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Measuring Nitrogen Transformation in Wastewater Impacted Streams Using In-Situ Benthic Chambers

Makenzi Beltran
Utah State University

MEASURING NITROGEN TRANSFORMATION IN WASTEWATER IMPACTED STREAMS USING IN-SITU BENTHIC CHAMBERS

by

Makenzi Beltran

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Approved:

_____	_____
R. Ryan Dupont, Ph.D. Major Professor	Joan E. McLean, M.S. Committee Member
_____	_____
Bethany Neilson, Ph.D. Committee Member	Richard S. Inouye, Ph.D. Vice Provost for Graduate Studies

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ABSTRACT

MEASURING NITROGEN TRANSFORMATION IN WASTEWATER IMPACTED STREAMS USING IN-SITU BENTHIC CHAMBERS

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Makenzi Beltran

Utah State University, 2019

Major Professor: Dr. R. Ryan Dupont
Department: Engineering

The Environmental Protection Agency (EPA) issued a state mandated numeric nutrient standard development for nitrogen and phosphorus. Nitrogen transformation rates are specifically required as part of the numeric nitrogen standard development. An in-situ benthic chamber study was conducted across two wastewater impacted streams in Utah to determine the methodology necessary for obtaining the required nitrogen transformation rates. The study included the use of an isotopically enriched $^{15}NO_3^-$ dosing solution. The measurements of labelled and non-labelled nitrogen species were then used to determine transformation rates for nitrification, denitrification, assimilation, dissimilatory nitrate reduction to ammonia (DNRA) and anaerobic ammonium oxidation (ANAMMOX) within the streams.

In order to determine the impact from wastewater effluent, the chambers were installed upstream and downstream of wastewater reclamation facilities at two separate locations. The initial study took place in July and August of 2016 at East Canyon Creek in Park City, Utah near the East Canyon Wastewater Reclamation Facility. The second

study took place in June of 2017 at Box Elder Creek in Brigham City, Utah near the Brigham City Wastewater Treatment Plant.

Significant nitrification rates were only found at the downstream East Canyon and downstream Box Elder Creek locations, likely due to the relatively higher ammonium levels compared to their respective upstream location. Significant 0-order and 1st-order denitrification rates were statistically the same for downstream and upstream locations at both the East Canyon and Box Elder Creek study sites showing no impact of the WWTPs on denitrification. In the instances where various methods produced significant rates at an individual location, there were no significant differences between the rates. Variability across the analysis methods was still evident, as downstream East Canyon was the only location where all denitrification analysis methods produced significant results. Assimilation rates were only significant at the upstream East Canyon and Box Elder Creek locations, while significant but very low ANAMMOX and DNRA rates were only found at the downstream East Canyon site. Labelled nitrogen studies did not prove to be necessary for determining denitrification and nitrification, however, they would be required if assimilation, ANAMMOX, or DNRA rates were desired.

(167 pages)

PUBLIC ABSTRACT

Measuring Nitrogen Transformation in Wastewater Impacted Streams Using In-Situ Benthic Chamber

Makenzi Beltran

Acrylic chambers and metal frames were installed at the sediment-water interface of streams impacted by the effluent from wastewater reclamation facilities in order to determine nitrogen rates for nitrification, denitrification, assimilation, ANAMMOX, and DNRA. Each chamber was dosed with an isotopic form of nitrate ($^{15}NO_3^-$), and both isotopic (^{15}N) and non-isotopic (^{14}N) samples were collected. The project locations included East Canyon Creek near the East Canyon Wastewater Reclamation Facility in Park City, Utah and Box Elder Creek near the Brigham City Wastewater Treatment Plant in Brigham City, Utah. Separate chamber measurements were conducted upstream and downstream of each wastewater reclamation facility in order to determine the impact of the wastewater effluent on the stream. At the conclusion of the study, significant rates for both traditional (nitrification, denitrification, assimilation) and non-traditional nitrogen transformations (DNRA, ANAMMOX) were found at various locations. Specific transformations were found exclusively upstream or exclusively downstream of the wastewater treatment plant. Transformations that were found both upstream and downstream of the treatment plants were not significantly different, indicating no impact from the WWTPs on nitrogen transformations. Additionally, the use of isotopic nitrogen for the study did not prove necessary for determining nitrification and denitrification rates.

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INTRODUCTION

Nitrogen (N) is often a limiting nutrient in the environment (Roberston & Groffman, 2015). It is a contributor to growth and is therefore essential to all forms of life, however, excess nitrogen can have detrimental effects. In aquatic environments, an excess of nutrients can lead to an increase in algae growth, leading to eutrophication. Depletion of oxygen can also occur with high levels of ammonium (NH_4^+) due to the nitrification process utilizing oxygen to convert NH_4^+ to nitrate (NO_3^-). The harmful effects of oxygen depletion to aquatic and surrounding ecosystems make it important to maintain healthy levels of nitrogen in all bodies of water. To understand the nutrient loading required to maintain healthy conditions in an aquatic ecosystem, an understanding of nitrogen transformations and their respective rates is necessary (Roberston & Groffman, 2015). The Environmental Protection Agency (EPA) issued a nutrient standard development program across the United States where each state is responsible for determining numeric criteria for nitrogen and phosphorus pollution (Stoner, 2011). A major component to these developments is creating nitrogen and phosphorous regulations for the effluent from wastewater reclamation facilities that discharge into surface water systems. In order to create nutrient regulations, the impact of wastewater effluent on their respective water bodies needs to be understood, not only by determining the levels of nitrogen in the discharge, but also the transformation rates of nitrogen species (Stoner, 2011; Roberston & Groffman, 2015).

Monitoring nitrogen transformation rates in wastewater impacted streams can be a difficult task to accomplish with in situ methods due to varying ambient conditions.

Water levels, weather, and general accessibility to different locations can all impact the ability to carry out a successful in situ study. The use of laboratory methods for determining nitrogen transformation rates increases feasibility by creating a controlled environment. However, in order to develop these laboratory methods, an initial in situ study is necessary to determine the accuracy of the laboratory monitoring techniques. The goal of this project was to develop an in situ benthic chamber method that provides site specific transformation rate data to which results from a separate laboratory study can be compared. Comparable data among the chamber and laboratory methods will then ultimately determine the reliability of the laboratory methods. Therefore, the development of a reliable benthic chamber method can lead to the development of representative laboratory methods that can be utilized by wastewater treatment plants throughout Utah and other locations. This will provide a simpler and more accessible way to monitor nitrogen discharges from wastewater reclamation facilities, to determine their impacts, and to subsequently develop site-specific nitrogen standards for individual wastewater treatment plants.

OBJECTIVES

Objective 1 - Chamber Design

The main goal of this project is to determine a design, as well as the necessary installation and operating procedures, that will provide representative measurements of nitrogen transformations taking place under ambient environmental conditions within streams impacted by wastewater treatment plant discharges. Considerations for the design of the chamber include ease of use and chamber dimensions. The frame must be rigid and tough enough to be driven into the sediment and the depth must also be sufficient to minimize chamber losses due to hyporheic exchange during in situ measurements. The main consideration for the design of the chamber is its dimensions. The volume of the chamber must be large enough to contain at least 90% of its original water volume after all sampling has been complete, based on a previous chamber study by Stewardson (2016). The height of the chamber must also be less than the depth of the stream in order for the chambers to remain completely submerged and naturally insulated for the duration of the study. Further efforts to prevent leaks include monitoring hyporheic flow with the use of mini-piezometers in order to determine installation locations for the frames that will minimize potential loss from upwelling or downwelling during in situ measurements.

Objective 2 - Sampling Procedures & Analytical Methods

The main goal of this objective is to determine and select nitrogen measurement methods, including sampling procedures and subsequent analytical methods, for the chamber study so various nitrogen transformations of interest can be accurately monitored. Methods for tracking leaks in the chamber system were also selected. The

sampling procedures for the different analytes vary and each procedure was designed to prevent contamination. Analytical methods were determined based on the compounds of interest and their expected concentrations.

Objective 3 – Determining Rates & Mass Balance

The main goal of this objective is to determine the appropriate methods for calculating rates of the various nitrogen transformations found in the stream and for completing a mass balance of the system within the chambers. The use of a tracer within each chamber provided information on nitrogen loss from the chambers over the duration of the study. Percent losses below the acceptable value of 30%, predetermined from the chamber study by Stewardson (2016), gives confidence in the representativeness of the calculated rates. These in situ rates were considered “true” transformation rates, and serve as a baseline measurement for comparison with rates generated in the lab studies to determine appropriate laboratory methods. Nitrogen mass balances were also completed in order to demonstrate that all nitrogen was accounted for and in turn serve as a secondary method for tracking any losses in the system.

LITERATURE REVIEW

Nitrogen Transformation

The traditional nitrogen transformation cycle includes ammonification, nitrification, denitrification, and nitrogen assimilation. Non-traditional nitrogen transformations include dissimilatory nitrate reduction to ammonia (DNRA) and anaerobic ammonium oxidation (ANAMMOX), with recent studies showing the importance of ANAMMOX as a significant source of N_2 formation (Trimmer et al., 2003). Figure 1 shows the nitrogen transformation cycle including traditional and non-traditional transformations.

Ammonification – Ammonification, or nitrogen mineralization, is the conversion of organic nitrogen to ammonium. Methods for determining ammonification rates include $^{15}N\text{-}NH_4^+$ isotope dilution which gives both the net and gross rates (Herbert, 1999). When measuring nitrogen uptake using ^{15}N, high rates of ammonification can become an issue through rapid conversion of organic nitrogen to ammonium, and in turn can lead to underestimating the nitrogen uptake rates (Dugdale & Wilkerson, 1986). Ultimately, $^{15}NH_4^+$ enrichments were not used in this benthic chamber study and ammonification was not measured.

Anaerobic Ammonium Oxidation (ANAMMOX) – Anaerobic ammonium oxidation, the direct conversion of ammonium to nitrogen gas, can be an important nitrogen process that contributes to the permanent removal of nitrogen from an aquatic

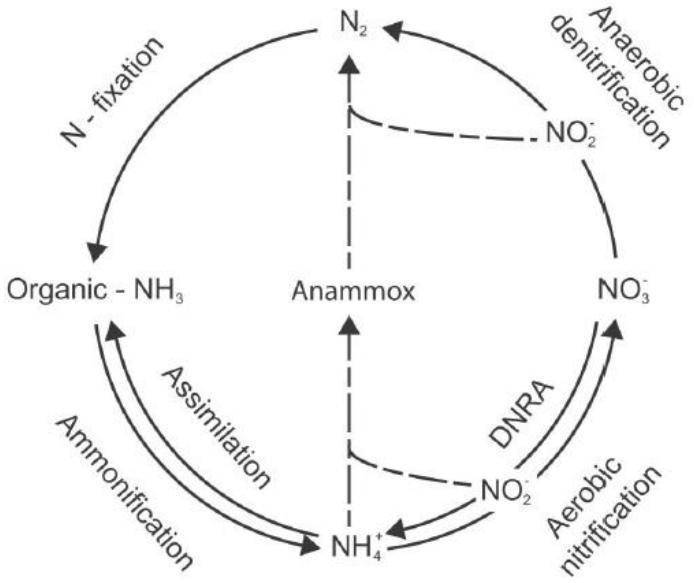

Figure 1: Nitrogen Transformations (Trimmer et al., 2003).

ecosystem. Although the anaerobic oxidation of ammonium was originally thought to be coupled with the reduction of nitrate, it was found that it is coupled with the reduction of nitrite (Trimmer et al., 2003). ANNAMOX rates have been found to increase with increased sulfide content, as high levels of sulfide inhibit the competition with denitrifiers for nitrate and nitrite (Hou et al., 2012). The reduction of sulfate to hydrogen sulfide is coupled with the decomposition of organic matter. Low levels of organic carbon and low bioreactive organic matter have also been linked to higher rates of ANNAMOX (Hou et al., 2012).

Nitrification – Nitrification is the process in which the reduced forms of nitrogen as ammonium (NH_4^+), ammonia (NH_3), and organic-N are converted to an oxidized form of nitrogen as nitrate (NO_3^-) and nitrite (NO_2^-). The process occurs in the presence of

oxygen and autotrophic ammonia oxidizing bacteria, the most common being *Nitrosomonas,* as well as *Nitrobacter*, which is responsible for the subsequent conversion of nitrite to nitrate. Nitrification is an important water quality consideration due to the ion charge of the constituent having an effect on its mobility in negatively charged soil. Negatively charged nitrite and nitrate will move faster through a soil system compared to positively charged ammonium (Roberston & Groffman, 2015). Furthermore, nitrification produces trace gases nitric oxide (NO) and nitrous oxide (N_2O), both of which contribute significantly to greenhouse gas emissions (Norton et al., 2011).

Denitrification – Denitrification is the process where oxidized nitrogen, in the form of $NO_3^-$and NO_2^-, is converted to nitrogen gas (N_2), removing the nitrogen from the system. The process occurs under anoxic conditions and in the presence of heterotrophic denitrifying bacteria. In aquatic ecosystems, the benthic zone is a major contributor to denitrification (Bohlke et al., 2004), with the highest rates of denitrification occurring in the shallower sediments (Lansdown et al., 2012 & Stelzer et al., 2011). Temperature, the supply of nitrate and organic matter, and the oxygen concentration all influence the rate of denitrification (Seitzinger, 1988). Macrophytes play a large role in rates of denitrification in aquatic ecosystems. Nitrification seems to be the main source of nitrate for denitrification (Seitzinger, 1988), and macrophytes aid in nitrification by releasing oxygen through their roots (Herbert, 1999 & Seitzinger, 1988). Macrophytes also aid in the stimulation of denitrification by releasing carbon through rhizomes and roots from trapped organic matter in the sediments surface, as well as through root exudates (Herbert, 1999). Although measuring denitrification can be difficult because of a high

nitrogen gas background, ^{15}N tracer and ^{15}N pairing techniques have been used as quantification methods for the denitrification reaction (Cornwell et al., 1999).

Dissimilatory Nitrate Reduction to Ammonium (DNRA) – Dissimilatory nitrate reduction to ammonium (DNRA), or nitrate ammonification, is typically found in sediments with a high organic content (Koike & Hattori, 1978). Dissimilatory nitrate reduction to ammonium rates were found to be the highest during the late summer, which is also the time when the surface sediment tends to be the most reduced (Jorgenson, 1989). Reduced sediment conditions may increase DNRA rates due to a higher free sulfide content that can inhibit denitrification, another form of dissimilatory reduction of nitrate (Jorgenson, 1989). Although denitrification and DNRA are both forms of dissimilatory reduction of nitrate, denitrification decreases the total nitrogen in the system while with DNRA, the total nitrogen content remains the same and the process creates more available nitrogen for nitrification and assimilation by microorganisms (An & Gardner, 2002). In a study by Lansdown et al. (2012), DNRA rates in hyporheic sediments were determined by using a $^{15}NO_3^-$ tracer and measuring the levels of $^{15}NH_4^+$ over time. DNRA potential varied among the samples, however, no correlation was found between the rates and the depth of the sediment or the habitat (i.e., a pool or riffle area within the stream) of the sediments.

Nitrogen Assimilation – Where denitrification and DNRA are dissimilatory forms of nitrogen removal, nitrogen assimilation, or the biological uptake of nitrogen, is the assimilatory pathway of nitrogen removal. The relative importance of nitrogen assimilation in an aquatic ecosystem is difficult to determine and therefore is often

unclear (Mulholland et al., 2008, O'Brien et al., 2012). Assimilation itself could serve as a permanent sink for nitrate from the water column, or it can only serve as a temporary sink. After assimilation, nitrogen can be released upon the death of organisms as organic-N. This organic-N can be remineralization to ammonium and then possibly be oxidized to nitrate after nitrification. Indirect denitrification, a coupled mineralization/nitrification/ denitrification reaction, could also occur after assimilation (O'Brien et al., 2012). In a study by Böhlke et al. (2004), nitrogen assimilation rates were estimated by measuring suspended particulate nitrogen during a tracer study. Although the study found that the suspended nitrogen was not an important sink for nitrate, without nitrogen measurements in benthic organisms or sediments, assimilation cannot be completely ruled out as an unimportant nitrate sink (Böhlke et al., 2004). O'Brien et al. (2012) found that remineralization was a significant transformation for the assimilated nitrogen, while only 10% of the assimilated nitrogen was released by indirect denitrification. In smaller streams, higher nitrogen assimilation rates have also been correlated to low nitrogen loading rates (Mulholland et al., 2008).

^{15}N Isotope Techniques

^{15}N Isotope Dilution – The isotope dilution tracer method consists of ^{15}N addition to the product pool, causing a dilution of the ^{15}N as production of non-isotope enriched nitrogen species occurs (Norton & Stark, 2011). When using a $^{15}NO_3^-$ tracer, the isotope dilution method can directly determine gross nitrification rates (Equation 1) and indirectly measure NO_3^- consumption rates (Equation 2) (Norton & Stark, 2011). While

net nitrification, the change in nitrate over time, is typically what is measured in field and lab studies, the use of $^{15}NO_3^-$ allows for the determination of gross nitrification.

$$Gross\ Nitrification\ Rate = \frac{(P_0 - P_t)}{t} \times \frac{\log(\frac{P_0}{P_t})}{\log(\frac{I_0}{I_t})} \quad (1)$$

$$Gross\ NO_3^-Consumption\ Rate = \frac{(P_0 - P_t)}{t} \times \frac{log(\frac{P_0}{P_t})}{log(\frac{I_0}{I_t})} - (\frac{P_t - P_0}{t}) \quad (2)$$

where P_0 is the NO_3^--N concentration at t = 0, P_t is the NO_3^--N concentration at time t, I_0 is the ^{15}N atom % above background at t = 0, I_t is the ^{15}N atom % above background at time t, and t is the time interval of the measurement.

The ^{15}N dilution method assumes that the isotope is uniformly distributed and that the transformation rates remain constant throughout the experiment. According to Norton & Stark (2011), although there is a slight preference by microbes for ^{14}N over ^{15}N, the discrimination is still a small source of error relative to other potential sources of error when using KNO_3 solutions with high ^{15}N enrichments (such as 99 atom %^{15}N). Additionally, short incubation times can help with the constant rate assumption. For the isotope dilution method, a ^{15}N enrichment of the NO_3^- pool should be at least 25 to 50 atom % (Norton & Stark, 2011).

^{15}N Isotope Pairing – The isotope pairing tracer method consists of a ^{15}N addition to the substrate pool and tracking the combined $^{14}N/^{15}N$ pairs in the product pool in order to determine nitrogen transformation rates. In a study by Nielsen (1992), intact sediment cores were sampled from a site, and the water column was replaced with $^{14}NO_3^-$ free and

N_2 free water. A $^{15}NO_3^-$ solution was then injected into the water column. Beginning with a $^{14}NO_3^-$free water column meant that any $^{14}NO_3^-$ production would come from nitrification. There were then four more series containing six cores, two of which had a high and low level of $^{15}NO_3^-$ relative to the in situ concentration of $^{14}NO_3^-$, another with blocked nitrification, and a fourth used only for O_2 and $^{14}NO_3^-$ measurements. All N_2 species were measured ($^{14}N^{14}N$, $^{14}N^{15}N$, $^{15}N^{15}N$) in order to calculate denitrification rates. The ^{15}N isotope pairing technique has been used in many studies by collecting intact sediment cores and running experiments in the lab (Nielsen, 1992; Rysgaard et al., 1993; Pelegri et al., 1994; Risgaard-Petersen et al., 1994; van Lujin et al., 1996). In a study by Nielsen & Glud (1996), the isotope pairing technique was applied *in situ* through the use of benthic chambers. While the studies previously mentioned were mainly determining denitrification and nitrification rates, the isotope pairing technique has also been used as a method for determining DNRA (An & Gardner, 2002).

Benthic Chamber Study

Benthic chamber studies are in-situ methods for monitoring the processes taking place within a local, specific area of a water body. The typical goal of benthic chamber studies is to create a closed system in order to track a specific constituent over predetermined time periods. In a benthic chamber study conducted by Smith et al. (2009), a dome-shaped chamber was used with a diameter of 0.6 m and an overall volume of 59 L. The chamber was made of clear acrylic with two 1.3 cm PVC pipes used as support bars attached to the chamber. There were 1.3 cm holes drilled through the acrylic chamber that were fitted with rubber stoppers that were then penetrated with syringe

needles which had a 2-way syringe valve attached. These two holes acted as the sampling and mixing port for the chamber. The dome-shaped chamber was inserted approximately 5 to 10 cm into the sediment. This tracer study utilized isotopically enriched nitrate, nitrite, and ammonium in order to determine various nitrogen transformations, as well as sodium bromide in order to determine system leaks.

In a study by O'Brien et al. (2012) an acrylic chamber was also used, however, this chamber had a trapezoidal cross section with a total volume of 15 L. The study utilized a submersible pump and PVC tubes in the front and back of the chamber in order to maintain a flow within the chamber. The chambers also contained a sampling port, and a separate port fitted with a DO sensor. The chamber attached to an aluminum frame which was inserted 10 cm into the sediment, where it was positioned flush with the sediment for 7 to 14 days prior to the study. The frames had a lip where the chambers attached and were sealed through the use of a rubber gasket and ultimately secured using elastic cords. The study utilized a $^{15}NO_3^-$ enriched solution to follow nitrogen transformations. To keep track of losses within the system, small amounts of a fluorescent dye was used as a visual indicator and a sodium bromide solution was used as a tracer for leak quantification.

In a recent benthic chamber study by Stewardson (2016), a rectangular acrylic chamber and aluminum frame were used. Fittings were attached at downstream and upstream ends of the chamber, where flexible plastic tubing was then attached. The flexible plastic tubing was connected at a submersible pump in order to maintain a flow within the chamber. A sampling port was fitted onto the downstream tubing, while a

dosing port was fitted onto the upstream tubing. A dissolved oxygen probe was also fitted onto the chamber. In order to create a seal, rubber foam weather-strip tape was attached to the aluminum frame, and spring clamps were used to hold the frame and chamber together. A $^{15}NO_3^-$ enrichment solution was used to track the nitrogen transformations and a sodium bromide solution was used to quantify leaks within the system. The initial incubation period was 21 hours, at which point the chambers were removed from the aluminum frame. A re-installation of the chambers took place three more times, at Days 2, 9, and 16 from the original installation, in order to track the nitrogen transformations of any remaining labelled nitrogen taken up into the sediments and/or macrophytes within the chambers. The study found no significant amount of labelled nitrogen remained after the initial 21 hours sampling period.

Hyporheic Exchange Flow

Hyporheic flow is considered the subsurface flow that is beneath and adjacent to a stream (Käser et al., 2009). Therefore, hyporheic exchange flow is considered the exchange between a stream and hyporheic zone. Hyporheic exchange flow can be into the stream, also known as a gaining stream, or into the direction of the groundwater, also known as a losing stream (Kalbus et al., 2006). A gaining stream, or upwelling conditions, can supply the stream with dissolved nutrients, while a losing stream, or downwelling conditions, provides dissolved oxygen and organic matter to the microbes and invertebrates in the hyporheic zone (Boulten et al., 1998). Various methods exist for measuring the flux of water due to hyporheic flow including; bag-type seepage meters, heat tracers, mass balance techniques, and Darcy's law based methods (Kalbus et al.,

2006). The use of minipiezometers is one of the Darcy's law based method utilized for calculating vertical hydraulic gradient (VHG) (Baxter et al., 2003; Kalbus et al., 2006; Schmadel et al., 2014).

In a study by Käser et al. (2009), minipiezometers were constructed from PVC pipes with a 32-mm inner diameter and an open-ended bottom. The bottom 12 cm of the PVC pipe was perforated with 7 mm diameter holes (approximately 60 holes) that were covered by a nylon mesh. The minipiezometers were installed through the use of a gasoline-powered auger. In studies by Baxter et al. (2003) and Schmadel et al. (2014), similar minipiezometers were used with a different installation method. Instead of an auger, the installation unit consisted of an outer stainless steel sleeve/casing, a solid cold-roll steel pointed driver rod that fit inside the casing, the minipiezometers, and a hammer cap to fit over the top of the rod. To install, the driver rod was placed inside the casing and the pair was hammered into the ground using the hammer cap. Once the desired depth into the sediment (typically between 25-40 cm) was reached, the driver rod was removed and replaced with the minipiezometer. When the minipiezometer was in place, the casing was pulled out of the sediment while holding the minipiezometer in place. Although most of the minipiezometers equilibrated within minutes, some took several hours. After the equilibration of the minipiezometers, the vertical hydraulic gradient (VHG) was determined by calculating the $\Delta h/\Delta l$ ratio, where Δh is the difference in head between the water level inside the minipiezometer and the surface level of the stream, and Δl is the depth below the streambed surface to just above the perforated section of the

minipiezometer. A positive VHG indicates upwelling conditions while a negative VHG indicates downwelling conditions.

MATERIALS & METHODS

Study Sites

Two project sites were selected based on an earlier cooperative modeling study by Utah State University (USU) and the Utah Department of Environmental Quality (UDEQ) (Neilson et al., 2012). The project sites used in the study by Neilson et al. (2012) are all locations of interest to the UDEQ. Selecting project sites that were also used in the modeling study provides an additional set of data to compare the project results to.

The first selected project site was in East Canyon Creek in Park City, Utah (elevation 7000 ft). Chambers were located both upstream and downstream of the East Canyon Water Reclamation Facility (ECWRF) (Figure 2).

Figure 2: East Canyon field study site.

The ECWRF utilizes a modified oxidation ditch with advanced biological and chemical treatment for nutrient removal. The treatment facility has a capacity of 4 MGD and treats wastewater from Park City, The Canyons, and the western Snyderville Basin. The treated wastewater is discharged into East Canyon Creek, which then flows into East Canyon Reservoir.

The second selected project site was in Box Elder Creek in Brigham City, Utah (elevation 4436 ft). Chambers were located both upstream and downstream of the Brigham City Water Treatment Plant (Figure 3).

Figure 3: Box Elder Creek field study site.

This treatment plant utilizes a conventional oxidation ditch and treats an average of 3 MGD. It is also a combined compost/green waste/recycling facility. The plant

consists of two aerated ditches, two clarifiers, one aerated digester, and 17 drying beds. The treated wastewater is discharged into Box Elder Creek.

Chamber Design

Each chamber consists of a metal frame (Figure 4a) that can be pushed into the sediment to which an in situ chamber can be attached. Figure 4b shows a frame and the full frame and chamber assembly.

a. b.

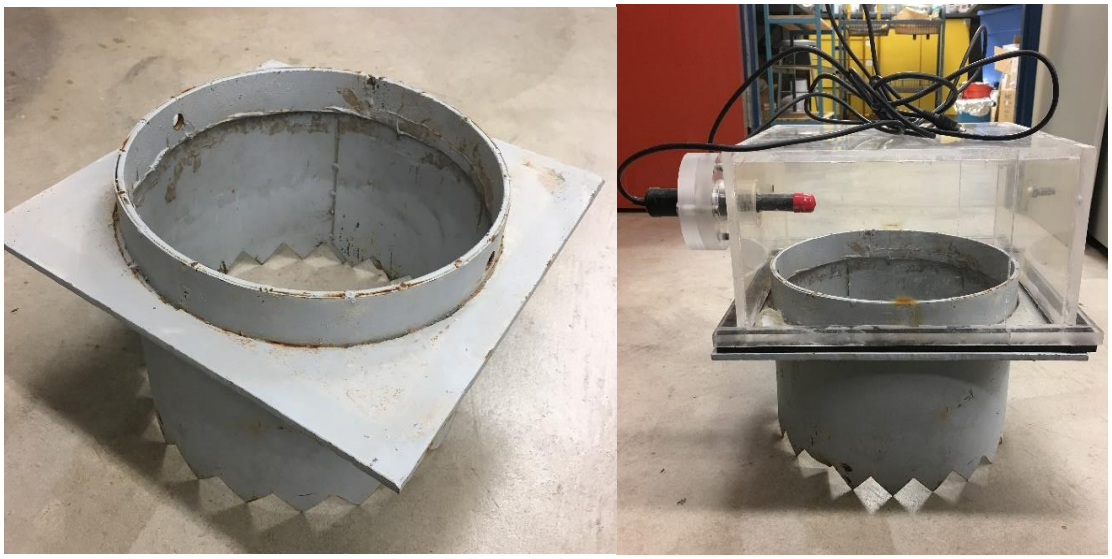

Figure 4: Benthic chamber, a. frame, b. frame and chamber assembly.

The chambers used for the project were modified from those used in the study conducted by Stewardson (2016). The original design consisted of a rectangular frame and chamber. The original aluminum frame had a height of 15.24 cm (6 in), with the lip at the top of the frame and flat edges all around. This design led to issues due to difficulty installing the frames into the sediments found at the site locations for this project. The

frame was changed and made circular to increase range of motion while pushing it into the sediment. The rigid, serrated edges at the bottom of the frame were added to enable the frame to penetrate coarse or otherwise resistive sediments. The new frame design includes a lip 2.54 cm (1 in) from the top of the frame that forms a square perimeter to which the acrylic chamber is attached. The frame has a radius of 30.48 cm (12 in) with a height of 15.24 cm (6 in) below the lip. The acrylic chambers from the study by Stewardson (2016) were altered to a square design in order to fit on top of the new circular frames. The new chambers measure 30.48 cm x 30.48 cm (12 in x 12 in) with a height of 12.7 cm (5 in), for a final volume of 14.16 L (864 in^3). Each chamber was fitted with an Extech DO meter/data logger for continuous dissolved oxygen data collection throughout the study. Spring clamps and rubber foam weather-strip tape were used to create a tight seal between the chamber and frame.

Chamber Installation

The frames are pushed into the sediments with the use of a frame extension (Figure 5) until the lip is flush with the streambed. The frame extension fits onto the lip of the frame and is held in place by a metal rod. Handles at the top of the frame extension allow for extra leverage when pushing the frames into the sediment.

