# Vadose Zone and Groundwater Nitrate Study

*Lower Platte North Natural Resources District*

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By: Daniel Snow and Jessica Garcia Nascimento
University of Nebraska-Lincoln Water Sciences Laboratory

Nebraska Water Center
Daugherty Water for Food Global Institute

University of Nebraska

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## Abbreviations

| | |
|---|---|
| NRD | Natural Resources District |
| $NO_3$-N | Nitrate as nitrogen; specifically measures the amount of nitrogen in the nitrate ion in the sample |
| $NH_4$-N | Ammonia as nitrogen; specifically measures the amount of nitrogen in the ammonia ion in the sample |
| g | Gram; measures mass |
| mg | Milligram (1,000mg = 1g); measures mass |
| µg | Microgram (1,000,000 µg = 1g); measures mass |
| L | Liter; measures volume |
| mL | Milliliter (1,000mL = 1L); measures volume |
| $g/cm^3$ | Grams per cubic centimeter (1 $g/cm^3$ = 1 g/mL); measures mass over volume, also known as density |
| mg/L | Milligrams per liter (1,000,000 mg/L = 1 $g/cm^3$ = 1 g/mL); measures mass over volume, also known as density |
| µg/g (ppm) | Microgram per gram and parts per million; measure mass over mass, also known as mass percent (1 µg/g = 1 ppm) |
| ng/g (ppb) | Nanograms per gram and parts per billion; measure mass over mass, also known as mass percent (1 ng/g = 1 ppb) |
| lbs-N/Acre-ft | Pounds nitrogen per acre-foot; measure weight nitrogen over volume soil (1 acre-ft = 1,233.48 $m^3$) |

### Definitions and calculations of parameters listed in vadose zone profile data

| PARAMETER | CALCULATION |
|---|---|
| **DEPTH** | Start Depth - Stop Depth |
| **GRAVIMETRIC WATER CONTENT** | Water (g) / Dry Sample (g) |
| **BULK DENSITY** | Dry Sample (g) / Sample Volume (mL) |
| **PH** | Scale of 1 – 14 |
| **$NO_3$-N (µG/G)** | ($NO_3$-N (mg/L) * L of Extract * 1000 µg) / sample weight (g) |
| **NH4-N (µG/G)** | ($NH_4$-N (mg/L) * L of Extract * 1000 µg) / sample weight (g) |
| **POREWATER $NO_3$-N (MG/L)** | $NO_3$-N (µg/g) / Gravimetric Water Content |
| **LBS-N/ACRE-FT** | ($NO_3$-N (µg/g) * $2.2x10^{-9}$ (lb/µg) * Bulk Density (g/mL)) / $8.11x10^{-10}$ (Acre-ft/mL) |
| **LITHOLOGIC DESCRIPTION** | Sediment Type, Iron (Chemical or Physical), Organic Matter, Color |
| **SAND %** | (Sand (g) / Sample (g)) * 100 |
| **SILT %** | (Silt (g) / Sample (g)) * 100 |
| **CLAY %** | (Clay (g) / Sample (g)) * 100 |

## Introduction

Nitrate-nitrogen (nitrate-N or $NO_3$-N) is the most common contaminant affecting aquifers worldwide[1,3,4] and nonpoint source contamination of groundwater has been well documented for years[2,3]. Nebraska has some of the most extensive groundwater quality records from across the country, and this rich dataset provides a useful source of information on land use practices that lead to a reduction in groundwater nitrate-N concentrations. Vadose zone monitoring has been conducted in many areas throughout the state to help assess the changing amount of nitrate-N stored in the unsaturated zone, associated transport rates, and potential for impacting groundwater $NO_3$-N concentrations. Continued monitoring of this region between the crop root zone and the water table will help better assess when changing nutrient and irrigation practices are having an effect on nitrate loading. Repeated sampling over several years can help estimate the rate of travel and predict when and where nitrate stored in the vadose zone will intercept the water table, as well as provide insight to general concentrations of that nitrate in groundwater when it reaches the water table. This report describes a 2-year investigation of vadose zone and groundwater nitrate in the Lower Platte North Natural Resource District (LPNNRD) by the University of Nebraska between August 2019 to December 2020. The Lower Platte North and its contractor, EA Engineering, identified the area of interest, scheduled core and water samples collection, and delivered samples to the Water Sciences Laboratory. Additional data on groundwater nitrate levels in the district was provided to include with this report.

## Objectives

The overall objectives of this project included:

1. Collect continuous cores, which are described and geologically classified, and chemically analyze composited subsamples every 2 to 5 feet.
    a. Analyze core subsamples for gravimetric moisture content, bulk density, and pH.
    b. Analyze selected core subsamples for nitrate isotopes, arsenic, and uranium and graph results to indicate changes in composition versus depth below surface.
    c. Calculate the nitrate amount in the vadose zone by lbs/acre and at discrete depths.
    d. Analyze selected subsamples for particle size analysis.
2. Estimate the vertical transit rate of water and nitrate at specific locations using data obtained from the vadose zone samples.
3. Analyze groundwater samples by the LPNNRD for nitrate isotopes, uranium, arsenic and summarize results in tabular or graphical format, providing some interpretation with respect to nitrogen sources and measured concentrations

## Use of Nitrate Isotope Analysis

The stable isotope composition of nitrate can provide information about the predominant sources of nitrogen and whether nitrate has been affected by denitrification since formation in the soil. Nitrate is

composed of multiple stable isotopes of nitrogen and oxygen, and the composition or proportion of these isotopes changes in a predictable way in surface and groundwater systems. Moreover, nitrogen from specific sources has been shown to have a unique isotope composition or "fingerprint" which has led to several studies investigating the utility of linking nitrogen sources to nitrate contamination. Figure 1 illustrates ranges of the isotope composition of nitrogen sources (fertilizer, natural soil nitrogen, manure, and septic nitrogen) and the effect of denitrification on nitrate from a single source. Fractionation of the residual nitrate isotope composition during denitrification has been well documented [1] and must be considered when using nitrate isotope analysis for source determination. The stable isotope composition is measured and expressed as a delta "δ" per mil relative to a known reference standard using the following equation:

$$\delta(‰) = \frac{R_{sample} - R_{standard}}{R_{standard}} x1000$$

Where $R_{sample}$ and $R_{standard}$ are the ratios in heavy and light isotopes in a sample and reference standard. The reference standard for nitrogen isotope analysis is atmospheric nitrogen while the reference standard for oxygen isotope analysis is seawater. The use of atmospheric nitrogen as a reference standard is fortuitous for isotope fingerprinting because commercial nitrogen fertilizer is manufactured from the air.

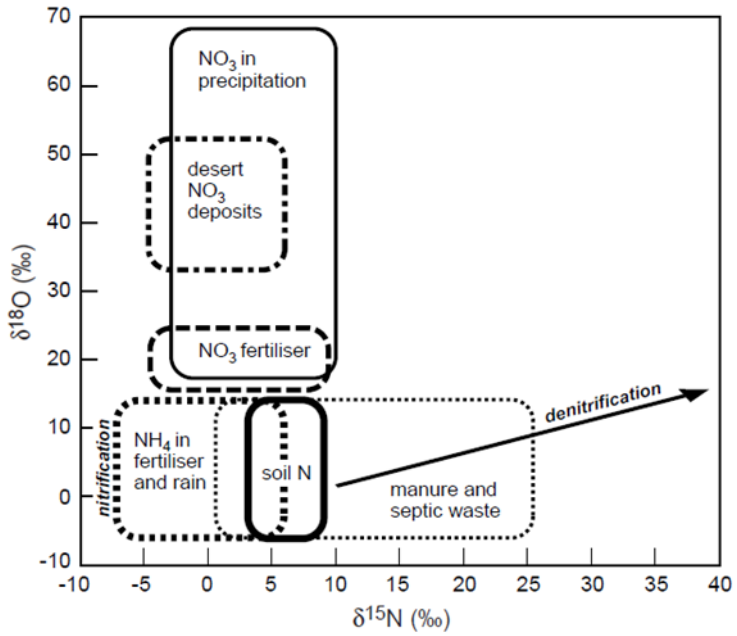


***Figure 1. Typical ranges of delta 15N and delta18O of nitrate compared to different sources of nitrogen and the predicted effect from denitrification [1].***

Measurement of both the nitrogen and oxygen isotope composition of nitrate allows better evaluation of the potential effect of $\delta^{15}$N-$NO_3$ enrichment due to denitrification assuming the original nitrogen isotope composition is in the range of commercial fertilizer nitrogen. As shown in Figure 1, the oxygen isotope and nitrogen isotope composition of nitrate affected by denitrification are predicted to increase in a straight line. If multiple samples plot along with a similar trend, then the enrichment is likely due to denitrification. A group of samples affected by denitrification will also show a negative slope in the plot of nitrate concentration versus $\delta^{15}$N-$NO_3$ content [1].

## Area of Study

This report describes the investigation of vadose zone nitrate in the Bellwood Phase 2, Richland and Schuyler Phase 2 and 3 Groundwater Management Areas in the central region of the LPNNRD (Figure 2). The NRD instituted Phase 2 management near Bellwood in 2003, and Richland-Schuyler in 2004 in response to elevated nitrate levels in this region [2]. Parts of the Bellwood Phase 2 area were moved to Phase 1 in response to declining groundwater nitrate concentrations, while concentrations in the Richland-Schuyler Phase 2 and 3 areas continued to increase.

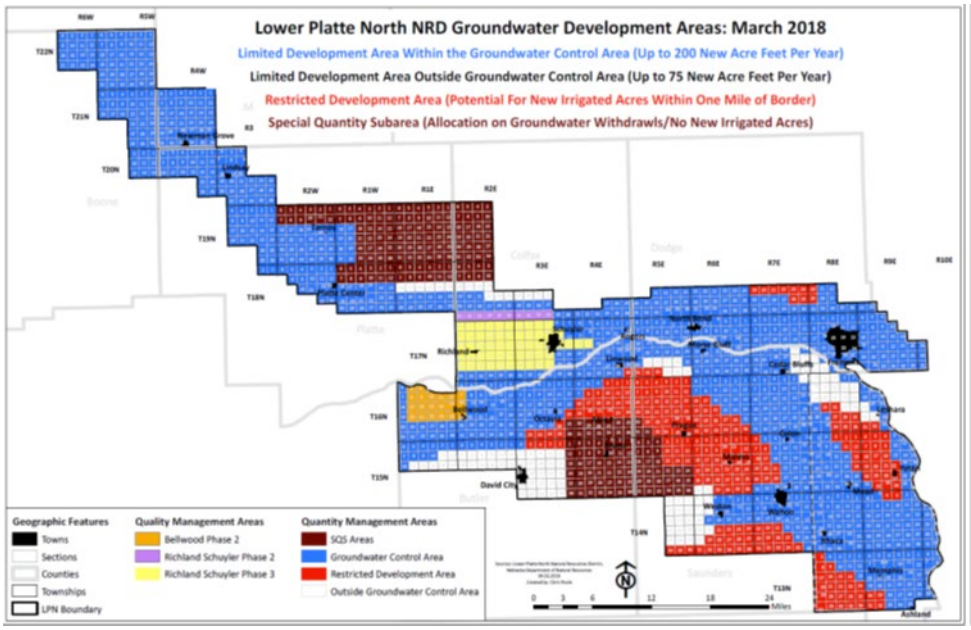


**Figure 2. Locations of the Bellwood and Richland-Schuyler Groundwater Management areas included in this study [2]. Approximate location of vadose zone sampling outlined in yellow.**

**Geologic Setting.** This region of the LPNNRD is located immediately downstream of the confluence of the Loup and Platte Rivers and groundwater contamination vulnerability (Figure 3) has been classified as "Group B" by [3]. The extent of nitrate contamination in Group B areas of Nebraska have increased by an average of 3330-3700 hectare per year (8230-9140 acres per year) as defined by median and maximum groundwater nitrate concentrations. In the LPNNRD, soil drainage is likely heterogeneous with a generally short distance to the water table in both well-drained and poorly drained soils. The shallow alluvial aquifer of these areas in Nebraska are mainly Quaternary sands and

gravels overlain by silty and sandy clay soils. The Platte River Valley at Schuyler contains a complex fill of alluvial and eolian sediments that overlie Cretaceous shale and limestones [4]. Alluvial floodplain deposits are bounded by terrace deposits (silts and clays interbedded with sands) and eolian loess (wind-blown silts) upland. Upland loess areas have a higher topographic relief and alluvial terrace and floodplain deposits. Group A areas are vulnerable to rapid nitrate leaching under aerobic conditions with little potential for denitrification. Group B, which includes this study, is characterized by well-drained silt loam soils with less rapid infiltration rates and, depending on conditions more potential for denitrification [3].

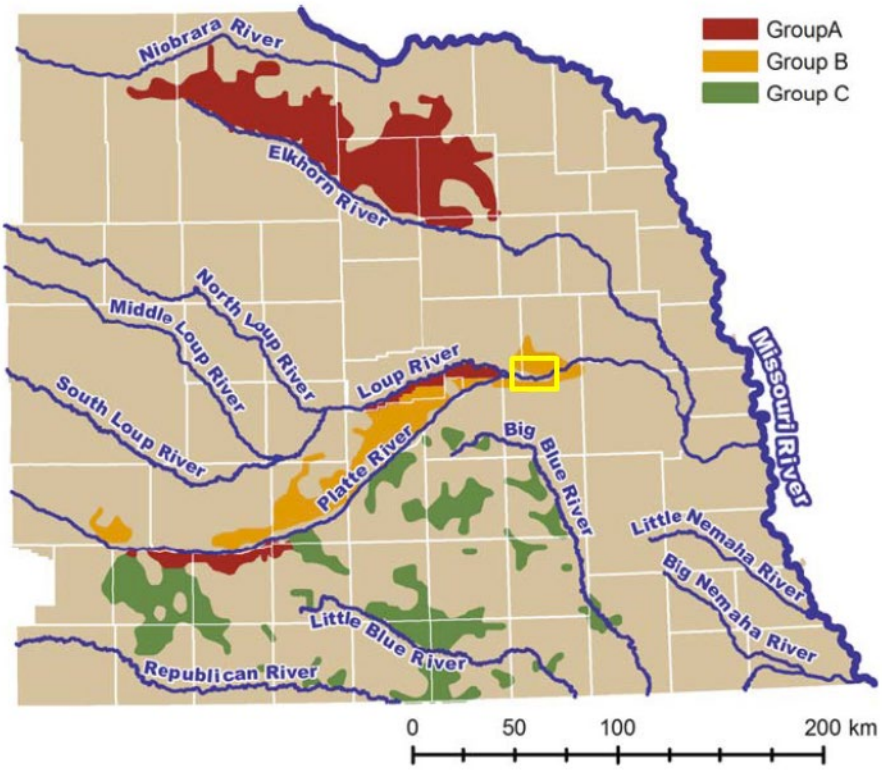


**Figure 3. Groundwater nitrate-N vulnerability groups as defined by predominant irrigation, soil drainage characteristics, vadose zone thickness, and lithology [3]. The approximate location of the study area is indicated by a yellow rectangle.**

Thirty (30) vadose zone core samples were collected by EA Engineering from areas used primarily for agricultural production (Table 1) and delivered to the Water Sciences Laboratory in November and December 2019. Figure 4 shows the location of 6 deep core samples (DS) and 24 shallow samples (SS), which were collected as representative samples. Deep sample sediments were cored from the surface to the water table wherever possible. Sampled vadose zone depths ranged from 15-77 feet below the land surface. Shallow representative samples were collected from 1-10 feet below the land

surface.

