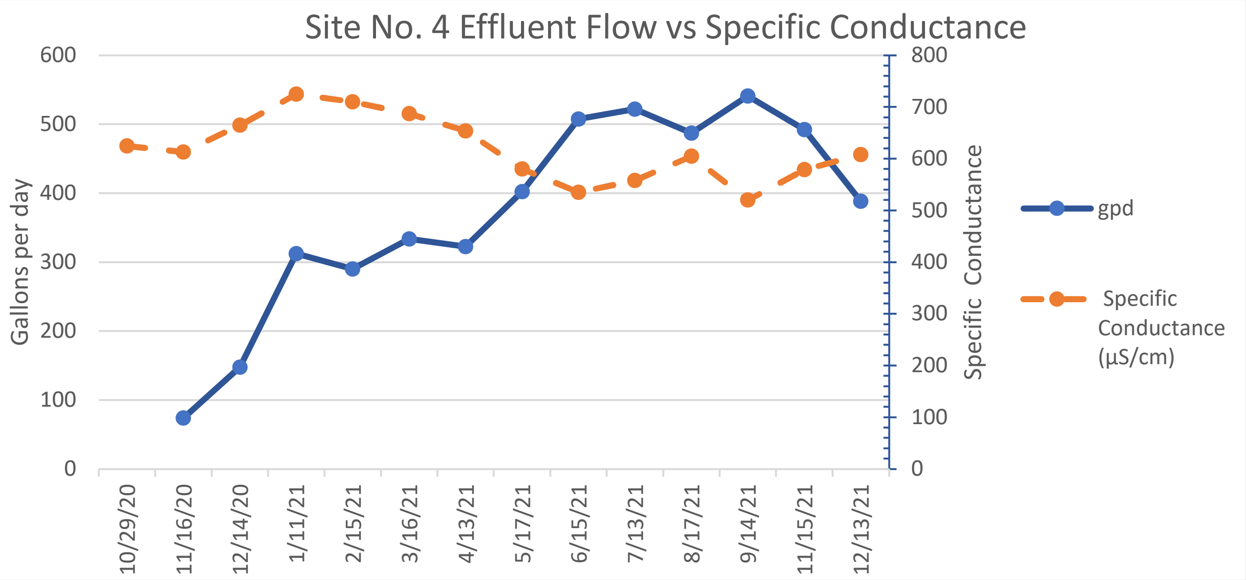


CHART 5-14 Site 4



SITE 4 PUMP CHAMBER EFFLUENT OBSERVATIONS

Following are some observations from studying the data from the effluent samples taken from the pump chamber prior to discharge to the leachfield.

1. The effluent temperature varies with the time of year, and more specifically, the climatic temperatures. A low of 6.4 ^oC was observed in January, and a high of 21.4 ^oC was observed in June. Effluent temperatures have a direct effect on the temperature of the leachfield. There could be a benefit to insulating the septic and pump tanks from the frost in the ground.
2. The effluent pH is fairly constant throughout the year, averaging 7.43, with a standard deviation of 0.2.
3. The effluent Ammonia, NH_4, is fairly consistent averaging 39.1 mg/l, with a standard deviation of 4.9.
4. The effluent Nitrate is essentially nonexistent due to anaerobic digestion of organic Nitrate to Ammonia.
5. The effluent Chloride averages 20.7 mg/l, with a standard deviation of 3.4.
6. The effluent Phosphorus averages 4.87 mg/l, with a standard deviation of 1.7, and Phosphate averages 14.9 mg/l, with a standard deviation of 5.1.

SITE 4 LYSIMETER SAMPLE OBSERVATIONS

Following are some observations from studying the data from the lysimeter samples taken from the leachfield. Lysimeter 1 (LY1) was intended to pull samples from approximately 12 inches below the bottom of the infiltrators. Lysimeter 2 (LY2) was intended to pull samples from approximately 36 inches below the bottom of the infiltrators.