To install the chambers onto the frame, they are held upside down under water until they are completely filled. The chambers are then rotated underneath the water surface to avoid air from entering the chamber, and are fitted onto the frames. Two spring clamps are then placed on each side of the chamber. The connecting tubing is held under

water parallel to the flow to fill it with water and remove air trapped within the tubing prior to being attached to the chamber.

The tubing was first attached to the outlet end of the chamber and then to the inlet end of the submersible pump while being held under water. While still remaining under water, the tubing was then attached to the outlet end of the pump and then to the inlet end of the chamber. This setup, shown in Figure 6, allows for the flow within the chamber to be in the same direction as the stream.

a. b.

Figure 5: Frame extension, a. used during frame installation, b. outside of water.

Approximately 6 days prior to the beginning of the downstream and upstream field studies, site visits were conducted in order to select possible locations for the chamber installations. This included the installation of minipiezometers to determine hyporheic water upwelling or downwelling conditions in the river reach segment being monitored.

Minipiezometers were only installed at locations where water depth was sufficient for chamber installation. Locations were chosen where there was near-neutral

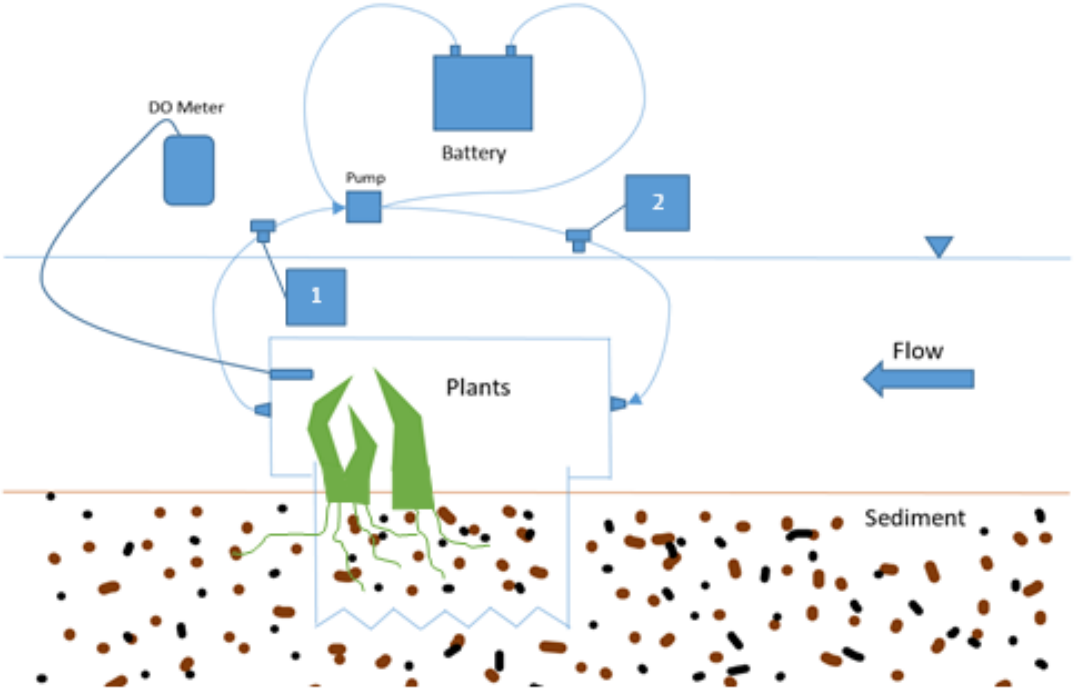

Figure 6: Chamber setup, 1 = dosing location, 2= water/dissolved N2 sampling.

groundwater influence relative to the locations selected for minipiezometer installation. Since site selection can be limited due to water depth, finding completely neutral conditions in an area where chambers can also be successfully installed may not be feasible. It was still of interest to pick the locations closest to neutral as possible. In addition to selecting sites where the chambers could be completely submerged in water, finding sites where the streambed was still accessible was also critical in order to be able to install the chambers. After locations were selected from the above criteria, chambers were installed and leak tests of the chambers were conducted. The leak test included six chamber setups, all dosed with a 30 mL KBr tracer solution (70.2 g KBr/L) to achieve a

bromide concentration of 100 mg Br^-/L within each chamber. Samples were taken for background as well as at 0, 1, and 4 hours with the assumption, based on observations in earlier trials (Stewardson, 2016), that any unacceptable leaks of greater than 30% tracer loss (arbitrarily chosen based on practicality and the data found from the Stewardson (2016) study) within the chambers could be detected within 4 hours.

At the conclusion of the leak test, the chambers were disassembled with the exception of the frames which were left onsite at their installed locations. In the case where substantial bromide loss was found within the chambers at specific locations, new locations for the chambers were selected and the leak test were carried out again. If the leak test results were within the acceptable range for tracer loss, the field study included the same six chamber setup that was used for the leak test. Sampling was identical among the six chambers through the duration of the 24-hour study. In addition to using bromide as a tracer for the leak tests, it was also used as a tracer during the final 24-hour studies at each of the study locations. In the literature regarding in-situ benthic chamber studies, there were no discussions about the use of an extra, non-reactive tracer to help account for losses. For this study, the bromide tracer was used during the 4-hour leak tests and the final 24-hour final studies to track the losses within the system, and ultimately to correct the final data set for those losses during the final studies.

At the conclusion of the field study, once all of the samples were transported back to the laboratory, bromide analyses were conducted first in order to determine the three locations that produced the best acceptable tracer recovery (<30% loss). The three locations selected then served as the triplicate for the study and were the only samples

used for the completion of the data analysis. This subset facilitated sample handling throughout the sample analysis procedures, specifically the diffusion procedure for ^{15}N analysis. The diffusion procedure utilizes three canning jars per individual sample and the analysis of three chambers alone requires approximately 150 jars per study site. Therefore, using the samples from only three of the six chambers run during the study greatly increased the feasibility of the analyses that were conducted.

The downstream field study was conducted first at each site. On the second day of the downstream field study, after the 24-hour sampling period had been completed, the chamber setup was completely taken down and reinstalled at the upstream location of the site. The upstream leak test was completed that same day, and the field study at the upstream location was conducted 6 days later (chosen arbitrarily).

Sampling

Water Samples – Each chamber was dosed with a 30 mL solution containing KBr (70.2 g KBr/L) and $K^{15}NO_3$ to achieve a 100 mg Br^-/L and 25% $^{15}NO^-_3$ enrichment within each chamber. The initial (T_0) sample was taken 12 minutes after dosing, at which point three volumes of the chamber should have been cycled through the tubing. A total of five water samples were collected at 0 (T_0), 1, 4, 12, and 24 hours after dosing, each in a 250 mL Nalgene bottle, for a total chamber water volume removal of 9.8%. The samples are preserved with H_2SO_4 to pH<2, and stored on ice during transport to the UWRL for analysis of NO^-_3-N, NH^+_4-N, TN, $^{15}NO^-_3$-N, $^{15}NH^+_4$-N, ^{15}TN, and Br^-.

Plant/Sediment Samples - Plant and sediment samples from each chamber were collected at two separate times from within the area of each frame, once before the chambers were attached to the frames and again at the end of the 24-hr study period after the chambers were detached from the frames. Sediment samples were collected using a single PVC sediment core per chamber. Each sediment core was 7.62 cm (3 in) long and 4.13 cm (1-5/8 in) in diameter (Figure 7). When sediment samples were collected, they were composited in the field for each chamber by taking three individual sediment core samples and placing them into a plastic Ziploc sample bag designated for each respective chamber.

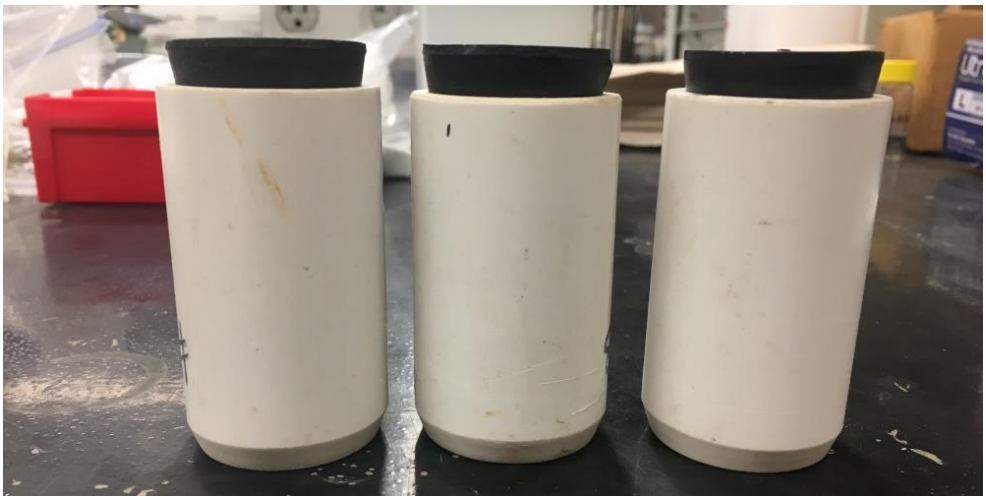

Figure 7: Field sediment cores.

Plant clippings (≈ 4 g wet weight) were collected before the chambers were attached, and all remaining plant matter within a chamber, including what could be obtained as roots, was collected at the end of the 24-hour sampling period. All sediment and plant samples were stored in Ziploc bags on ice during transport to the UWRL.

Dissolved Gas Samples - Prior to the field study, 14 mL double-septa Exetainer®s were evacuated to below 30 mtorr. In order to minimize evacuation time, 10 vacuum stations (Figure 8) were linked together with the use of vacuum fittings, plastic tubing, and hose clamps. Each vacuum station was comprised of a cut-off Luer lock syringe tightened into the tubing with the use of hose clamps, and BD PrecisionGlide Needles (18G x 1 1/2) attached to the syringes. The piece of tubing attached at the end of the vacuum fittings series was then attached to a vacuum gage and ultimately to the vacuum pump. The Exetainer®s were then stored inside secondary glass vials filled with UHP He-purged water (Figure 9).

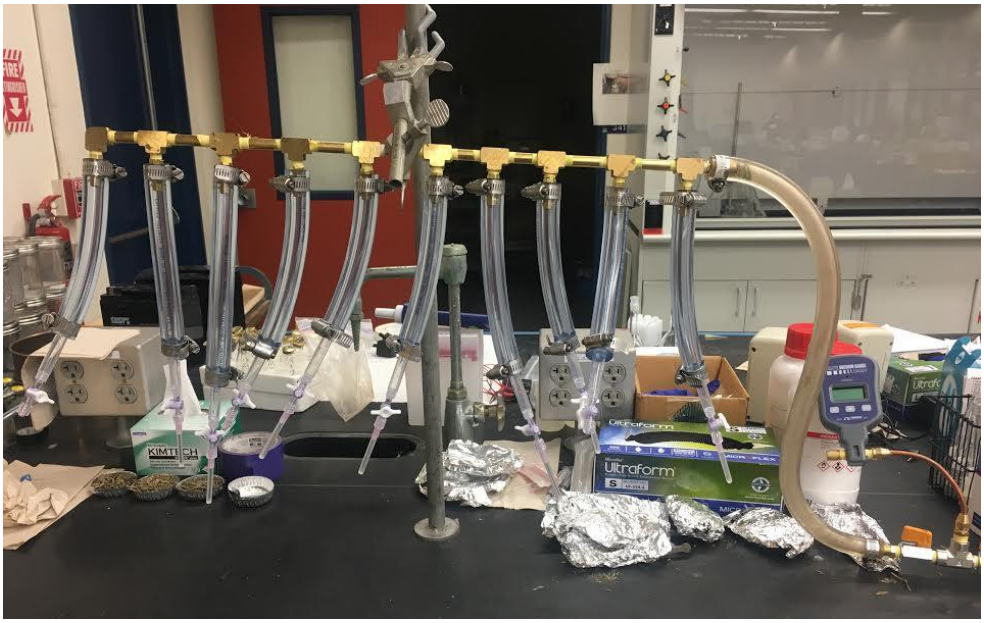

Figure 8: Vacuum system for Exetainer® evacuation.

Figure 9: Exetainer® in secondary glass vial.

The same UHP helium gas used to purge the water for Exetainer® storage was also used to create the headspace necessary for the dissolved N_2 analysis. In order to create the headspace, a 1-L multilayer foil lined gas sampling bag was filled with the UHP helium gas prior to going to the field. The dissolved N_2 sampling periods matched that of the water samples. Using a 60 mL Luer Lock syringe with plastic flexible tubing and a BD PrecisionGlide Needle (22G x 1, 0.7 mm x 25 mm) attached, 30 mL of water were sampled. The syringe and tubing were held underwater during sampling to prevent air contamination. After the water sample was taken, 20 mL of helium were pulled into the syringe keeping the syringe, needle and gas bag submerged under water. The gas-water filled syringe was then agitated for 5 minutes to reach equilibrium between the gas and water phases. To sample the gas, the syringe was then held upside down and the needle was used to puncture the Exetainers® while under the helium purged water.

Injecting 20 mL of gas creates the desired over-pressurized Exetainer® conditions for subsequent dissolved N_2 analysis. For the dissolved N_2 sampling procedure SOP, see Appendix A.

Analytical Methods

The collected water samples were pH neutralized at the Utah Water Research Laboratory. For NO_3-N + NO_2-N and NH_4^+-N analysis, the water samples were filtered through a 0.45-µm nylon membrane filter and analyzed on a Seal Analytical AQ2 Discrete Analyzer using the cadmium coil reduction/azo dye method (EPA Method 353.2) and the alkaline phenate method (EPA Method 350.1), respectively. For TN, water samples underwent a persulfate digestion (EPA Method 350.1) and were then filtered through a 0.45-µm filter and analyzed on an AQ2 instrument for NO_3-N + NO_2-N.

For the determination of $^{15}NO_3$-N + $^{15}NO_2$-N and $^{15}NH_4^+$-N in the water column, water samples underwent a diffusion technique described by Stark and Hart (1996). For the diffusion procedures, acid traps are made from Teflon pipe thread tape and Whatman #1 filter paper. Disks are cut from the Whatman #1 filter paper using a hole punch, placed onto the Teflon pipe thread, and 5 µL of 2.5M $KHSO_4$ are added to each disk in order to trap the NH_4. Figure 10 shows the completed acid traps once they were closed off and sealed using an 11-mm diameter culture tube.

For the $^{15}NH_4^+$ analyses, 30 mL of sample were added to an acid-rinsed canning jar followed by 5g of KCl to increase ionic strength, 0.2g of MgO which drives the NH_4 into its gaseous phase (NH_3), and an acid trap. The jar was then tightly sealed, swirled,

Figure 10: Acid traps used in the diffusion procedure.

and inverted. For the $^{15}NO_3^-$ analysis, 30 mL of sample were added to an acid-rinsed canning jar followed also by 5g of KCl and 0.2g of MgO. However, these jars were then placed into an over at 60°C for 2-3 hours in order to volatilize any existing NH_4^+ in the sample. The jars were then removed and an acid trap was added, followed by an additional 0.2g of MgO and 0.4g of Devarda's Alloy which converts the NO_3^- to NH_3. The jars were then tightly sealed, swirled, and inverted. For total isotopic nitrogen analysis (^{15}TN), the water underwent a persulfate digestion and then the diffusion procedure for NO_3^-. Ultimately each water sampling event for each chamber resulted in three jars, one each for $^{15}NH_4^+$, $^{15}NO_3^-$, and ^{15}TN analyses. All of the samples were diffused within the jars for 7 days, swirling the contents at least daily. At the end of the 7 days, the acid traps were removed from each jar, rinsed with DDW, blotted dry, and

placed in a 24-well plate to be dried in a desiccator containing sulfuric acid for 1 day. After the acid traps were dried, they were pulled apart and the disks were placed into a tin capsule and sent to the Utah State University Stable Isotope Laboratory for analysis via continuous-flow direct combustion and mass spectrometry. For the full diffusion procedure used see the Modified ^{15}N Diffusion Procedure for $^{15}NO_3^-$ and $^{15}NH_4^+$ SOP in Stewardson (2016).

These water samples were also used to determine the Br^- concentration (± 0.1 mg/L) using an ion-selective electrode using EPA Method 9211. The Exetainers®, with the sampled gas, were sent to the University of California-Davis Stable Isotope Facility for dissolved $^{15}N_2$ gas analysis using an isotope-ratio mass spectrometer.

Sediment samples underwent a KCl extraction using methods described in Mulvaney (1996) for labelled and non-labelled nitrate and ammonium analysis. For the KCl extraction SOP, see Appendix B. For NO_3-N + NO_2-N and NH_4^+-N analysis within the sediment, liquid extracts from each sample were filtered through a 0.45-µm nylon membrane filter and analyzed on a Seal Analytical AQ2 Discrete Analyzer using the previously mentioned methods. For the analysis of $^{15}NO_3$-N + $^{15}NO_2$-N and $^{15}NH_4^+$-N within the sediment, liquid extracts were directly pipetted into a pint sized jar to undergo the diffusion procedure described previously. For total labelled nitrogen analysis within the sediment, sediment samples underwent digestion (EPA Method LG602). The liquid extracts were directly pipetted into a pint sized jar to undergo the diffusion procedure for $^{15}NO_3^-$ analysis previously described. For non-labelled total nitrogen analysis, sediment samples were sent to the Utah State University Analytical Laboratory (USUAL) where samples were analyzed via combustion. Plant samples were freeze dried, after which the

samples were crushed and weighed into a tin capsule. The samples were sent to the Utah State University Stable Isotope Laboratory for labelled and non-labelled total nitrogen analysis via combustion.

Data Reduction Methods

Equations for calculating denitrification rates through the isotope pairing technique were outlined in Nielsen (1992). The $^{15}NO_3^-$ denitrification rates (D_{15}) were calculated using Equation 3, the sum of ^{15}N in the produced labeled N_2.

$$D_{15} = (14N15N) + 2(15N15N) \quad (3)$$

The $^{14}NO_3^-$ denitrification rates (D_{14}) were then calculated from the D_{15} rates using Equation 4.

$$D_{14} = D_{15} \times f_{14}/f_{15} \quad (4)$$

where f_{14} and f_{15} are the ^{14}N and ^{15}N fractions in the NO_3^- pool that were reduced by the denitrifying bacteria. Relating the fractions of ^{14}N and ^{15}N in the NO_3^- pool to the N_2 species produced, assuming the species were well-mixed in the system, gives the following ratio.

$$\frac{14N15N}{15N15N} = \frac{2f_{14}f_{15}}{f_{15}f_{15}} \quad (5)$$

Rearranging Equation 5 to isolate the frequencies leads to Equation 6.

$$\frac{f_{14}f_{15}}{f_{15}f_{15}} = \frac{(14N15N)}{2(15N15N)} \quad (6)$$

The determined ratio from Equation 6 was then substituted for the ^{14}N and ^{15}N frequencies in Equation 4 for a D_{14} equation that can be calculated by the actual data measured as shown in Equation 7.

$$D_{14} = ((14N15N) + 2(15N15N)) \times (\frac{(14N15N)}{2(15N15N)}) \quad (7)$$

In the study by Nielsen (1992), the water column was replaced to contain only $^{15}NO_3^-$ and therefore the D_{15} value represented denitrification in the water column and the D_{14} value represented the denitrification coupled to nitrification in the sediment. In cases where $^{15}NO_3^-$ is added to a water column with $^{14}NO_3^-$ already in the system, the D_{15} value is solely related to the $^{15}NO_3^-$ in the water and the D_{14} value is representative of the ambient denitrification within the entire system. The ^{14}N and ^{15}N frequencies of the water nitrate pool, f_{14}^w and f_{15}^w respectively, are then used to calculate the ambient $^{14}NO_3^-$ denitrification rate of the water column (D_{14}^w), as shown in Equation 8.

$$D_{14}^w = D_{15} \times {f_{14}^w}/{f_{15}^w} \quad (8)$$

The coupled nitrification-denitrification rate from the sediment (D_{14}^n) then becomes the difference between the D_{14} and D_{14}^w values, shown in Equation 9.

$$D_{14}^n = D_{14} - D_{14}^w \quad (9)$$

ANAMMOX, anaerobic ammonium oxidation, is another nitrogen transformation that directly produces dissolved nitrogen gas. When using the isotope pairing technique to track nitrogen transformations, ANAMMOX will only produce $^{28}N_2$ and $^{29}N_2$, through $^{14}NO_2^-$ and $^{15}NO_2^-$ pairings with $^{14}NH_4^+$. Therefore, in systems where denitrification and ANAMMOX coexist, the production of $^{29}N_2$ can be used to determine both denitrification and ANAMMOX rates. In a study by Risgaard-Petersen et al. (2003), the isotope pairing technique discussed in Nielsen et al. (1992) was applied to a system where both denitrification and ANAMMOX existed and Equation 7 was adjusted to Equation 10 to account for the ANAMMOX reaction.

$$p_{14} = (D_{29} + A_{29} + 2 \times D_{30}) \times \frac{(D_{29}+A_{29})}{2(D_{30})} \quad (10)$$

where, D_{29} and A_{29} are the denitrification and ANAMMOX rates contributing to $^{29}N_2$ production, respectively, and D_{30} is the denitrification rate contribution to $^{30}N_2$ production. Based on the understanding of denitrification and ANAMMOX contributions to the N_2 production, the ANAMMOX rate can be solved for as shown in Equations 11 and 12.

$$D_{29} = 2 \times r_{14} \times p30N_2 \quad (11)$$

$$A_{29} = p29N_2 - D_{29} \quad (12)$$

where, D_{29} is the denitrification rate from the random pairing of $^{14}NO_3^-$ and $^{15}NO_3^-$, r_{14} is the $^{14}NO_3^-$ to $^{15}NO_3^-$ ratio in the NO_x^- reduction zone. The production of $^{28}N_2$ from ANAMMOX can then be estimated using the following equation.

$$A_{28} = r_{14} \times A_{29} \quad (13)$$

The DNRA rates were calculated using a modified equation from a study by Porubsky et al. (2008), shown below.

$$R_{DNRA} = ([15NH_4^+]_{Final} - [15NH_4^+]_{Initial}) \times (A^{-1}T^{-1}) \quad (14)$$

where, R_{DNRA} is the DNRA rate, $^{15}NH_4^+{}_{Initial}$ is the initial $^{15}NH_4^+$ concentration, $^{15}NH_4^+{}_{Final}$ is the final $^{15}NH_4^+$ concentration, A is the surface area (m^2), and T is the incubation time (hours). The assimilation results were determined by the isotope enriched data from the diffusion technique. The rates were calculated using Equation 15 (Dupont et al. 2015).

$$R_{Assimi} = F_{15NO_3^-} - D_t - A_{29} - R_{DNRA} \quad (15)$$

where, R_{Assimi} is the microbial nitrate assimilation rate, $F_{15NO_3^-}$ is the total $^{15}NO_3^-$ removal from the chamber, and D_t is the denitrification rate for $^{15}NO_3^-$ determined by adding twice the value of $^{30}N_2$ production to D_{29}. The assimilation rate is essentially determined by taking the total rate of $^{15}NO_3^-$ removal from the system and subtracting the denitrification, ANAMMOX, and DNRA rates determined through the ^{15}N data. Assimilation, therefore, includes any removal of $^{15}NO_3^-$ from the system not accounted

for through the above transformations. This could be plant uptake (where applicable) or microbial assimilation in the soils.

Mass Balance

The initial analysis of the benthic chamber study included adjusting for fluid losses from the in situ chambers using bromide concentrations measured over time in the chambers, as well as the ^{15}N lost through sampling, followed by the ^{15}N mass balance of the system at the 0 and 24-hour sampling times. The equation used for bromide correction is shown below (Stewardson, 2016).

$$A_{measured} = A_{actual}(\%_{remaining}) + A_{background}(\%_{loss}) \quad (16)$$

where $A_{measured}$ is the measured atom % of the sample, A_{actual} is the atom % of the sample without any fluid loss of the system, $\%_{remaining}$ is the remaining bromide in the chamber, $A_{background}$ is the background atom % within the chamber, and $\%_{loss}$ is the bromide loss within the chamber. The equation assumes the percent of bromide remaining in the chamber corresponds to the percent of ^{15}N remaining from the original dosing solution. It also assumes that the bromide lost throughout the study is being replaced with background stream water. The mass of ^{15}N for each water, sediment, plant, and dissolved gas sample was scaled up from the sample size to the size of the respective compartments in the chamber. Since all of the ^{15}N samples are reported on a mass basis, the results were scaled up by converting the masses to concentrations using the sample size (volume for water samples, mass for plant and sediment samples). The volume of sediment in the chamber was then calculated by multiplying the surface area and the selected depth of 6

inches (the depth of the frame). The volume of plants within the chambers was determined from the collection of the all plant material at the completion of the study.

The background ^{15}N in the water, sediment, plants and dissolved gas was determined from the background samples and ultimately subtracted from each subsequent sample. The organic-^{15}N was then determined by subtracting the $^{15}NO_3^-$-N and $^{15}NH_4^+$-N masses from the ^{15}TN mass at each sampling time. The total ^{15}N in the water was calculated and used to determine how much ^{15}N mass left the system during each sampling event. The final, total ^{15}N at each sampling time was calculated by adding the $^{15}NO_3^{--}N$, $^{15}NH_4^+$-N, and organic-^{15}N in the water and the sediment, the $^{15}N_2$, the ^{15}TN in the plants, and adding back in the ^{15}N lost through sampling. The percent recovery was then determined by taking the total ^{15}N calculated at each sampling time and dividing it by the mass of ^{15}N added to each chamber.

Experimental Matrix

In order to summarize the constituents analyzed from the various environmental compartments, and how they were utilized throughout the experiment in data analysis, Table 1 shows a complete experimental matrix for the study.

The experimental matrix shown in Table 1 does not depict the entire list of constituents that were analyzed throughout the study, but rather the constituents that were directly used in the determination of either a rate or that were used in the mass balance. As shown in Table 1, the constituents analyzed within the sediment and plant phases of the chamber were solely used for the completion of the mass balance. The rates

Table 1: Experimental matrix for the field chamber study.

	Sample	Constituents	For Determination Of:	Through the Use Of:
Water	250 mL Nalgene	NO_3^--N	Denitrification	Linear Regression
		NH^+_4-N	Nitrification	Linear Regression
		$^{15}NO_3^-$-N	Denitrification	Equation 1
			Nitrification	Equation 2
			Assimilation	Equation 14
			Mass Balance	0 & 24-hr Summation
		$^{15}NH^+_4$-N	DNRA	Equation 13
			Mass Balance	0 & 24-hr Summation
		^{15}TN	Mass Balance	0 & 24-hr Summation
		Br^-	Chamber Loss Correction	Equation 15
	14 mL Exetainer	$^{14}N_2$	Denitrification	Equations 3-7
		$^{15}N_2$	Denitrification	Equation 3-7
			ANAMMOX	Equations 11 & 12
			Mass Balance	0 & 24-hr Summation
Sediment	Grab Sample (core)	$^{15}NO_3^-$-N	Mass Balance	0 & 24-hr Summation
		$^{15}NH^+_4$-N	Mass Balance	0 & 24-hr Summation
		^{15}TN	Mass Balance	0 & 24-hr Summation
Plant	Grab Sample	^{15}TN	Mass Balance	0 & 24-hr Summation

determined in the study came directly from the constituents analyzed in the water phase. Although assimilation does include interactions with plant and soil material, the actual assimilation rate is determined solely from transformation rates in the water phase (Equation 15). Figure 11, an altered version of Figure 1, shows a summary of the rates that were determined in the study, and the water phase constituents used for determining these rates.

As shown in Figure 11, some of the rates were determined through the use of various water phase constituents, while other rates were determined through the sole use of one water phase constituent.

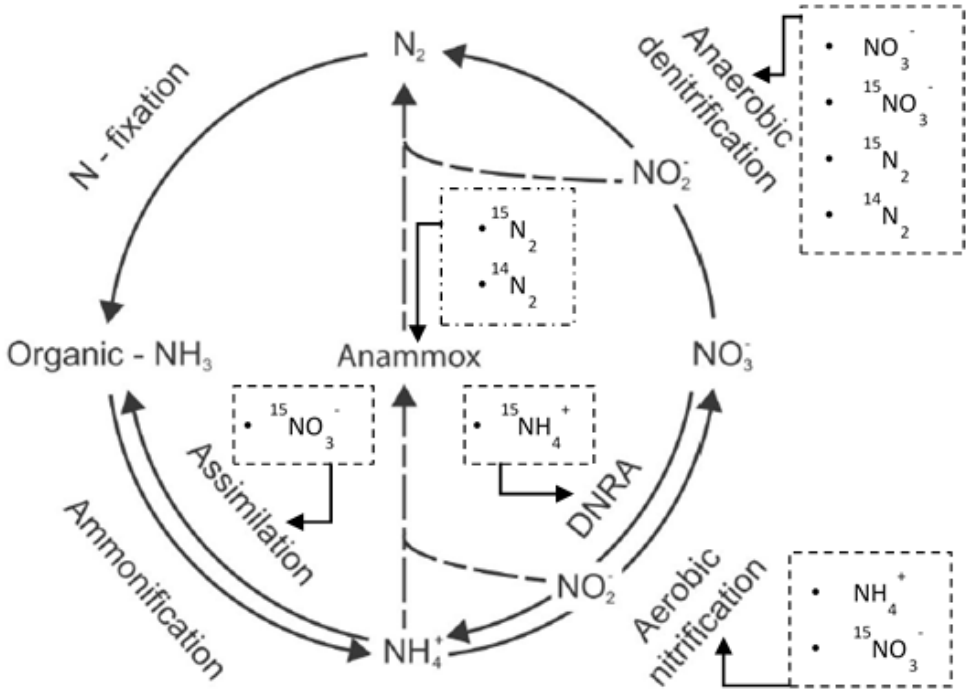

Figure 11: Summary of rates determined in the field study and the constituents used for the determination of each rates (modified from Trimmer et al., 2003).