**Table 1. Coring locations sampled in LPNNRD in 2019**

| No. | Site | Location | History | Irrigation method |
|---|---|---|---|---|
| **1** | DS-31-2019 | 41.4957127125; -97.1391908122 | Corn | Center pivot |
| **2** | DS-32-2019 | 41.4634900506; -97.1917666978 | Corn | Center pivot |
| **3** | DS-33-2019 | 41.4456590355; -97.2239917991 | Corn | Center pivot |
| **4** | DS-35-2019 | 41.4962723661; -97.2487412702 | Corn | Center pivot |
| **5** | DS-38-2019 | 41.4629776247; -97.2522929018 | Soybeans | NA |
| **6** | DS-39-2019 | 41.478874804; -97.2522793081 | Corn | Center pivot |
| **7** | SS-01-2019 | 41.4372847904; -97.0611142375 | Turf | NA |
| **8** | SS-02-2019 | 41.4358855174; -97.0635670016 | Turf | NA |
| **9** | SS-03-2019 | 41.4622279379; -97.0447318336 | Corn | NA |
| **10** | SS-04-2019 | 41.4232678187; -97.0782114649 | Alfalfa | NA |
| **11** | SS-05-2019 | 41.445203621; -97.2186696707 | Cover Crop | NA |
| **12** | SS-07-2019 | 41.4280117969; -97.2146784713 | Soybeans | NA |
| **13** | SS-08-2019 | 41.408970017; -97.2099130122 | Grass | NA |
| **14** | SS-09-2019 | 41.4091315261; -97.2128628368 | Sudan Grass, Cover Crop | NA |
| **15** | SS-10-2019 | 41.4196621992; -97.1941894434 | Grass-old alfalfa | NA |
| **16** | SS-11-2019 | 41.4597987306; -97.179794079 | Chopped Corn | NA |
| **17** | SS-13-2019 | 41.439027278; -97.0305036947 | Corn | Center pivot |
| **18** | SS-14-2019 | 41.4236819596; | Sudan Grass, Cover Crop | Center pivot |

| | | | | |
|---|---|---|---|---|
| | | -97.0303969123 | | |
| **19** | SS-16-2019 | 41.4564356872; -97.082587755 | Corn | Center pivot |
| **20** | SS-18A-2019 | 41.4521329645; -97.1092605075 | Corn | Center pivot |
| **21** | SS-18B-2019 | 41.4520500324; -97.1160980092 | Corn | Center pivot |
| **22** | SS-19-2019 | 41.4485025705; -97.1178774955 | Corn | Center pivot |
| **23** | SS-26-2019 | 41.4277590942; -97.1878891794 | Soybeans | Center pivot |
| **24** | SS-28-2019 | 41.4362040778; -97.1606532202 | Corn | Gated pipe |
| **25** | SS-B01-2019 | 41.3804787998; -97.3409073198 | Corn | Gated pipe |
| **26** | SS-B05-2019 | 41.3662898078; -97.3146470836 | Native grass/pasture | |
| **27** | SS-B07-2019 | 41.3702383741; -97.2921133047 | Corn | Center pivot |
| **28** | SS-B11-2019 | 41.3522055985; -97.3301626991 | Alfalfa | Center pivot |
| **29** | SS-B16-2019 | 41.3778599083; -97.2466730413 | Corn | Gated pipe |
| **30** | SS-B22-2019 | 41.3395186353; -97.2489222598 | Soybeans | Gated pipe |

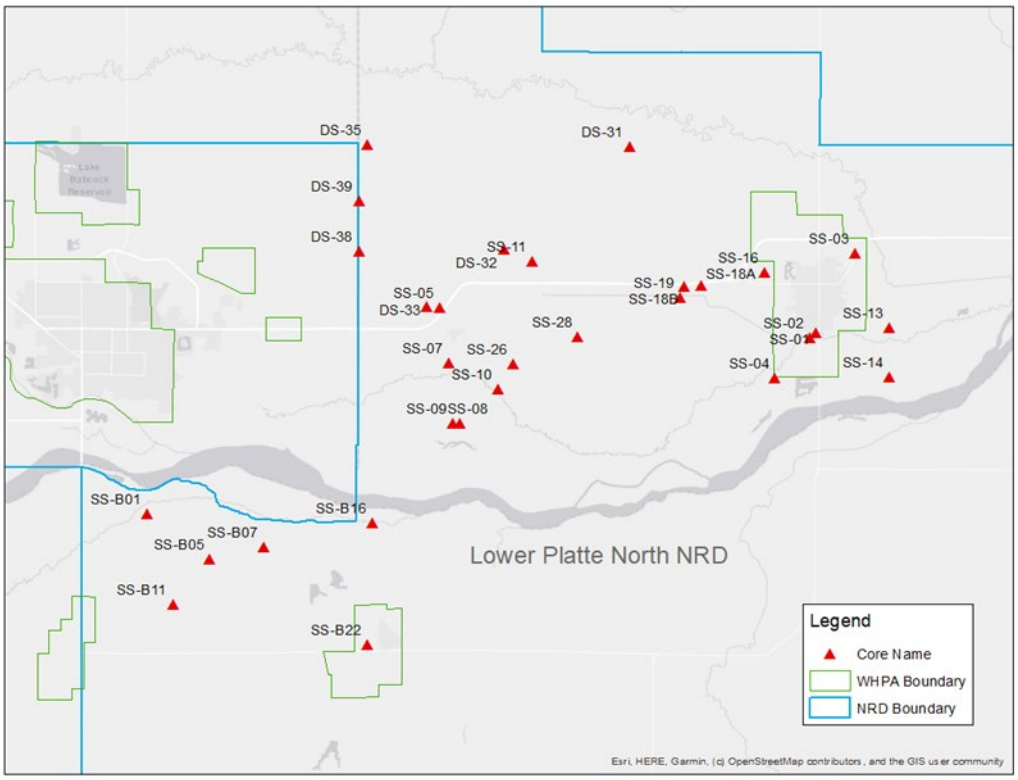


**Figure 4. Location of vadose zone soil sampling sites in LPNNRD collected by EA Engineering in 2019.**

## Field and Laboratory Methods

### Core Collection and Processing

To complete Objective 2, core samples were collected by EA Engineering using standard field collection methods associated with direct-push sampling of unconsolidated materials. Delivered cores and grab samples processed using standardized vadose zone sampling methods at the Water Sciences Laboratory. All cores were stored frozen at -20°C until they could be sectioned, described, and composited for the analytical methods described below.

### Nitrate, Arsenic, Uranium and Nitrate Isotope Analysis

In the laboratory, core sections were removed from the freezer and allowed to partially defrost. Cores were divided into 2-foot intervals for compositing, though shorter intervals were used where there was a visible change in lithology. For each subsample, a portion of the core that was representative of the entire sample was separated and returned to the freezer. Out of this remainder, a portion of fresh sample was taken for measurement of bulk density and water content by weighing a known volume, oven drying the sample for 24 hours at 105°C, and then reweighing the sample. The difference in weight represented the water content, which can be divided by the moist sample to determine gravimetric water content. The remaining moist sample was homogenized and left to air dry overnight. The following day the air

dried soil was ground using a mortar and pestle or Wiley Mill. Approximately 15 grams of each ground subsample was taken for particle analysis. Five grams were mixed with 5 mL of purified water to measure sediment pH. Ten grams were mixed with a 1M KCl solution and loaded on a wrist action shaker for one hour to extract $NO_3$-N and $NH_4$-N. Extracts were preserved with sulfuric acid and batched for colorimetric analysis on a Lachat Quikchem 8500 flow injection autoanalyzer. The quality of the analytical results were checked by analysis of method blanks, fortified blanks and duplicates. A standard test soil was also extracted and analyzed with each batch of twenty samples. The results of the quality controls are summarized in Appendix 3. Calculations used for the final results are summarized in the beginning of the report under Abbreviations section.

Composites from two cores (SS-11 and DS-38) were selected for characterization of acid leachable arsenic and uranium concentrations using microwave assisted acid digestion and inductively coupled plasma mass spectrometry (ICP-MS). Selected samples with elevated nitrate concentrations were reextracted with 1M KCl and analyzed for nitrate isotopes using the azide method [5]. The azide reduction process uses a two-step chemical conversion involving alkaline Cd-reduction of dissolved nitrate to nitrite, followed by an acidic reaction of nitrite with azide to produce nitrous oxide ($N_2O$). $N_2O$ is purged and cryogenically trapped on an Isoprime Tracegas pre concentrator interfaced with a GVI Isoprime isotope ratio mass spectrometer. Trapped $N_2O$ is chromatographically separated from nitrogen gas, and ions with m/z =44, 45, and 46 are simultaneously separate and monitored on a multi-collector magnetic sector mass spectrometer. Standard nitrate solutions from known, isotopically-characterized nitrate are processed and analyzed in the same way as samples, and the results are used for calibrating the mass spectrometer.

Groundwater samples collected by LNNRD staff were analyzed for arsenic, uranium, nitrate, and nitrate isotopes. Arsenic and uranium concentrations were determined by ICP-MS using a Thermo ICAP RQ inductively coupled plasma mass spectrometer. Nitrate concentrations were determined by automated Cd-reduction [6] using a Seal AQ2 autoanalyzer. Nitrate isotopes were determined using the azide reduction method [5], similar to the procedure described for soil extracts. Laboratory quality controls for all methods included analysis of laboratory method blanks, fortified blanks, fortified matrix samples and duplicates each analyzed at a rate of 5%.

Additional nitrate-N measurements for 2019 and 2020 were made available by the LPNNRD to be included in this report and help to determine spatial trends in nitrate concentrations throughout the district.

## Results

A summary of the processing timeline for nitrate-N, ammonia-N, pH, moisture, and textural analysis is provided in Table 2. Calculations for each parameter are listed in the Abbreviations section of this report and a summary of the average results for each core is provided in Table 3. Graphs of nitrate-N, ammonia-

N, gravimetric moisture content, and porewater equivalent nitrate-N concentrations measured for each core are provided in Appendix 1.

**Table 2. Vadose zone soil cores summary of characteristics and processing timeline.**

| No. | Site | Sampled | Extracted | Water Table (ft) | Total Depth (ft) |
|---|---|---|---|---|---|
| **1** | DS-31-2019 | 12/10/2019 | 2/21/2020 | | 77 |
| **2** | DS-32-2019 | 12/10/2019 | 2/21/2020 | 49 | 45 |
| **3** | DS-33-2019 | 12/9/2019 | 4/16/2018 | 13 | 15 |
| **4** | DS-35-2019 | 12/10/2019 | 2/14/2020 | 63 | 60 |
| **5** | DS-38-2019 | 12/9/2019 | 2/28/2020 | 63 | 65 |
| **6** | DS-39-2019 | 12/9/2019 | 3/6/2020 | 75 | 65 |
| **7** | SS-01-2019 | 11/19/2019 | 2/5/2020 | -- | 6.5 |
| **8** | SS-02-2019 | 11/19/2019 | 2/5/2020 | -- | 6 |
| **9** | SS-03-2019 | 11/19/2019 | 2/5/2020 | -- | 7 |
| **10** | SS-04-2019 | 11/19/2019 | 2/5/2020 | -- | 6.5 |
| **11** | SS-05-2019 | 11/19/2019 | 2/7/2020 | -- | 9 |
| **12** | SS-07-2019 | 11/25/2019 | 1/24/2020 | -- | 4.5 |
| **13** | SS-08-2019 | 11/19/2019 | 2/7/2020 | -- | 2.5 |
| **14** | SS-09-2019 | 11/19/2019 | 2/7/2020 | -- | 1 |
| **15** | SS-10-2019 | 11/19/2019 | 2/7/2020 | -- | 7.5 |
| **16** | SS-11-2019 | 11/19/2019 | 2/7/2020 | -- | 10 |
| **17** | SS-13-2019 | 11/25/2019 | 1/24/2020 | -- | 7.5 |
| **18** | SS-14-2019 | 11/25/2019 | 1/28/2020 | -- | 4.5 |
| **19** | SS-16-2019 | 11/25/2019 | 1/24/2020 | -- | 6 |
| **20** | SS-18A-2019 | 11/25/2019 | 1/24/2020 | -- | 3.5 |
| **21** | SS-18B-2019 | 11/25/2019 | 1/24/2020 | -- | 3 |
| **22** | SS-19-2019 | 11/25/2019 | 1/24/2020 | -- | 4 |
| **23** | SS-26-2019 | 11/25/2019 | 1/24/2020 | -- | 3.5 |
| **24** | SS-28-2019 | 11/25/2019 | 1/24/2020 | -- | 4 |
| **25** | SS-B01-2019 | 11/26/2019 | 1/30/2020 | -- | 7.5 |
| **26** | SS-B05-2019 | 11/26/2019 | 1/30/2020 | -- | 1 |
| **27** | SS-B07-2019 | 11/26/2019 | 1/30/2020 | -- | 4 |
| **28** | SS-B11-2019 | 11/26/2019 | 1/30/2020 | -- | 8 |
| **29** | SS-B16-2019 | 11/25/2019 | 1/28/2020 | -- | 9.5 |
| **30** | SS-B22-2019 | 11/25/2019 | 1/28/2020 | -- | 10 |