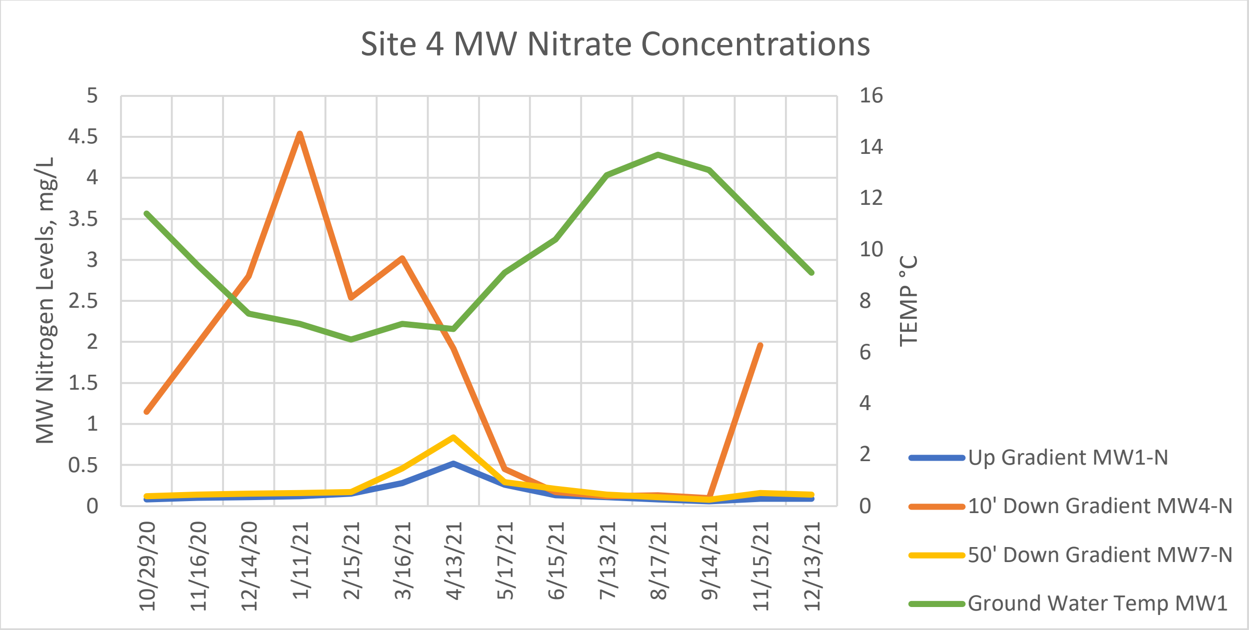
1. The lysimeter water temperatures vary with time of year, and more specifically, the ground temperature. Lysimeter temperatures are affected by the temperature of the applied effluent and ground temperature/frost. LY1 temperatures were not measured.
2. LY1 pH was not measured. LY2 pH was generally similar to the effluent pH in the winter, indicating that nitrification in the aerobic zone of the leachfield was not lowering the pH. LY2 pH in the summer was lower than the effluent pH, indicating that nitrification was taking place in the warmer months. Nitrification reduces the alkalinity (pH buffer) 7 ppm for each NH_4 ppm that is reduced to Nitrate.
3. LY1 Ammonia was variable. LY2 Ammonia was lower than the effluent Ammonia indicating nitrification. Nitrification is affected by available Oxygen, temperature, and pH. The nitrification efficiency in the winter months was not substantially different than in the summer months.
4. LY1 Nitrogen levels were variable. LY2 Nitrogen levels were variable but generally highest in the winter and lowest in the summer months. Denitrification, the conversion of NO_3 to Nitrite and Nitrogen gas, occurs in an anoxic condition where there is insufficient Dissolved Oxygen for the biological activity, resulting in the bacteria using the Oxygen in the NO_3 for metabolism. Denitrification is dependent upon Dissolved Oxygen, temperature, and a carbon source for the biological degradation.
5. Chloride concentration in the samples from the lysimeters is variable but generally about the same as the Chloride levels in the effluent.
6. Phosphorus and Phosphate concentration in the lysimeters were very low and much lower than the effluent concentrations, probably due to adsorption to the soil particles.

SITE 4 MONITORING WELL SAMPLE OBSERVATIONS

Following are some observations from studying the data from the monitoring well samples taken from Site 4. Monitoring Well 1 (MW1) is the upgradient monitoring well. Monitoring Well 2 (MW2) is located in the center of the leachfield. Monitoring Wells 3 through 5 (MW3, MW4 and MW5) are located approximately 10 feet downgradient of the leachfield. Monitoring Wells 6 and 7 (MW6 and MW7) are approximately 50 feet downgradient of the leachfield. Based on field reports of septic tank effluent odor in samples from MW2 and test results, it is probable that there was a cross connection between the leachfield distribution system and MW2.