Statistical Analyses

The three chambers used in the study for data analyses were treated as a triplicate sample set at each location. Linear regressions were performed to estimate the nitrogen transformation rates generated from non-isotope samples, and the statistical significance ($p \leq 0.05$) of the slope of the regression line was used to evaluate the validity of the estimate. An Analysis of Covariance (ANCOVA) was used to determine if the regressions for each chamber at each site were statistically different ($p \leq 0.05$). For each statistically significant different regression, a separate rate was reported. For regressions among chambers that were not statistically different, a regression for the combined data

points was reported. The residuals for each regression were plotted to determine Normal Independent and Identically Distributed (NIID) conditions. For the rates determined by the equations listed in the previous sections, an Analysis of Variance (ANOVA) was performed to determine if there was a statistically significant difference ($p \leq 0.05$) between the chambers at each location. Finally, an ANOVA was used to determine statistical differences among rates generated from the range of analyses (both non-isotope and isotope based methods) used in the study.

RESULTS & DISCUSSION

Background Stream Water Quality

The background conditions at each study site and locations for nitrate, ammonium, pH, and DOC are shown in Table 2.

Table 2: Background stream water quality parameters (average ± std. dev.)

Location	NO_3^--N (mg/L)	NH_4^+-N (mg/L)	pH	DOC (mg C/L)
East Canyon Downstream	1.52 ± 0.04	0.20 ± 0.02	7.8	4.98 ± 0.05
East Canyon Upstream	0.45 ± 0.18	0.08 ± 0.01	7.8	4.43 ± 0.09
Box Elder Creek Downstream	0.48 ± 0.05	0.96 ± 0.01	6.9	7.67 ± 0.21
Box Elder Creek Upstream	0.41 ± 0.01	ND	7.2	7.90 ± 0.06

**ND signifies non-detect.*

Water samples were taken at the start of each field study and analyzed on the AQ2 for background nitrate and ammonium. Ammonium concentrations were higher at the downstream locations at both study sites than their respective upstream locations, likely due to the effluent from the wastewater treatment facility. East Canyon nitrate levels were an order of magnitude larger downstream than upstream. For Box Elder Creek the nitrate levels downstream of the Brigham City Water Treatment Plant were slightly higher than upstream concentrations. The background pH for East Canyon was measured from the USGS gauge station. The USGS gauge station is located downstream of the East Canyon Water Reclamation Facility, yet upstream of the downstream location used in the study. The background pH values for Box Elder Creek were determined through the use of a pH probe prior to beginning the study. The background DOC

concentrations for East Canyon were determined through samples taken December 2016. These may not be reflective of the DOC in the stream during the field study that took place between July and August of 2016. The background DOC concentrations for Box Elder Creek were determined by samples taken during July 2017, approximately 1 month after the field study that took place during June 2017.

Mixing & Hydraulic Efficiencies of Chamber

Due to concerns about potential dead spaces within the chamber leading to low recoveries, mixing and hydraulic efficiency tests were conducted for the chambers utilizing a salt solution accompanied by rhodamine in order to provide quantitative and qualitative tracking of flow moving through the chambers. For dosing, 30 mL of a 141,600 mg NaCl/L solution containing approximately 2 drops of concentrated rhodamine were used in order to achieve a final concentration of 300 mg NaCl/L within the chamber, as well as a visible color change of the water in the chamber. The setup of the mixing and hydraulic efficiency tests included a full sink of water where a frame was completely submerged. A white garbage bag was placed on top of the frame (bottom of the chamber), covering the entire top surface in order to close off the opening and ultimately simulate the sediment-water interface. A metal clamp was placed on top the garbage bag, in the middle of the frame, in order to prevent it from floating up while frame was submerged in water. The chamber was then placed and secured with metal clamps over the top of the frame and garbage bag, also completely submerged under water. A SCHOTT Duran 250 mL jar fitted with a specific conductivity probe connected to a Fisher Scientific Accumet Model 30 conductivity meter was connected to the tubing

in order to collect continuous measurements. The tubing and pump were then attached to the chamber in the same way as was done in the field. Three different configurations for the tubing were then tested for mixing and hydraulic efficiency. A legend for the schematics of the various tubing setups tested is shown in Figure 12.

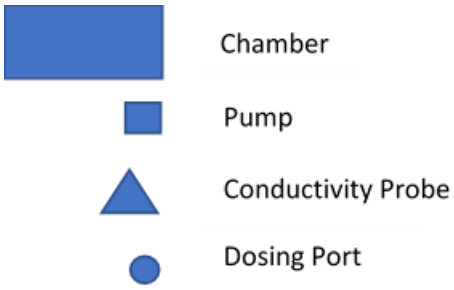

Figure 12: Tubing setup schematic legend for subsequent mixing efficiency figures.

Figure 13 shows the specific conductivity results for the first configuration tested. Configuration #1 had the dosing port on the outlet side of the chamber and subsequently the inlet side of the pump. The initial spike in specific conductivity was likely due to the placement of the specific conductivity probe, which started measuring the NaCl prior to its dilution within the chamber. It took approximately 2.5 minutes to reach equilibrium within the chamber, with a hydraulic efficiency of 0.625. The hydraulic efficiency was calculated by taking the ratio of time of equilibrium to time it took to cycle through one full volume of the chamber (4 minutes). Figure 14 shows how the rhodamine solution mixed within the chamber at various stages of the test.

As shown in Figure 14, as soon as the rhodamine solution entered the chamber, it traveled to the opposite side from where it entered, where it then began spreading to the

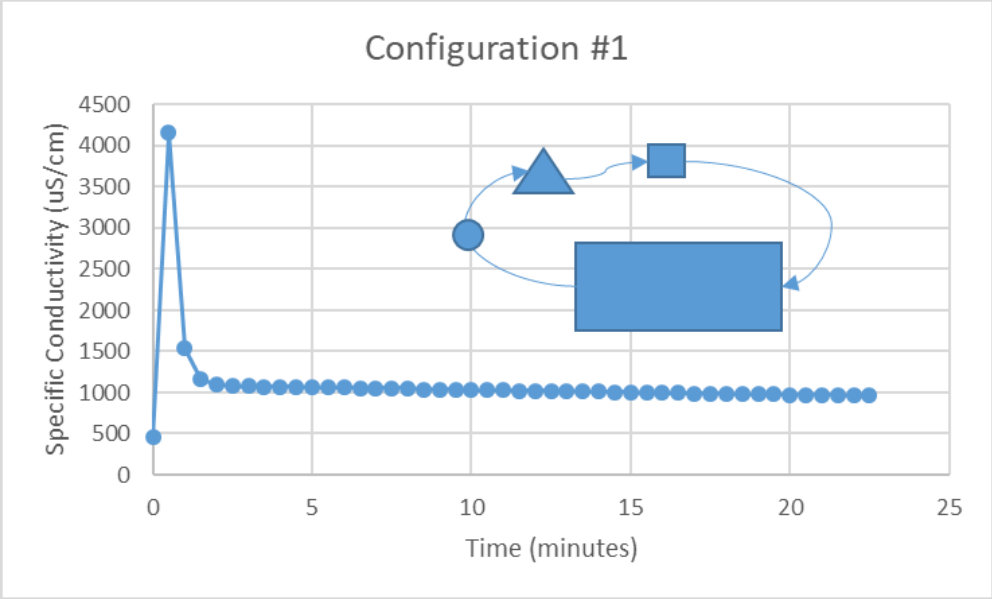

Figure 13: Configuration #1 and specific conductivity results.

a. b. c.

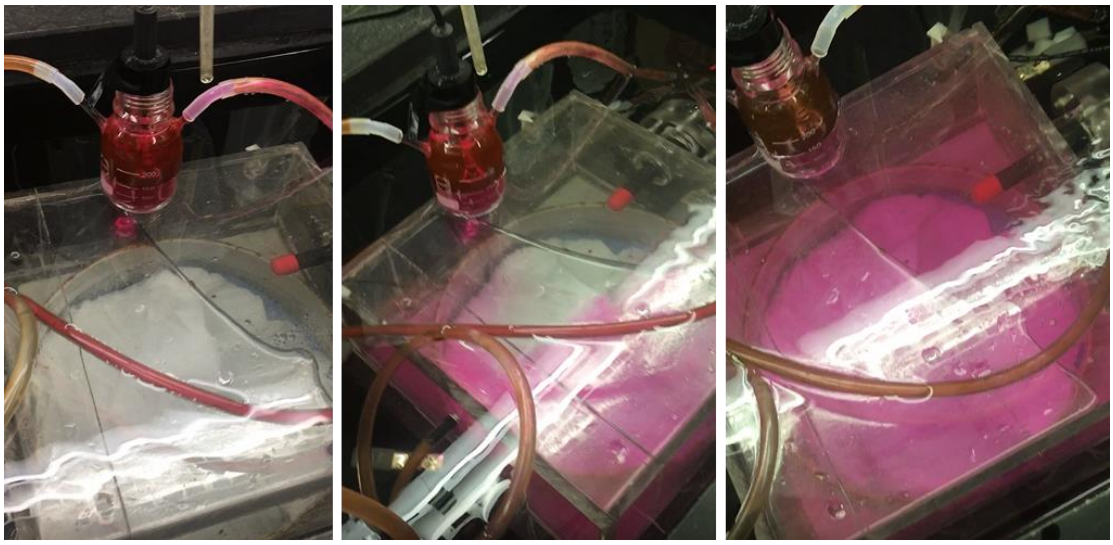

Figure 14: Rhodamine solution throughout mixing test, a. 10 seconds, b. 25 seconds, c. 2.5 minutes.

sides of the chamber. Within 2.5 minutes, the solution had traveled back to the inlet side of the chamber and then through the middle. Visually and numerically there did not appear to be any dead spaces within the chamber.

Configurations #2 and #3 (Figure 15 and Figure 16) both had the dosing port on the outlet side of the pump and inlet side of the chamber. The only difference between the two configurations was the location of the specific conductivity probe. Configuration #2 had a 0.625 hydraulic efficiency (2.5 minutes to equilibrium), while configuration #3 had a 0.75 hydraulic efficiency (3 minutes to equilibrium). Neither configuration displayed the same initial spike that the first configuration did, likely due to the fact that the

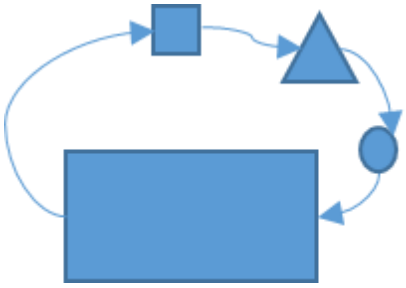

Figure 15: Tubing set up for Configuration #2.

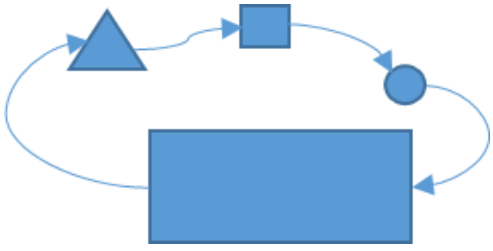

Figure 16: Tubing set up for Configuration #3.

specific conductivity probe was not directly downstream of the dosing port before water moved into the chamber. Configurations #2 and #3 did follow the same visual mixing patterns as Configuration #1. Ultimately, Configuration #1 was used at East Canyon and Configuration #2 was used at Box Elder Creek. With the results of the mixing and hydraulic efficiencies test it was clear that there were no differences in mixing conditions despite the difference in dosing port locations between the two sites. Additionally, questions regarding potential dead spaces in the chamber were resolved. For the raw data of the tests, see Appendix C.

Final Site Chamber Configuration & Sampling Schedule

The leak test for the downstream location at East Canyon was conducted on July 19, 2016, approximately 80 m (262 ft) downstream of the East Canyon Water Reclamation Facility discharge point. Once in the field, a large crack was found in one of the chambers so ultimately the leak test only included five of the six chambers. Due to water depth in East Canyon Creek, the chambers had to be concentrated near the right bank. All of the five chambers contained aquatic vegetation. Figure 17 and Figure 18 show the location of the chambers.

The leak test results showed that Chambers 1 through 3 were all within the allowed bromide loss, thus they were the chosen locations for the final study. See Appendix D for the raw bromide data. The final study for the downstream East Canyon Creek site took place July 25th-26th, 2016.

Figure 17: East Canyon downstream leak test chamber locations facing downstream.

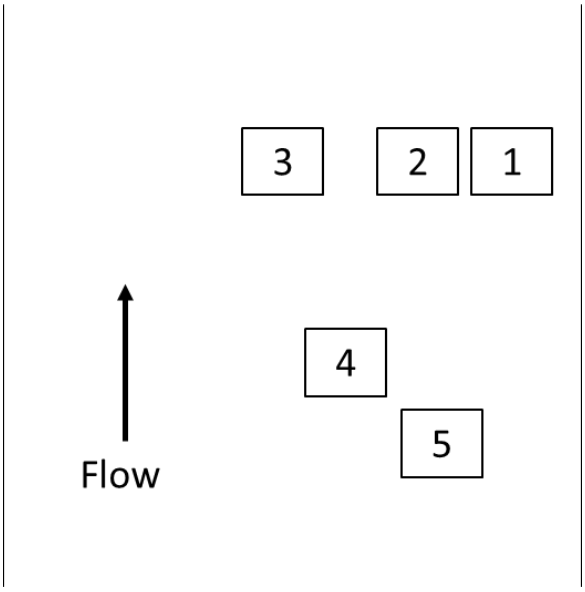

Figure 18: East Canyon downstream leak test chamber locations.

The leak test for the upstream East Canyon Creek site then took place on July 26th, 2016 after the 24-hr sampling period at the downstream site and approximately 515 m (1,690 ft) upstream of the East Canyon Water Reclamation Facility discharge point. Figure 19 and Figure 20 show the locations of the chambers used in the upstream site.

Figure 19: East Canyon upstream leak test chamber locations facing upstream.

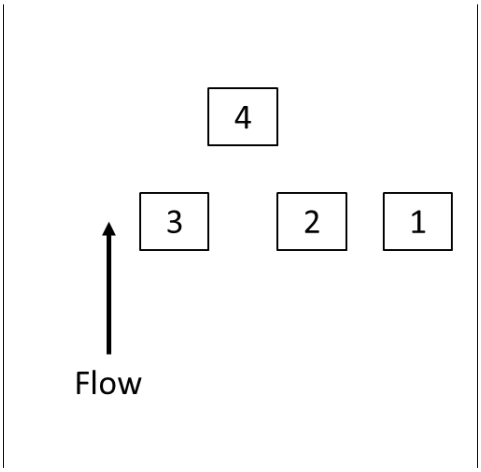

Figure 20: East Canyon upstream leak test chamber locations.

Due to water levels at the upstream East Canyon site only four chambers could be successfully installed, none of which contained aquatic vegetation. The leak test results showed that Chambers 1-3 were within the acceptable bromide loss of <30%, and they were the chosen locations for the final study. The final East Canyon upstream study took place between August 1st-2nd, 2016.

The leak test for the downstream Box Elder Creek site took place on May 24th, 2017 approximately 850 m (2,789 ft) downstream of the Brigham City Wastewater Treatment Plant discharge point and approximately 384 m (1,260 ft) from the discharge confluence with Box Elder Creek. Figure 21 and Figure 22 show the locations of these chambers. All six chambers contained aquatic vegetation.

Figure 21: Box Elder Creek downstream leak test chamber locations. Aerial view. Water flowing from top to bottom of picture.

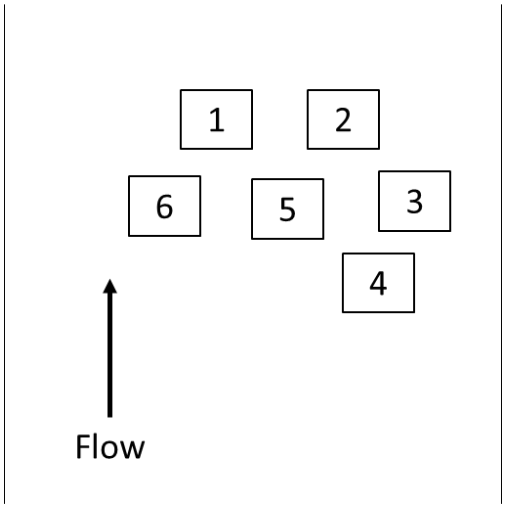

Figure 22: Box Elder Creek downstream leak test chamber locations.

During the leak test, it was found that one of the tubing connections on Chamber 6 had come off, therefore samples from that chamber were no longer used for analysis. The bromide results for the leak test of the remaining five chambers showed that all bromide loss was within the acceptable amount and therefore the chamber locations did not change for the field study. The initial field study for downstream Box Elder Creek took place between May 31st-June-1st, 2017, the anticipated 6 days after the leak test. However, complications with the dissolved N_2 sampling procedure led to a loss of multiple samples and ultimately the field study was postponed. The final field study for downstream Box Elder Creek took place between June 5th-6th, 2017. At this point water levels had increased such that frames #5 and #6 were inaccessible for chamber installation. Therefore, only Chambers #1-#4 were operated during the field study.

The initial leak test for upstream Box Elder Creek took place on June 6th, 2017, approximately 657 m (2,155 ft) from the confluence of the Brigham City Wastewater

Treatment Plant discharge with Box Elder Creek. After returning on the seventh day following the leak test to begin the field study, water levels had risen to a depth that made it impossible to install the chambers where the frames had originally been installed. After returning multiple times over the following 2 weeks to find no change in the water levels, three of the frames were removed and re-installed in a shallower location and a leak test was conducted at the new locations on June 20th, 2017. Keeping three of the frames in the deeper area ensured there would still be a triplicate to work with in case water levels suddenly decreased again. Ultimately, the re-installed frames were the locations used in the final study. The locations of the chambers are shown in Figure 23 and Figure 24. None of these chambers contained aquatic vegetation.

Figure 23: Box Elder Creek upstream leak test chamber locations. Flow moves from left to right in photo.

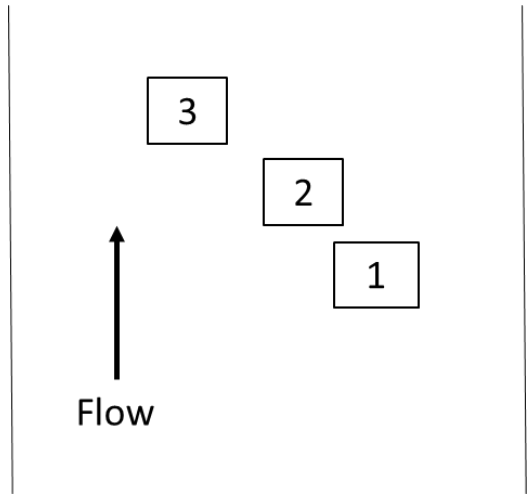

Figure 24: Box Elder Creek upstream leak test chamber locations.

The final field study for upstream Box Elder Creek took place June 27th-28th, 2017, 7 days after the leak test for the new frame locations. As seen in Figure 23, a bucket was placed on top of Chamber 2 in order to place the batteries in a location that the tubing and pump connections for the chambers could reach. The bucket also remained there for the duration of the final study.

Hyporheic Exchange

All of the minipiezometers were installed into the sediment to a depth of 177.8 mm (7 inches) from the bottom of the minipiezometer. The length of the perforated section on each minipiezometer is 76.2 mm (3 inches). This gives a Δl value of 101.6 mm (4 inches) for each of the minipiezometers. A Δh value, or the difference in head between the water level inside of the minipiezometer and the surface level of the stream next to each minipiezometer, was recorded. The VHG, or the Δh/Δl ratio for each of the minipiezometers, was then calculated and was also reported.

For the downstream East Canyon field study, the locations of the minipiezometers with respect to the chambers can be found in Figure 25, with the squares representing the chambers and the ovals representing the minipiezometers. The arrow shows the direction of the flow. There was one minipiezometer installed nearby each of the chambers. Table 3 shows the Δh and VHG values on July 25, 2016, the initial day of the downstream field study.

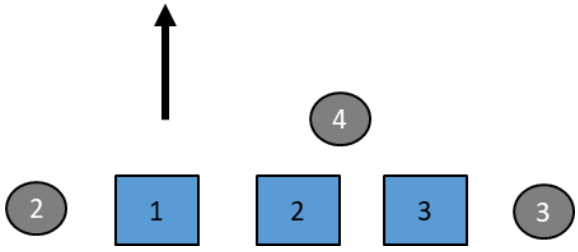

Figure 25: East Canyon downstream field study minipiezometer locations.

Table 3: East Canyon downstream minipiezometer data.

Piezo	Δh (mm)	VHG
2	10	0.10
3	15	0.15
4	10	0.10

The positive Δh and VHG values indicate upwelling conditions at the site. The average VHG among the three minipiezometers was 0.11, and based on the 95% confidence interval of ± 0.03, Minipiezometers 2-4 are equivalent. Furthermore, based on the 95% confidence interval they are all statistically not neutral (VHG=0) but rather are

all upwelling. Based on the bromide data that are discussed in the following section, there was no apparent correlation between VHG and leaks within the chamber. For example, Chambers 1 and 2 had different bromide results although they were located directly next to each other with their surrounding piezometers (2 and 4) yielding the same VHG.

Figure 26 shows the minipiezometer locations for the upstream East Canyon study. There was one minipiezometer installed near each of the chambers. Table 4 shows the Δh and VHG values on August 1st, 2016, the first day of the upstream field study.

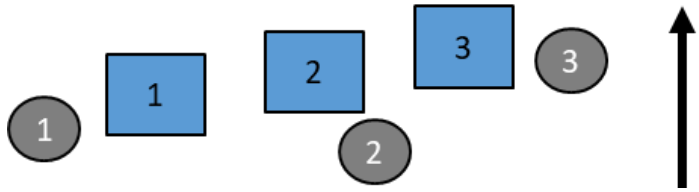

Figure 26: East Canyon upstream field study minipiezometer locations.

Table 4: East Canyon upstream field study minipiezometer data.

Piezo	Δh (mm)	VHG
1	7	0.07
2	2	0.02
3	0	0

The positive Δh and VHG values for Minipiezometers 1 and 2 indicate upwelling conditions, while the 0 values for Minipiezometer 3 indicate neutral conditions. The average VHG among the chambers is 0.03. Based on the 95% confidence interval of ± 0.04 the VHG for all three minipiezometers are equivalent and statistically 0, or neutral.

Figure 27 shows the minipiezometer locations for the Box Elder Creek downstream field study. There was at least one minipiezometer installed near each chamber. Table 5 shows the Δh and VHG values on June 5, 2017, the first day of the downstream field study.

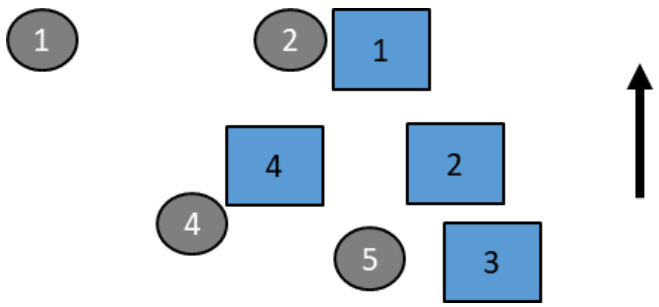

Figure 27: Box Elder Creek downstream minipiezometer locations.

Table 5: Box Elder Creek downstream minipiezometer data.

Piezo	Δh (mm)	VHG
1	5	0.05
2	17	0.17
4	12	0.12
5	16	0.16

The positive Δh and VHG values for each of the minipiezometers indicate upwelling conditions. The average VHG for the four minipiezometers was 0.12. Based on the 95% confidence interval of ± 0.05, the four minipiezometers are equivalent. All four minipiezometers are also statistically not neutral (VHG ≠ 0), but rather are all upwelling. Based on the bromide data discussed in the following section, there was no apparent

correlation between VHG and bromide loss. Minipiezometers with the closest VHGs were nearby chambers that yielded different bromide loss within the chambers.

Figure 28 shows the minipiezometer locations for the Box Elder Creek upstream field study. There was at least one minipiezometer installed near each of the chambers. Table 6 shows the Δh and VHG values on June 27th, 2017, the first day of the upstream field study.

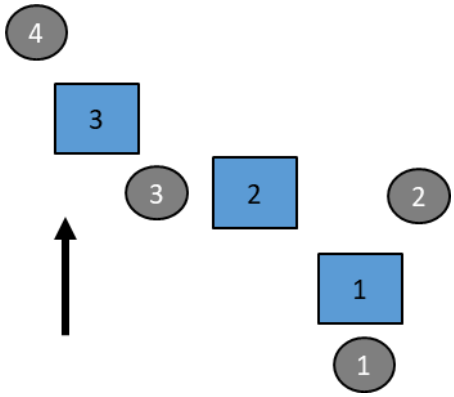

Figure 28: Box Elder Creek upstream field study minipiezometer locations.

Table 6: Box Elder Creek upstream field study minipiezometer data.

Piezo	Δh (mm)	VHG
1	-4	-0.04
2	2	0.02
3	4	0.04
4	3	0.03

The positive Δh and VHG values for Minipiezometers 2-4 indicate upwelling conditions, while the negative Δh and VHG value for Minipiezometer 1 indicates downwelling conditions. The average VHG for all four minipiezometers was 0.01. Based

on the 95% confidence interval for the VHG of ± 0.03, all four minipiezometers are equivalent and statistically 0, or neutral. As shown in the following section, Chamber 1 saw the largest loss of bromide over the 24-hour sampling period at this location. The chamber was closest to Minipiezometer 1 which was the only downwelling minipiezometer across the entire study. Despite this, there were chambers with larger VHGs at different locations that had smaller bromide loss. Ultimately, understanding the hyporheic conditions at each location throughout the study provided some insight regarding possible hyporheic exchange, but the average VHG did not appear to be a clear predictor of losses within the chambers. This is likely due to the heterogeneity of sediment properties and hyporheic exchange that can occur in river systems.

Bromide

The bromide results from the final field studies at each location are discussed below. The bromide concentration and percent loss results for the downstream East Canyon field study are shown in Table 7.

Table 7: East Canyon downstream bromide results.

East Canyon Downstream						
Time	**Chamber 1**		**Chamber 2**		**Chamber 3**	
hr	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*
0	103	0%	114	0%	35	0%
1	103	0%	109	4%	55	-58%
4	103	0%	101	11%	68	-94%
12	103	0%	80	30%	71	-102%
24	99	4%	74	35%	83	-139%

According to the bromide data, Chamber 1 did not experience any noticeable leaking until the 24-hour sampling period at which point the loss was only at 4%. Chamber 2 saw noticeable leakage throughout the duration of the study, with losses up to 30% at 12 hours and at 35% at 24 hours. Chamber 2 was still used for further analysis, as it was decided the maximum loss of 35% was acceptable in this case in order to provide data from more than one chamber at this site. The bromide concentrations in Chamber 3 increased over the 24-hour period, giving negative percentage loss values. These results raised questions about the mixing conditions in the chamber, therefore Chamber 3 was not used in any further analysis.

For the upstream East Canyon field study, there was a switch in the source of bromide for dosing. Ultimately a miscalculation for the dosing solution resulted in bromide concentrations within the chamber too small to differentiate from background levels. Although there were no bromide data for the upstream East Canyon field study, all three chambers were used for the separate analyses, as the ^{15}N mass balance recovery results (described below) were used to show acceptable leakage within each chamber.

The bromide concentration and percent loss results for the downstream Box Elder Creek study are shown in Table 8. All of the bromide results for the chambers were within the acceptable range. However, Chambers 1-3 had the concentrations closest to the anticipated concentration from the dosing solution and were ultimately chosen as the triplicate for the remaining analyses.

Table 8: Box Elder Creek downstream bromide results.

Box Elder Creek Downstream								
Time	**Chamber 1**		**Chamber 2**		**Chamber 3**		**Chamber 4**	
hr	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*
0	86.4	0%	105.2	0%	93.5	0%	73.8	0%
1	86.4	0%	101.1	4%	89.9	3%	73.8	0%
4	83.1	4%	101.1	4%	89.9	3%	65.6	11%
12	83.1	4%	97.2	8%	86.4	7%	71.0	4%
24	79.9	8%	97.2	8%	86.4	7%	71.0	4%

The bromide concentration and percent loss results for the upstream Box Elder Creek study are shown in Table 9. Due to complications with the tubing from Chamber 2, a 24-hour sample could not be collected. The remaining bromide losses were all within the acceptable range, therefore all of the chambers were used for the remaining analyses. For raw bromide data, see Appendix D.

Table 9: Box Elder Creek upstream bromide results.

Box Elder Creek Upstream						
Time	**Chamber 1**		**Chamber 2**		**Chamber 3**	
hr	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*	*Br (ppm)*	*% Loss*
0	85.6	0%	89.3	0%	82.1	0%
1	82.1	4%	85.6	4%	78.7	4%
4	78.7	8%	82.1	8%	75.5	8%
12	75.5	12%	78.7	12%	72.4	12%
24	66.6	22%			69.5	15%

Dissolved Oxygen & Temperature

The Extech DO meters/dataloggers used for the chambers recorded dissolved oxygen and temperature. Due to the impact oxygen has on the nitrogen cycle and the

impact temperature has on kinetics, it was critical to obtain dissolved oxygen and temperature data in order to better understand the system and the calculated rates. During the downstream East Canyon field study, issues arose with the handling of the Extech DO meter/dataloggers which led to the inability of obtaining continuous measurements for Chambers 1 and 2. Due to these issues, at each sampling period the DO reading from Chambers 1 and 2 was recorded from the DO meters. The DO meter/datalogger for Chamber 3 appeared to be working and therefore there were no individual DO recordings for this chamber. However, at approximately 5 pm the datalogger for Chamber 3 stopped recording the continuous measurements for reasons unknown. Unfortunately, no DO measurements for Chamber 3 were recorded due to the belief that the datalogger was working correctly. Background DO and temperature data were obtained from the USGS Station 10133800 East Canyon Creek Near Jeremy Ranch, UT, located approximately 25 m (82 ft) upstream of the chambers, in the middle of the stream and not immediately surround by any vegetation.