**Table 3. Deep vadose zone soil cores averages**

| Site | Bulk Density ($g/cm^3$) | Gravimetric Water Content (g/g dry sed) | pH | $NH_4$-N (µg/g) | $NO_3$-N (µg/g) | Pore Water $NO_3$-N (mg/L) | Soil $NO_3$-N (lbs- N/Acre-Ft) | Total Soil $NO_3$-N (lbs-N/acre) |
|---|---|---|---|---|---|---|---|---|
| **DS-31-2019** | 0.89 | 0.08 | 8.30 | 0.45 | 0.52 | 8.82 | 1.19 | 19.0 |
| **DS-32-2019** | 0.85 | 0.09 | 8.45 | 0.45 | 1.23 | 14.87 | 3.13 | 28.0 |
| **DS-33-2019** | 1.08 | 0.17 | 6.92 | 0.46 | 6.69 | 42.55 | 19.76 | 59.0 |
| **DS-35-2019** | 0.89 | 0.10 | 8.60 | 0.49 | 3.11 | 41.38 | 7.17 | 93.0 |
| **DS-38-2019** | 0.89 | 0.12 | 8.52 | 0.50 | 3.17 | 16.75 | 7.36 | 96.0 |
| **DS-39-2019** | 0.86 | 0.10 | 8.40 | 0.57 | 1.35 | 27.25 | 3.12 | 41.0 |
| **Average** | **0.91** | **0.11** | **8.20** | **0.49** | **2.68** | **25.27** | **6.96** | **56.0** |

**Table 4. Shallow vadose zone sample averages**

| Site | Gravimetric Water Content (g/g dry sed) | pH | $NH_4$-N (µg/g) | $NO_3$-N (µg/g) | Pore Water $NO_3$-N (mg/L) |
|---|---|---|---|---|---|
| **SS-01-2019** | 0.09 | 8.01 | 0.84 | 0.36 | 6.08 |
| **SS-02-2019** | 0.19 | 7.87 | 0.95 | 0.82 | 3.44 |
| **SS-03-2019** | 0.11 | 7.82 | 1.41 | 0.72 | 5.66 |
| **SS-04-2019** | 0.16 | 7.87 | 1.18 | 1.02 | 5.83 |
| **SS-05-2019** | 0.05 | 6.84 | 0.60 | 0.21 | 4.43 |
| **SS-07-2019** | 0.14 | 7.42 | 0.87 | 3.05 | 20.47 |
| **SS-08-2019** | 0.21 | 8.20 | 0.83 | 1.02 | 4.68 |
| **SS-09-2019** | 0.20 | 7.96 | 1.94 | 1.86 | 9.38 |
| **SS-10-2019** | 0.12 | 6.79 | 1.63 | 0.32 | 2.83 |
| **SS-11-2019** | 0.14 | 6.68 | 1.46 | 61.77 | 499.01 |
| **SS-13-2019** | 0.12 | 8.28 | 0.97 | 3.70 | 27.78 |
| **SS-14-2019** | 0.16 | 7.84 | 0.88 | 3.68 | 23.33 |
| **SS-16-2019** | 0.11 | 8.47 | 1.13 | 5.05 | 51.86 |
| **SS-18A-2019** | 0.18 | 7.9 | 2.37 | 8.71 | 47.57 |
| **SS-18B-2019** | 0.28 | 7.87 | 2.20 | 4.40 | 15.87 |
| **SS-19-2019** | 0.42 | 7.63 | 2.46 | 3.31 | 7.80 |
| **SS-26-2019** | 0.19 | 7.25 | 0.66 | 3.84 | 20.35 |
| **SS-28-2019** | 0.13 | 7.92 | 1.89 | 2.74 | 20.53 |
| **SS-B01-2019** | 0.10 | 8.02 | 1.39 | 12.91 | 125.16 |

| | | | | | |
|---|---|---|---|---|---|
| **SS-B05-2019** | 0.16 | 8.17 | 2.70 | 1.92 | 11.95 |
| **SS-B07-2019** | 0.24 | 8.42 | 5.51 | 4.35 | 17.79 |
| **SS-B11-2019** | 0.06 | 7.33 | 1.30 | 0.75 | 18.34 |
| **SS-B16-2019** | 0.10 | 7.77 | 0.46 | 5.47 | 58.87 |
| **SS-B22-2019** | 0.19 | 7.70 | 0.42 | 3.09 | 17.31 |
| **Average** | **0.16** | **7.75** | **1.50** | **5.63** | **42.76** |

## Discussion

Six deep vadose zone cores were collected from the northern portion of the study area (Figure 1). Individual profiles for these cores are included in the Appendix 1 and a summary of the averages is showed in Table 3. Locations DS-31, DS-32, DS-33, DS-35, and DS-39 are all described as pivot-irrigated corn, while DS-38 land use is soybean (Table 1). Shallow samples were collected from grass, corn, and soybean cropland irrigated and non-irrigated (Table 1). The average deep vadose zone nitrate ranged from 0.52 at location DS-31 to 6.69 μg/g at DS-33 and when expressed as pore water range from 8.82 to 42.5 mg/L $NO_3$-N, respectively. Pore water nitrate is calculated by multiplying the measured dry weight nitrate-N by the gravimetric moisture content, and provides a direct comparison to groundwater nitrate-N concentrations in mg/L. The depth profile at DS-31 shows relatively low moisture content, and uniformly low nitrate concentrations below 10' suggesting little accumulation in these sandy loam sediments. The water table at core DS-33 was intercepted at 13 feet below the surface and resulted in only 3 composite samples in organic-rich clay and loamy sand sediments (Figure A3). Porewater nitrate increased with depth to approximately 52 mg/L near the water table. The profile at location DS-38 (Figure A5, soybean crop) indicates a distinct peak in sediment and porewater nitrate concentrations (reaching 20 μg/g and over 80 mg/L respectively) at approximately 15 feet below the surface. Average vadose zone nitrate-N at these locations range from 1.19 to 19.76 lbs-N/acre-ft (Table 3) and total stored nitrate-N ranged from 19 to 96 lbs N/acre.

Shallow soil cores, drilled to a depth of up to 10 feet, were collected from a larger area and help to characterize surface inputs to vadose zone nitrate. Average sediment nitrate-N in the shallow vadose soil samples ranged from 0.21 to 61.77 μg/g, with an overall average of 5.63 μg/g (Table 4). Because the majority of these samples are within or just below the crop root zone, this nitrate source may be available for plant uptake during subsequent crop years. Averaging dry weight and porewater nitrate concentrations for each reported land use show that nitrate concentrations are roughly 3 times higher beneath corn than under soybean, and approximately 5 times higher than alfalfa or grass/cover crops (Figure 5). Ammonia-N concentrations in the shallow core samples are generally higher than in the deep vadose cores averaging 0.42 to 5.51 μg/g compared to a range of 0.45 to 0.57 in deep vadose zone core samples. Only a single sample was collected at several locations, including SS-09, SS-18A, SS-19, SS-26, SS-28, and SS-B05.

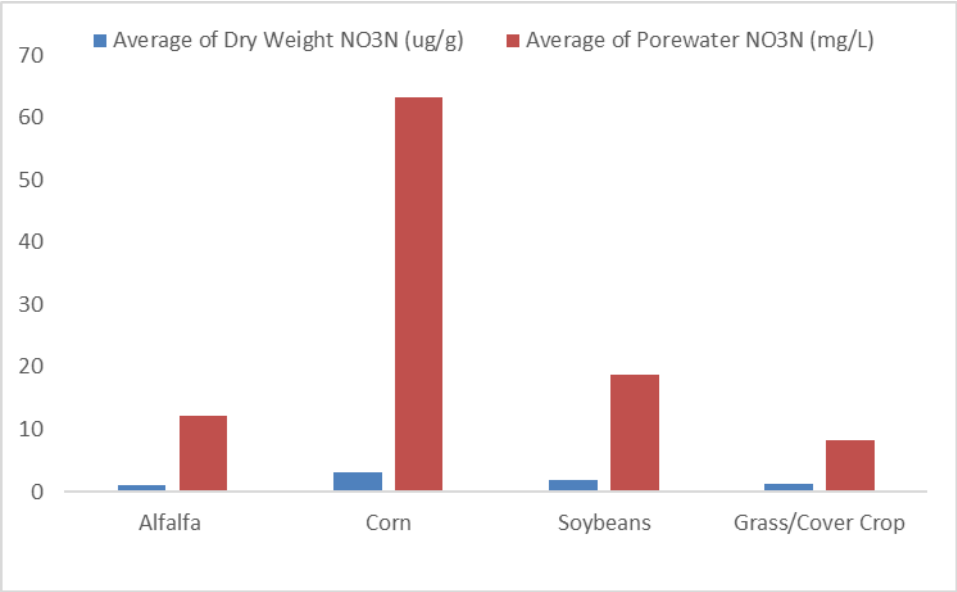


**Figure 5. Comparison of average dry weight nitrate and porewater nitrate concentrations by reported land use.**

## Vadose Zone Arsenic and Uranium

Cores SS-11 and DS-38 were selected for characterization of acid-leachable arsenic and uranium concentrations to evaluate these sediments as a source of geogenic contaminants to groundwater. Arsenic concentrations range from 0.46 to 8.98 μg/g at both locations, while uranium concentrations range from 0.17 to 1.44 μg/g (Appendix 2). Concentrations are at a maximum in the near surface samples suggesting a possible association with finer textured soil. Mean uranium concentrations in surface (0-2") soils are reported to be in the range of 2-3 μg/g, while arsenic concentrations are reported to average near 7-8 μg/g in this area [7]. Depending on the form of arsenic and uranium in surface soils, these trace elements be leached into the water table.

## Groundwater Samples

Thirty-one groundwater samples were collected by the LPNNRD staff during the summer and fall of 2019 and 2020. These were processed and analyzed for dissolved arsenic, uranium, nitrate-N, and nitrate isotopes. Results for arsenic and uranium a presented in Table 5 together with the USEPA maximum contaminant levels for public drinking water systems. Arsenic concentrations averaged 4.2±4.2 μg/L and were below the maximum contaminant level in all but 2 samples (Table 5). Uranium concentrations averaged 12±10 μg/L and exceeded the USEPA maximum contaminant level in 1 sample.

**Table 5. Results of groundwater arsenic and uranium concentrations.**

| Sample_ID | Collection Date | Arsenic (ug/L) | Uranium (ug/L) |
|---|---|---|---|
| **USEPA Drinking Water Standards (µg/L)** | | **10.0** | **30.0** |
| **BSE23-16-1** | 7/17/2019 | 4.76 | 7.81 |
| **G-002937** | 7/18/2019 | 2.41 | 4.50 |
| **G-006771R** | 7/29/2019 | 4.72 | 7.79 |
| **G-046365** | 7/29/2019 | 3.94 | 12.77 |
| **G-004887** | 7/29/2019 | 3.00 | 4.08 |
| **G-055480A** | 7/30/2019 | 3.17 | 1.85 |
| **G-136580A** | 7/31/2019 | 1.00 | 0.11 |
| **SW5219W** | 8/6/2019 | 2.78 | 3.77 |
| **SW4819W** | 8/6/2019 | 3.39 | 7.25 |
| **G-001739** | 8/8/2019 | 3.13 | 5.77 |
| **G-020497** | 9/3/2019 | 2.30 | 6.22 |
| **G-113877** | 9/3/2019 | 2.73 | 0.15 |
| **G-001817** | 7/24/2020 | 4.14 | 17.56 |
| **G-004315** | 7/24/2020 | 2.16 | 6.03 |
| **G-002068** | 7/24/2020 | 3.58 | 18.00 |
| **G-122133** | 7/27/2020 | 19.67 | 22.85 |
| **G-068733** | 7/27/2020 | 4.57 | 23.87 |
| **G-014893** | 7/27/2020 | 2.25 | 6.33 |
| **G-026576** | 7/28/2020 | 2.04 | 14.52 |
| **G-007336** | 7/30/2020 | 1.86 | 18.53 |
| **G-004966** | 8/4/2020 | 2.69 | 4.72 |
| **G-046365** | 8/12/2020 | 3.76 | 20.56 |
| **G-002068** | 8/13/2020 | 3.49 | 20.71 |
| **G-068733** | 8/20/2020 | 4.96 | 21.60 |
| **G-004315** | 8/20/2020 | 2.08 | 5.70 |
| **G-014893** | 8/21/2020 | 2.36 | 6.74 |
| **G-001817** | 8/26/2020 | 4.28 | 19.14 |
| **G-122133** | 8/26/2020 | 19.56 | 22.53 |
| **G-076286** | 9/1/2020 | 4.33 | 49.07 |
| **G-011527** | 9/1/2020 | 4.72 | 15.16 |
| **G-135549** | 9/2/2020 | 0.84 | 1.68 |

### Spatial Distribution of Groundwater Nitrate

Roughly 480 sample results for groundwater nitrate were supplied for this report and used to generate a map of the overall nitrate distribution (Figure 6) and comparison to the area of the vadose zone

investigation (Figure 6). Approximately half of the samples were collected by NRD staff and the rest by producers. The distribution suggests that the current area of interest is most highly affected by elevated groundwater nitrate. Groundwater nitrate from samples across the district averages 10.6±8.2 mg/L, with the highest concentration near 60 mg/L. Within the study area (Figure 7), nitrate-N concentrations average 12.4 ±8.0 mg/L.