9. Monitoring well sample temperatures are indicative of the groundwater temperature. Monitoring well water temperatures vary seasonally and are generally the same for MW1 and MW3 through MW7.
10. Monitoring well water pH was very consistent and generally the same for MW1 and MW3 through MW7. The water in MW2 had a lower pH than the other monitoring wells, probably due to the nitrification process that was occurring in the leachfield.
11. Monitoring well Dissolved Oxygen (DO) did not show a consistent pattern of reduction from MW1 to MW3 through MW7. Some monthly samples (August and September) did show a downgradient decrease in DO, indicating that there could be some Oxygen demand imposed on the groundwater by the effluent from the leachfield. Overall, DO levels increased with the decrease in groundwater temperature in sync with the DO saturation, but there was still DO available for biological activity.
12. Specific Conductance measurements in the monitoring wells shows the effect of the groundwater diluting the dissolved solids in the effluent. High Specific Conductance in MW2 indicates probable cross connection.
13. Ammonia concentrations in the monitoring wells, with the exception of MW2, were not measurable. Ammonia in MW2 was probably due to cross connection.
14. Nitrate nitrogen concentrations in MW1 (upgradient) and MW5, MW6 and MW7 (downgradient) ranged from 0.08 to 0.84 ppm, being the highest in April. The Nitrogen concentrations in MW2 and MW4 were highest in the winter indicating reduced denitrification. The Nitrate concentrations in MW6 and MW7 were considerably lower than MW2 through MW4 due to additional denitrification and dilution with groundwater.
15. Chloride concentrations in the monitoring wells show the effect of the groundwater diluting the Chloride from the effluent. Chloride in MW2 indicates cross connection.
16. The reduced Phosphorus and Phosphate concentrations in the monitoring wells show the effect of the groundwater diluting the effluent leachate and the adsorption in the soil. MW2 did show high Phosphorus and Phosphate concentration, probably due to cross connection.

CHART 5-15 Site 4



6. Comparison of Empirical Data to Published Studies

The results of the analysis of the septic tank effluent from the three sites was similar to published data:

TABLE 6-1 Study Results vs Published Data

	3 Site Ave.	**Published**			
Septic Tank Effluent		Mean	Std Dev.	# Sites	
Temperature (°C)	11.2				
pH	7.54	7.4	0.2	17	Geary and Lucas, 2019(12)
Specific Conductance (µS/cm)	693	1480	131	17	Geary and Lucas, 2019(12)
Ammonia, NH4 (mg/l)	39	72	37	111	Robertson et al., 2019(6)
Nitrogen, N as NO_2 and NO_3 (mg/l)	0.04	0.2	0.2	10	Geary and Lucas, 2019(12)
Chloride (mg/l)	27.0	64		106	Robertson et al., 2019(6)
Phosphorus (mg/l)	4.4	4.6	4.2	37	Withers et al., 2011(13)
Phosphate (mg/l)	13.8				

Leachfields analyzed in this study in general perform better than published data, however there is very little published data on leachfield performance, only lab columns and short-term testing before the biomat is formed on the surface of the drainfield.

The location and installation of the lysimeters in an existing leachfield is problematic; installation of lysimeters during construction of the leachfield would provide better sampling capability. However, the development of the biomat on the surface of the leachfield takes time, and therefore early sampling, within the first year of lysimeters constructed with the leachfield, may not be indicative of the leachfield treatment efficiency.

Much of the published data on groundwater contamination from leachfields is based on monitoring wells with the results showing the contaminate plume and reduction of the contaminates as the groundwater flows away from the leachfield. This study did not have a sufficient number of monitoring wells at each site to clearly establish the plume and develop a groundwater flow model.

Utilizing Chloride and Specific Conductance as a tracer to indicate dilution with groundwater is common with other studies and was effective in this study. Some published studies used NO_3, Na, minor and trace constituents such as Boron, or artificial sweeteners (Acesulfame and Sucralose), however the concentrations of these constituents in domestic wastewater are very low compared to background values in groundwater and are therefore difficult to monitor.

Ammonia was almost completely oxidized in the unsaturated zone at all three sites, an average of 97.1% reduction. Published data indicates that this level of oxidation is typical of properly-constructed leachfields with sufficient unsaturated zone for oxidation of the septic tank effluent prior to mixing with the groundwater.

Nitrate was removed by denitrification in the leachfield, 50.2% at Site 1 and 96.3% at Site 4. Site 2 did not exhibit any denitrification in the leachfield, possibly due to the location of the lysimeters. All three sites did show effective denitrification prior to the first monitoring wells 10 feet downgradient of the leachfield. These results are consistent with the variability in published data as the treatment efficiency of the leachfield is dependent on the leachfield design, soil types, and effluent application.

The average Nitrogen removal from all three sites, based on the samples from the lysimeters, was 46.2%. Site 1 removed 48.2% of the Nitrogen, Site 2 did not remove Nitrogen, Site 4 removed 92.1% of the Nitrogen. This variability in Nitrogen removal is similar to published data because of the variability in design, climate, and soil types.

Based on results from the lysimeters, the average Total Phosphorus removal was 71.4%. Site 1 removed 35.5% of the Phosphorus, Site 2 removed 92.1% of the Phosphorus, and Site 4 removed 90.7% of the Phosphorus. These results are better than most published studies, however again it is difficult to compare these results to published studies because of the difference in soil types, pH, and leachfield construction.