Figure 29 shows the DO and temperature measurements for the background downstream East Canyon field study. Figure 30 shows the DO and temperature measurements throughout the field study, some of which are continuous measurements and the rest being the single recorded measurements at the sampling time.

The background DO and all of the initial DO readings from each chamber averaged 9.2 mg/L (±0.8). Throughout the study the measured DO within each of the chambers began to increase while the background DO measurements decreased. The background DO measurements followed a similar trend to that of the background temperature, showing the presence of photosynthesis. As mentioned previously, the three downstream chambers

contained plant material which likely contribute to photosynthesis, ultimately causing of the increase in DO with the increase of temperature. The background DO measurements decreased as the sun went down and remained at approximately 6 mg/L throughout the night. This decrease can be attributed to plant respiration within the stream. Since there were no DO measurements for the chambers throughout the night, it cannot be determined whether the DO in the chambers followed a similar trend as the background stream.

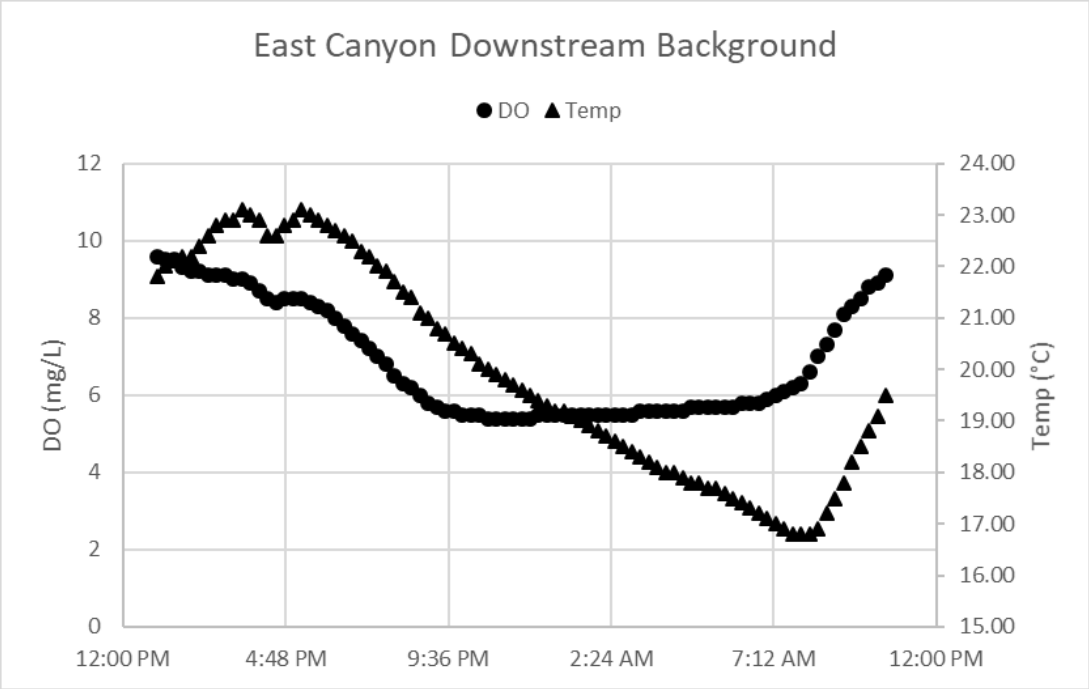

Figure 29: East Canyon Downstream background DO and temperature data obtained from USGS Station 10133800 (U.S. Geological Survey, 2017).

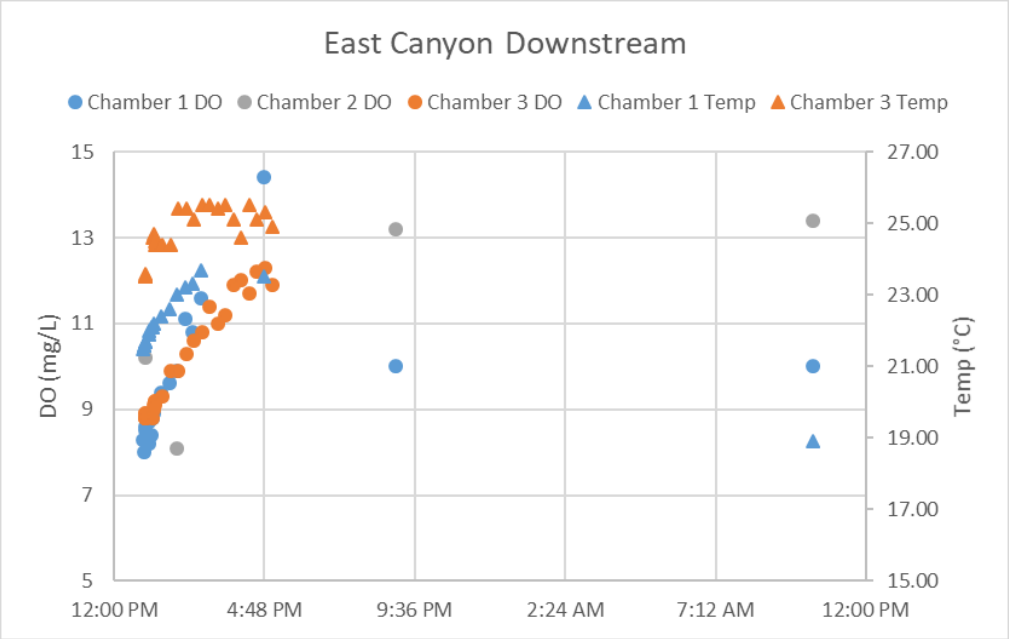

Figure 30: DO and temperature measurements for the downstream East Canyon field study.

There was a statistically significant difference among the temperature within Chambers 1 and 3, as well as with the background stream. The average temperatures in Chambers 1, 3, and the background stream were 22.2°C, 24.7°C, and 19.9°C, respectively. Chambers 1 and 2 were located in an area slightly more shaded than where Chamber 3 was located. This possibly explains the higher temperatures in Chamber 3 versus Chamber 1 and the background stream. Although the temperature data collected for Chambers 1 and 3 and the background stream are significantly different, they do follow a similar trend.

During the upstream East Canyon field study, issues with one of the DO probes resulted in no DO data for Chamber 3. Background stream temperature data were obtained from USGS Station 10133800 East Canyon Creek Near Jeremy Ranch, UT

located approximately 550 m (1804 ft) downstream of the chambers, as well as downstream of the wastewater effluent discharge point. Figure 31 shows the background DO and temperature results for the upstream East Canyon field study. Figure 32 shows the temperature data for the upstream East Canyon study.

The background DO data had an opposite trend to the background temperature. This indicates a lack of photosynthesis present in the stream. Contrary to what was seen in the background stream, Chambers 1 and 2 both showed a steady decrease in DO through the duration of the field study following the same trend as temperature. Although the upstream chambers did not contain plant material that could support the presence of photosynthesis, the sediment upstream was more clayey than was found downstream and

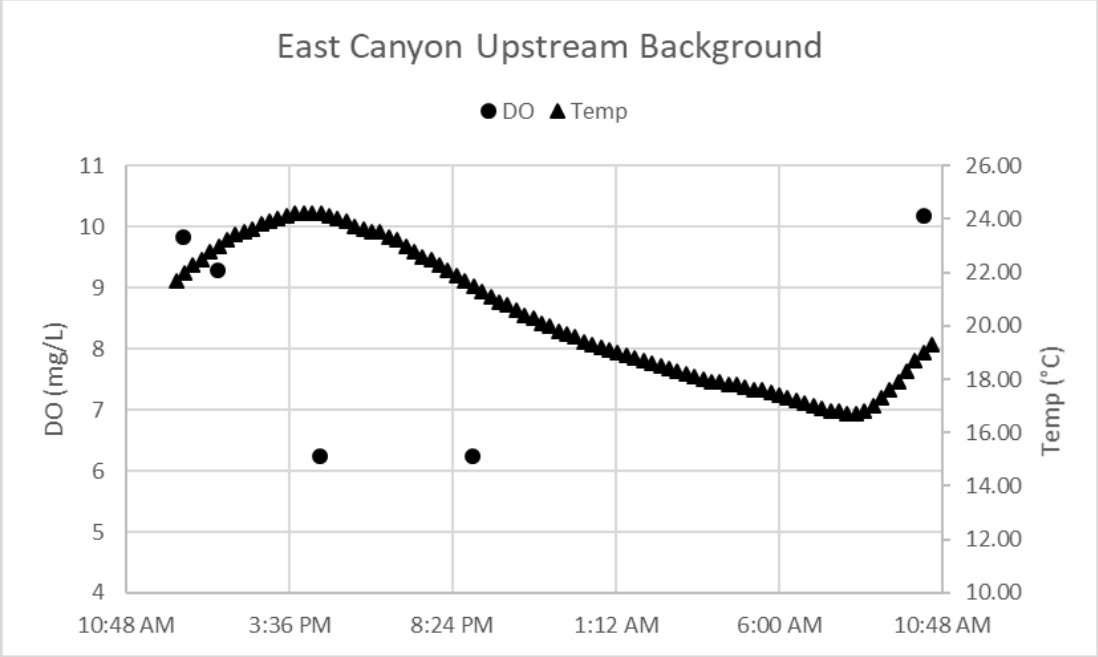

Figure 31: East Canyon upstream background DO and temperature data obtained from USGS Station 10133800 (U.S. Geological Survey, 2017).

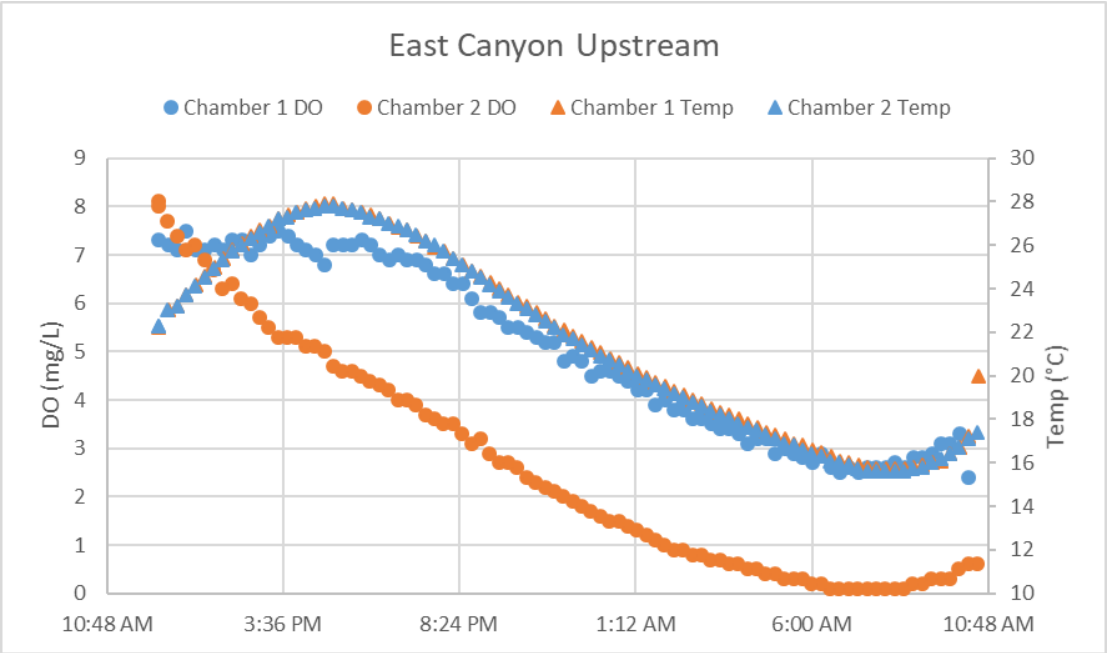

Figure 32: DO and temperature measurements for the upstream East Canyon field study.

appeared more reduced as well. This indicates a potentially higher oxygen demand and could explain why the DO dropped in the chambers during the field study.

There was no statistically significant difference between the temperature in Chambers 1 and 2 at the upstream East Canyon field location. The average temperature in the two chambers was 21.7°C. The average temperature of the background stream was 20.4°C, which was significantly different than the temperature within the chambers. This difference would be expected as the background temperature data were obtained from the USGS station location downstream of the study location and downstream of the East Canyon Water Reclamation Facility, as well. Additionally, the location contained no shading which could have contributed to heat trapped within the chambers creating the higher temperatures. Although the average temperatures within the chambers and the

background stream are different, the temperature both in the chambers and the stream reached their peak at approximately 5 pm and were at their low point at approximately 8 am during the study period.

For the downstream Box Elder Creek field study, an Extech DO meter/ datalogger was used to measure and record continuous data for the background stream. Only two of the triplicate chambers chosen for analysis were fitted with available dataloggers. The DO probe fitted to the third chamber (Milkwaukee MW600 Dissolved Oxygen Meter) did not have datalogging capabilities and therefore only single measurements at each sampling period were recorded. The Milkwaukee MW600 Dissolved Oxygen Meter attached to Chamber 3 also did not report any temperature data and therefore no temperature data was available for Chamber 3. The Extech DO meter/datalogger for Chamber 2 stopped recording continuous measurements around 10 pm. At this point, there had been three consecutive DO measurements of 0 mg/L. The next DO measurement recorded was at 10:30 am, at which point the DO was reading 2.6 mg/L. Figure 33 shows the DO results for the downstream Box Elder Creek field study. Figure 34 shows the DO and temperature data for the Box Elder Creek downstream field study. Each chamber followed the same trend as the background DO and temperature within the stream. The stream and the chambers reached the highest DO level between noon and 4 pm, and by midnight had become anaerobic. The DO continued to decrease with decreasing temperature in the background stream and within the chambers, indicating a presence of photosynthesis and respiration. The downstream location contained long

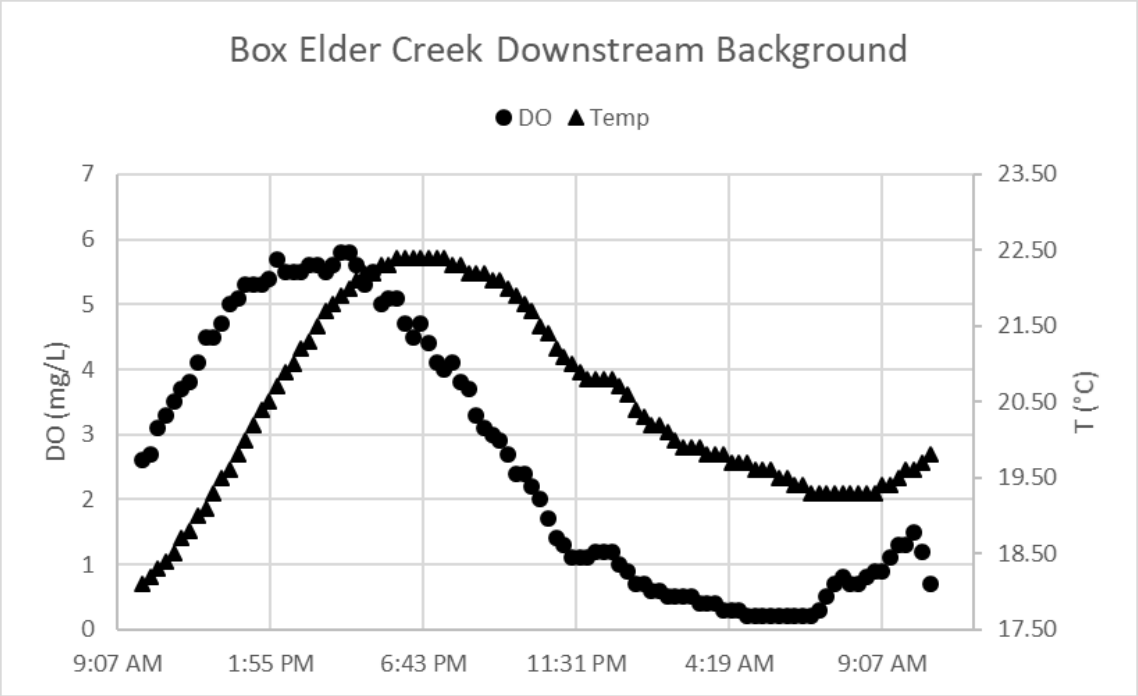

Figure 33: Box Elder Creek downstream background DO and temperature data.

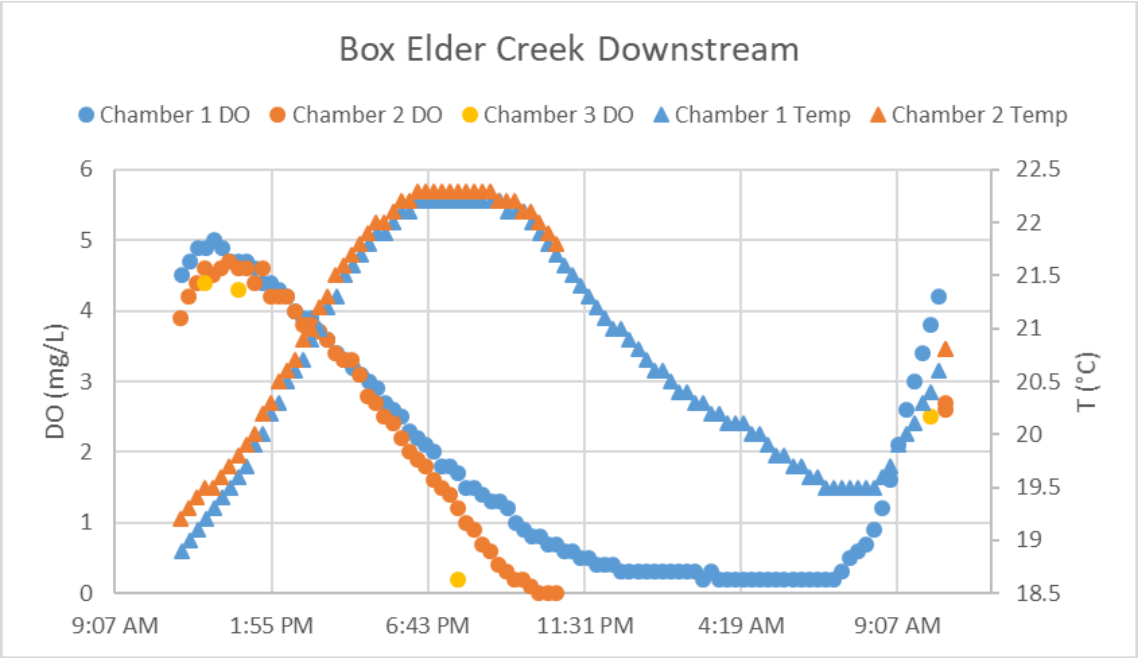

Figure 34: DO and temperature measurements from the downstream Box Elder Creek field study.

stretches of vegetation across the streambed and each of the chambers had plant material in them, likely attributing to photosynthesis. Although the downstream East Canyon chambers also contained vegetation, the DO did not drop to anaerobic conditions at any observed point. There was a decrease throughout the night in the stream, following a similar pattern to what was seen at the downstream Box Elder Creek location, but never became anaerobic either. The sediment at the downstream Box Elder Creek location differed from what was seen at the downstream East Canyon location in that it was darker and more clayey. This lead to the conclusion that the sediment itself was more reduced than East Canyon and therefore led to completely anaerobic conditions throughout the night.

There was no statistically significant difference between the temperature within Chamber 1 and the background stream. Although the temperature data looks nearly identical between the chambers and the stream, the temperature within Chamber 2 was statistically different than the temperature in Chamber 1, as well as the background stream. The average temperature within Chamber 1 and the stream was 20.6°C, while the average temperature in Chamber 2 was 21.3°C. The location was fairly shaded and therefore could have helped keep the temperature within the chambers similar to what was seen in the stream by preventing excess heating of the chambers.

For the upstream Box Elder Creek field study, continuous DO and temperature measurements were recorded for each chamber as well as the background stream. An apparent malfunction with the datalogger for Chamber 2 resulted in a halt of data recording between approximately 6 am to 10 am. Figure 35 shows the background DO

and temperature results for upstream Box Elder Creek. Figure 36 shows the DO and temperature data for upstream Box Elder Creek.

It appeared that the three chambers followed the overall trend of the background stream, however with different maxima and minima. The streambed did not contain any plant material, therefore neither did any of the chambers. This can explain the minimal change in background DO within the stream. Background DO also increased with decreasing temperature, indicating lack of influence from photosynthesis or respiration. The DO in Chamber 2 did not increase as much as was seen in Chambers 1 or 3, and

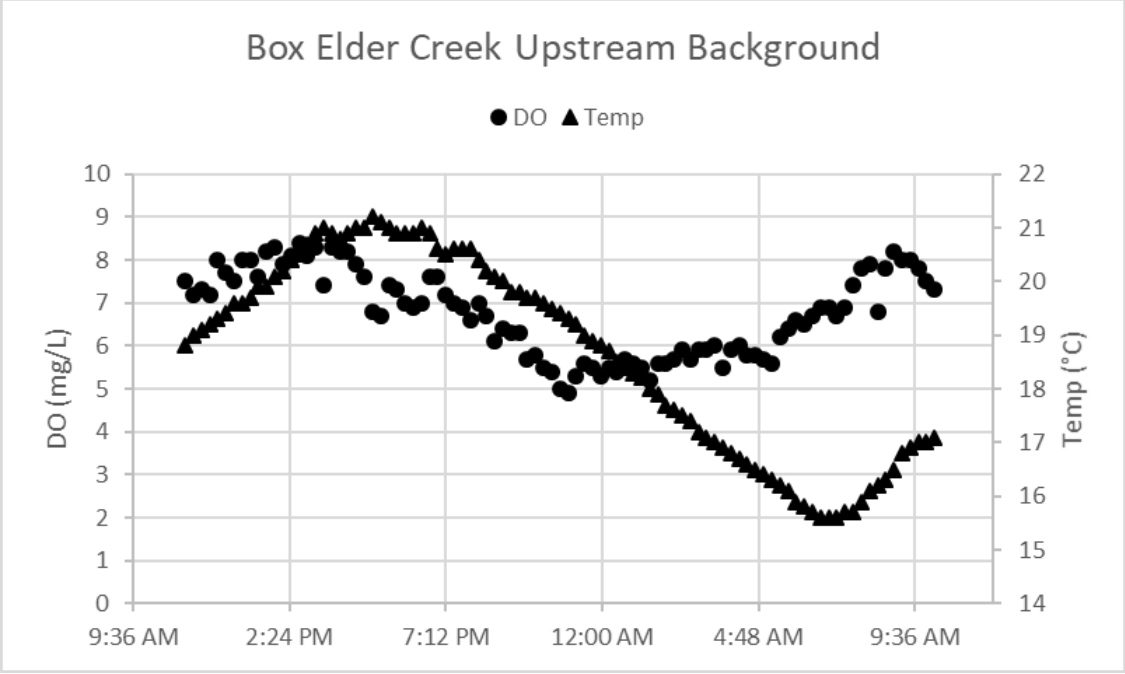

Figure 35: Box Elder Creek upstream background DO and temperature data.

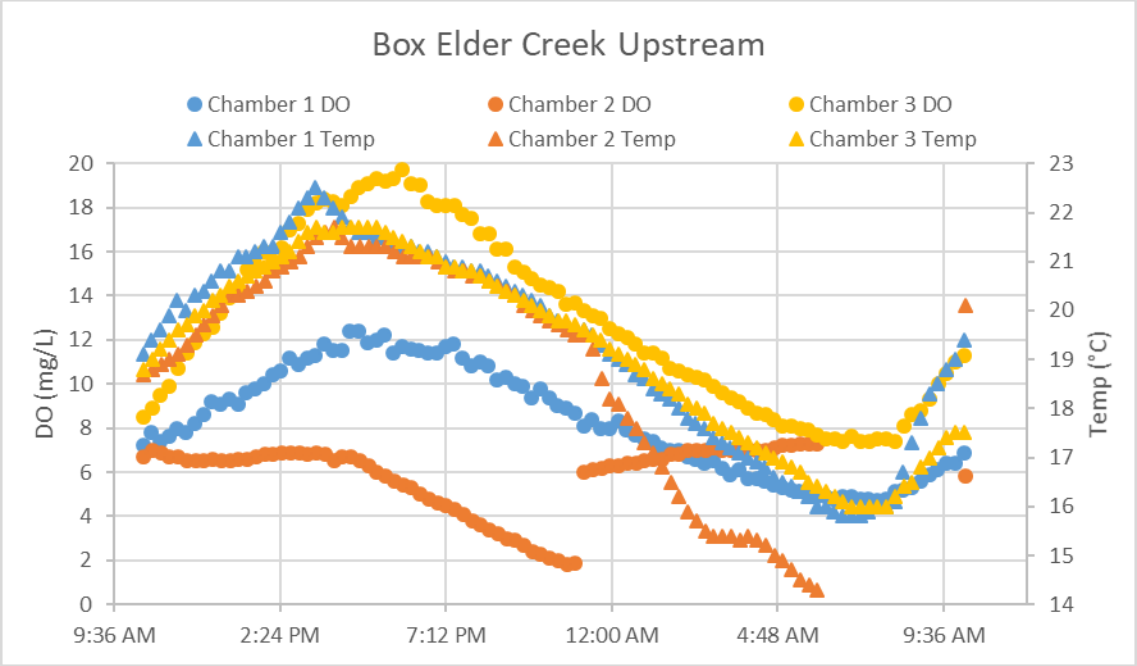

Figure 36: DO and temperature measurements for the upstream Box Elder Creek field study.

actually decreased past the stream background concentration until around 11 pm. This could have been due to the bucket that was placed above the chamber to hold the batteries in place, which created extra shading conditions for the chamber. At this point the DO made a sudden jump from 1.9 mg/L to 6 mg/L within the 15-minute recording intervals. After this jump in DO, Chamber 2 began to read closer to the background stream DO. At the completion of the field study upon removing the frames from the sediment, a thin layer of algae had formed over the frame of Chamber 3. The layer was too thin to collect a sample, however, it could possibly explain the dramatic increase in DO that was seen in the chamber as benthic algae can influence DO similar to rooted plants. For the raw DO data see Appendix E.

There was no statistically significant difference among the temperatures within each chamber and the background stream. The average temperature for all of the chambers and the stream was 19°C. The temperature at the upstream Box Elder Creek location peaked at approximately 3 pm and was lowest at approximately 6 am. For the raw temperature data and statistical analysis results, see Appendix F.

Mass Balance

Once all of the data were adjusted for losses within the system using the previously discussed bromide results, including the ^{15}N mass, the ^{15}N mass balances were completed for each study site. All of the ^{15}N recoveries were calculated by comparing the total ^{15}N in the system to the estimated amount of ^{15}N added into the system based on the $K^{15}NO_3^-$ dose. As previously discussed, due to the bromide results for the East Canyon downstream field study it was decided that Chamber 3 would not be included in any further analysis. The 24-hour TN results for the plant sample of Chamber 1 were lost due to mechanical issues with the instrument at the USU Stable Isotope Laboratory. Additionally, the 0-hour N_2 samples for both Chambers 1 and 2 were lost during the shipment process due to breakage of the secondary glass vials. The lost 24-hour TN value for Chamber 1 was replaced by the 24-hour TN value from Chamber 2. Since the chambers were treated as triplicates, similar conditions within each chamber were assumed. Although the chambers were not identical and could provide data that were statistically different, it was assumed the mass balances would be more representative if data were substituted rather than eliminated due to the loss of a sample for a specific data point. This practice was also carried out in previous chamber studies (Stewardson, 2016).

The 0-hour N_2 values were precluded from the mass balance, therefore the 0-hour recoveries do not include a measurement for the 0-hour N_2. Table 10 shows the ^{15}N recovery results for downstream East Canyon. All of the percent recoveries were calculated using the estimated ^{15}N mass from the dosing solution.

Table 10: East Canyon downstream field study ^{15}N recoveries.

Chamber	0-hour	24-hour
1	69%	77%
2	93%	85%

The 0-hour recovery for Chamber 1 was lower than the 24-hour recovery, which could be due to the lack of N_2 data for that time. The difference between the 0-hour and 24-hour recoveries for both chambers were less than 10%, indicating low losses within each system. The bromide data for Chamber 1 and Chamber 2 showed maximum losses of 4% and 35%, respectively. Both the mass balance recoveries and the bromide loss data provide confidence in the remaining results from Chambers 1 and 2. Figure 37 shows the distribution of ^{15}N within each chamber at 0-hour and 24-hours. Each of the percentages were normalized to the total mass found in the chamber at each time interval instead of the estimated ^{15}N mass from the dosing solution. Therefore, all percentages add up to 100% at each time interval shown in Figure 37.

For Chambers 1 and 2 the majority of the ^{15}N was in the NO_3^- water phase at 0-hour and 24-hours. The largest increase of ^{15}N found was within the dissolved N_2 phase, signifying high levels of denitrification and potentially ANAMMOX. The plant organic-

a. b.