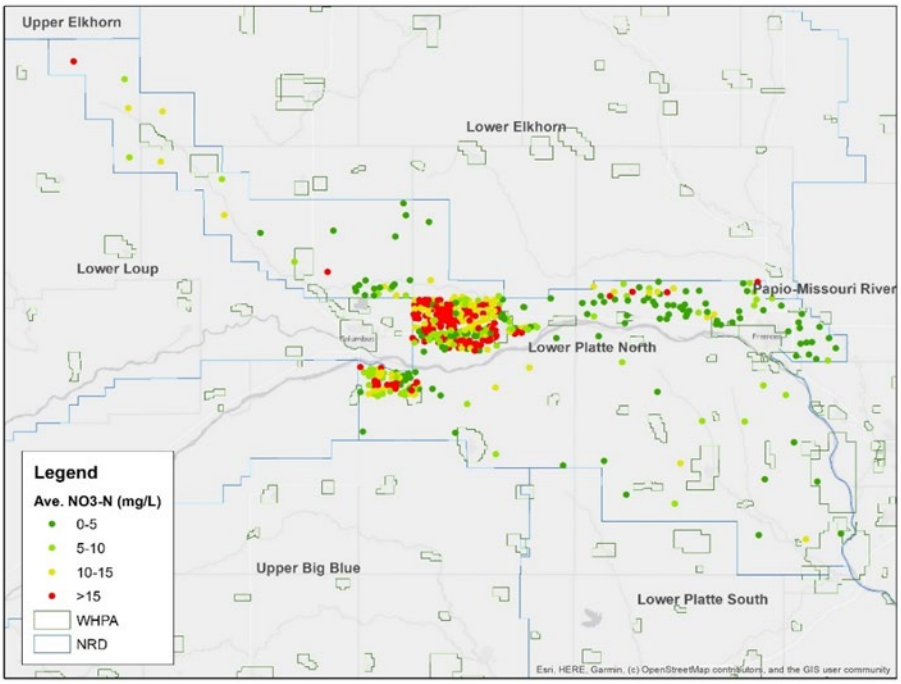


**Figure 6. Overall distribution of nitrate-N concentrations in groundwater samples collected by NRD staff and producers in 2019 and 2020.**

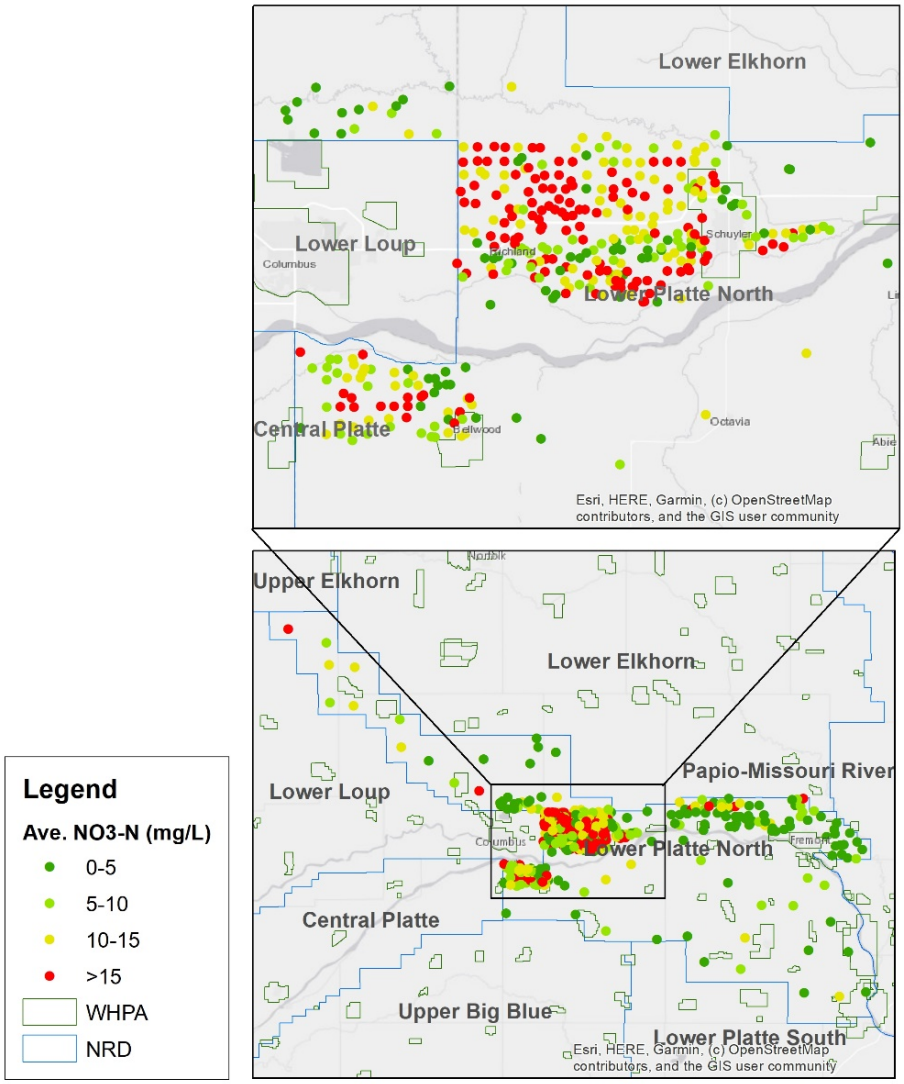


**Figure 7. Distribution of groundwater nitrate-N concentrations based on data supplied by the LPNNRD in the present study area (upper map) and across the district.**

## Nitrate Isotope Trends from Study Area

Table 6 Summarizes the well water sample nitrate concentrations are summarized together with the nitrogen isotope composition. Nitrate-N concentrations averaged 16.7(±11.4) mg/L while the $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ composition averaged +5.59 ‰ and +5.97‰ respectively.

**Table 6. Summary of nitrate concentrations and isotope composition from the study area.**

| Sample ID | Collection Date | NO3-N (mg/L) | $\delta^{15}NO_3$ (‰) | $\delta^{18}O\text{-}NO_3$ (‰) |
|---|---|---|---|---|
| **BSE23-16-1** | 7/17/2019 | 9.21 | 5.85 | 18.56 |
| **G-002937** | 7/18/2019 | 48.35 | 8.52 | 13.75 |
| **G-004887** | 7/29/2019 | 31.73 | +6.61 | +0.29 |
| **G-046365** | 7/29/2019 | 16.73 | +2.61 | +2.29 |
| **G-055480I** | 7/30/2019 | 18.27 | +4.31 | +1.91 |
| **G-136580I** | 7/31/2019 | 28.01 | +3.91 | +4.30 |
| **SW5219W** | 8/6/2019 | 9.57 | +4.70 | +1.56 |
| **SW4819W** | 8/6/2019 | 8.62 | +5.30 | -0.81 |
| **G-001739** | 8/8/2019 | 10.50 | +6.57 | +7.94 |
| **G-020497** | 9/3/2019 | 10.89 | +9.16 | +6.52 |
| **G-026329** | 9/3/2019 | 0.03 | +6.49 | +4.40 |
| **G-026328** | 9/3/2019 | 30.73 | +5.11 | +8.30 |
| **G-026576** | 7/28/2020 | 32.38 | +4.73 | +5.95 |
| **G-007336** | 7/30/2020 | 11.37 | +4.08 | +3.95 |
| **G-004966** | 8/4/2020 | 17.12 | +6.34 | +4.45 |
| **G-046365** | 8/12/2020 | 13.75 | +5.03 | +4.82 |
| **G-002068** | 8/13/2020 | 14.96 | +8.57 | +6.41 |
| **G-068733** | 8/20/2020 | 10.26 | +8.50 | +10.37 |
| **G-004315** | 8/20/2020 | 27.19 | +8.50 | +3.77 |
| **G-014893** | 8/21/2020 | 24.45 | +5.09 | +4.11 |
| **G-001817** | 8/26/2020 | 12.35 | +3.93 | +5.63 |
| **G-122133** | 8/26/2020 | 15.58 | +3.01 | +5.94 |
| **G-076286** | 9/1/2020 | 13.21 | -0.89 | +3.33 |
| **G-011527** | 9/1/2020 | 0.62 | +11.50 | +13.52 |
| **G-135549** | 9/2/2020 | 0.32 | +2.20 | +7.91 |
| **Average** | | **16.65** | **+5.59** | **+5.97** |
| **Std Deviation** | | **11.43** | **2.63** | **4.40** |

A graph of nitrate-N concentrations versus $\delta^{15}N\text{-}NO_3$ (Figure 8) shows no significant correlation in these wells. Comparing the ranges of $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ for these samples to typical ranges shown in Figure 1 suggests that about half have nitrogen isotope composition characteristic of nitrogen from commercial fertilizers while the remaining are a mixture of organic nitrogen sources (manure or septic systems) and fertilizer nitrogen (Figure 8). One sample was found to plot in the range for nitrate fertilizer and six fall in the range characteristic of nitrogen from organic nitrogen sources such as manure. These $\delta^{15}N$ enriched nitrate samples also show a predictable increase in $\delta^{18}O\text{-}NO_3$ expected from denitrification of nitrate. Based on this trend, denitrification likely has affected groundwater nitrate in these samples. Plots of the $\delta^{15}N$ versus the inverse and natural log of nitrate-N concentrations show evidence of both mixing and denitrification.

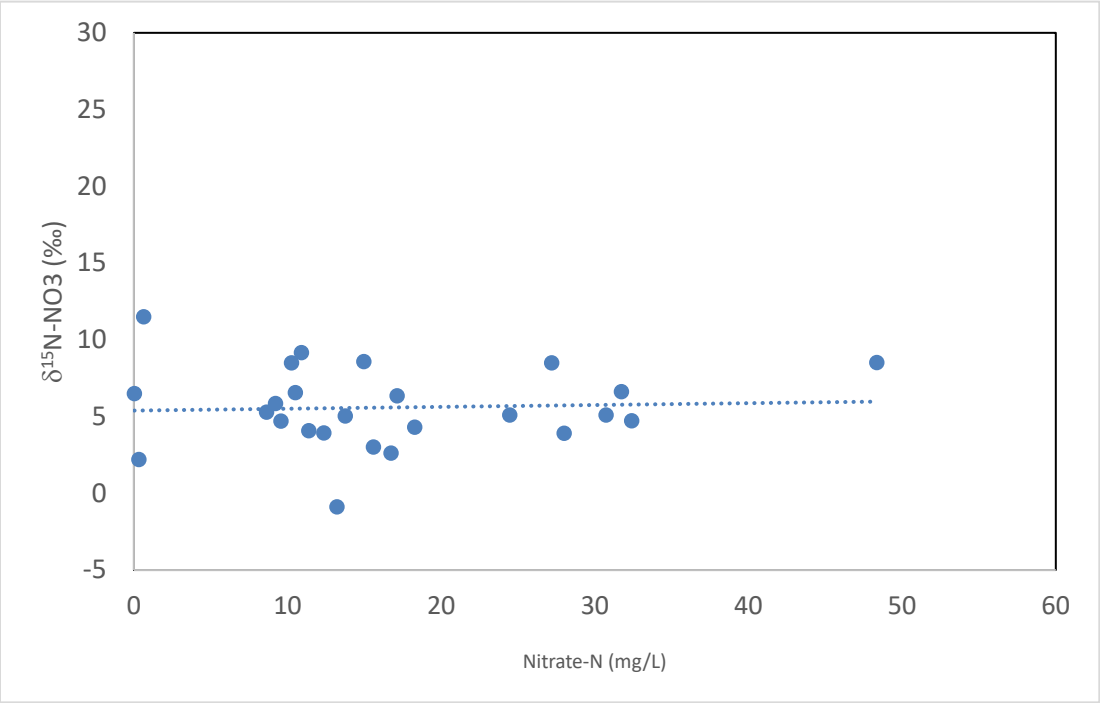


**Figure 8. Relationship between well water nitrate concentrations and δ 15N-NO3 composition.**

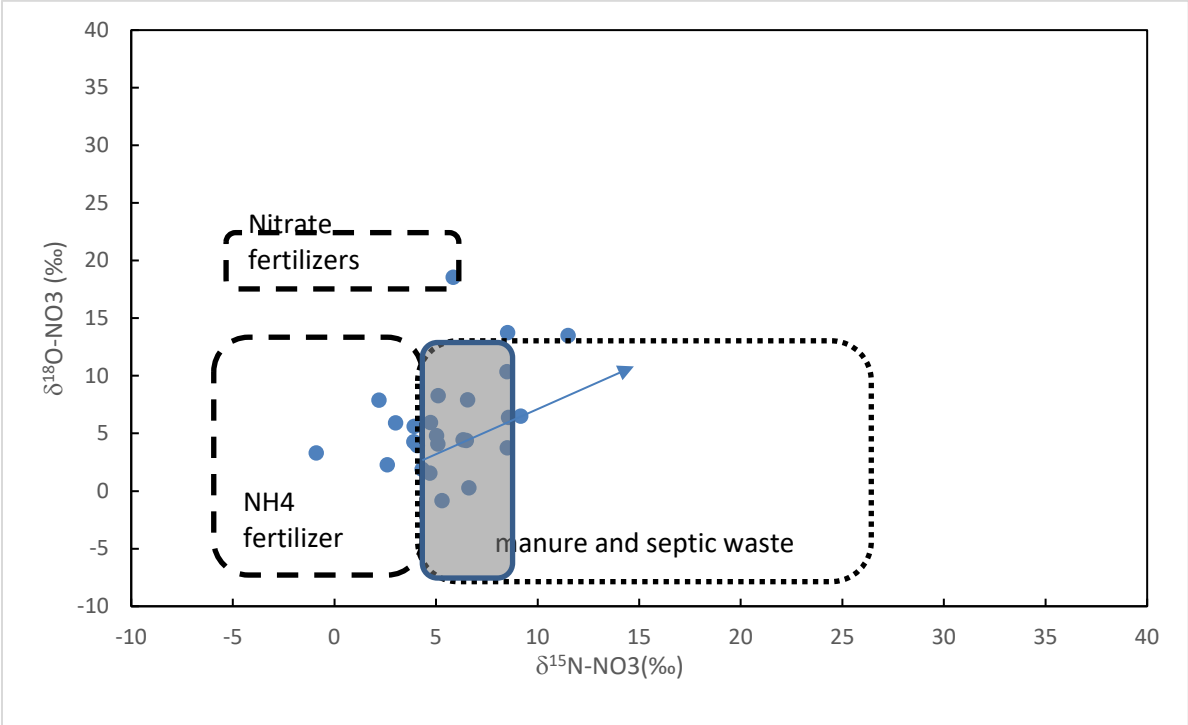


**Figure 9. Variation of well water nitrogen and oxygen isotope composition compared to ranges for different nitrogen sources shown in Figure 3. Grey area represents the range for soil nitrogen and mixed sources of inorganic and organic nitrogen sources, and the arrow shows the expected trend from denitrification.**

Six grab samples of groundwater at the water table were collected during vadose zone coring and analyzed for nitrate concentrations and nitrate isotope composition. Table 7 summarizes the results of these samples with nitrate concentrations that ranges up to 125 mg/L. Nitrate isotope composition at the water table is comparable to the isotope composition from the wells in this area with most characteristic of commercial fertilizer nitrogen.

**Table 7. Summary of nitrate concentrations and nitrate isotope composition of grab samples collected during coring of DS-32, 33, 34, 35, 38, 39, and 54.**

| Sample ID | Collection Date | Nitrate-N (mg/L) | $^{15}N$-$NO_3$ (‰) | $^{18}O$-$NO_3$ (‰) |
|---|---|---|---|---|
| **DS-33-13** | 12/11/2019 | 122.27 | +1.55 | +0.80 |
| **DS-54-13** | 12/11/2019 | 125.03 | +3.73 | +4.73 |
| **DS-35-63** | 12/11/2019 | 100.64 | +8.18 | +8.05 |
| **DS-38-63** | 12/11/2019 | 5.76 | +9.03 | +6.31 |
| **DS-39-75** | 12/11/2019 | 36.68 | +6.29 | +6.05 |
| **DS-32-49** | 12/11/2019 | 91.65 | +12.53 | +6.80 |

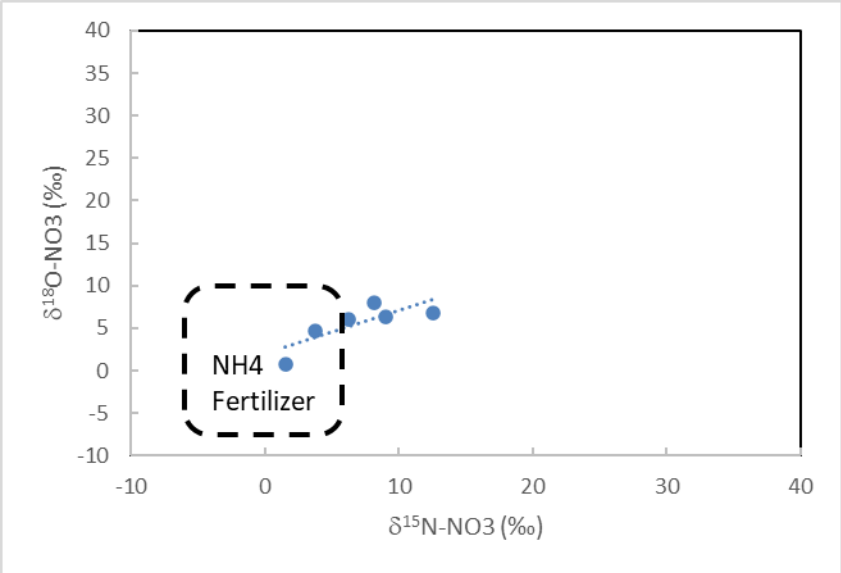


**Figure 10. Variation of nitrate isotope composition in grab samples collected at the water table at vadose cores DS-32, 33, 35, 38, 39, and 54. The trend line is a liner regression plot.**

Figure 10 shows that nitrate isotope composition for the grab samples from these locations follow the expected trend for denitrification at these sites. Extracts of core samples from two locations (SS-11 and DS-38) were analyzed for also nitrate isotope composition and the results are summarized in Table 8.