Overall Phosphate removal in the leachfield was 72.2%. Site 1 removed 33.2% of the Phosphate, Site 2 removed 91.9% of the Phosphate, and Site 4 removed 92.2% of the Phosphate. This variation could be due to differences in laundry detergents and the leachfield loading rates at the individual sites.

7. Conclusions

It appears that Site 1 has a leaking septic tank or pump chamber based on the low pumping rate in winter and high pump rate in June. The leak could be at the opening in the chamber where the pipe enters or exits.

Site 4 septic tank effluent and leachfield had the highest temperature in winter; this could be because it had more earth cover over the infiltrators than the other sites.

Site 2 had the lowest Nitrogen removal, had nitrification but no denitrification as measured by the lysimeters. Site 2 was a gravel bed, not infiltrators. However, Site 2 did have Nitrogen removal below the lysimeters as evidenced by the Nitrogen concentration in the downgradient monitoring wells.

Overall, the three sites showed an average Ammonia (nitrification) removal of 97.1%. The majority of the nitrification occurred in the first 12 inches of the leachfield.

Based on the samples from the lysimeters, the three sites showed an average Total Nitrogen removal of 46.2%; Site 1 Nitrogen removal was 48.2%, Site 2 was 0, and Site 4 Total Nitrogen removal was 92.1%. Average Chloride removal for all three sites was 7.4%.

Average Phosphorus removal for all three sites was 71.4%. Site 1 was lowest at 35.5% while Site 2 and Site 4 had Phosphorus removal of 92.1% and 90.7%, respectively.

Average Phosphate removal for all three sites was 72.2%. Site 1 was the lowest at 33.4%, while Site 2 and Site 3 had Phosphate removal of 91.9% and 92.2%, respectively.

Based on tracer constituents, Chloride and Specific Conductance, there is significant dilution of Nitrogen and Phosphorus when they reach the groundwater.

The Nitrogen concentration in the immediate downgradient monitoring well 10 feet from the leachfield increased, over upgradient MW1, an average of 0.89 mg/l at Site 1, 0.14 mg/l at Site 2, and 1.44 mg/l at Site 4.

The Nitrogen concentration in the immediate downgradient monitoring well 50 feet from the leachfield increased, over upgradient MW1, an average of 0.27 mg/l at Site 1, 0.07 mg/l at Site 2, and 0.07 mg/l at Site 4.

The largest increase in the monitoring well Nitrogen concentration occurred during the winter months.

The Total Phosphorus concentration in the immediate downgradient monitoring well 10 feet from the leachfield increased, over upgradient MW1, an average of 0.020 mg/l at Site 1, 0.015 mg/l at Site 2, and 0.34 mg/l at Site 4.

The Total Phosphorus concentration in the immediate downgradient monitoring well 50 feet from the leachfield increased, over upgradient MW1, an average of 0.001 mg/l at Site 1, 0.001 mg/l at Site 2, and 0.037 mg/l at Site 4.

If future studies are conducted it would be helpful, if budget allows, to track the Total Organic Carbon (TOC) from the septic tank effluent through the lysimeters and monitoring wells. TOC has become an important parameter used to monitor overall levels of organic compounds present. TOC does not provide direct quantitative correlation between Total Organic Carbon and the Biochemical Oxygen Demand (BOD) but is an easy-to-measure, general indicator of the approximate level of organic contamination in the water. Tracking the reduction in TOC would provide an indication of the aerobic reduction of organic matter through the leachfield and groundwater aquifer.

For the leachfield wells (MW2), it could be helpful to have only the lower section of the PVC well within groundwater be perforated and the top portion solid PVC, to help reduce the likelihood of leachate short circuiting into the well. Also, it would be advantageous to place bentonite in the annular space between the steel well pipe and the PVC monitoring pipe for at least four feet below the bottom of the leachfield prior to pulling the steel pipe to provide a monitoring well surface seal.

8. Recommendations

Septic System Design Modifications

1. Require that septic tank and pump chamber be insulated to retain heat from household wastewater and reduce cooling effect of frozen ground. Do not allow tank and pump chamber to be placed under plowed surfaces without additional insulation.
2. Encourage the use of infiltrators and require a minimum of 1.5 to 2 feet of cover to provide more insulation above the drainfield.
3. Leak test septic tank and pump chamber after construction.

Septic System Operational Suggestions

1. Assure that septic tanks are pumped at least every 5 years.
2. Assure an inspection of the septic system, at least, each time the septic tank is pumped.
3. Close leachfield vents in winter.

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