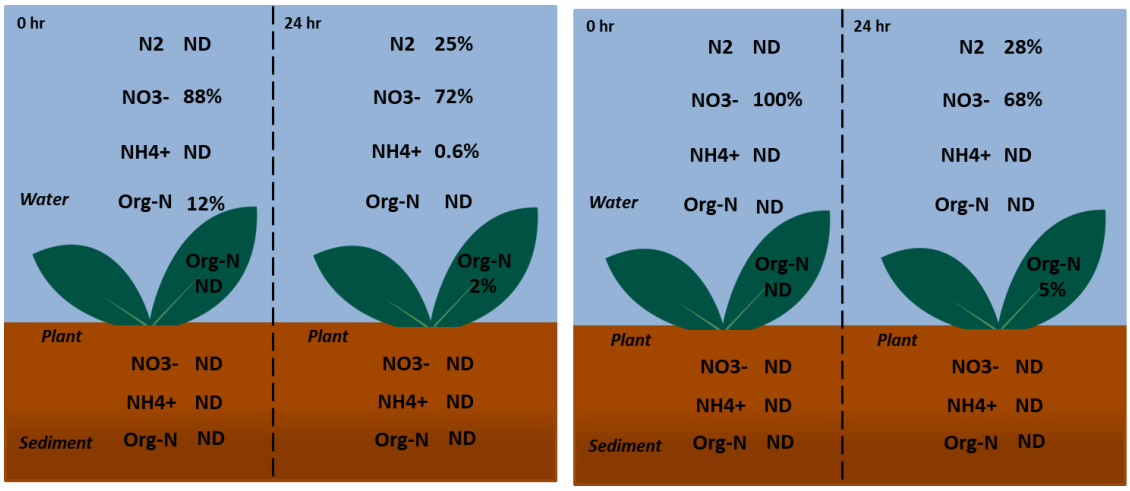

Figure 37: East Canyon downstream ^{15}N distribution in chambers, a. Chamber 1, b. Chamber 2. All percentages were normalized to the total measured ^{15}N mass within each chamber at each time period. ND=non-detect.

N phase also saw an increase of ^{15}N with both chambers over the 24-hour time period, showing potential for plant uptake. Chamber 1 also had an unusually high ^{15}N value in the organic-N water phase at 0-hours. The organic-N was determined by calculating the difference in the measured ^{15}TN and the sum of the measured $^{15}NO_3^-$ and $^{15}NH_4^+$ in the water phase. The 12% ^{15}N in the organic-N water phase was likely a result of an unusually high ^{15}TN reading for that sample time, accompanied by a small $^{15}NO_3^-$ reading relative to the ^{15}TN. There was a slight increase of ^{15}N in the NH_4^+ water phase for Chamber 1 but not for Chamber 2 and no ^{15}N was found in the sediment above background for either chamber. The increase of ^{15}N in the NH_4^+ water phase shows a potential for DNRA.

For the upstream East Canyon field study, no samples were lost that directly affected the calculation of the 0-hour and 24-hour recoveries for any chamber. Table 11 shows the recovery results for upstream East Canyon.

Table 11: East Canyon upstream field study ^{15}N recoveries.

Chamber	0-hour	24-hour
1	112%	62%
2	119%	88%
3	93%	50%

Chambers 1 and 2 both had recoveries above 100%. This means the total ^{15}N in the system surpassed the estimated ^{15}N added to the system based off of the dosing solution. As previously described, the process required to obtain the labelled data for the water, sediment, and plant phases involves multiple steps. Although there are measures in place to prevent any sample contamination, the number of steps involved for the labelled data can be the major cause of variability with the results and ultimately why the percent recoveries are above 100%. Additionally, due to the low $K^{15}NO_3^-$ mass required for the dosing solution, the measuring process could have contributed to variability with the actual mass of ^{15}N added to the system compared to the calculated mass of ^{15}N necessary to reach the desired enrichment. Chamber 3 saw a low ^{15}N recovery at 24-hours (approximately 50% of the estimated ^{15}N added to the system) that could not be accounted for through bromide tracer corrections as there was no bromide data for this location. Due to the low 24-hour recovery it was decided that data from this chamber would not be used in any additional analyses. There was a large difference in 0 and 24-hour recoveries for Chamber 1, however, the basis for determining sufficient recoveries

lies more with the recovery's proximity to 100% than in the comparison between 0 to 24-hour values. The bromide tracer provides sufficient representation of losses within the stream, with less variability in the measurements due to the simpler bromide analysis methods. Therefore, the goal for the ^{15}N percent recoveries at both the 0 and 24-hour period is to be near 100% rather than to be near each other. Ultimately, the 62% recovery found in Chamber 1 at 24-hours was determined to be sufficient taking into consideration all of the previously discussed variability with the ^{15}N data and it was used in the remaining analyses along with Chamber 2. Figure 38 shows the ^{15}N distribution for Chambers 1 and 2 at 0-hour and 24-hours.

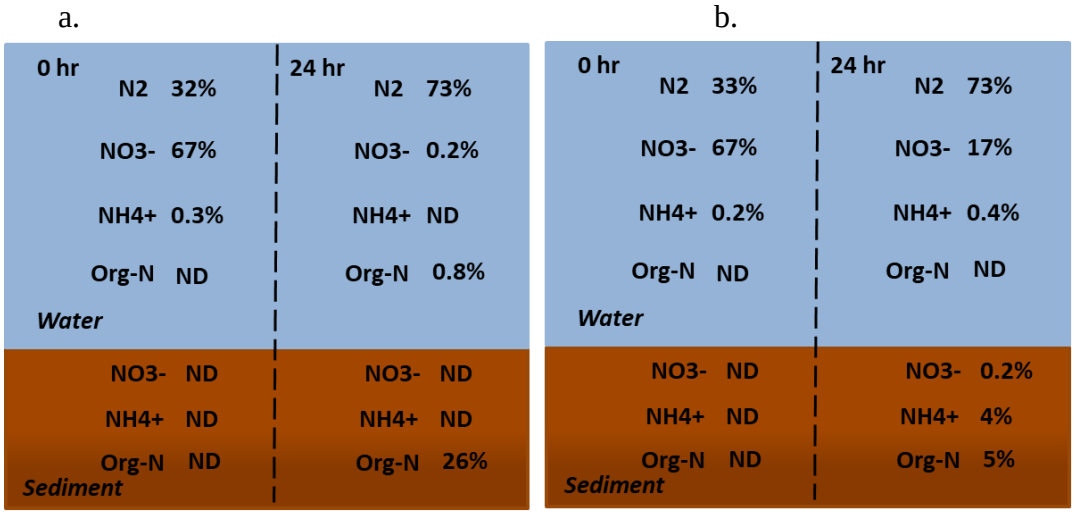

Figure 38: East Canyon upstream ^{15}N distributions in chambers, a. Chamber 1, b. Chamber 2. All percentages were normalized to the total measured ^{15}N mass within each chamber at each time period. ND=non-detect.

The majority of the ^{15}N was found in the NO_3^- water phase in both chambers at 0-hours. More ^{15}N was found in the dissolved N_2 phase at 0-hours than was seen downstream, however, this could be due to the loss of the 0-hour $^{15}N_2$ data for the

downstream chambers. Since the ^{15}N is introduced into the system as $^{15}NO_3^-$, it would be expected that for the 0-hour time period nearly 100% of the ^{15}N would be in the water NO_3^- phase. Ultimately, the dissolved N_2 phase saw the highest increase in ^{15}N over 24-hours for both chambers. The rapid introduction of ^{15}N to the dissolved N_2 phase, along with the high increase over time, indicates a potential for significant denitrification and/or ANAMMOX. There was an increase of ^{15}N in the sediment organic-N phase for both chambers, although an order of magnitude larger for Chamber 1 than seen in Chamber 2. This difference in percent ^{15}N between the chambers is due to the almost complete loss of ^{15}N in the water NO_3^- phase for Chamber 1, which led to the mass of ^{15}N in the sediment organic-N phase to be weighted more heavily in comparison to the rest of the system. The large decrease of ^{15}N in the water NO_3^- phase for Chamber 1 could have been caused by overall fluid losses within the system. The lack of bromide data for this site prevents there being any additional information on fluid losses within the systems, however, Chamber 1 did have a lower 24-hour ^{15}N recovery compared to Chamber 2 so fluid losses for Chamber 1 are likely. Ultimately, the actual mass of ^{15}N in the sediment organic-N phase for Chambers 1 and 2 are within the same order of magnitude. The increase of ^{15}N in the sediment signifies potential for assimilation in the system. Chamber 1 saw a decrease in $^{15}NH_4^+$ reflecting a potential for nitrification and Chamber 2 saw an increase in $^{15}NH_4^+$ over 24-hours which reflects a potential for DNRA in these systems.

For the downstream Box Elder Creek study, the sediment 0-hour $^{15}NO_3^-$ sample was lost due to a leak with the diffusion jar. An average of the sediment 0-hour $^{15}NO_3^-$ samples from Chambers 1 and 3 were used as a substitute for the missing sample result for Chamber 2. No other samples that directly affected the 0-hour and 24-hour ^{15}N

recovery calculations were lost. Table 12 shows the downstream Box Elder Creek field ^{15}N recovery results.

Table 12: Box Elder Creek downstream field study ^{15}N recoveries.

Chamber	0-hour	24-hour
1	105%	93%
2	122%	111%
3	112%	84%

The 0-hour and 24-hour ^{15}N recoveries for each chamber were all close to 100%. There were a few recoveries above 100%, which could have been caused by the possible variability in the ^{15}N data that was previously discussed. The differences between the 0-hour and 24-hour recoveries for each chamber were all low, corresponding well to the bromide data that shows a maximum loss of 8% for all three chambers. Figure 39 shows the Box Elder Creek downstream ^{15}N distributions in the chambers.

For each chamber, the majority of the ^{15}N was in the NO_3^- water phase at the 0-hour time period, however nearly a third of the ^{15}N was in the dissolved N_2 phase within each chamber at this time 0 as well, similar to what was seen at the upstream East Canyon site. The dissolved N_2 phase saw the largest increase in ^{15}N over the 24-hour time period within each chamber, indicating a strong potential for denitrification and possibly ANAMMOX. Each chamber also saw an increase of ^{15}N in the NH_4^+ water phase, with Chamber 1 seeing the largest increase, indicating the potential for DNRA in the system. Chamber 1 yielded a slight increase of ^{15}N in the NH_4^+ in the sediment phase. Chambers 1 and 2 also saw an increase of ^{15}N in the organic-N sediment phase, with Chamber 2

seeing the largest increase. The increase of ^{15}N in the sediments suggest nitrogen assimilation in these systems.

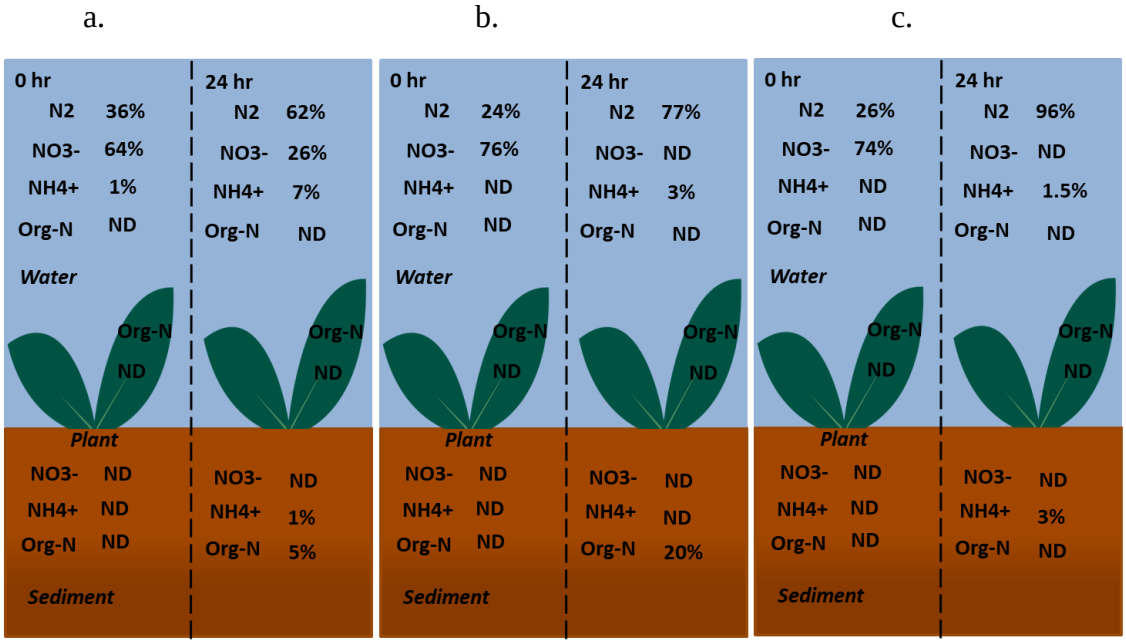

Figure 39: Box Elder Creek downstream ^{15}N distributions in chambers, a. Chamber 1, b. Chamber 2, c. Chamber 3. All percentages were normalized to the total measured ^{15}N mass within each chamber at each time period. ND=non-detect.

At the 24-hour sampling period for the upstream Box Elder Creek field study, the water level had decreased in the stream so approximately 1 inch of Chambers 1 and 2 were above the water. The inside of Chamber 1 was still full with water and was circulating water through the tubing. A large quantity of air had entered Chamber 2 such that the water level inside the chamber was below the inlet and outlet of the tubing, therefore no water was circulating through the Chamber 2 tubing at this time. These conditions led to the inability of collecting any 24-hour water samples for Chamber 2. Averages of the 24-hour samples from Chambers 1 and 3 were originally used to substitute the missing data for Chamber 2. When the 0-hour and 24-hour recoveries were

calculated across the chambers, Chamber 3 had a 24-hour recovery below 50%. The ^{15}N atom% for the NO_3^- data for the 24-hour time period was below 1% for Chamber 3, while Chamber 1 was closer to 10%. Further discrepancies with the 24-hour NO_3^- data from the labelled and non-labelled data led to the omission of the 24-hour data for all three chambers, using the 12-hour data as the final sampling time for the analyses. Although sediment data are only available for the 0-hour and 24-hour sampling periods, less than 5% of the ^{15}N was found in the sediment at 24-hours for these chambers and therefore not having sediment data for the 12-hour sampling time is not expected to impact the recovery significantly. Table 13 shows the upstream Box Elder Creek ^{15}N recovery results using a 12-hr sampling period for this location.

Table 13: Box Elder Creek upstream field study ^{15}N recoveries.

Chamber	0-hour	12-hour
1	118%	93%
2	130%	86%
3	106%	63%

Using the ^{15}N data at 12-hours as the final time for the field study improved the final recoveries for all three chambers by at least 10%. There were 0-hour recoveries larger than 100%, as also seen at two of the three other locations. Again, the multiple steps and factors that go into the ^{15}N analysis could have been the cause for the variability in the recoveries. Ultimately, all of the recoveries were found sufficient to continue with all three chambers for the remaining analyses. Figure 40 shows the Box Elder Creek upstream ^{15}N distributions in the chambers.

a. b. c.

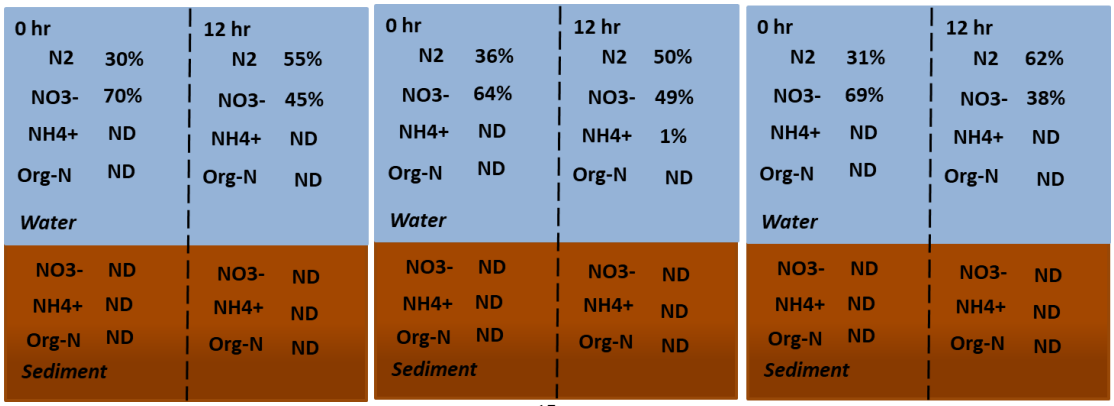

Figure 40: Box Elder Creek upstream ^{15}N distributions in chambers at the 12-hr sampling period, a. Chamber 1, b. Chamber 2, c. Chamber 3. All percentages were normalized to the total measured ^{15}N mass within each chamber at each time period. ND=non-detect.

For the Box Elder Creek upstream field study, the majority of the ^{15}N remained within the NO_3^- water phase and the dissolved N_2 phase. Most of the ^{15}N was measured as NO_3^- at the 0-hour time period, however nearly a third was already in the dissolved N_2 phase similar to what was seen at the downstream Box Elder Creek site. This indicates rapid rates of denitrification and potentially ANAMMOX. Chamber 2 also saw a slight increase of ^{15}N in the NH_4^+ water phase, showing a potential for DNRA. Although at the 12-hour time period there were no sediment samples collected for analysis, the 24-hour results showed that less than 5% of the ^{15}N ended up in the sediment phase. Thus, the 12-hour sediments recoveries shown in Figure 40 are likely reflective of the conditions for each chamber. For the full mass balance tables see Appendix G.

AQ2 Nitrification & Denitrification Rates

The AQ2 data provided 0-order and 1st-order denitrification and nitrification rates from NO_3^- and NH_4^+ concentrations, respectively. The 0-order rates were determined by

regressing the reported concentrations against time. The 1st-order rate was determined by regressing the $\ln(C/C_0)$ values for each data point against time, where C is the concentration for the data point at time t, and C_0 is the concentration at time 0. A decline in NO_3^- over time signified denitrification, while a decline in NH_4^+ over time signified nitrification. The slopes of the linear regressions fitted to the data are the reported rates. An ANCOVA was used to determine statistical differences among data sets from each replicate chamber at a specified site. A separate linear regression, and in turn a separate rate, was determined for data sets that were statistically different.

For the downstream East Canyon field study, the ANCOVA analysis showed that the 0-order NO_3^- data sets were not statistically different between chambers 1 and 2 (p-value = 0.09). Figure 41 shows an example of the linear regressions for the downstream East Canyon NO_3^- data.

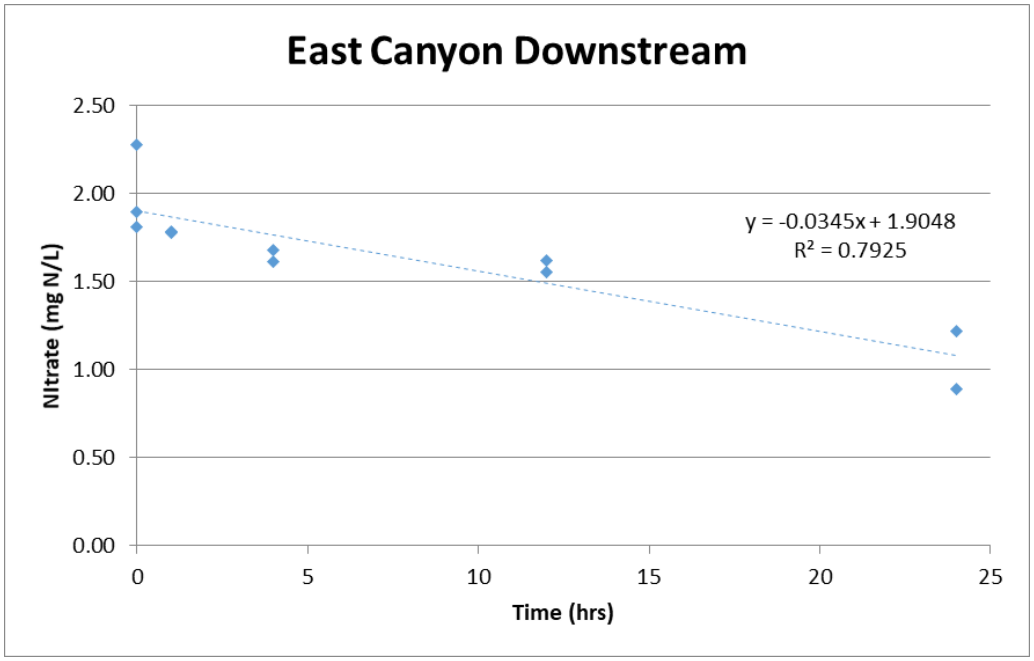

Figure 41: East Canyon downstream NO_3^- data linear regression.

Table 14 shows the denitrification rates determined from the NO_3^- AQ2 data for the various sites. An ANCOVA was used for each site and a single reported rate indicates that there were no statistically significant differences among the chambers. A separate ANCOVA analysis was used for the 0-order and 1st-order data and in some instances significant differences among chambers varied on the data set being analyzed, meaning the 0-order and 1st-order reported rates can come from different chamber combinations as indicated in Table 14.

Table 14: AQ2 in situ chamber-derived denitrification rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	R2	P-Value	1st-Order Rate (1/hr)	R2	P-Value
East Canyon Downstream	0.0351[a]	0.77	2.6E-04	0.024[b]	0.86	2.48E-05
East Canyon Upstream	0.005	0.00	0.92	0.002	0.00	0.85
Box Elder Creek Downstream	0.017[a]	0.68	9.0E-05	0.052[b]	0.68	9.04E-05
Box Elder Creek Upstream C1&3	0.021[a]	0.93	1.7E-05			
Box Elder Creek Upstream C2	0.019[a]	0.99	3.4E-03			
Box Elder Creek Upstream				0.060[b]	0.95	1.66E-08

All of the rates highlighted in green are statistically significant (p-value ≤ 0.05). Superscripts indicate statistically the same rates based on an ANCOVA result (p-value ≤ 0.05).

All of the regressions are based on the 0-24-hour time period. For the Box Elder Creek upstream NO_3^- data, the 0-order regressions for Chambers 1 and 3 were not statistically different while Chamber 2 was. Therefore, two separate 0-order denitrification rates are reported. The 1st-order regressions were not statistically different among the three chambers and therefore only one 1st-order rate is reported. Upstream at

East Canyon Creek did not see any significant denitrification rates in 0-order or 1st-order. However, all of the significant 0-order denitrification rates for downstream East Canyon, and upstream and downstream at Box Elder Creek are within the same order of magnitude. An ANCOVA showed that the significant 0-order and 1st- order rates are not statistically different.

Table 15 shows the nitrification rates determined from the NH_4^+ AQ2 data for the various sites. As previously discussed, a decrease in NH_4^+ indicates nitrification within the chambers and therefore a negative regression means the presence of nitrification. To represent the presence of nitrification the negative slope of the regression was reported as a positive value in Table 15, while when a rate is reported as a negative value in Table 15, this means it had a positive regression slope indicating no nitrification.

Table 15: AQ2 in situ chamber-derived nitrification rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	R2	P-Value	1st-Order Rate (1/hr)	R2	P-Value
East Canyon Downstream C1	0.0054	0.10	0.28			
East Canyon Downstream C2	0.0011	0.01	0.38			
East Canyon Downstream				0.037[a]	0.33	0.05
East Canyon Upstream C1	-0.0004	0.64	0.03			
East Canyon Upstream C2	-0.0005	0.23	0.23			
East Canyon Upstream				-0.0007	0.54	0.01
Box Elder Creek Downstream	0.0086	0.09	0.14			
Box Elder Creek Downstream C1&2				0.021[a]	0.57	0.005
Box Elder Creek Downstream C3				-0.006	0.00	0.48

All of the rates highlighted in green are statistically significant (p-value≤0.05). Superscripts indicate statistically similar rates based on an ANCOVA result (p-value ≤ 0.05).

For the downstream and upstream East Canyon 0-order rates, Chambers 1 and 2 were significantly different and therefore two separate rates are reported. For the downstream and upstream East Canyon 1st-order rates, there was no statistically significant difference between Chambers 1 and 2 and therefore only an average rate from the two chambers is reported. There was no significant difference between the 0-order rates from Chambers 1, 2, and 3 downstream East Canyon therefore only one, average rate between the chambers is reported. For the 1st-order rates, Chambers 1 and 2 were not significantly different therefore an average rate for the two chambers is reported. Chamber 3 saw a significantly different 1st-order rate from Chambers 1 and 2 and therefore a separate rate is reported. The only significant nitrification rates were the 1st-order regressions from the East Canyon downstream site, and from Chambers 1 and 2 from the downstream Box Elder Creek site. Significant downstream nitrification rates could be the result of higher ammonium levels. Upstream East Canyon saw lower ammonium levels than what was found downstream and the NH_4^+ data for upstream Box Elder Creek were below the detection limit. Both of these nitrification rates were within the same order of magnitude. An ANCOVA showed that the two significant nitrification rates were not statistically different.

$^{15}N_2$ Denitrification Rates

The 0-order denitrification rates from the $^{15}N_2$ data were calculated using Equations 3-7. Since the rates were determined through the use of an equation, the average 0-order rate across the chambers was reported along with the standard deviation and 95% confidence interval of the average. The 1st-order denitrification rates from the

$^{15}N_2$ data were determined through the $^{29}N_2$ and $^{30}N_2$ production over time, assuming the $^{28}N_2$ concentrations in the chamber would remain near saturation through the duration of the study. An $\ln(C/C_0)$ value was calculated at the 0-hour and 24-hour time period (or 12-hours for upstream Box Elder Creek) for each chamber at each location. A regression between the first and last data points for each chamber at each location (six data points total) was then used to determine a $^{29}N_2$ and $^{30}N_2$ denitrification rate, along with a correlation coefficient and a p-value for these regressions, as shown in Figure 42.

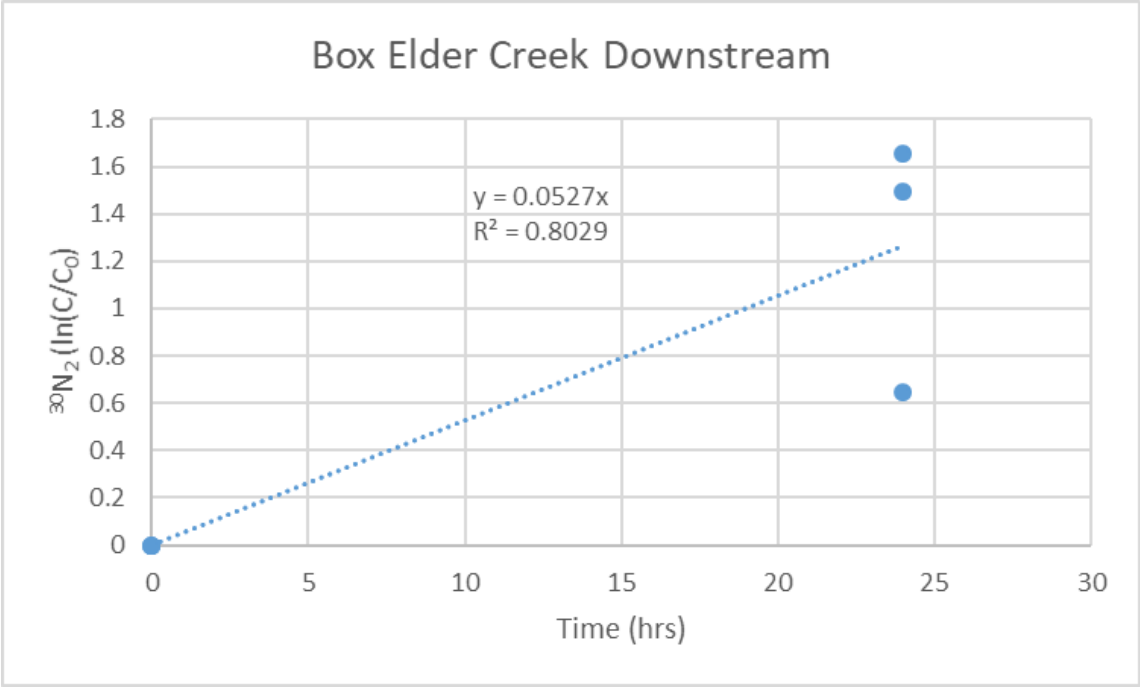

Figure 42: Box Elder Creek $^{30}N_2$ 1st-order regression.

Although this is inherently a "2-point" regression, the variability among the 0-hour values and the 24-hour or 12-hour values between the chambers at each location

created a source for error among the rates preventing a correlation coefficient of 1 for each of the regressions. Table 16 shows the denitrification results from the $^{15}N_2$ data.

Table 16: $^{15}N_2$ in situ chamber-derived denitrification rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	Std Dev	95% CI	1st-Order Rate (1/hr)	R2	P-Value
East Canyon Downstream	0.02	0.006	0.009			
East Canyon Downstream $^{29}N_2$				0.018[a]	0.995	8.45E-06
East Canyon Downstream $^{30}N_2$				0.039[a]	0.664	0.048
East Canyon Upstream	0.01	0.001	0.002			
East Canyon Upstream $^{29}N_2$				0.015[a]	0.818	0.013
East Canyon Upstream $^{30}N_2$				0.030	0.586	0.076
Box Elder Creek Downstream	0.02	0.008	0.009			
Box Elder Creek Downstream $^{29}N_2$				0.030[a]	0.797	0.017
Box Elder Creek Downstream $^{30}N_2$				0.053[b]	0.803	0.016
Box Elder Creek Upstream	0.02	0.020	0.023			
Box Elder Creek Upstream $^{29}N_2$				0.009	0.151	0.447
Box Elder Creek Upstream $^{30}N_2$				0.021	0.544	0.430

All of the rates highlighted in green are statistically significant. Superscripts indicate statistically similar rates based on an ANCOVA result (p-value ≤ 0.05).

The 0-order denitrification rates at both East Canyon locations and downstream Box Elder Creek were all statistically significant and within the same order of magnitude. Based on the 95% confidence intervals of the average 0-order denitrification rate the significant 0-order rates are all statistically the same. The $^{29}N_2$ 1st-order denitrification rates were also statistically significant at both East Canyon locations and at downstream Box Elder Creek. The downstream locations at East Canyon and downstream locations at Box Elder Creek all produced statistically significant $^{30}N_2$ denitrification rates. All of the

significant 1st-order denitrification rates were within the same order of magnitude. An ANCOVA showed that all of the significant 1st-order rates are statistically the same except for the downstream Box Elder Creek $^{30}N_2$ rate. The upstream Box Elder Creek location did not produce statistically significant denitrification rates.