Soil extracts from location SS-11 show slightly enriched $\delta^{15}N\text{-}NO_3$ characteristic of a mixed source while those from DS-38 all fall in the range of a commercial fertilizer nitrogen source with no evidence for denitrification within each core (Table 8). Both locations show higher levels of nitrate concentrations in the top 10-15 of the vadose zone.

The distribution of the $^{15}N\text{-}NO_3$ composition is shown in Figure 11. The majority of samples are consistent with a source of commercial nitrate, ranging between -5 and +5 ‰. One sample well G-011527, collected in the northeastern corner of the study area is +11.5‰ but this same sample has a very low nitrate concentration (0.62 mg/L), and is most likely enriched from denitrification. While livestock manure application may affect total nitrogen application across this study area, these results suggest that long term overapplication of commercial fertilizer has provided the source of nitrogen.

**Table 8. Summary of nitrate concentrations and nitrate isotope results for cores SS-11 and DS-38.**

| Sample ID | Collection Date | $NO_3N$ (µg/g) | $\delta^{15}N\text{-}NO_3N$ (‰) | $\delta^{18}O\text{-}NO_3$ (‰) |
|---|---|---|---|---|
| **SS-11-0-4** | 11/19/2019 | 34.0 | +9.07 | +10.71 |
| **SS-11-4-5.5** | 11/19/2019 | 115.0 | +6.49 | +10.98 |
| **SS-11-5.5-10.5** | 11/19/2019 | 36.3 | +9.34 | +11.67 |
| **EA115-38-5** | 3/11/2020 | 1.94 | +2.63 | +10.65 |
| **EA116-38-10** | 3/11/2020 | 11.58 | +3.97 | +15.14 |
| **EA117-38-14** | 3/11/2020 | 20.04 | +2.37 | +10.58 |
| **EA118-38-20** | 3/11/2020 | 4.82 | +2.48 | +6.97 |
| **EA119-38-25** | 3/11/2020 | 0.37 | -5.83 | +2.94 |
| **EA120-38-30** | 3/11/2020 | 0.33 | +0.66 | +12.40 |
| **EA121-38-35** | 3/11/2020 | 0.26 | +0.14 | +14.49 |
| **EA122-38-40** | 3/11/2020 | 0.41 | +1.28 | +12.37 |
| **EA123-38-45** | 3/11/2020 | 0.25 | +0.01 | +8.51 |
| **EA124-38-50** | 3/11/2020 | 0.36 | +1.10 | +12.34 |
| **EA125-38-55** | 3/11/2020 | 0.25 | +0.19 | +11.91 |
| **EA126-38-60** | 3/11/2020 | 0.23 | +0.13 | +12.02 |
| **EA127-38-65** | 3/11/2020 | 0.37 | +2.19 | +10.25 |

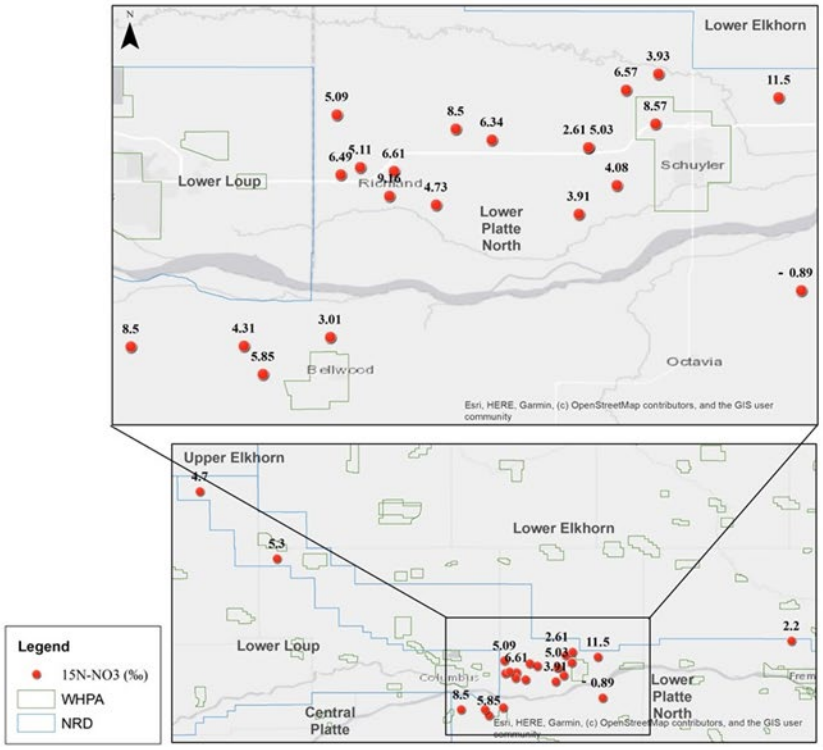


***Figure 11. Distribution of 15N-nitrate isotope composition in all groundwater samples collected for this study.***

## Conclusions

Based on the trends of groundwater and vadose zone nitrate levels in this area of the LPNNRD, there is clearly continued loading of nitrate to the water table. The Bellwood Phase 2, Richland and Schuyler Phase 2 and 3 Groundwater Management Areas have some of the highest groundwater nitrate concentrations of the district. Analysis of six deep vadose zone samples shows pore water nitrate concentrations with location averages ranging 8.82 from 42.55 mg/L, similar to local groundwater concentrations. Vadose zone nitrate was highest beneath cropland with continuous corn and soybeans, while alfalfa, grass, and cover crops had much lower nitrate levels. Except for 2 wells, arsenic and uranium concentrations in groundwater samples were generally below the maximum contaminant level for drinking water. Stable isotope analysis of nitrate in the groundwater and vadose zone samples indicates over half of nitrate nitrogen is likely from the overapplication of commercial fertilizer. Several samples show evidence of enrichment by denitrification, especially grab samples taken near the water table, and several have nitrogen isotope composition characteristic of a mixture of organic (manure) nitrogen and commercial fertilizer. Comparison of sites with enriched nitrogen to manure application can help confirm the importance of this source. The majority of samples, however, have nitrogen isotope composition similar to commercial (inorganic) nitrogen, and thus efforts to limit the application of fertilizer is

recommended. Future vadose zone and groundwater sampling in these areas will provide information on the effectiveness of any changes in nutrient management practices.

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## Quality Assurance Objectives

The results of quality control samples analyzed for this project are summarized in Appendix 3. One of the objectives of this project is to develop a set of protocols that can be used to help standardize coring, measurement, organization, and presentation of the information collected from vadose zone monitoring projects. A list of the standard operating procedures used in this project is provided in Appendix 3. The intention is to both improve and simplify the data collection over time and areas so that results will be comparable and trends can be better identified.

# Appendix 1: Graphs of Results by Core

**DS-31-2019**

Total N load= 19 lbs-N/Acre

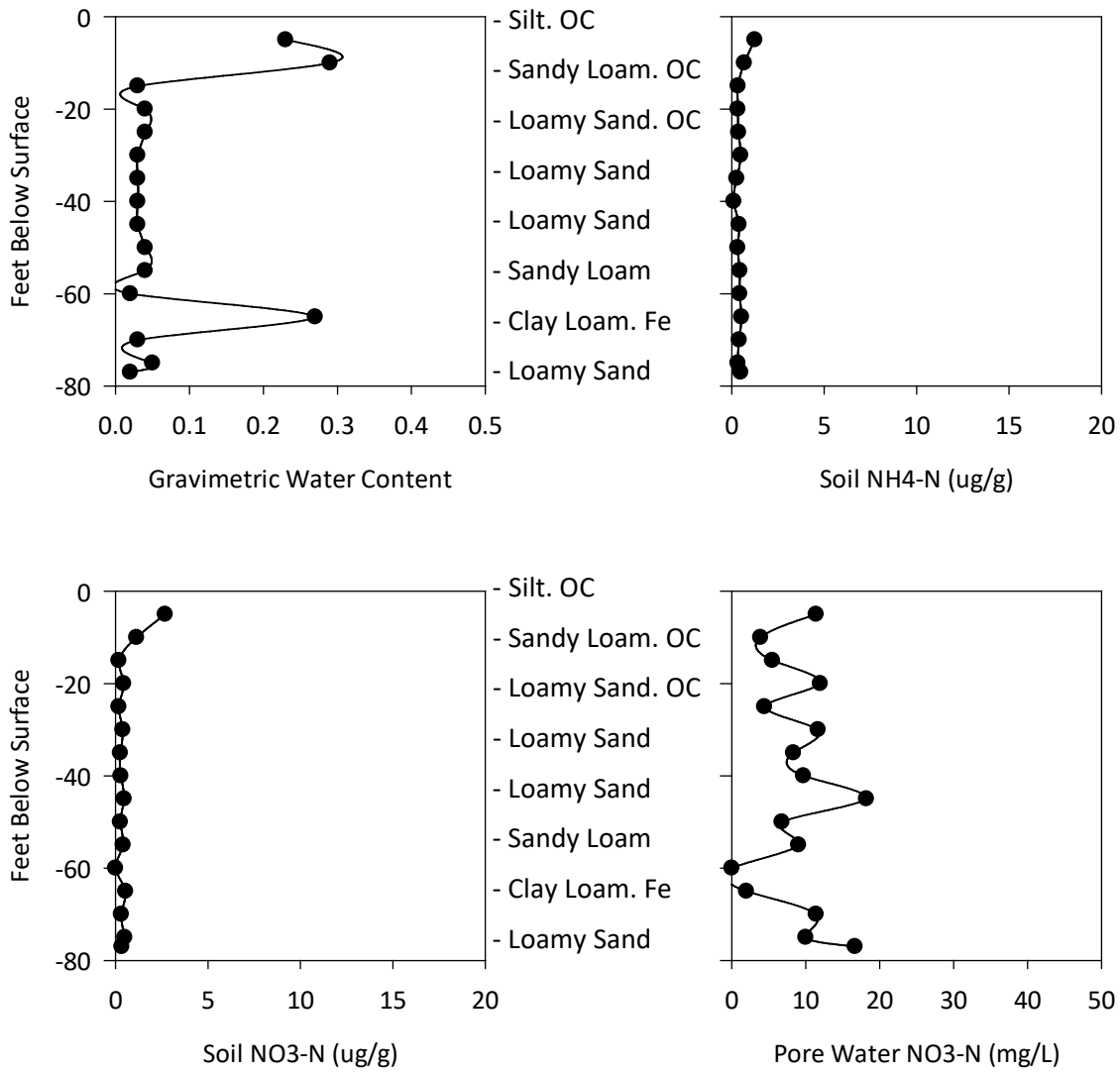


**Figure A1. DS-31-2019 Graphs.**

Notes: DS-31-2019 : small pivot on 40 acres, irrigated from G-065523. Crop has been harvested.

**DS-32-2019**

Depth to water: 49 feet, indicated below in dash lines

Total N load= 28 lbs-N/Acre

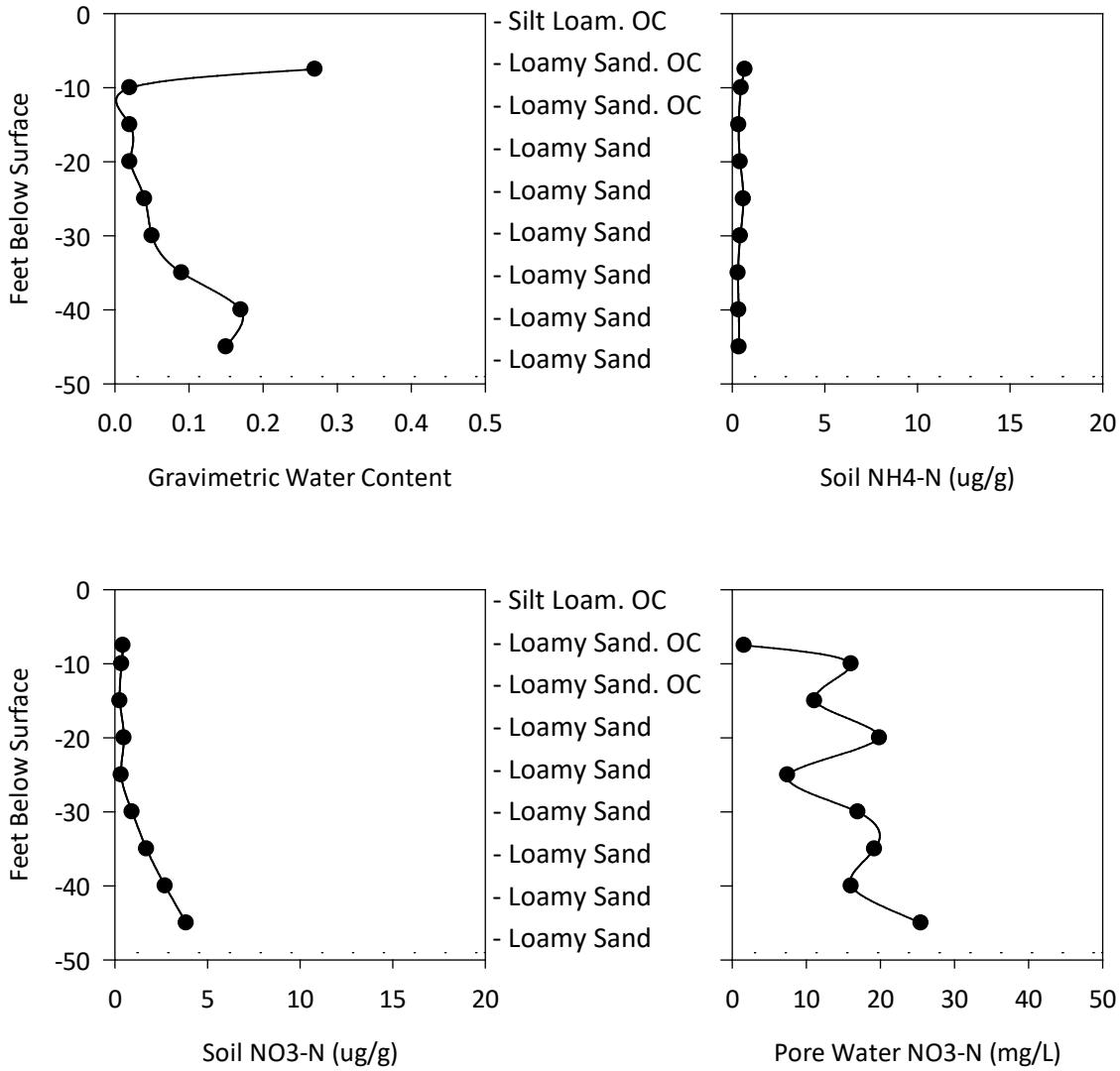


**Figure A2. DS-32-2019 Graphs.**

Notes: DS-32-2019: irrigated from G-053560 and uses feedlot lagoon water from Kluck's feedlot in section 9. Corn has been harvested.