^{15}N

The ^{15}N data were used to determine 0-order ANAMMOX rates through the use of Equations 11 and 12. A 0-order ANAMMOX rate was calculated at each time step for each chamber at all of the locations. An ANOVA was used to determine if the ANAMMOX rates for each chamber were statistically different at each location. Table 17 shows the ANAMMOX rate results.

Table 17: ANAMMOX in situ chamber-derived rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	n	95% CI
East Canyon Downstream C1	5.07E-04	4	4.71E-04
East Canyon Downstream C2	2.67E-03	4	1.06E-03
East Canyon Upstream	-1.64	8	2.8
Box Elder Creek Downstream	-31.52	15	27.8
Box Elder Creek Upstream	-1.96E-03	10	2.55E-03

All of the rates highlighted in green are statistically significant.

Significant ANAMMOX rates were only found at the downstream East Canyon location. The ANAMMOX rates produced by each chamber were statistically different

and therefore two separate rates are reported. The ANAMMOX rates calculated at all other locations produced negative rates indicating no presence of ANAMMOX.

The ^{15}N data were also used to determine 0-order DNRA rates through the application of Equation 13. The equation used for calculating DNRA rates only produces a 0-order rate, therefore no 1st-order rate data for DNRA were obtained. The DNRA rate was calculated at each time step for each chamber at each location. A negative rate indicates no DNRA was detected. An ANOVA was used to determine if there was a statistical difference among the rates from each chamber at each location. Table 18 shows the DNRA rate results.

Table 18: DNRA in situ chamber Equation 13-derived rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	n	95% CI
East Canyon Downstream	1.42E-04	8	1.18E-04
East Canyon Upstream	1.67E-05	8	6.16E-05
Box Elder Creek Downstream	5.76E-04	15	7.29E-04
Box Elder Creek Upstream	4.93E-05	10	6.85E-05

All of the rates highlighted in green are statistically significant.

A significant DNRA rate was found only at the downstream East Canyon location. The satisfactory ^{15}N recoveries from the downstream East Canyon chambers, along with the increase in $^{15}NH_4^+$ found, further supports this conclusion. Although chambers across various locations also saw an increase in $^{15}NH_4^+$, notably the downstream Box Elder Creek chambers, the variance between the rates of increase at the

respective locations was wide and did not produce a “non-zero” rate based on the 95% confidence interval. As previously mentioned, the DNRA calculations were performed at each time step for each chamber and the ANOVA test included each of these calculated rates. The remaining three locations showing positive, yet not “non-zero”, DNRA rates could indicate a potentially significant impact from time of day on DNRA rates. This would mean that DNRA could be present, however, the variance between the rates across a 24-hour period is wide enough that significant “non-zero” rates could not be determined.

The ^{15}N data were used to determine 0-order assimilation rates through the application of Equation 14. A 0-order assimilation rate was calculated at each time step for each chamber. A negative rate indicates no assimilation was detected. An ANOVA was then used to determine if there were statistical differences among the rates from each chamber at each location. Table 19 shows the assimilation rates results.

Table 19: Assimilation in situ chamber Equation 14-derived rates for East Canyon and Box Elder Creek study sites.

Location	0-Order Rate (mg/L-hr)	n	95% CI
East Canyon Downstream	1.50E-04	8	1.81E-02
East Canyon Upstream	1.18E-02	8	1.15E-02
Box Elder Creek Downstream	-8.55E-04	15	6.36E-03
Box Elder Creek Upstream	1.00E-02	10	4.57E-03

All of the rates highlighted in green are statistically significant.

Significant 0-order assimilation rates were found for the upstream locations at East Canyon and Box Elder Creek. The assimilation rates at these locations are within the

same order of magnitude and equivalent based on the overlapping 95% confidence intervals. An increase of ^{15}N in the sediment within the upstream East Canyon chambers supports the positive "non-zero" rate. The upstream Box Elder Creek chambers saw no increase in ^{15}N in the sediment phase, however, a thin layer of algae that was ultimately not sampled and tested appeared on the chambers at this location and could potentially explain this result. As shown in Equation 14, the microbial assimilation was calculated by taking the difference of the total $^{15}NO_3^-$ removal from the chamber and the denitrification, ANAMMOX, and DNRA rates for each time step. A positive and statistically significant assimilation rate, therefore, indicates that there was a $^{15}NO_3^-$ removal that was not accounted for through the above named nitrogen transformations. The overall assumption being that $^{15}NO_3^-$ removal that did not come from denitrification, ANAMMOX, or DNRA, would have been removed by assimilation. Ultimately, $^{15}NO_3^-$ could have been removed by the algae that formed in the upstream Box Elder Creek chambers, which supports why a significant positive assimilation rate was calculated, however, no ^{15}N increase was seen in the sediment phase. Similar to what was seen for DNRA rates, there was an increase of ^{15}N in the sediment phase for the downstream Box Elder Creek chambers although no positive rate could be calculated. This again could be due to a wide variance among assimilation rates over the 24-hour period. The downstream East Canyon chambers saw a ^{15}N increase in the plant phase, however a not "non-zero" rate was calculated, once again a possible indication that time of day influenced the rate. For the raw ^{15}N data, see Appendix H.

Rates Summary

The significant nitrogen transformation rates produced at each location from the various methods were compared against each other and against existing literature data. In the case of significant overlapping rates from different methods at a specific location, the data from each method was grouped to produce a single rate that was reported for the overall comparison across locations. The units for the rates have been adjusted from 1/hr to 1/d in order to reflect the rates found in the literature. Table 20 shows the 1st-order denitrification rates determined from this study along with 1st-order denitrification rates found in a study by Reddy et al. (1979). The 1979 study was testing flooded organic soil as a treatment system for nitrate removal from agricultural drainage water. The denitrification rates come from experiments using low oxygen demand flood water and high oxygen demand flood water run at 18°C.

Table 20: Significant 1st-Order denitrification rate comparisons. Superscripts indicate equivalent rates based on overlapping 95% CI.

Location	Method	Rate	95% CI	Units
East Canyon Downstream	AQ2, $^{29}N_2$, $^{30}N_2$	0.65[a]	0.22	1/d
Box Elder Creek Downstream	AQ2, $^{29}N_2$, $^{30}N_2$	1.08[b]	0.27	1/d
East Canyon Upstream	$^{29}N_2$	0.34[a]	0.23	1/d
Box Elder Creek Upstream	AQ2	1.44[b]	0.22	1/d
Reddy, et al. (1979)	Low Oxygen Demand	0.751	N/A	1/d
Reddy, et al. (1979)	High Oxygen Demand	0.292	N/A	1/d

The denitrification rates produced from the AQ2, $^{29}N_2$, and $^{30}N_2$ data for both downstream locations were statistically the same at each location based on overlapping 95% confidence intervals, therefore one denitrification rate is reported. The denitrification rates produced at both the downstream and upstream sites at East Canyon were statistically the same. The denitrification rates produced at both the downstream and upstream sites at Box Elder Creek were also statistically the same, although on average an order of magnitude larger than what was found at East Canyon. The downstream Box Elder Creek chambers saw an obvious decrease in oxygen over the course of the night, which was not found at the downstream East Canyon chambers therefore potentially explaining the higher denitrification rates. The upstream Box Elder Creek chambers did not see the same level of decrease in oxygen as what was seen downstream Box Elder Creek, however, the rates were calculated over a 12-hour period which could have potentially skewed the rate to appear higher. There were no 95% confidence intervals provided for the 1st-order rates generated from the study by Reddy et al. (1979), therefore determining the extent of the range of confidence on these rates and ultimately how they overlap with the rates from this study is not entirely possible. However, the low oxygen demand and high oxygen demand denitrification rates from the 1979 study did fall in the 95% confidence interval range for the East Canyon sites. The upstream locations at East Canyon and Box Elder Creek also only saw significant 1st-order denitrification from one of the analysis methods. Each analysis method requires various stages of preparation prior to obtaining the data and determining the nitrogen transformation rate. Although precautions are in place to prevent contamination and other man-made errors, each stage of preparation can potentially bring an additional source of error. When certain methods

provide significant rates for a specific location that other methods do not, it can be a reflection on the variability across analysis methods.

Table 21 shows comparisons for 0-order denitrification rates generated in this study and 0-order denitrification rates generated from studies by Baker & Vervier (2004) and Pinay et al. (2009). In the study by Baker & Vervier (2004) an in situ acetylene block assay was used to generate denitrification rates in a NO_3^- contaminated portion of the Garonne River. In the study by Pinay et al. (2009), denitrification rates were generated from a salmon river in Alaska receiving significant nitrogen loads from the ocean.
As shown in Table 21, all of the significant 0-order denitrification rates from this study are equivalent based on overlapping 95% confidence intervals. Although multiple analysis methods provided 0-order denitrification rates that were statistically the same at various sites, grouping the data in order to determine a single rate per site was not possible due to conflicting methods of determining the rates across the analyses. The 95% confidence intervals for the 0-order denitrification rates generated from the studies by Baker & Vervier (2004) and Pinay et al. (2009) were not provided, therefore determining if the range of confidence for these rates overlapped with the rates from this study was not possible. However, on average the rates were an order of magnitude larger than the 0-order denitrification rates generated in this study. The 2004 and 2009 studies took place in nitrogen contaminated areas which likely contain concentrations of NO_3^- much higher than were seen in East Canyon Creek or Box Elder Creek, causing the higher denitrification rates.

Table 21: Significant 0-order denitrification rate comparisons. Superscripts indicate equivalent rates based on overlapping 95% CI.

Location	Method	Rate	95% CI	Units
East Canyon Downstream	AQ2	0.035[a]	0.014	mg N/L-hr
East Canyon Downstream	N_2	0.02[a]	0.009	mg N/L-hr
East Canyon Upstream	N_2	0.01[a]	0.002	mg N/L-hr
Box Elder Creek Downstream	AQ2	0.02[a]	0.009	mg N/L-hr
Box Elder Creek Downstream	N_2	0.02[a]	0.009	mg N/L-hr
Box Elder Creek Upstream C1&3	AQ2	0.021[a]	0.005	mg N/L-hr
Box Elder Creek Upstream C2	AQ2	0.019[a]	0.005	mg N/L-hr
Baker & Vervier (2004)	High Flow	0.21	N/A	mg N/L-hr
Baker & Vervier (2004)	Low Flow	0.11	N/A	mg N/L-hr
Pinay et al. (2009)	N/A	0.24	N/A	mg N/L-hr

Table 22 shows the nitrification rates generated from this study, as well as the nitrification rate found at Box Elder Creek in the QUAL2KW study (Neilson et al., 2012).

Table 22: Significant 1st-Order nitrification rate comparisons. Superscripts indicate equivalent rates based on overlapping 95% CI.

Location	Method	Rate	95% CI	Units
East Canyon Downstream	AQ2	0.89[a]	0.88	1/d
Box Elder Creek Downstream C1&2	AQ2	0.49[a]	0.11	1/d
QUAL2Kw	Box Elder Creek	3.6	N/A	1/d

Significant nitrification rates were only found in the downstream locations of both sites. The significant nitrification rates generated from this study are equivalent based on the 95% confidence intervals. There were no 95% confidence intervals provided for the

Box Elder Creek nitrification rates generated in the QUAL2KW study (Neilson et al., 2012), however, the average rate was an order of magnitude larger than the nitrification rates generated in this study. Due to the amount of assumptions and level of uncertainties associated with modeling, the Box Elder Creek nitrification rate from the QUAL2Kw study was included as a potentially relevant reference and not as a value for significant comparisons.

Table 23 shows the assimilation rates generated from this study, as well as the range of assimilation rates found in the study by O'Brien et al. (2012).

Table 23: Significant assimilation rates. Superscripts indicate equivalent rates based on overlapping 95% CI.

Location	Method	Rate	95% CI	Units
East Canyon Upstream	^{15}N	163[a]	159	µmol/m^2-hr
Box Elder Creek Upstream	^{15}N	138[a]	63	µmol/m^2-hr
O'Brien et al., 2012		350-400	NA	µmol/m^2-hr

Significant assimilation rates were only found in the upstream locations of both sites. Although the upstream chambers at both East Canyon and Box Elder Creek did not contain plants, the equation used for assimilation rates assumes $^{15}NO_3^-$ that was not removed through denitrification, assimilation, or DNRA, was removed by assimilation. This includes potential uptake in the soil. As previously discussed, a thin layer of algae formed in the upstream Box Elder Creek that could have also served as a sink for the labelled nitrate. The significant assimilation rates generated from this study are equivalent based on the 95% confidence intervals. The rates measured in this study were

statistically lower than the assimilation rates reported in the O'Brien et al. (2012) study. However, the rates were all within the same order of magnitude.

The significant rates found at each location from each site were compared against each other in order to determine not only the presence of the nitrogen transformations within the system, but the prominence of each transformation process. Figure 43 shows the nitrogen transformation processes that produced a significant rate at the downstream East Canyon site. The thickness of the arrows compares the presence of each nitrogen transformation rate at each of the sites. A bolder arrow signifies a higher rate.

At the downstream East Canyon location, significant rates for nitrification, denitrification, ANAMMOX, and DNRA were found. Significant denitrification rates were found from multiple analysis methods and produced the highest nitrogen transformation rates, followed by nitrification, ANAMMOX, and DNRA.

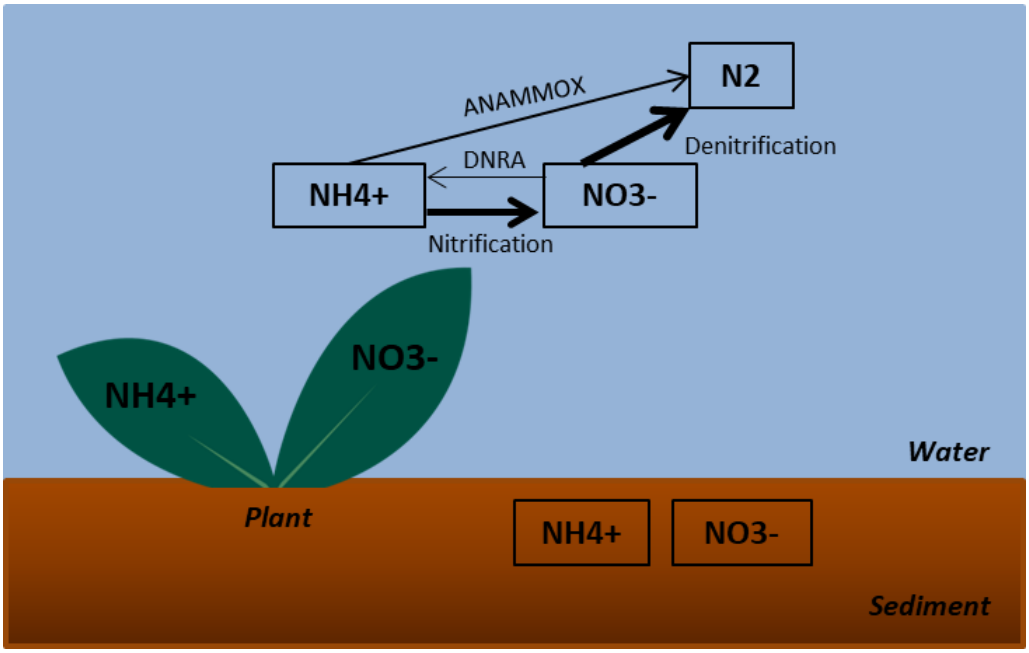

Figure 43: Nitrogen transformations found at the downstream East Canyon location.

Figure 44 shows the various nitrogen transformations that produced significant rates at the upstream East Canyon siteAt the upstream East Canyon location, significant rates were only found for denitrification and assimilation. Only two analysis methods produced significant denitrification rates, however, the significant rates that were produced were still higher than the assimilation rates found. Due to the variability across analysis methods for denitrification, the lack of a significant denitrification rate from each of the analyses was not interpreted as an indication that denitrification was not present nor did it impact the conclusion of its overall prominence with respect to other transformations within the system.

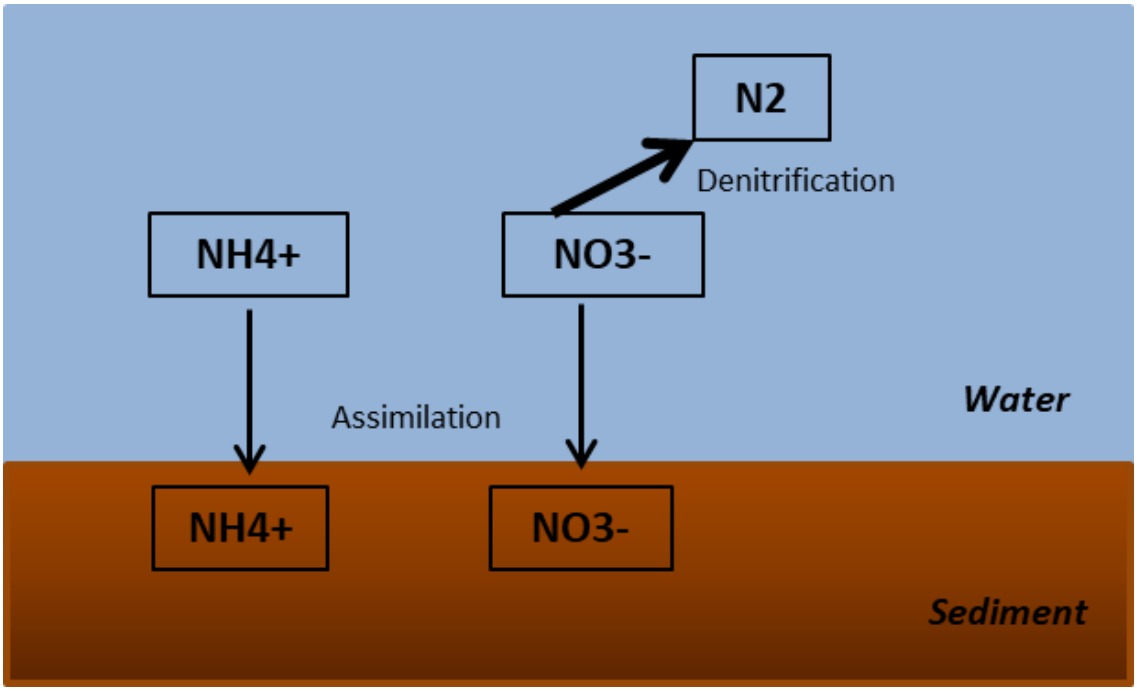

Figure 44: Nitrogen transformations found at the upstream East Canyon location.

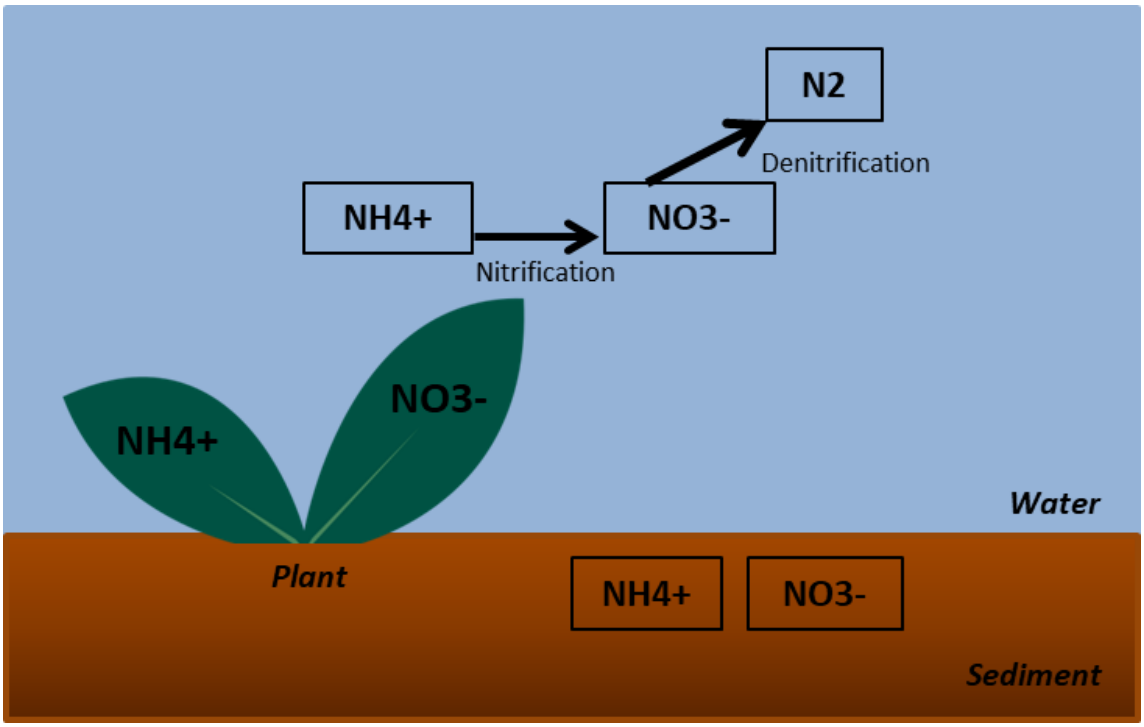

Figure 45: Nitrogen transformations found at the downstream Box Elder Creek location.

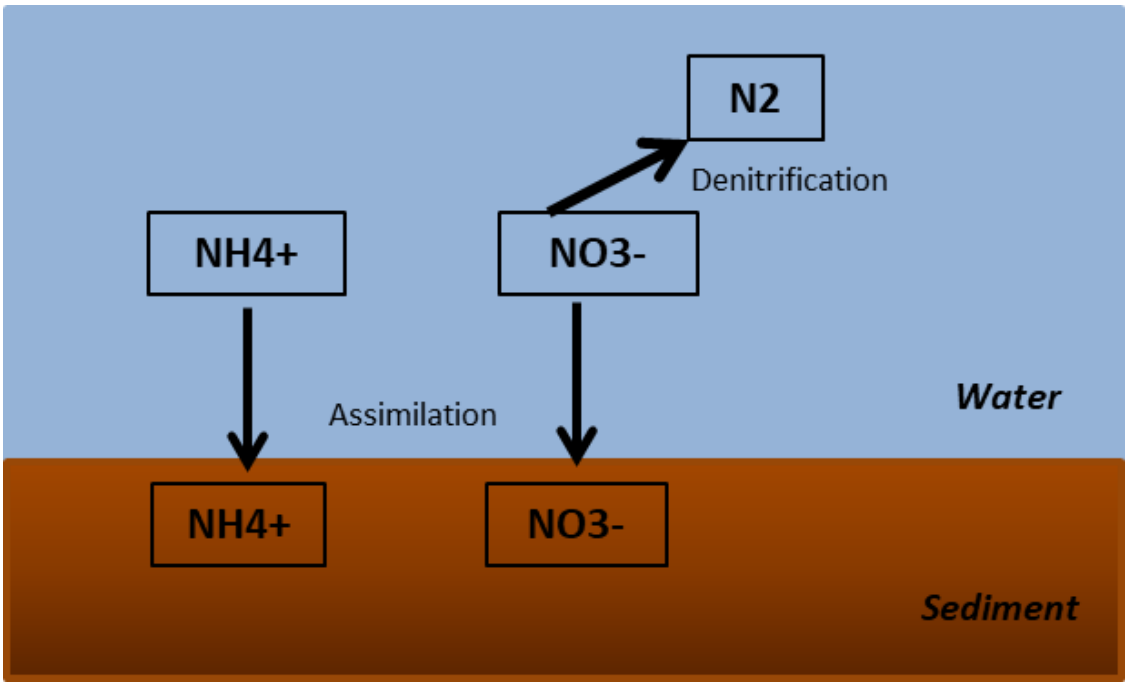

Figure 46: Nitrogen transformations found at the upstream Box Elder Creek location.

Figure 45 shows the significant nitrogen transformation rates found at the downstream Box Elder Creek location. At the downstream Box Elder Creek location, significant rates were only found for denitrification and nitrification with denitrification producing the higher rates. Significant denitrification rates were produced through all of the analyses methods used in this study for denitrification.

Figure 46 shows the significant nitrogen transformations found at the upstream Box Elder Creek location. Similar to the upstream East Canyon location, the upstream Box Elder Creek location only produced significant rates for denitrification and assimilation. The significant denitrification rates were only produced from the non-labelled AQ2 data.

CONCLUSIONS

The first objective of this study was to develop a chamber and frame design that could be installed in various locations with a range of sediment types. Additionally, it was critical to develop a design that would minimize leaks and ultimately create a closed system within the chamber. The final chamber design proved easy to install in sediments containing large rocks as well as in fine clay sediments. Special attention should consistently be paid to the installation process in order to successfully create the desired closed system and leak tests should always be performed after chamber installation and prior to beginning a study. The bromide tracer data collected from the chambers showed satisfactory closed system conditions at various sites, however, recovery issues were still present and a sensitivity to chamber content loss was evident.

The second objective was to develop sampling procedures that would prevent contamination of the samples, and to select analytical methods that could analyze the constituents of interest at their respective concentration ranges. Based on the QA/QC conducted throughout the analysis stage, issues from contamination were minimal. The $^{15}N_2$ data saw the most issues with contamination and a number of samples from the East Canyon study could not be used. The sampling method was altered for Box Elder Creek and fewer samples were compromised, however, the $^{15}N_2$ method was still the most sensitive to contamination. Variability among the analysis methods was also evident throughout the data analysis phase. Each analysis method requires its own respective preparation and the possibility for error increases with each step. Measures were consistently in place to prevent operator error, however, variability with the results

showed that discrepancies were still present. Overall, sufficient data were successfully collected and analyzed to complete the study.

The third objective was to produce ^{15}N mass balances with recoveries near 100% and to determine significant nitrogen transformation rates at the selected field sites. At East Canyon at least two of the chambers produced satisfactory ^{15}N mass balance recoveries. Issues surrounding the chambers did not allow for the study to run with more than three chambers which decreased the possibility of running a successful triplicate. The issues at East Canyon were addressed and the appropriate changes were made prior to beginning the Box Elder Creek study. Ultimately, a successful triplicate was run at both the upstream and downstream Box Elder Creek sites that produced satisfactory ^{15}N mass balance recoveries.

Significant denitrification and nitrification transformation rates were produced across the two study sites. Additionally, with the use of $^{15}NO_3^-$, ANAMMOX, DNRA, and assimilation rates could also be successfully calculated. Significant ANAMMOX, DNRA, and assimilation rates were found at various locations across the two study sites, although the overall rates of these transformations were 1 to 2 orders of magnitude lower than nitrification and denitrification rates. In the cases where both labelled and non-labelled data produced significant denitrification rates, there was no statistical difference between the analysis methods. The major role that labelled nitrate played in the study was to enable the determination of ANAMMOX, DNRA, and nitrogen assimilation rates. If ANAMMOX, DNRA, and nitrogen assimilation transformations are not significantly impacting a site, due to the complexity of the labelled data analysis, non-labelled data can be used to generate nitrification and denitrification rates.

The in-situ benthic chamber studies were conducted upstream and downstream of the WWTPs in order to determine the impact of WWTP effluent on test streams. In this study, significant nitrification rates were only found at the downstream locations of both project sites. This could be driven by higher ammonium and nitrifier population levels in the downstream locations coming from the WWTP effluent. At East Canyon, there were no significant differences between the downstream and upstream 0-order and 1^{st}-order denitrification rates. Box Elder Creek also showed no significant difference between upstream and downstream locations for the 0-order and 1^{st}-order denitrification rates. Ultimately, nitrate levels in the water were relatively low at both Box Elder Creek and East Canyon Creek. Additionally, the East Canyon Wastewater Reclamation Facility completely denitrifies and the Brigham City Wastewater Treatment Plant is a relatively small plant. Both factors suggest the potential for limited impact on their respective receiving stream. It is likely that if the study was conducted upstream and downstream of a WWTP that discharges larger flows, or does not include advanced nitrogen removal in the treatment process, a significant difference would have been observed. Additionally, the distance upstream and downstream of the WWTP could potentially alter the impact.

ENGINEERING SIGNIFICANCE

Although nitrogen, a limiting nutrient in the environment, is essential to all life, excess levels can have harmful effects on water bodies. Excess nitrogen can lead to eutrophication through an increase in plant and algae growth, as ultimately to oxygen depletion in a water system. The EPA has issued a nutrient standard development program that requires each state to determine numeric criteria for nitrogen and phosphorus in the various water bodies located within that state. A major component of the program is effluent standards from wastewater treatment plants. Due to the transformative nature of nitrogen in water, the addition of nitrogen to a water body is not the inherent threat but rather it is the addition of excess nitrogen that could overload the system. Since each water system is unique, nitrogen standards are generally site-specific. In order to develop these site-specific nitrogen standards, it is important to not only know the concentrations of nitrogen in the system but the nitrogen transformation rates as well.

Developing an in-situ method for determining valid, site-specific nitrogen transformation rates is important as it allows for a method of validating lab-based methods. Using lab-based methods to generate nitrogen transformation rates can be less time consuming and less expensive than field-based in situ methods, being a more feasible way for WWTPs to determine the nitrogen transformation rates downstream of their discharge locations. Developing an in-situ chamber method and subsequent lab-based methods for determining valid, site specific nitrogen transformation rates also helps in the development of the State of Utah's nutrient discharge standards by improving the accuracy of the water quality models used in the TMDL program.

The in-situ benthic chamber study also increases the understanding of the nitrogen transformation processes and how important these processes are in the overall fate of nitrogen in natural systems. The labelled isotope tracer techniques allow for the quantification of ANAMMOX, DNRA, and nitrogen assimilation processes in the system, as well as the role they play in natural waters and how these and the rest of the nitrogen transformation processes in streams are impacted by WWTP discharges.