**DS-33-2019**

Depth to water: 13 feet, indicated below in dash lines

Total N load= 59 lbs-N/Acre

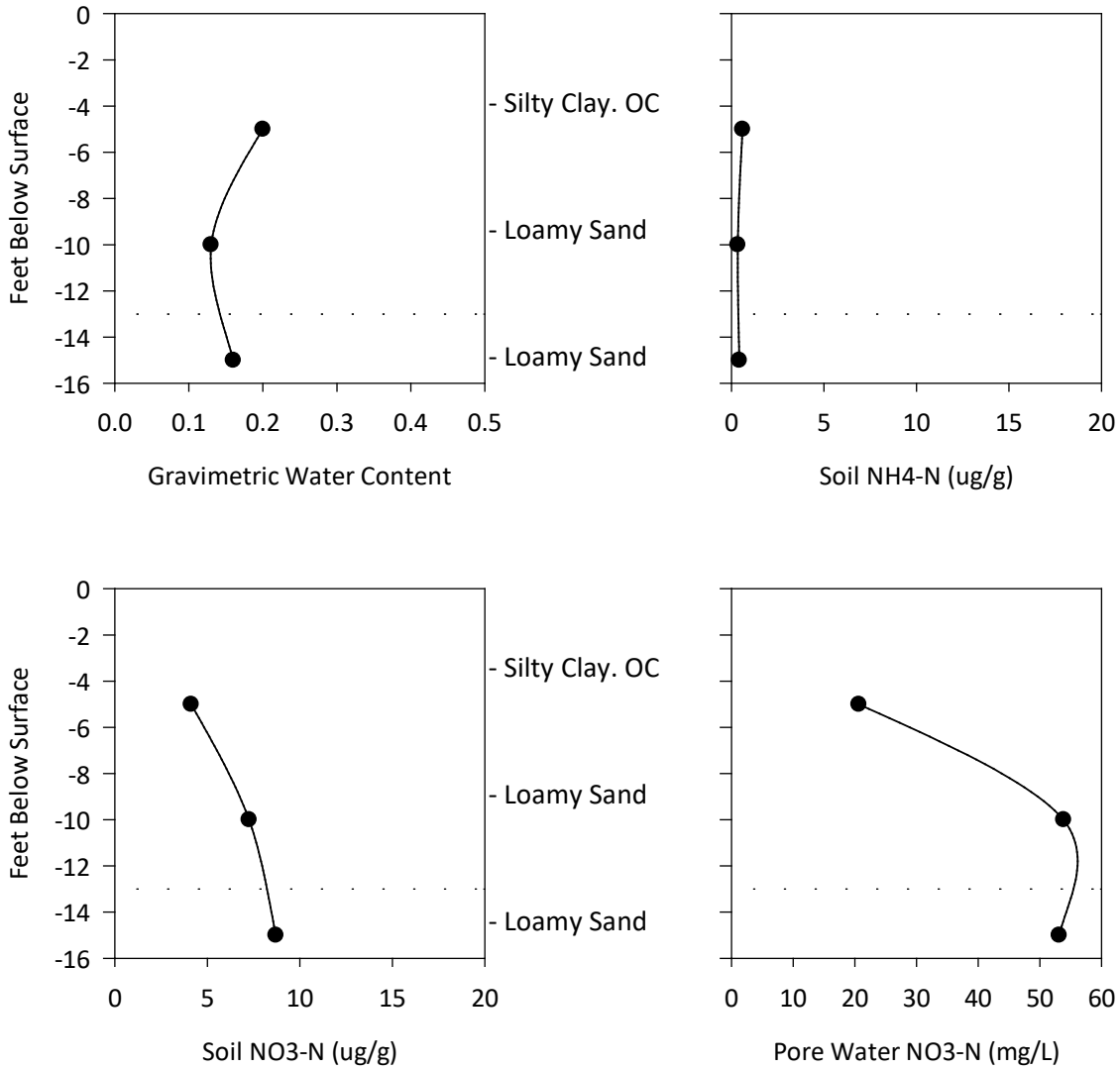


**Figure A3. DS-33-2019 Graphs.**

Notes: DS-33-2019: near middle of section. Corn has been harvested. On the old map, it seems to show an old paleo valley which goes through the middle of the section from west to east.

**DS-35-2019**

Depth to water: 63 feet, indicated below in dash lines

Total N load= 93 lbs-N/Acre

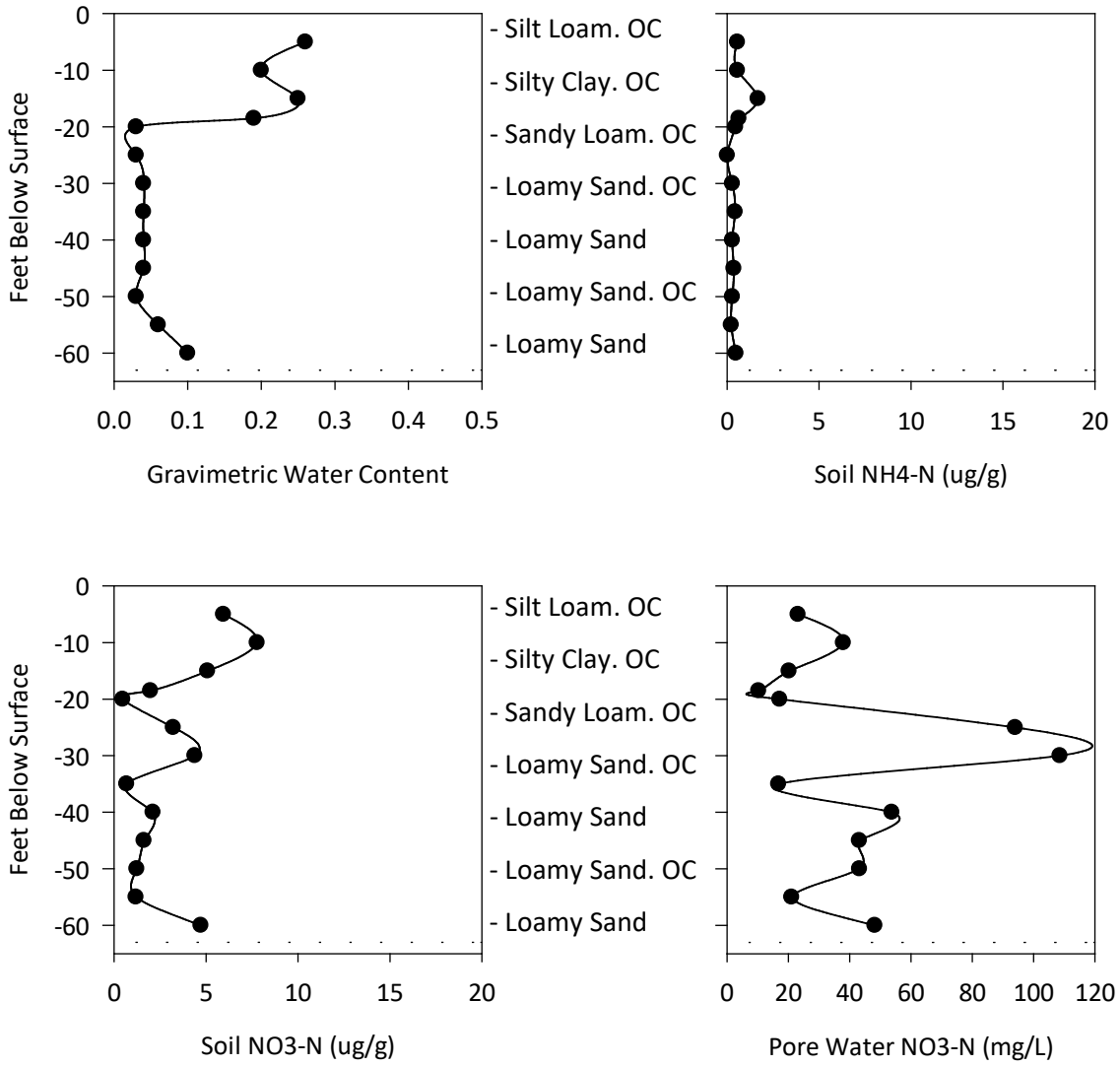


**Figure A4. DS-35-2019 Graphs.**

Notes: DS-35-2019: sample northwest of the pivot point, east of bins. Crop has been harvested. Irrigation well G-074435. Priority site – near NRD boundaries with feedlot up gradient.

**DS-38-2019**

Depth to water: 63 feet, indicated below in dash lines

Total N load= 96 lbs-N/Acre

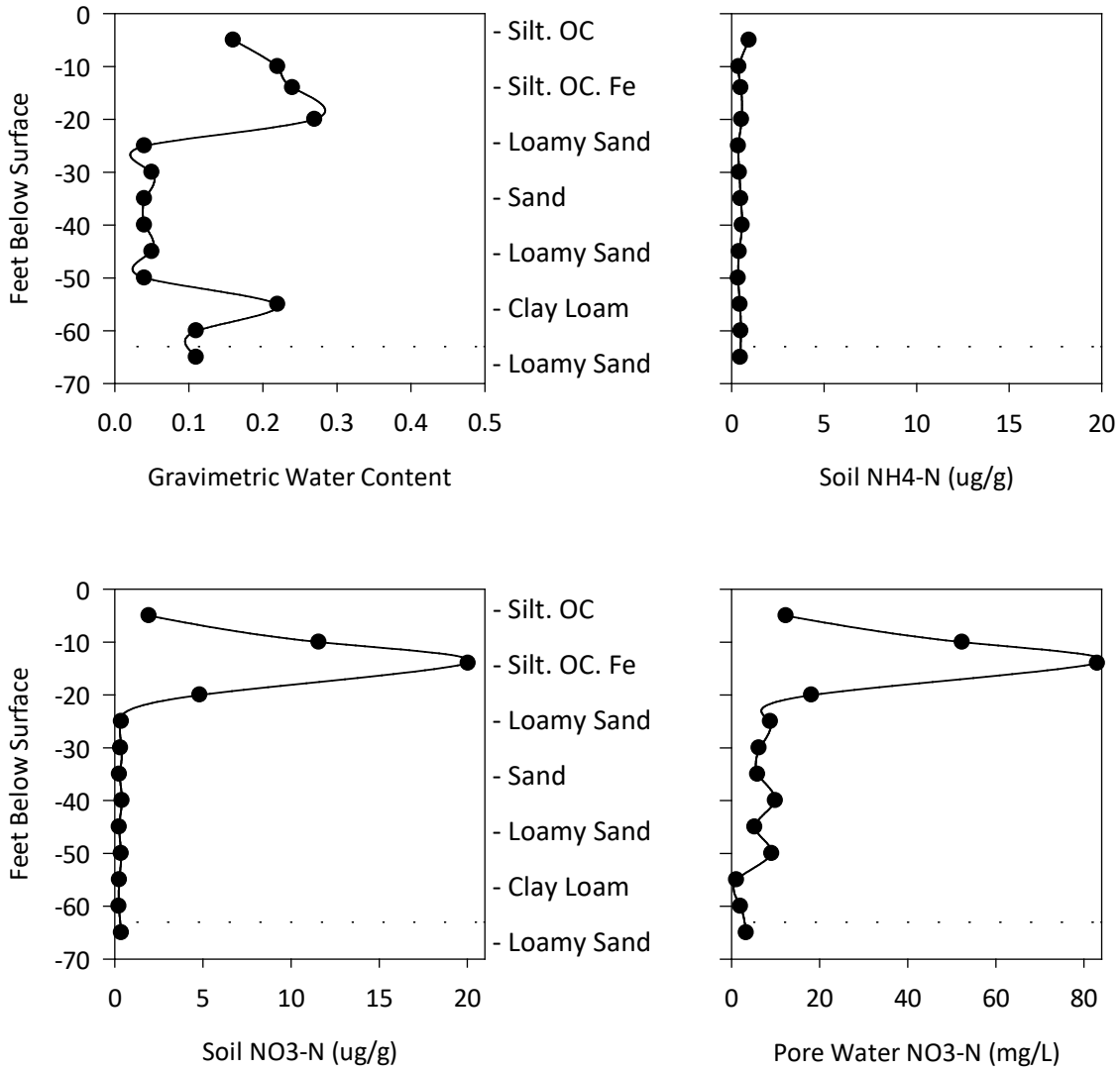


**Figure A5. DS-38-2019 Graphs.**

Notes: DS-38-2019: irrigation well G-072430 near center of NW¼, also near NRD boundaries.