FUTURE STUDIES

The major aspect of the chamber study necessary for successful results is to create a closed system within the chambers and minimize leaks. A valid triplicate chamber set would be ideal for the various analyses in order to provide statistical information on the variance at each location. Obtaining a valid triplicate chamber set that produced favorable bromide tracer results can be a challenge, and the best way to ensure a successful triplicate is to run more than just three chambers in the field. This step was added once some of the field work had already been completed, and ultimately only duplicate chamber sets could be used for the determination of nitrogen transformation rates in this field study. Additionally, if resources allow it would be beneficial to analyze the first few bromide tracer samples in the field as the chamber study is running. This would give immediate information on how the dose is mixing within the chambers. Any obvious issues within the chambers could then be addressed early on in the field study.

The field study also encountered many physical limitations. Instances occurred where due to the water level, chambers could only be installed in very specific locations within the streams and often it proved difficult to collect data from a complete cross-section. Ensuring that the water levels at the selected sites are favorable for chamber installation, or at the very least, that the field crew has the capability of working in various water levels, would ultimately be a helpful way to access more portions of a stream and in turn obtain more representative data.

Another limitation for the field study was the number of samples that were feasible to analyze. The diffusion jar procedure calls for at least three jars per sample and approximately 70 jars were used at each location at each site (nearly 300 jars for the entire study). If there is a need to analyze samples from more than three chambers, adjusting the sampling times to reduce the number of samples could make the handling of the samples much more feasible.

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APPENDICES

Appendix A: N_2 Sampling SOP

Dissolved $^{15}N_2$ Sampling and Preparation for Analysis

1. Purge 12 mL vials with He for 10 min prior to evacuation
2. Evacuate 12 mL vials to <50 mTorr while they are submerged in He purged water. Store evacuated vials in He purged water-filled containers.
3. Collect 30 mL of sample water into a 60 mL plastic syringe fitted with a stopcock-
4. Expel bubbles to eliminate any headspace and close the stopcock
5. Submerge the syringe containing the sample in water in a tub kept at stream temperature
6. Introduce 18 mL of high purity He to the syringe while it is submerged in water
7. Gently agitate the submerged syringe for 10 min to achieve equilibration of dissolved N_2 with the headspace
8. Inject 14 mL of headspace gas into a 12 mL, pre-evacuated vial kept submerged below ~5 mm of water.

Appendix B: KCl Extraction SOP

KCl Extraction for Sediments

Summary

The 2M KCl solution is used to facilitate ion exchange for any NO_3 and NH_3 that has sorbed to the sediments. The KCl will solubilize the NO_3 and NH_3 and keep it in solution. The purpose is to determine the initial and final NO_3 and NH_3 concentrations of the sediment use in other experiment for the overall mass balance of the system.

Materials

1 L volumetric flask
60 mL glass sample vial with flat bottom and lid
2 M KCl (149.1 g/L)
Shaker
Aluminum weigh boats

Procedure

1. **Soil Moisture Content**
    a. Record the weight of an aluminum boat
    b. Tare the boat then add 10 g ± 0.5 g (record weight) of saturated sediment sample
    c. Place the sample into a drying oven (60-105°C) until mass does not change
    d. Weigh (and record) the dried boat and sediment sample on the same scale
    e. Subtract the weight of the dry boat/sediment sample from the wet boat/sediment sample to determine the amount of water in the sediment
2. **Extraction Procedure**
    a. Weigh out a 3 g ± 0.5 g (record weight) saturated sediment sample in a 50 mL centrifuge tube (not Teflon tubes)
    b. Add 30 mL of 2 M KCl to centrifuge tube
    c. Arrange samples on shaker so that the length of the vial is parallel to the direction of movement of the shaker table. Shake for 1 hour at low speed
    d. Centrifuge at 10,000 for 15 minutes
    e. Prepare samples for diffusion:
        a. Pull 30 mL of liquid extract from sample vial using a pipette and put into a pint sized jar

    OR

    f. Prepare samples for AQ2:
        a. Pull 15 mL of liquid extract from centrifuge tube using a pipette. Filter sample through a 45µm syringe filter into a 16 mL plastic sample vial and cap

Data Analysis

1. Collect results of AQ2 and analyze first for QC, adjust results as needed base off of QC
2. Normalize the data by multiplying by volume of KCl solution added (30mL) and dividing by mass of soil added (using recorded soil weights)
3. Plot initial and final data

Appendix C: Mixing & Hydraulic Efficiencies Test Raw Data

#1		#2		#3	
Time	Sp. Cond.	Time	Sp. Cond.	Time	Sp. Cond.
minutes	*uS/cm*	*minutes*	*uS/cm*	*minutes*	*uS/cm*
0	455	0	445	0	427
0.5	4160	0.5	1120	0.5	1120
1	1540	1	1120	1	1100
1.5	1160	1.5	1080	1.5	1110
2	1100	2	1080	2	1110
2.5	1080	2.5	1070	2.5	1110
3	1080	3	1070	3	1100
3.5	1070	3.5	1070	3.5	1100
4	1070	4	1070	4	1100
4.5	1070	4.5	1070	4.5	1100
5	1060	5	1070	5	1100
5.5	1060	5.5	1070	5.5	1100
6	1060	6	1070	6	1100
6.5	1050	6.5	1070	6.5	1100
7	1050	7	1070	7	1100
7.5	1050	7.5	1070	7.5	1100
8	1050	8	1070	8	1110
8.5	1040	8.5	1070	8.5	1110
9	1040	9	1070	9	1110
9.5	1040	9.5	1070	9.5	1110
10	1030	10	1070	10	1110
10.5	1030	10.5	1070	10.5	1100
11	1030	11	1070	11	1100
11.5	1020	11.5	1070	11.5	1100
12	1020	12	1070	12	1100
12.5	1020	12.5	1070	12.5	1100
13	1020	13	1070	13	1100
13.5	1010	13.5	1070	13.5	1100
14	1010	14	1070	14	1100
14.5	1000	14.5	1070	14.5	1100
15	1000	15	1070	15	1100
15.5	999	15.5		15.5	1100
16	994	16		16	1100
16.5	993	16.5		16.5	1100

17	990	17		17	1100
17.5	988	17.5		17.5	1100
18	985	18		18	1100
18.5	982	18.5		18.5	1100
19	980	19		19	1100
19.5	976	19.5		19.5	1100
20	972	20		20	1100
20.5	971	20.5		20.5	1110
21	970	21		21	1110
21.5	967	21.5		21.5	1110
22	964	22		22	1110
22.5	964	22.5		22.5	1110
23		23		23	1110
23.5		23.5		23.5	1110
24		24		24	1100
24.5		24.5		24.5	1100
25		25		25	1100
25.5		25.5		25.5	1100
26		26		26	1100
26.5		26.5		26.5	1100
27		27		27	1100
27.5		27.5		27.5	1100
28		28		28	1100
28.5		28.5		28.5	1100
29		29		29	1100
29.5		29.5		29.5	1100
30		30		30	1100

Appendix D: Bromide Raw Data

East Canyon Downstream Leak Test				
Chamber	**Time**	**mV**	**PPM**	**% Loss**
1	Background	91	6	
1	0	15	121	
1	1	14	126	-4%
1	4	15	121	0%
2	Background	100	4.39	
2	0	15	121.25	
2	1	15	121.25	0%
2	4	15	121.25	0%
3	Background	96	5.14	
3	0	27	75.90	
3	1	18	107.85	-42%
3	4	17	112.14	-48%
4	Background	96	5.14	
4	0	19	103.72	
4	1	19	103.72	0%
4	4	23	88.73	14%
5	Background	94	5.55	
5	0	15	121.25	
5	1	16	116.60	4%
5	4	16	116.60	4%

East Canyon Upstream Leak Test				
Chamber	**Time**	**mV**	**PPM**	**% Loss**
1	Background	114	1.39	
1	0	22	63.18	
1	1	21	65.86	-4%
1	4	20	68.65	-9%
2	Background	108	1.78	
2	0	18	74.59	
2	1	18	74.59	0%
2	4	18	74.59	0%
3	Background	112	1.51	
3	0	21	65.86	
3	1	20	68.65	-4%
3	4	20	68.65	-4%
4	Background	104	2.10	
4	0	16	81.05	
4	1	15	84.48	-4%
4	4	15	84.48	-4%

East Canyon Downstream				
Chamber	**Time**	**mV**	**PPM**	**% Loss**
B-1		106	3.9	
B-2		108	3.6	
B-3		110	3.4	
1	0	20	103.1	0%
1	1	20	103.1	0%
1	2	20	103.1	0%
1	3	20	103.1	0%
1	4	21	99.2	4%
1	4	21	99.2	4%
2	0	5	113.6	0%
2	1	6	109.2	4%
2	2	8	101.0	11%
2	3	10	79.9	30%
2	4	12	73.6	35%
3	0	30	34.9	0%
3	1	19	55.0	-58%
3	2	14	67.7	-94%
3	3	13	70.6	-102%
3	4	9	83.3	-139%

East Canyon Upstream			
Chamber	**Time**	**mV**	**PPM**
B-1		105	1.5
B-2		107	1.3
B-3		110	1.2
1	0	110	1.1
1	1	95	2.1
1	2	95	2.1
1	3	102	1.5
1	4	104	1.4
1	4	104	1.4
2	0	101	1.6
2	1	96	2.0
2	2	99	1.7
2	3	102	1.5
2	4	103	1.5
3	0	101	1.6
3	1	98	1.8
3	2	101	1.6
3	3	105	1.3
3	4	105	1.3

Box Elder Creek Downstream Leak Test				
Chamber	**Time**	**mV**	**Br (mg/L)**	**% Loss**
B-1		130	0.6	
B-2		130	0.6	
B-3		132	0.5	
1	0	26	65.7	0%
1	1	26	65.7	0%
1	4	26	65.7	0%
2	0	16	103.2	57%
2	1	17	98.6	50%
2	4	17	98.6	0%
3	0	14	112.9	15%
3	1	15	108.0	9%
3	4	16	103.2	5%
4	0	21	82.3	17%
4	1	21	82.3	0%
4	4	22	78.7	4%
5	0	17	98.6	20%
5	1	18	94.3	15%
5	4	19	90.1	9%

Box Elder Creek Upstream Leak Test				
Chamber	**Time**	**mV**	**Br (mg/L)**	**% Loss**
B-1		127	1.2	
1	0	14	110.1	
1	1	13	114.6	4%
1	4	14	110.1	0%
2	0	14	110.1	
2	1	14	110.1	0%
2	4	90	5.2	95%
3	0	19	90.1	
3	1	19	90.1	0%
3	4	22	79.9	11%

Box Elder Creek Downstream			
Chamber	**Time**	**mV**	**Br (mg/L)**
B-1		112	2.1
B-2		115	1.9
B-3		115	1.9
2	0	22	73.8
2	1	22	73.8
2	2	25	65.6
2	3	23	71.0
2	4	23	71.0
3	0	18	86.4
3	1	18	86.4
3	2	19	83.1
3	3	19	83.1
3	4	20	79.9
4	0	13	105.2
4	1	14	101.1
4	2	14	101.1
4	3	15	97.2
4	4	15	97.2
5	0	16	93.5
5	1	17	89.9
5	2	17	89.9
5	3	18	86.4
5	4	18	86.4

Box Elder Creek Upstream				
Chamber	**Time**	**mV**	**Br (mg/L)**	**% Loss**
B-1		133	0.6	
B-2		133	0.6	
B-3		132	0.6	
1	0	15	85.6	0%
1	1	16	82.1	4%
1	2	17	78.7	8%
1	3	18	75.5	12%
1	4	21	66.6	22%
2	0	14	89.3	0%
2	1	15	85.6	4%
2	2	16	82.1	8%
2	3	17	78.7	12%
2	4			
3	0	16	82.1	0%
3	1	17	78.7	4%
3	2	18	75.5	8%
3	3	19	72.4	12%
3	4	20	69.5	15%

Appendix E: Dissolved Oxygen (mg/L) Raw Data

Box Elder Creek							
Upstream							
Chamber 1		Chamber 2		Chamber 3		Background	
Time	DO	Time	DO	Time	DO	Time	DO
10:25 AM	7.2	10:27 AM	6.7	10:26 AM	8.5	11:12 AM	7.5
10:40 AM	7.8	10:42 AM	7	10:41 AM	8.9	11:27 AM	7.2
10:55 AM	7.4	10:57 AM	6.9	10:56 AM	9.5	11:42 AM	7.3
11:10 AM	7.6	11:12 AM	6.7	11:11 AM	9.9	11:57 AM	7.2
11:25 AM	8	11:27 AM	6.7	11:26 AM	10.7	12:12 PM	8
11:40 AM	7.8	11:42 AM	6.5	11:41 AM	11.4	12:27 PM	7.7
11:55 AM	8.2	11:57 AM	6.5	11:56 AM	11.9	12:42 PM	7.5
12:10 PM	8.6	12:12 PM	6.5	12:11 PM	12.3	12:57 PM	8
12:25 PM	9.2	12:27 PM	6.6	12:26 PM	12.6	1:12 PM	8
12:40 PM	9.1	12:42 PM	6.5	12:41 PM	13.2	1:27 PM	7.6
12:55 PM	9.3	12:57 PM	6.5	12:56 PM	13.9	1:42 PM	8.2
1:10 PM	9.1	1:12 PM	6.6	1:11 PM	14.4	1:57 PM	8.3
1:25 PM	9.6	1:27 PM	6.6	1:26 PM	15.2	2:12 PM	7.9
1:40 PM	9.8	1:42 PM	6.7	1:41 PM	15.5	2:27 PM	8.1
1:55 PM	10	1:57 PM	6.8	1:56 PM	16	2:42 PM	8.4
2:10 PM	10.4	2:12 PM	6.8	2:11 PM	15.6	2:57 PM	8.1
2:25 PM	10.6	2:27 PM	6.9	2:26 PM	16.2	3:12 PM	8.3
2:40 PM	11.2	2:42 PM	6.9	2:41 PM	17	3:27 PM	7.4
2:55 PM	10.9	2:57 PM	6.9	2:56 PM	17.3	3:42 PM	8.3
3:10 PM	11.2	3:12 PM	6.8	3:11 PM	17.9	3:57 PM	8.2
3:25 PM	11.3	3:27 PM	6.9	3:26 PM	18.2	4:12 PM	8.2
3:40 PM	11.8	3:42 PM	6.8	3:41 PM	18.4	4:27 PM	7.9
3:55 PM	11.5	3:57 PM	6.5	3:56 PM	18.3	4:42 PM	7.6
4:10 PM	11.5	4:12 PM	6.7	4:11 PM	18.1	4:57 PM	6.8
4:25 PM	12.4	4:27 PM	6.7	4:26 PM	18.5	5:12 PM	6.7
4:40 PM	12.4	4:42 PM	6.5	4:41 PM	18.9	5:27 PM	7.4
4:55 PM	11.9	4:57 PM	6.3	4:56 PM	19.1	5:42 PM	7.3

5:10 PM	12	5:12 PM	6	5:11 PM	19.3	5:57 PM	7
5:25 PM	12.2	5:27 PM	5.8	5:26 PM	19.2	6:12 PM	6.9
5:40 PM	11.4	5:42 PM	5.6	5:41 PM	19.3	6:27 PM	7
5:55 PM	11.7	5:57 PM	5.4	5:56 PM	19.7	6:42 PM	7.6
6:10 PM	11.6	6:12 PM	5.3	6:11 PM	19.1	6:57 PM	7.6
6:25 PM	11.5	6:27 PM	5	6:26 PM	19	7:12 PM	7.2
6:40 PM	11.4	6:42 PM	4.8	6:41 PM	18.3	7:27 PM	7
6:55 PM	11.4	6:57 PM	4.6	6:56 PM	18.1	7:42 PM	6.9
7:10 PM	11.7	7:12 PM	4.5	7:11 PM	18.1	7:57 PM	6.6
7:25 PM	11.8	7:27 PM	4.3	7:26 PM	18.1	8:12 PM	7
7:40 PM	11.2	7:42 PM	4.1	7:41 PM	17.7	8:27 PM	6.7
7:55 PM	10.8	7:57 PM	3.8	7:56 PM	17.5	8:42 PM	6.1
8:10 PM	11	8:12 PM	3.6	8:11 PM	16.8	8:57 PM	6.4
8:25 PM	10.8	8:27 PM	3.4	8:26 PM	16.8	9:12 PM	6.3
8:40 PM	10.2	8:42 PM	3.2	8:41 PM	16.1	9:27 PM	6.3
8:55 PM	10.3	8:57 PM	3	8:56 PM	16.1	9:42 PM	5.7
9:10 PM	10	9:12 PM	2.9	9:11 PM	15.3	9:57 PM	5.8
9:25 PM	9.9	9:27 PM	2.7	9:26 PM	15.1	10:12 PM	5.5
9:40 PM	9.4	9:42 PM	2.4	9:41 PM	14.8	10:27 PM	5.4
9:55 PM	9.8	9:57 PM	2.3	9:56 PM	14.5	10:42 PM	5
10:10 PM	9.4	10:12 PM	2.1	10:11 PM	14.4	10:57 PM	4.9
10:25 PM	9	10:27 PM	2	10:26 PM	14.2	11:12 PM	5.3
10:40 PM	8.9	10:42 PM	1.8	10:41 PM	13.6	11:27 PM	5.6
10:55 PM	8.7	10:57 PM	1.9	10:56 PM	13.7	11:42 PM	5.5
11:10 PM	8.1	11:12 PM	6	11:11 PM	13.3	11:57 PM	5.3
11:25 PM	8.4	11:27 PM	6.1	11:26 PM	13.1	12:12 AM	5.5
11:40 PM	8	11:42 PM	6.2	11:41 PM	13	12:27 AM	5.4
11:55 PM	8	11:57 PM	6.3	11:56 PM	12.5	12:42 AM	5.7
12:10 AM	8.3	12:12 AM	6.3	12:11 AM	12.3	12:57 AM	5.6
12:25 AM	7.9	12:27 AM	6.4	12:26 AM	12.1	1:12 AM	5.5
12:40 AM	7.7	12:42 AM	6.4	12:41 AM	11.8	1:27 AM	5.2
12:55 AM	7.5	12:57 AM	6.5	12:56 AM	11.4	1:42 AM	5.6
1:10 AM	7.4	1:12 AM	6.6	1:11 AM	11.4	1:57 AM	5.6
1:25 AM	7.1	1:27 AM	6.6	1:26 AM	11.2	2:12 AM	5.7
1:40 AM	7	1:42 AM	6.8	1:41 AM	10.7	2:27 AM	5.9
1:55 AM	7	1:57 AM	6.8	1:56 AM	10.6	2:42 AM	5.7
2:10 AM	6.7	2:12 AM	7	2:11 AM	10.4	2:57 AM	5.9
2:25 AM	6.6	2:27 AM	7	2:26 AM	10.3	3:12 AM	5.9
2:40 AM	6.4	2:42 AM	7	2:41 AM	10.2	3:27 AM	6
2:55 AM	6.5	2:57 AM	7.1	2:56 AM	9.9	3:42 AM	5.5
3:10 AM	6.2	3:12 AM	7	3:11 AM	9.6	3:57 AM	5.9

3:25 AM	5.9	3:27 AM	7	3:26 AM	9.4	4:12 AM	6
3:40 AM	6.1	3:42 AM	7	3:41 AM	9.2	4:27 AM	5.8
3:55 AM	5.7	3:57 AM	7	3:56 AM	8.9	4:42 AM	5.8
4:10 AM	5.7	4:12 AM	7	4:11 AM	8.7	4:57 AM	5.7
4:25 AM	5.6	4:27 AM	7	4:26 AM	8.6	5:12 AM	5.6
4:40 AM	5.4	4:42 AM	7.1	4:41 AM	8.4	5:27 AM	6.2
4:55 AM	5.3	4:57 AM	7.2	4:56 AM	8.1	5:42 AM	6.4
5:10 AM	5.2	5:12 AM	7.2	5:11 AM	8.1	5:57 AM	6.6
5:25 AM	5.1	5:27 AM	7.3	5:26 AM	8	6:12 AM	6.5
5:40 AM	5.1	5:42 AM	7.3	5:41 AM	7.9	6:27 AM	6.7
5:55 AM	4.9	5:57 AM	7.3	5:56 AM	7.7	6:42 AM	6.9
6:10 AM	4.9	10:14 AM	5.8	6:11 AM	7.5	6:57 AM	6.9
6:25 AM	4.8			6:26 AM	7.5	7:12 AM	6.7
6:40 AM	4.9			6:41 AM	7.4	7:27 AM	6.9
6:55 AM	4.9			6:56 AM	7.6	7:42 AM	7.4
7:10 AM	4.8			7:11 AM	7.4	7:57 AM	7.8
7:25 AM	4.8			7:26 AM	7.4	8:12 AM	7.9
7:40 AM	4.7			7:41 AM	7.5	8:27 AM	6.8
7:55 AM	4.8			7:56 AM	7.5	8:42 AM	7.8
8:10 AM	5.1			8:11 AM	7.4	8:57 AM	8.2
8:25 AM	5.2			8:26 AM	8.1	9:12 AM	8
8:40 AM	5.3			8:41 AM	8.6	9:27 AM	8
8:55 AM	5.6			8:56 AM	8.8	9:42 AM	7.8
9:10 AM	5.9			9:11 AM	9.3	9:57 AM	7.5
9:25 AM	6.1			9:26 AM	10	10:12 AM	7.3
9:40 AM	6.4			9:41 AM	10.5		
9:55 AM	6.4			9:56 AM	11		
10:10 AM	6.9			10:11 AM	11.3		

Box Elder Creek

Downstream

Chamber 1		Chamber 2		Chamber 3		Background	
Time	DO	Time	DO	Time	DO	Time	DO
11:09 AM	4.5	11:08 AM	3.9			9:52 AM	2.6
11:24 AM	4.7	11:23 AM	4.2			10:07 AM	2.7
11:39 AM	4.9	11:38 AM	4.4			10:22 AM	3.1
11:54 AM	4.9	11:53 AM	4.6	11:53 AM	4.4	10:37 AM	3.3
12:09 PM	5	12:08 PM	4.5	12:53 PM	4.3	10:52 AM	3.5
12:24 PM	4.9	12:23 PM	4.6	7:38 PM	0.2	11:07 AM	3.7
12:39 PM	4.7	12:38 PM	4.7	10:09 AM	2.5	11:22 AM	3.8
12:54 PM	4.7	12:53 PM	4.6			11:37 AM	4.1
1:09 PM	4.7	1:08 PM	4.6			11:52 AM	4.5
1:24 PM	4.6	1:23 PM	4.4			12:07 PM	4.5
1:39 PM	4.4	1:38 PM	4.6			12:22 PM	4.7
1:54 PM	4.4	1:53 PM	4.2			12:37 PM	5
2:09 PM	4.3	2:08 PM	4.2			12:52 PM	5.1
2:24 PM	4.2	2:23 PM	4.2			1:07 PM	5.3
2:39 PM	4	2:38 PM	4			1:22 PM	5.3
2:54 PM	3.9	2:53 PM	3.8			1:37 PM	5.3
3:09 PM	3.9	3:08 PM	3.8			1:52 PM	5.4
3:24 PM	3.7	3:23 PM	3.7			2:07 PM	5.7
3:39 PM	3.6	3:38 PM	3.6			2:22 PM	5.5
3:54 PM	3.4	3:53 PM	3.4			2:37 PM	5.5
4:09 PM	3.3	4:08 PM	3.3			2:52 PM	5.5
4:24 PM	3.2	4:23 PM	3.3			3:07 PM	5.6
4:39 PM	3.1	4:38 PM	3.1			3:22 PM	5.6
4:54 PM	3	4:53 PM	2.8			3:37 PM	5.5
5:09 PM	2.9	5:08 PM	2.7			3:52 PM	5.6
5:24 PM	2.7	5:23 PM	2.5			4:07 PM	5.8
5:39 PM	2.6	5:38 PM	2.4			4:22 PM	5.8
5:54 PM	2.5	5:53 PM	2.2			4:37 PM	5.6
6:09 PM	2.3	6:08 PM	2			4:52 PM	5.3
6:24 PM	2.2	6:23 PM	1.9			5:07 PM	5.5

6:39 PM	2.1	6:38 PM	1.8			5:22 PM	5
6:54 PM	2	6:53 PM	1.6			5:37 PM	5.1
7:09 PM	1.8	7:08 PM	1.5			5:52 PM	5.1
7:24 PM	1.8	7:23 PM	1.4			6:07 PM	4.7
7:39 PM	1.7	7:38 PM	1.2			6:22 PM	4.5
7:54 PM	1.5	7:53 PM	1			6:37 PM	4.7
8:09 PM	1.5	8:08 PM	0.9			6:52 PM	4.4
8:24 PM	1.4	8:23 PM	0.7			7:07 PM	4.1
8:39 PM	1.3	8:38 PM	0.6			7:22 PM	4
8:54 PM	1.3	8:53 PM	0.4			7:37 PM	4.1
9:09 PM	1.2	9:08 PM	0.3			7:52 PM	3.8
9:24 PM	1	9:23 PM	0.2			8:07 PM	3.7
9:39 PM	0.9	9:38 PM	0.2			8:22 PM	3.3
9:54 PM	0.8	9:53 PM	0.1			8:37 PM	3.1
10:09 PM	0.8	10:08 PM	0			8:52 PM	3
10:24 PM	0.7	10:23 PM	0			9:07 PM	2.9
10:39 PM	0.7	10:38 PM	0			9:22 PM	2.7
10:54 PM	0.6	10:35 AM	2.6			9:37 PM	2.4
11:09 PM	0.6	10:35 AM	2.7			9:52 PM	2.4
11:24 PM	0.5					10:07 PM	2.2
11:39 PM	0.5					10:22 PM	2
11:54 PM	0.4					10:37 PM	1.7
12:09 AM	0.4					10:52 PM	1.4
12:24 AM	0.4					11:07 PM	1.3
12:39 AM	0.3					11:22 PM	1.1
12:54 AM	0.3					11:37 PM	1.1
1:09 AM	0.3					11:52 PM	1.1
1:24 AM	0.3					12:07 AM	1.2
1:39 AM	0.3					12:22 AM	1.2
1:54 AM	0.3					12:37 AM	1.2
2:09 AM	0.3					12:52 AM	1
2:24 AM	0.3					1:07 AM	0.9
2:39 AM	0.3					1:22 AM	0.7
2:54 AM	0.3					1:37 AM	0.7
3:09 AM	0.2					1:52 AM	0.6
3:24 AM	0.3					2:07 AM	0.6
3:39 AM	0.2					2:22 AM	0.5
3:54 AM	0.2					2:37 AM	0.5
4:09 AM	0.2					2:52 AM	0.5
4:24 AM	0.2					3:07 AM	0.5
4:39 AM	0.2					3:22 AM	0.4

4:54 AM	0.2					3:37 AM	0.4
5:09 AM	0.2					3:52 AM	0.4
5:24 AM	0.2					4:07 AM	0.3
5:39 AM	0.2					4:22 AM	0.3
5:54 AM	0.2					4:37 AM	0.3
6:09 AM	0.2					4:52 AM	0.2
6:24 AM	0.2					5:07 AM	0.2
6:39 AM	0.2					5:22 AM	0.2
6:54 AM	0.2					5:37 AM	0.2
7:09 AM	0.2					5:52 AM	0.2
7:24 AM	0.3					6:07 AM	0.2
7:39 AM	0.5					6:22 AM	0.2
7:54 AM	0.6					6:37 AM	0.2
8:09 AM	0.7					6:52 AM	0.2
8:24 AM	0.9					7:07 AM	0.3
8:39 AM	1.2					7:22 AM	0.5
8:54 AM	1.6					7:37 AM	0.7
9:09 AM	2.1					7:52 AM	0.8
9:24 AM	2.6					8:07 AM	0.7
9:39 AM	3					8:22 AM	0.7
9:54 AM	3.4					8:37 AM	0.8
10:09 AM	3.8					8:52 AM	0.9
10:24 AM	4.2					9:07 AM	0.9
						9:22 AM	1.1
						9:37 AM	1.3
						9:52 AM	1.3
						10:07 AM	1.5
						10:22 AM	1.2
						10:37 AM	0.7

East Canyon

Upstream

Chamber 1		Chamber 2		Background	
Time	DO	Time	DO	Time	DO
12:12 PM	7.3	12:11 PM	8	12:28 PM	9.83
12:28 PM	7.2	12:12 PM	8.1	1:28 PM	9.29
12:43 PM	7.1	12:27 PM	7.7	4:28 PM	6.25
12:58 PM	7.5	12:42 PM	7.4	8:59 PM	6.25
1:13 PM	7.1	12:57 PM	7.1	10:15 AM	10.17
1:28 PM	7.1	1:12 PM	7.2		
1:43 PM	7.2	1:27 PM	6.9		
1:58 PM	7.1	1:42 PM	6.7		
2:13 PM	7.3	1:57 PM	6.3		
2:28 PM	7.3	2:12 PM	6.4		
2:43 PM	7	2:27 PM	6.1		
2:58 PM	7.2	2:42 PM	6		
3:13 PM	7.4	2:57 PM	5.7		
3:28 PM	7.5	3:12 PM	5.5		
3:43 PM	7.4	3:27 PM	5.3		
3:58 PM	7.2	3:42 PM	5.3		
4:13 PM	7.1	3:57 PM	5.3		
4:28 PM	7	4:12 PM	5.1		
4:43 PM	6.8	4:27 PM	5.1		
4:58 PM	7.2	4:42 PM	5		
5:13 PM	7.2	4:57 PM	4.7		
5:28 PM	7.2	5:12 PM	4.6		
5:43 PM	7.3	5:27 PM	4.6		
5:58 PM	7.2	5:42 PM	4.5		
6:13 PM	7	5:57 PM	4.4		
6:28 PM	6.9	6:12 PM	4.3		
6:43 PM	7	6:27 PM	4.2		
6:58 PM	6.9	6:42 PM	4		
7:13 PM	6.9	6:57 PM	4		
7:28 PM	6.8	7:13 PM	3.9		