**DS-39-2019**

Depth to water: 75 feet
Total N load= 41 lbs-N/Acre

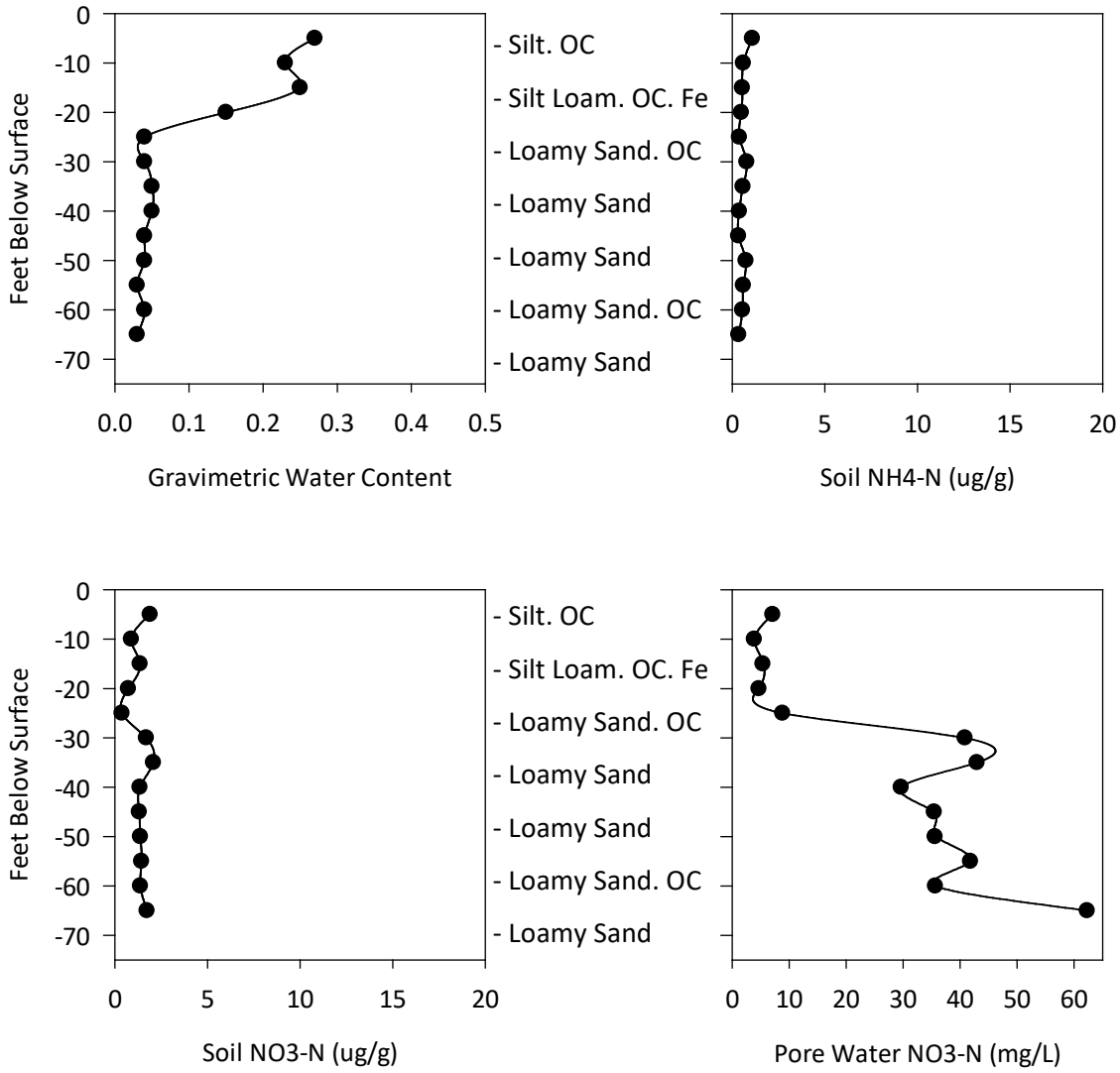


**Figure A5. DS-39-2019 Graphs.**

Notes: DS-39-2019: corn has been harvested; irrigation well G-039544 near center of NW¼, also near NRD boundaries.

# Appendix 2: Tables of Results by Core

## DS-31-2019

| Core Depth | Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|---|
| -5 | 0.71 | 0.23 | 7.72 | 1.25 | 2.68 | 11.42 | 5.16 | Dark Brown. Silt. OC |
| -10 | 0.88 | 0.29 | 8.43 | 0.68 | 1.13 | 3.91 | 2.69 | Light Brown. Silty Clay. OC |
| -15 | 1.02 | 0.03 | 8.88 | 0.34 | 0.18 | 5.50 | 0.49 | Tan. Sandy Loam. OC |
| -20 | 0.89 | 0.04 | 8.77 | 0.33 | 0.43 | 11.96 | 1.05 | Tan. Loamy Sand. OC |
| -25 | 0.92 | 0.04 | 8.8 | 0.37 | 0.17 | 4.44 | 0.42 | Tan. Loamy Sand. OC |
| -30 | 0.92 | 0.03 | 8.6 | 0.48 | 0.39 | 11.68 | 0.98 | Tan. Loamy Sand. OC |
| -35 | 0.85 | 0.03 | 7.51 | 0.27 | 0.25 | 8.34 | 0.58 | Tan. Loamy Sand |
| -40 | 0.89 | 0.03 | 7.94 | 0.11 | 0.28 | 9.70 | 0.68 | Tan. Loamy Sand |
| -45 | 0.91 | 0.03 | 8.06 | 0.39 | 0.46 | 18.20 | 1.13 | Tan. Loamy Sand |
| -50 | 0.90 | 0.04 | 8.23 | 0.32 | 0.25 | 6.78 | 0.62 | Tan. Loamy Sand |
| -55 | 1.11 | 0.04 | 8.33 | 0.44 | 0.40 | 9.04 | 1.21 | Tan. Sandy Loam |
| -60 | 0.77 | 0.02 | 8.24 | 0.43 | 0.00 | 0.00 | 0.00 | Tan. Sandy Loam |
| -65 | 0.90 | 0.27 | 7.93 | 0.53 | 0.54 | 1.98 | 1.31 | Light Brown. Clay Loam. Fe |
| -70 | 0.94 | 0.03 | 8.55 | 0.40 | 0.31 | 11.41 | 0.78 | Tan. Loamy Sand |
| -75 | 0.82 | 0.05 | 8.46 | 0.34 | 0.49 | 10.01 | 1.10 | Tan. Loamy Sand |
| -77 | 0.86 | 0.02 | 8.31 | 0.48 | 0.33 | 16.68 | 0.77 | Tan. Loamy Sand. OC |

## DS-32-2019

| Core Depth | Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|---|
| -7.5 | 0.62 | 0.27 | 8.07 | 0.69 | 0.44 | 1.61 | 0.73 | Light Brown. Silt Loam. OC |
| -10 | 0.87 | 0.02 | 8.74 | 0.49 | 0.36 | 16.06 | 0.86 | Tan. Loamy Sand. OC |
| -15 | 0.79 | 0.02 | 8.52 | 0.35 | 0.26 | 11.13 | 0.56 | Tan. Loamy Sand. OC |
| -20 | 0.83 | 0.02 | 8.2 | 0.43 | 0.49 | 19.88 | 1.09 | Tan. Loamy Sand |
| -25 | 0.79 | 0.04 | 8.19 | 0.60 | 0.33 | 7.48 | 0.72 | Tan. Loamy Sand |
| -30 | 0.82 | 0.05 | 8.57 | 0.44 | 0.92 | 16.97 | 2.06 | Tan. Loamy Sand |
| -35 | 0.92 | 0.09 | 8.66 | 0.32 | 1.70 | 19.21 | 4.26 | Tan. Loamy Sand |
| -40 | 0.85 | 0.17 | 8.29 | 0.35 | 2.71 | 16.05 | 6.27 | Tan. Loamy Sand |
| -45 | 1.11 | 0.15 | 8.79 | 0.37 | 3.84 | 25.47 | 11.60 | Tan. Loamy Sand |

## DS-33-2019

| Core Depth | Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|---|
| -5 | 1.03 | 0.20 | 6.81 | 0.60 | 4.12 | 20.65 | 11.56 | Dark Brown. Silty Clay. OC |
| -10 | 1.11 | 0.13 | 6.93 | 0.35 | 7.25 | 53.86 | 21.96 | Tan. Loamy Sand |
| -15 | 1.09 | 0.16 | 7.01 | 0.43 | 8.70 | 53.14 | 25.76 | Tan. Loamy Sand |

## DS-35-2019

| Core Depth | Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|---|
| -5 | 0.83 | 0.26 | 6.46 | 0.56 | 5.94 | 23.18 | 13.38 | Dark Brown. Silt Loam. OC |
| -10 | 0.63 | 0.20 | 7.86 | 0.56 | 7.77 | 37.96 | 13.30 | Light Brown. Silt Loam. OC. Fe |
| -15 | 0.83 | 0.25 | 8.03 | 1.68 | 5.08 | 20.22 | 11.53 | Light Brown. Silty Clay. OC |
| -18.5 | 1.05 | 0.19 | 8.19 | 0.64 | 1.98 | 10.33 | 5.66 | Light Brown. Silty Clay. OC |
| -20 | 1.05 | 0.03 | 8.77 | 0.46 | 0.46 | 17.18 | 1.33 | Tan. Sandy Loam. OC |
| -25 | 0.89 | 0.03 | 8.79 | 0.02 | 3.21 | 94.07 | 7.74 | Tan. Loamy Sand. OC |
| -30 | 0.94 | 0.04 | 8.84 | 0.29 | 4.39 | 108.63 | 11.24 | Tan. Loamy Sand. OC |
| -35 | 0.92 | 0.04 | 9.09 | 0.44 | 0.68 | 16.84 | 1.70 | Tan. Loamy Sand. OC |
| -40 | 0.88 | 0.04 | 9.14 | 0.29 | 2.11 | 53.81 | 5.06 | Tan. Loamy Sand |
| -45 | 0.82 | 0.04 | 9.22 | 0.37 | 1.62 | 43.17 | 3.61 | Tan. Loamy Sand. OC |
| -50 | 0.91 | 0.03 | 9.12 | 0.29 | 1.23 | 43.21 | 3.03 | Tan. Loamy Sand. OC |
| -55 | 0.86 | 0.06 | 9.22 | 0.23 | 1.19 | 21.08 | 2.80 | Tan. Loamy Sand |
| -60 | 1.00 | 0.10 | 9.13 | 0.49 | 4.72 | 48.26 | 12.78 | Tan. Loamy Sand |

## DS-38-2019

| Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|
| 0.75 | 0.16 | 7.6 | 0.95 | 1.94 | 12.38 | 3.98 | Light Brown. Silt. OC |
| 0.76 | 0.22 | 8.11 | 0.40 | 11.58 | 52.36 | 23.88 | Light Brown. Silt |
| 0.89 | 0.24 | 7.79 | 0.51 | 20.04 | 83.05 | 48.30 | Light Brown. Silt. OC. Fe |
| 0.95 | 0.27 | 7.97 | 0.54 | 4.82 | 18.16 | 12.46 | Light Brown. Clay. OC. Fe |
| 0.90 | 0.04 | 8.64 | 0.37 | 0.37 | 8.84 | 0.91 | Tan. Loamy Sand |
| 0.80 | 0.05 | 8.74 | 0.42 | 0.33 | 6.24 | 0.71 | Tan. Sand |
| 0.84 | 0.04 | 8.94 | 0.50 | 0.26 | 5.92 | 0.59 | Tan. Sand |
| 1.05 | 0.04 | 9.02 | 0.57 | 0.41 | 9.96 | 1.16 | Tan. Loamy Sand |
| 0.97 | 0.05 | 8.76 | 0.42 | 0.25 | 5.27 | 0.65 | Tan. Loamy Sand |
| 0.85 | 0.04 | 8.57 | 0.36 | 0.36 | 9.13 | 0.83 | Tan. Loamy Sand |
| 0.99 | 0.22 | 8.71 | 0.46 | 0.25 | 1.13 | 0.68 | Tan. Clay Loam |
| 0.86 | 0.11 | 8.98 | 0.51 | 0.23 | 2.05 | 0.54 | Tan. Loamy Sand |
| 1.01 | 0.11 | 8.93 | 0.48 | 0.37 | 3.33 | 1.02 | Tan. Loamy Sand |

## DS-39-2019

| Core Depth | Bulk Density | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) | Cal. Nitrate (NO3-N) | Lithologic Description |
|---|---|---|---|---|---|---|---|---|
| -5 | 0.69 | 0.27 | 7.15 | 1.09 | 1.90 | 7.11 | 3.54 | Dark Brown. Silt. OC |
| -10 | 0.69 | 0.23 | 8.01 | 0.60 | 0.88 | 3.89 | 1.65 | Light Brown. Silt. OC. Fe |
| -15 | 0.84 | 0.25 | 7.99 | 0.54 | 1.36 | 5.38 | 3.10 | Light Brown. Silt Loam. OC. Fe |
| -20 | 1.15 | 0.15 | 8.48 | 0.49 | 0.73 | 4.70 | 2.27 | Light Brown. Silt. OC |
| -25 | 0.91 | 0.04 | 8.86 | 0.39 | 0.38 | 8.86 | 0.93 | Tan. Loamy Sand. OC |
| -30 | 0.95 | 0.04 | 8.29 | 0.79 | 1.69 | 40.87 | 4.38 | Tan. Loamy Sand |
| -35 | 0.83 | 0.05 | 8.39 | 0.58 | 2.08 | 42.97 | 4.69 | Tan. Loamy Sand |
| -40 | 0.77 | 0.05 | 8.43 | 0.39 | 1.35 | 29.64 | 2.84 | Tan. Loamy Sand |
| -45 | 0.87 | 0.04 | 8.73 | 0.34 | 1.31 | 35.45 | 3.11 | Tan. Loamy Sand |
| -50 | 0.84 | 0.04 | 8.89 | 0.74 | 1.37 | 35.60 | 3.14 | Tan. Loamy Sand |
| -55 | 0.82 | 0.03 | 8.77 | 0.60 | 1.44 | 41.83 | 3.23 | Tan. Loamy Sand. OC |
| -60 | 0.89 | 0.04 | 8.73 | 0.56 | 1.37 | 35.65 | 3.32 | Tan. Loamy Sand |
| -65 | 0.93 | 0.03 | 8.47 | 0.35 | 1.73 | 62.30 | 4.37 | Tan. Loamy Sand |

## SS-01-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -3 | 0.10 | 7.82 | 1.32 | 0.54 | 5.58 |
| -4 | 0.03 | 8.14 | 0.50 | 0.42 | 11.87 |
| -6.5 | 0.14 | 8.08 | 0.69 | 0.12 | 0.81 |

## SS-02-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -2 | 0.24 | 7.88 | 1.37 | 1.59 | 6.54 |
| -6 | 0.14 | 7.85 | 0.52 | 0.05 | 0.34 |

## SS-03-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -2 | 0.17 | 7.35 | 1.98 | 1.56 | 9.14 |
| -4.5 | 0.08 | 7.87 | 1.31 | 0.22 | 2.66 |
| -7 | 0.07 | 8.25 | 0.93 | 0.39 | 5.19 |

## SS-04-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1.5 | 0.18 | 7.79 | 1.88 | 1.79 | 9.82 |
| -6.5 | 0.13 | 7.95 | 0.47 | 0.25 | 1.85 |

## SS-05-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1.5 | 0.08 | 6.38 | 1.17 | 0.26 | 3.24 |
| -5 | 0.03 | 6.96 | 0.00 | 0.18 | 5.07 |
| -9 | 0.04 | 7.19 | 0.64 | 0.20 | 4.97 |

SS-07-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -2 | 0.17 | 6.73 | 0.77 | 5.46 | 32.38 |
| -4 | 0.16 | 7.6 | 1.83 | 2.35 | 14.33 |
| -4.5 | 0.09 | 7.94 | 0.00 | 1.35 | 14.69 |

SS-08-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1.5 | 0.24 | 8.13 | 1.06 | 1.53 | 6.39 |
| -2.5 | 0.17 | 8.26 | 0.60 | 0.52 | 2.97 |

SS-09-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1 | 0.20 | 7.96 | 1.94 | 1.86 | 9.38 |

SS-10-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -4 | 0.16 | 6.24 | 2.00 | 0.39 | 2.38 |
| -7.5 | 0.07 | 7.34 | 1.25 | 0.24 | 3.29 |

SS-11-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -4 | 0.17 | 6.49 | 2.27 | 34.00 | 200.82 |
| -5.5 | 0.20 | 6.46 | 2.11 | 115.00 | 567.36 |
| -10 | 0.05 | 7.1 | 0.00 | 36.30 | 728.87 |

SS-13-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1 | 0.17 | 7.85 | 1.64 | 7.42 | 44.63 |
| -2.5 | 0.12 | 8.35 | 1.01 | 1.71 | 13.95 |
| -7.5 | 0.08 | 8.63 | 0.26 | 1.98 | 24.76 |

SS-14-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -0.5 | 0.11 | 7.26 | 0.71 | 1.78 | 15.78 |
| -1.5 | 0.20 | 8.02 | 1.65 | 3.71 | 18.85 |
| -4.5 | 0.16 | 8.24 | 0.29 | 5.55 | 35.36 |

SS-16-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -3.5 | 0.17 | 8.31 | 1.42 | 7.03 | 41.51 |
| -6 | 0.05 | 8.62 | 0.83 | 3.06 | 62.20 |

SS-18A-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -3.5 | 0.18 | 7.9 | 2.37 | 8.71 | 47.57 |

SS-18B-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -3 | 0.28 | 7.87 | 2.20 | 4.40 | 15.87 |

SS-19-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -4 | 0.42 | 7.63 | 2.46 | 3.31 | 7.80 |

SS-26-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -3.5 | 0.19 | 7.25 | 0.66 | 3.84 | 20.35 |

SS-28-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -4 | 0.13 | 7.92 | 1.89 | 2.74 | 20.53 |

SS-B01-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1 | 0.14 | 7.83 | 2.15 | 8.00 | 56.47 |
| -2.5 | 0.13 | 7.92 | 1.13 | 27.90 | 221.48 |
| -7.5 | 0.03 | 8.32 | 0.88 | 2.83 | 97.53 |

SS-B05-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1 | 0.16 | 8.17 | 2.70 | 1.92 | 11.95 |

SS-B07-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1 | 0.25 | 8.36 | 9.69 | 7.97 | 32.52 |
| -4 | 0.24 | 8.48 | 1.32 | 0.72 | 3.06 |

SS-B11-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -1.5 | 0.13 | 6.33 | 2.21 | 1.04 | 8.19 |
| -4.5 | 0.03 | 7.7 | 0.82 | 0.49 | 17.84 |
| -8 | 0.02 | 7.96 | 0.87 | 0.71 | 28.99 |

SS-B16-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -2 | 0.22 | 7.09 | 0.79 | 10.90 | 50.35 |
| -6 | 0.03 | 8.07 | 0.00 | 2.93 | 84.40 |
| -9.5 | 0.06 | 8.16 | 0.59 | 2.58 | 41.86 |

SS-B22-2019

| Core Depth | Grav. Water Content | pH | Ammonium (NH4-N) | Nitrate (NO3-N) | Cal. Pore Water Nitrate (NO3-N) |
|---|---|---|---|---|---|
| -4.5 | 0.18 | 7.27 | 0.63 | 3.02 | 16.33 |
| -8 | 0.13 | 7.94 | 0.12 | 3.01 | 22.30 |
| -10 | 0.24 | 7.88 | 0.51 | 3.23 | 13.29 |

As and U- results for vadose zone core samples SS-11 and DS-38.

| Sample ID | Collection Date | Arsenic (μg/g) | Uranium (μg/g) |
|---|---|---|---|
| **SS-11-0-4** | 11/19/2019 | 8.06 | 1.44 |
| **SS-11-4-5.5** | 11/19/2019 | 7.75 | 0.86 |
| **SS-11-5.5-10.5** | 11/19/2019 | 0.67 | 0.22 |
| **EA115-38-5** | 3/11/2020 | 7.96 | 0.15 |
| **EA116-38-10** | 3/11/2020 | 8.98 | 1.37 |
| **EA117-38-14** | 3/11/2020 | 7.56 | 1.02 |
| **EA118-38-20** | 3/11/2020 | 6.60 | 0.94 |
| **EA119-38-25** | 3/11/2020 | 0.55 | 0.17 |
| **EA120-38-30** | 3/11/2020 | 0.61 | 0.25 |
| **EA121-38-35** | 3/11/2020 | 0.66 | 0.32 |
| **EA122-38-40** | 3/11/2020 | 0.46 | 0.22 |
| **EA123-38-45** | 3/11/2020 | 0.65 | 0.26 |
| **EA124-38-50** | 3/11/2020 | 0.62 | 0.26 |
| **EA125-38-55** | 3/11/2020 | 0.78 | 0.40 |
| **EA126-38-60** | 3/11/2020 | 0.74 | 0.34 |
| **EA127-38-65** | 3/11/2020 | 0.73 | 0.26 |

# Appendix 3: Results of Quality Control

| QC Summaries | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fortified Blanks | | | | | | | |
| Lab_ID_String | Sample_ID | Collection Date | NO3N (%) | NH4N | Batch | Analysis Date | Project |
| 19-9159 | LFB | 11/19/2019 | 103.20 | 87.60 | W19986 | 2/17/2020 | QA/QC |
| 20-471 | QA/QC LFB | 1/8/2020 | 103.40 | 105.4 | W20050 | 3/30/2020 | QA/QC |
| 20-504 | QA/QC LFB | 1/12/2020 | 104.40 | 111.8 | W20051 | 3/30/2020 | QA/QC |
| 20-845 | QA/QC LFB | 1/20/2020 | 100.40 | 112.8 | W20097 | 3/30/2020 | QA/QC |
| 20-974 | QA/QC LFB | 2/12/2020 | 102.40 | 92.00 | W20105 | 3/30/2020 | QA/QC |
| 20-6094 | LFB | 8/30/2020 | 102.00 | 92.00 | W20599 | 10/26/2020 | QA/QC |
| 20-6115 | LFB | 9/14/2020 | 102.00 | 92.00 | W20600 | 10/27/2020 | QA/QC |
| 20-6157 | LFB | 8/30/2020 | 102.00 | 92.00 | W20602 | 10/27/2020 | QA/QC |
| 20-6164 | LFB | 8/30/2020 | 102.00 | 92.00 | W20603 | 10/26/2020 | QA/QC |
| 20-6468 | LFB | 11/16/2020 | 113.60 | 113.60 | W20646 | 11/20/2020 | QA/QC |
| 20-6505 | LFB | 11/16/2020 | 113.60 | 113.60 | W20648 | 11/20/2020 | QA/QC |
| | | Averages (%) | 104.6 | 101.7 | | | |
| | | Standard Dev (%) | 4.9 | 10.5 | | | |
| Method Blanks | | | | | | | |
| 19-9160 | LRB | 11/19/2019 | 0.09 | 0.00 | W19986 | 2/17/2020 | QA/QC |
| 20-936 | QA/QC LRB | 2/10/2020 | 0.00 | 0.00 | W20104 | 3/30/2020 | QA/QC |
| 20-975 | QA/QC LRB | 2/12/2020 | 0.00 | 0.00 | W20105 | 3/30/2020 | QA/QC |
| 20-1817 | EA89-LRB | 3/11/2020 | 0.03 | 0.05 | W20150 | 3/13/2020 | QA/QC |
| 20-1839 | EA111-LRB | 3/11/2020 | 0.06 | 0.42 | W20151 | 3/13/2020 | QA/QC |
| 20-1862 | EA134-LRB | 3/11/2020 | 0.11 | 0.29 | W20152 | 3/13/2020 | QA/QC |
| 20-6095 | LRB | 8/30/2020 | 0.00 | 0.10 | W20599 | 10/26/2020 | QA/QC |
| 20-6158 | LRB | 8/30/2020 | 0.00 | 0.00 | W20602 | 10/27/2020 | QA/QC |
| 20-6165 | LRB | 8/30/2020 | 0.00 | 0.00 | W20603 | 10/26/2020 | QA/QC |
| 20-6469 | LRB | 11/16/2020 | 0.00 | 0.00 | W20646 | 11/20/2020 | QA/QC |
| 20-6488 | LRB | 11/16/2020 | 0.00 | 0.00 | W20647 | 11/20/2020 | QA/QC |
| 20-6506 | LRB | 11/16/2020 | 0.00 | 0.00 | W20648 | 11/20/2020 | QA/QC |
| Laboratory Duplicates | | | | | | | |
| **Lab_ID_String** | **Sample_ID** | **Collection_Date** | **NO3N** | **NH4N** | **Batch** | **Analysis Date** | |
| 19-9100 | SS-7-0-2 | 11/25/2019 | 5.45 | 0.48 | W19984 | 2/17/2020 | 19_AndD_LPNNRD_L |
| 19-9101 | SS-7-0-2 LD2 | 11/25/2019 | 5.46 | 0.77 | W19984 | 2/17/2020 | QA/QC |
| | | Range | 0.01 | 0.29 | | | |
| 19-9118 | SS-14-1.5-4.5 | 11/25/2019 | 5.56 | 0.34 | W19985 | 2/17/2020 | 19_AndD_LPNNRD_L |
| 19-9119 | SS-14-1.5-4.5 LD2 | 11/25/2019 | 5.55 | 0.29 | W19985 | 2/17/2020 | QA/QC |
| | | Range | 0.01 | 0.05 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20-1836 | EA108-32-45 | 3/11/2020 | 3.84 | 0.37 | W20151 | 3/13/2020 | 19_AndD_LPNNRD_L |
| 20-1837 | EA109R | 3/11/2020 | 3.63 | 0.47 | W20151 | 3/13/2020 | QA/QC |
| | | Range | 0.21 | 0.10 | | | |
| 20-6470 | SS-BAILEY 6-4.5-5 | 11/16/2020 | 1.21 | 1.03 | W20647 | 11/20/2020 | 19_AndD_LPNNRD_VADOSE_L |
| 20-6471 | SS-BAILEY 6-4.5-5 LD2 | 11/16/2020 | 0.90 | 2.02 | W20647 | 11/20/2020 | QA/QC |
| | | Range | 0.31 | 1.00 | | | |
| 20-6489 | SS-BOHAC 4-0-2 | 11/16/2020 | 1.14 | 2.76 | W20648 | 11/20/2020 | 19_AndD_LPNNRD_VADOSE_L |
| 20-6490 | SS-BOHAC 4-0-2 LD2 | 11/16/2020 | 1.11 | 2.80 | W20648 | 11/20/2020 | QA/QC |
| | | Range | 0.03 | 0.04 | | | |
| 20-6451 | SS-BAILEY 1-0-3 | 11/16/2020 | 5.57 | 0.97 | W20646 | 11/20/2020 | 19_AndD_LPNNRD_VADOSE_L |
| 20-6452 | SS-BAILEY 1-0-3 LD2 | 11/16/2020 | 5.70 | 1.57 | W20646 | 11/20/2020 | QA/QC |
| | | Range | 0.13 | 0.60 | | | |
| | | | | | | | |

## List of the Standard Operating Procedures (SOPs) used in this project

| Parameter | Units | Typical Sample size | Detection Limit | Expected range | Method Reference |
|---|---|---|---|---|---|
| Textural description | NA | Core section | NA | NA | Attachment 2.1: Soil Core Processing WSL SOP07_06_02.002 |
| Gravimetric water content | gm/gm solid | 100 grams | 0.005 | 0-0.35 | Attachment 2.1: Soil Core Processing |
| Bulk Density | $gm/cm^3$ | 50-70 $cm^3$ | NA | 1-3.0 | Attachment 2.1: Soil Core Processing |
| Soil pH | pH | 5 grams | NA | 5-8 | Attachment 2.1: Soil Core Processing |
| Soil NO3N and NH4N | µg/g | 10 grams | 0.005 | 0.0-100 | Attachment 2.3: Lachat QuikChem 8500 WSL SOP13_02_02_001 |
| Acid leachable metals | ng/g | 10 grams | 0.05 to 0.1 | 0.0-500 | Attachment 2.3: Lachat QuikChem 8500 |
| Particle size (sand/silt/clay) | (%) | 15 grams | NA | 0-100 | Attachment 2.8 Soil Particle Size Analysis |

| Analytical Method | SOP by Numbers | Dates Active |
|---|---|---|
| Plan, obtain, label, document, and store cores for further analyses | 1: Field Soil Coring | |
| Prepare a soil core subsample for instrumental analysis | 2: Soil Core Processing | 7/10/2018 – present |
| Core Extrusion | 2: Soil Core Processing | 7/10/2018 – present |
| NO3/NH4 & PH Processing | 2: Soil Core Processing | 7/10/2018 – present |
| PH | 2: Soil Core Processing | 7/10/2018 – present |
| Flow injection analysis | 3: Lachat QuikChem 8500 | |
| Particle size analysis | 4: Particle Fractionation and Particle-Size Analysis | 3/15/2018 – present |
| Inductively coupled plasma-mass spectrometry (ICP-MS) | 5: Microwave Assisted Acid | 3/2/2018 – present |

| | | |
|---|---|---|
| for analysis of element concentration | Digestion for Elemental Analysis by ICP-MS | |
| Inductively coupled plasma-mass spectrometry (ICP-MS) for elemental analysis | 6: Analysis of Dissolved Trace Elements in Aqueous Solutions by ICP-MS | 3/14/2018 – present |
| Microwave-assisted solvent extraction (MASE) and gas chromatography mass spectrometry (GC/MS) for analysis of herbicides in solid samples (i.e. soils, manure, etc) | 7: Analysis of herbicides in solid samples by MASE and GC/MS | 02/2017 – present |
| Soil texture analysis | 8: Soil Particle Size Analysis | |

To access the Standard Operating Procedures, please go to the Nebraska Vadose Zone website, and see Monitoring Guidance (http://nebraskavadose.unl.edu/monitoringguidance.asp).