7:43 PM	6.6	7:28 PM	3.7		
7:59 PM	6.6	7:43 PM	3.6		
8:14 PM	6.4	7:58 PM	3.5		
8:29 PM	6.4	8:13 PM	3.5		
8:44 PM	6.1	8:28 PM	3.3		
8:59 PM	5.8	8:43 PM	3.1		
9:14 PM	5.8	8:58 PM	3.2		
9:29 PM	5.7	9:13 PM	2.9		
9:44 PM	5.5	9:28 PM	2.7		
9:59 PM	5.5	9:43 PM	2.7		
10:14 PM	5.4	9:58 PM	2.6		
10:29 PM	5.3	10:13 PM	2.4		
10:44 PM	5.2	10:28 PM	2.3		
10:59 PM	5.2	10:43 PM	2.2		
11:14 PM	4.8	10:58 PM	2.1		
11:29 PM	4.9	11:13 PM	2		
11:44 PM	4.8	11:28 PM	1.9		
11:59 PM	4.5	11:43 PM	1.8		
12:14 AM	4.6	11:58 PM	1.7		
12:29 AM	4.6	12:13 AM	1.6		
12:44 AM	4.5	12:28 AM	1.5		
12:59 AM	4.4	12:43 AM	1.5		
1:14 AM	4.2	12:58 AM	1.4		
1:29 AM	4.2	1:13 AM	1.3		
1:44 AM	3.9	1:28 AM	1.2		
1:59 AM	4	1:43 AM	1.1		
2:14 AM	3.8	1:58 AM	1		
2:29 AM	3.8	2:13 AM	0.9		
2:44 AM	3.6	2:28 AM	0.9		
2:59 AM	3.6	2:44 AM	0.8		
3:14 AM	3.5	2:59 AM	0.8		
3:30 AM	3.4	3:14 AM	0.7		
3:45 AM	3.4	3:29 AM	0.7		
4:00 AM	3.3	3:44 AM	0.6		
4:15 AM	3.1	3:59 AM	0.6		
4:30 AM	3.2	4:14 AM	0.5		
4:45 AM	3.2	4:29 AM	0.5		
5:00 AM	2.9	4:44 AM	0.4		
5:15 AM	3	4:59 AM	0.4		
5:30 AM	2.9	5:14 AM	0.3		
5:45 AM	2.8	5:29 AM	0.3		

6:00 AM	2.7	5:44 AM	0.3		
6:15 AM	2.9	5:59 AM	0.2		
6:30 AM	2.6	6:14 AM	0.2		
6:45 AM	2.5	6:29 AM	0.1		
7:00 AM	2.6	6:44 AM	0.1		
7:15 AM	2.5	6:59 AM	0.1		
7:30 AM	2.6	7:14 AM	0.1		
7:45 AM	2.6	7:29 AM	0.1		
8:00 AM	2.6	7:44 AM	0.1		
8:15 AM	2.7	7:59 AM	0.1		
8:30 AM	2.6	8:14 AM	0.1		
8:45 AM	2.8	8:29 AM	0.1		
9:00 AM	2.8	8:44 AM	0.2		
9:15 AM	2.9	8:59 AM	0.2		
9:30 AM	3.1	9:14 AM	0.3		
9:45 AM	3.1	9:29 AM	0.3		
10:00 AM	3.3	9:44 AM	0.3		
10:15 AM	2.4	9:59 AM	0.5		
		10:15 AM	0.6		
		10:30 AM	0.6		

East Canyon

Downstream						USGS	
Chamber 1		Chamber 2		Chamber 3		Background	
Time	DO	Time	DO	Time	DO	Time	DO
12:56 PM	8.3			12:59 PM	8.8	1:00 PM	9.6
12:56 PM	8			12:59 PM	8.8	1:15 PM	9.5
12:57 PM	8.3			12:59 PM	8.8	1:30 PM	9.5
12:59 PM	8.6			12:59 PM	8.9	1:45 PM	9.3
12:59 PM	8.5	1:00 PM	10.2	1:00 PM	8.9	2:00 PM	9.2
1:07 PM	8.7	2:00 PM	8.1	1:14 PM	8.8	2:15 PM	9.2
1:08 PM	8.2	9:00 PM	13.2	1:16 PM	9	2:30 PM	9.1
1:11 PM	8.4	10:19 AM	13.4	1:17 PM	9.1	2:45 PM	9.1
1:14 PM	8.8			1:17 PM	9.1	3:00 PM	9.1
1:15 PM	8.9			1:17 PM	9.2	3:15 PM	9
1:30 PM	9.4			1:17 PM	9.2	3:30 PM	9
1:45 PM	9.6			1:32 PM	9.3	3:45 PM	8.9
2:00 PM	9.9			1:47 PM	9.9	4:00 PM	8.7
2:15 PM	11.1			2:03 PM	9.9	4:15 PM	8.5
2:30 PM	10.8			2:18 PM	10.3	4:30 PM	8.4
2:45 PM	11.6			2:33 PM	10.6	4:45 PM	8.5
4:46 PM	14.4			2:48 PM	10.8	5:00 PM	8.5
9:00 PM	10			3:03 PM	11.4	5:15 PM	8.5
10:19 AM	10			3:18 PM	11	5:30 PM	8.4
				3:33 PM	11.2	5:45 PM	8.3
				3:48 PM	11.9	6:00 PM	8.2
				4:03 PM	12	6:15 PM	8
				4:18 PM	11.7	6:30 PM	7.8
				4:33 PM	12.2	6:45 PM	7.6
				4:48 PM	12.3	7:00 PM	7.4
				5:03 PM	11.9	7:15 PM	7.2
						7:30 PM	7
						7:45 PM	6.8
						8:00 PM	6.5
						8:15 PM	6.3

						8:30 PM	6.2
						8:45 PM	6
						9:00 PM	5.8
						9:15 PM	5.7
						9:30 PM	5.6
						9:45 PM	5.6
						10:00 PM	5.5
						10:15 PM	5.5
						10:30 PM	5.5
						10:45 PM	5.4
						11:00 PM	5.4
						11:15 PM	5.4
						11:30 PM	5.4
						11:45 PM	5.4
						12:00 AM	5.4
						12:15 AM	5.5
						12:30 AM	5.5
						12:45 AM	5.5
						1:00 AM	5.5
						1:15 AM	5.5
						1:30 AM	5.5
						1:45 AM	5.5
						2:00 AM	5.5
						2:15 AM	5.5
						2:30 AM	5.5
						2:45 AM	5.5
						3:00 AM	5.5
						3:15 AM	5.6
						3:30 AM	5.6
						3:45 AM	5.6
						4:00 AM	5.6
						4:15 AM	5.6
						4:30 AM	5.6
						4:45 AM	5.7
						5:00 AM	5.7
						5:15 AM	5.7
						5:30 AM	5.7
						5:45 AM	5.7
						6:00 AM	5.7
						6:15 AM	5.8
						6:30 AM	5.8

						6:45 AM	5.8
						7:00 AM	5.9
						7:15 AM	6
						7:30 AM	6.1
						7:45 AM	6.2
						8:00 AM	6.3
						8:15 AM	6.6
						8:30 AM	7
						8:45 AM	7.3
						9:00 AM	7.7
						9:15 AM	8.1
						9:30 AM	8.3
						9:45 AM	8.5
						10:00 AM	8.8
						10:15 AM	8.9
						10:30 AM	9.1

Appendix F: Temperature (°C) Raw Data

Box Elder Creek

Upstream

Chamber 1		Chamber 2		Chamber 3		Background	
Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)
10:25 AM	19.1	10:27 AM	18.7	10:26 AM	18.8	11:12 AM	18.8
11:25 AM	19.4	11:27 AM	18.8	11:26 AM	19	12:12 PM	19
12:25 PM	19.6	12:27 PM	18.9	12:26 PM	19.2	1:12 PM	19.1
1:25 PM	19.9	1:27 PM	19	1:26 PM	19.4	2:12 PM	19.2
2:25 PM	20.2	2:27 PM	19.1	2:26 PM	19.6	3:12 PM	19.3
3:25 PM	20	3:27 PM	19.3	3:26 PM	19.7	4:12 PM	19.4
4:25 PM	20.3	4:27 PM	19.5	4:26 PM	19.9	5:12 PM	19.6
5:25 PM	20.4	5:27 PM	19.7	5:26 PM	20	6:12 PM	19.6
6:25 PM	20.6	6:27 PM	19.9	6:26 PM	20.2	7:12 PM	19.7
7:25 PM	20.8	7:27 PM	20.1	7:26 PM	20.3	8:12 PM	19.9
8:25 PM	20.8	8:27 PM	20.3	8:26 PM	20.5	9:12 PM	19.9
9:25 PM	21.1	9:27 PM	20.3	9:26 PM	20.6	10:12 PM	20.1
10:25 PM	21.1	10:27 PM	20.4	10:26 PM	20.7	11:12 PM	20.2
11:25 PM	21.2	11:27 PM	20.5	11:26 PM	20.8	12:12 AM	20.4
12:25 AM	21.3	12:27 AM	20.6	12:26 AM	20.9	1:12 AM	20.5
1:25 AM	21.3	1:27 AM	20.8	1:26 AM	21	2:12 AM	20.7
2:25 AM	21.6	2:27 AM	20.9	2:26 AM	21.1	3:12 AM	20.9
3:25 AM	21.8	3:27 AM	21	3:26 AM	21.2	4:12 AM	21
4:25 AM	22.1	4:27 AM	21.1	4:26 AM	21.4	5:12 AM	20.9
5:25 AM	22.3	5:27 AM	21.3	5:26 AM	21.6	6:12 AM	20.8
6:25 AM	22.5	6:27 AM	21.5	6:26 AM	21.7	7:12 AM	20.9
7:25 AM	22.3	7:27 AM	21.6	7:26 AM	21.6	8:12 AM	21
8:25 AM	22.1	8:27 AM	21.7	8:26 AM	21.6	9:12 AM	21
9:25 AM	21.9	9:27 AM	21.5	9:26 AM	21.7	10:12 AM	21.2
10:25 AM	21.7	10:27 AM	21.3	10:26 AM	21.7	11:12 AM	21.1
11:25 AM	21.6	11:27 AM	21.3	11:26 AM	21.7	12:12 PM	21
12:25 PM	21.6	12:27 PM	21.3	12:26 PM	21.7	1:12 PM	20.9

1:25 PM	21.5	1:27 PM	21.3	1:26 PM	21.7	2:12 PM	20.9
2:25 PM	21.5	2:27 PM	21.3	2:26 PM	21.6	3:12 PM	20.9
3:25 PM	21.4	3:27 PM	21.2	3:26 PM	21.5	4:12 PM	21
4:25 PM	21.3	4:27 PM	21.1	4:26 PM	21.4	5:12 PM	20.9
5:25 PM	21.3	5:27 PM	21.1	5:26 PM	21.3	6:12 PM	20.6
6:25 PM	21.2	6:27 PM	21.1	6:26 PM	21.2	7:12 PM	20.5
7:25 PM	21.2	7:27 PM	21.1	7:26 PM	21.1	8:12 PM	20.6
8:25 PM	21.1	8:27 PM	21	8:26 PM	21.1	9:12 PM	20.6
9:25 PM	21	9:27 PM	20.9	9:26 PM	20.9	10:12 PM	20.6
10:25 PM	20.9	10:27 PM	20.8	10:26 PM	20.9	11:12 PM	20.4
11:25 PM	20.9	11:27 PM	20.8	11:26 PM	20.8	12:12 AM	20.2
12:25 AM	20.8	12:27 AM	20.7	12:26 AM	20.8	1:12 AM	20.1
1:25 AM	20.8	1:27 AM	20.7	1:26 AM	20.7	2:12 AM	20
2:25 AM	20.7	2:27 AM	20.6	2:26 AM	20.6	3:12 AM	19.8
3:25 AM	20.6	3:27 AM	20.5	3:26 AM	20.5	4:12 AM	19.8
4:25 AM	20.5	4:27 AM	20.4	4:26 AM	20.4	5:12 AM	19.7
5:25 AM	20.4	5:27 AM	20.3	5:26 AM	20.3	6:12 AM	19.7
6:25 AM	20.3	6:27 AM	20.1	6:26 AM	20.2	7:12 AM	19.6
7:25 AM	20.2	7:27 AM	20	7:26 AM	20.1	8:12 AM	19.5
8:25 AM	20.1	8:27 AM	19.9	8:26 AM	20	9:12 AM	19.4
9:25 AM	19.9	9:27 AM	19.8	9:26 AM	19.9	10:12 AM	19.3
10:25 AM	19.8	10:27 AM	19.7	10:26 AM	19.8	11:12 AM	19.2
11:25 AM	19.7	11:27 AM	19.6	11:26 AM	19.8	12:12 PM	19
12:25 PM	19.6	12:27 PM	19.5	12:26 PM	19.7	1:12 PM	18.9
1:25 PM	19.6	1:27 PM	19.5	1:26 PM	19.6	2:12 PM	18.8
2:25 PM	19.5	2:27 PM	19.2	2:26 PM	19.5	3:12 PM	18.7
3:25 PM	19.3	3:27 PM	18.6	3:26 PM	19.4	4:12 PM	18.5
4:25 PM	19.1	4:27 PM	18.2	4:26 PM	19.2	5:12 PM	18.4
5:25 PM	19	5:27 PM	18.1	5:26 PM	19.1	6:12 PM	18.3
6:25 PM	18.9	6:27 PM	17.8	6:26 PM	19	7:12 PM	18.2
7:25 PM	18.7	7:27 PM	17.6	7:26 PM	18.9	8:12 PM	18
8:25 PM	18.6	8:27 PM	17.3	8:26 PM	18.8	9:12 PM	17.9
9:25 PM	18.4	9:27 PM	17.1	9:26 PM	18.6	10:12 PM	17.7
10:25 PM	18.3	10:27 PM	16.8	10:26 PM	18.5	11:12 PM	17.6
11:25 PM	18.2	11:27 PM	16.5	11:26 PM	18.4	12:12 AM	17.5
12:25 AM	18	12:27 AM	16.2	12:26 AM	18.3	1:12 AM	17.4
1:25 AM	17.8	1:27 AM	15.9	1:26 AM	18.1	2:12 AM	17.2
2:25 AM	17.7	2:27 AM	15.7	2:26 AM	18	3:12 AM	17.1
3:25 AM	17.6	3:27 AM	15.5	3:26 AM	17.9	4:12 AM	17
4:25 AM	17.4	4:27 AM	15.4	4:26 AM	17.7	5:12 AM	16.9
5:25 AM	17.3	5:27 AM	15.4	5:26 AM	17.6	6:12 AM	16.8

6:25 AM	17.2	6:27 AM	15.4	6:26 AM	17.5	7:12 AM	16.7
7:25 AM	17.1	7:27 AM	15.3	7:26 AM	17.4	8:12 AM	16.6
8:25 AM	17	8:27 AM	15.4	8:26 AM	17.3	9:12 AM	16.5
9:25 AM	16.9	9:27 AM	15.3	9:26 AM	17.2	10:12 AM	16.4
10:25 AM	16.8	10:27 AM	15.2	10:26 AM	17.1	11:12 AM	16.3
11:25 AM	16.6	11:27 AM	15	11:26 AM	17	12:12 PM	16.2
12:25 PM	16.5	12:27 PM	14.9	12:26 PM	16.9	1:12 PM	16.1
1:25 PM	16.4	1:27 PM	14.7	1:26 PM	16.8	2:12 PM	15.9
2:25 PM	16.3	2:27 PM	14.5	2:26 PM	16.7	3:12 PM	15.8
3:25 PM	16.2	3:27 PM	14.4	3:26 PM	16.5	4:12 PM	15.7
4:25 PM	16	4:27 PM	14.3	4:26 PM	16.4	5:12 PM	15.6
5:25 PM	16	5:27 PM	20.1	5:26 PM	16.3	6:12 PM	15.6
6:25 PM	15.9			6:26 PM	16.2	7:12 PM	15.6
7:25 PM	15.8			7:26 PM	16.1	8:12 PM	15.7
8:25 PM	15.8			8:26 PM	16	9:12 PM	15.7
9:25 PM	15.8			9:26 PM	16	10:12 PM	15.9
10:25 PM	15.9			10:26 PM	16	11:12 PM	16.1
11:25 PM	16			11:26 PM	16	12:12 AM	16.2
12:25 AM	16			12:26 AM	16	1:12 AM	16.3
1:25 AM	16.1			1:26 AM	16.2	2:12 AM	16.5
2:25 AM	16.7			2:26 AM	16.4	3:12 AM	16.8
3:25 AM	17.3			3:26 AM	16.5	4:12 AM	16.9
4:25 AM	17.8			4:26 AM	16.8	5:12 AM	17
5:25 AM	18.3			5:26 AM	17	6:12 AM	17
6:25 AM	18.5			6:26 AM	17.2	7:12 AM	17.1
7:25 AM	18.8			7:26 AM	17.4		
8:25 AM	19			8:26 AM	17.5		
9:25 AM	19.4			9:26 AM	17.5		

ANOVA P-Value: 0.171

Box Elder Creek

Downstream

Chamber 1		Chamber 2		Background	
Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)
11:09 AM	18.9	11:08 AM	19.2	9:52 AM	18.10
12:09 PM	19	12:08 PM	19.3	10:52 AM	18.20
1:09 PM	19.1	1:08 PM	19.4	11:52 AM	18.30
2:09 PM	19.2	2:08 PM	19.5	12:52 PM	18.40
3:09 PM	19.3	3:08 PM	19.5	1:52 PM	18.50
4:09 PM	19.4	4:08 PM	19.6	2:52 PM	18.70
5:09 PM	19.5	5:08 PM	19.7	3:52 PM	18.80
6:09 PM	19.6	6:08 PM	19.8	4:52 PM	19.00
7:09 PM	19.7	7:08 PM	19.9	5:52 PM	19.10
8:09 PM	19.9	8:08 PM	20	6:52 PM	19.30
9:09 PM	20	9:08 PM	20.2	7:52 PM	19.50
10:09 PM	20.2	10:08 PM	20.3	8:52 PM	19.60
11:09 PM	20.3	11:08 PM	20.5	9:52 PM	19.80
12:09 AM	20.5	12:08 AM	20.6	10:52 PM	20.00
1:09 AM	20.6	1:08 AM	20.7	11:52 PM	20.20
2:09 AM	20.7	2:08 AM	20.9	12:52 AM	20.40
3:09 AM	20.9	3:08 AM	21	1:52 AM	20.50
4:09 AM	21	4:08 AM	21.2	2:52 AM	20.70
5:09 AM	21.2	5:08 AM	21.3	3:52 AM	20.90
6:09 AM	21.3	6:08 AM	21.5	4:52 AM	21.00
7:09 AM	21.5	7:08 AM	21.6	5:52 AM	21.20
8:09 AM	21.6	8:08 AM	21.7	6:52 AM	21.30
9:09 AM	21.7	9:08 AM	21.8	7:52 AM	21.50
10:09 AM	21.8	10:08 AM	21.9	8:52 AM	21.70
11:09 AM	21.9	11:08 AM	22	9:52 AM	21.80
12:09 PM	21.9	12:08 PM	22	10:52 AM	21.90
1:09 PM	22	1:08 PM	22.1	11:52 AM	22.00
2:09 PM	22.1	2:08 PM	22.2	12:52 PM	22.10
3:09 PM	22.1	3:08 PM	22.2	1:52 PM	22.20

4:09 PM	22.2	4:08 PM	22.3	2:52 PM	22.20
5:09 PM	22.2	5:08 PM	22.3	3:52 PM	22.30
6:09 PM	22.2	6:08 PM	22.3	4:52 PM	22.30
7:09 PM	22.2	7:08 PM	22.3	5:52 PM	22.40
8:09 PM	22.2	8:08 PM	22.3	6:52 PM	22.40
9:09 PM	22.2	9:08 PM	22.3	7:52 PM	22.40
10:09 PM	22.2	10:08 PM	22.3	8:52 PM	22.40
11:09 PM	22.2	11:08 PM	22.3	9:52 PM	22.40
12:09 AM	22.2	12:08 AM	22.3	10:52 PM	22.40
1:09 AM	22.2	1:08 AM	22.3	11:52 PM	22.40
2:09 AM	22.2	2:08 AM	22.2	12:52 AM	22.30
3:09 AM	22.1	3:08 AM	22.2	1:52 AM	22.30
4:09 AM	22.1	4:08 AM	22.2	2:52 AM	22.20
5:09 AM	22.1	5:08 AM	22.1	3:52 AM	22.20
6:09 AM	22	6:08 AM	22.1	4:52 AM	22.20
7:09 AM	21.9	7:08 AM	22	5:52 AM	22.10
8:09 AM	21.8	8:08 AM	21.9	6:52 AM	22.10
9:09 AM	21.7	9:08 AM	21.8	7:52 AM	22.00
10:09 AM	21.6	10:08 AM	20.8	8:52 AM	21.90
11:09 AM	21.5	11:08 AM	20.8	9:52 AM	21.80
12:09 PM	21.4			10:52 AM	21.70
1:09 PM	21.3			11:52 AM	21.50
2:09 PM	21.2			12:52 PM	21.40
3:09 PM	21.1			1:52 PM	21.20
4:09 PM	21			2:52 PM	21.10
5:09 PM	21			3:52 PM	21.00
6:09 PM	20.9			4:52 PM	20.90
7:09 PM	20.8			5:52 PM	20.80
8:09 PM	20.7			6:52 PM	20.80
9:09 PM	20.6			7:52 PM	20.80
10:09 PM	20.6			8:52 PM	20.80
11:09 PM	20.5			9:52 PM	20.70
12:09 AM	20.4			10:52 PM	20.60
1:09 AM	20.4			11:52 PM	20.40
2:09 AM	20.3			12:52 AM	20.30
3:09 AM	20.3			1:52 AM	20.20
4:09 AM	20.2			2:52 AM	20.20
5:09 AM	20.2			3:52 AM	20.10
6:09 AM	20.1			4:52 AM	20.00
7:09 AM	20.1			5:52 AM	19.90
8:09 AM	20.1			6:52 AM	19.90

9:09 AM	20			7:52 AM	19.90
10:09 AM	20			8:52 AM	19.80
11:09 AM	19.9			9:52 AM	19.80
12:09 PM	19.8			10:52 AM	19.80
1:09 PM	19.8			11:52 AM	19.70
2:09 PM	19.7			12:52 PM	19.70
3:09 PM	19.7			1:52 PM	19.70
4:09 PM	19.6			2:52 PM	19.60
5:09 PM	19.6			3:52 PM	19.60
6:09 PM	19.5			4:52 PM	19.60
7:09 PM	19.5			5:52 PM	19.50
8:09 PM	19.5			6:52 PM	19.50
9:09 PM	19.5			7:52 PM	19.40
10:09 PM	19.5			8:52 PM	19.40
11:09 PM	19.5			9:52 PM	19.30
12:09 AM	19.5			10:52 PM	19.30
1:09 AM	19.6			11:52 PM	19.30
2:09 AM	19.7			12:52 AM	19.30
3:09 AM	19.9			1:52 AM	19.30
4:09 AM	20			2:52 AM	19.30
5:09 AM	20.1			3:52 AM	19.30
6:09 AM	20.3			4:52 AM	19.30
7:09 AM	20.4			5:52 AM	19.30
8:09 AM	20.6			6:52 AM	19.40
				7:52 AM	19.40
				8:52 AM	19.50
				9:52 AM	19.60
				10:52 AM	19.60
				11:52 AM	19.70
				12:52 PM	19.80

ANOVA P-Value: 0.000366

Tukey Test P-Value:

2-1: 0.01

4-1: 0.387

4-2: 0.0002

East Canyon

Upstream				USGS	
Chamber 1		Chamber 2		Background	
Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)
12:12 PM	22.2	12:11 PM	22.30	12:16 PM	21.70
12:28 PM	23	12:12 PM	22.30	12:30 PM	22.00
12:43 PM	23.2	12:27 PM	23.00	12:45 PM	22.30
12:58 PM	23.7	12:42 PM	23.20	1:00 PM	22.50
1:13 PM	24.2	12:57 PM	23.70	1:15 PM	22.80
1:28 PM	24.6	1:12 PM	24.10	1:30 PM	23.00
1:43 PM	25	1:27 PM	24.50	1:45 PM	23.20
1:58 PM	25.4	1:42 PM	24.90	2:00 PM	23.40
2:13 PM	25.8	1:57 PM	25.30	2:15 PM	23.50
2:28 PM	26.1	2:12 PM	25.70	2:30 PM	23.60
2:43 PM	26.4	2:27 PM	26.00	2:45 PM	23.80
2:58 PM	26.7	2:42 PM	26.30	3:00 PM	23.90
3:13 PM	26.9	2:57 PM	26.60	3:15 PM	24.00
3:28 PM	27.2	3:12 PM	26.90	3:30 PM	24.10
3:43 PM	27.4	3:27 PM	27.20	3:45 PM	24.20
3:58 PM	27.5	3:42 PM	27.30	4:00 PM	24.20
4:13 PM	27.7	3:57 PM	27.50	4:15 PM	24.20
4:28 PM	27.8	4:12 PM	27.60	4:30 PM	24.20
4:43 PM	27.9	4:27 PM	27.70	4:45 PM	24.10
4:58 PM	27.9	4:42 PM	27.80	5:00 PM	24.00
5:13 PM	27.7	4:57 PM	27.80	5:15 PM	23.90
5:28 PM	27.6	5:12 PM	27.70	5:30 PM	23.70
5:43 PM	27.5	5:27 PM	27.60	5:45 PM	23.60
5:58 PM	27.4	5:42 PM	27.50	6:00 PM	23.50
6:13 PM	27.2	5:57 PM	27.30	6:15 PM	23.50
6:28 PM	27	6:12 PM	27.20	6:30 PM	23.30
6:43 PM	26.8	6:27 PM	27.00	6:45 PM	23.20
6:58 PM	26.7	6:42 PM	26.90	7:00 PM	23.00
7:13 PM	26.4	6:57 PM	26.70	7:15 PM	22.80

7:28 PM	26.2	7:13 PM	26.50	7:30 PM	22.60
7:43 PM	25.9	7:28 PM	26.20	7:45 PM	22.50
7:59 PM	25.7	7:43 PM	26.00	8:00 PM	22.30
8:14 PM	25.4	7:58 PM	25.70	8:15 PM	22.10
8:29 PM	25.1	8:13 PM	25.40	8:30 PM	21.90
8:44 PM	24.8	8:28 PM	25.10	8:45 PM	21.70
8:59 PM	24.6	8:43 PM	24.80	9:00 PM	21.50
9:14 PM	24.3	8:58 PM	24.50	9:15 PM	21.30
9:29 PM	24	9:13 PM	24.20	9:30 PM	21.10
9:44 PM	23.7	9:28 PM	23.90	9:45 PM	20.90
9:59 PM	23.4	9:43 PM	23.60	10:00 PM	20.80
10:14 PM	23.2	9:58 PM	23.30	10:15 PM	20.60
10:29 PM	22.9	10:13 PM	23.10	10:30 PM	20.40
10:44 PM	22.6	10:28 PM	22.80	10:45 PM	20.30
10:59 PM	22.3	10:43 PM	22.50	11:00 PM	20.10
11:14 PM	22.1	10:58 PM	22.20	11:15 PM	20.00
11:29 PM	21.8	11:13 PM	21.90	11:30 PM	19.80
11:44 PM	21.6	11:28 PM	21.70	11:45 PM	19.70
11:59 PM	21.3	11:43 PM	21.40	12:00 AM	19.60
12:14 AM	21.1	11:58 PM	21.20	12:15 AM	19.40
12:29 AM	20.8	12:13 AM	20.90	12:30 AM	19.30
12:44 AM	20.6	12:28 AM	20.70	12:45 AM	19.20
12:59 AM	20.4	12:43 AM	20.50	1:00 AM	19.10
1:14 AM	20.1	12:58 AM	20.20	1:15 AM	19.00
1:29 AM	19.9	1:13 AM	20.00	1:30 AM	18.90
1:44 AM	19.7	1:28 AM	19.80	1:45 AM	18.80
1:59 AM	19.5	1:43 AM	19.60	2:00 AM	18.70
2:14 AM	19.3	1:58 AM	19.40	2:15 AM	18.60
2:29 AM	19.1	2:13 AM	19.20	2:30 AM	18.50
2:44 AM	18.9	2:28 AM	19.00	2:45 AM	18.40
2:59 AM	18.7	2:44 AM	18.80	3:00 AM	18.30
3:14 AM	18.5	2:59 AM	18.60	3:15 AM	18.20
3:30 AM	18.3	3:14 AM	18.40	3:30 AM	18.10
3:45 AM	18.2	3:29 AM	18.20	3:45 AM	18.00
4:00 AM	18	3:44 AM	18.00	4:00 AM	17.90
4:15 AM	17.8	3:59 AM	17.80	4:15 AM	17.90
4:30 AM	17.6	4:14 AM	17.60	4:30 AM	17.80
4:45 AM	17.4	4:29 AM	17.50	4:45 AM	17.80
5:00 AM	17.3	4:44 AM	17.30	5:00 AM	17.70
5:15 AM	17.1	4:59 AM	17.10	5:15 AM	17.60
5:30 AM	16.9	5:14 AM	16.90	5:30 AM	17.60

5:45 AM	16.8	5:29 AM	16.80	5:45 AM	17.50
6:00 AM	16.6	5:44 AM	16.60	6:00 AM	17.40
6:15 AM	16.5	5:59 AM	16.40	6:15 AM	17.30
6:30 AM	16.3	6:14 AM	16.30	6:30 AM	17.20
6:45 AM	16.1	6:29 AM	16.10	6:45 AM	17.10
7:00 AM	16	6:44 AM	16.00	7:00 AM	17.00
7:15 AM	15.9	6:59 AM	15.90	7:15 AM	16.90
7:30 AM	15.8	7:14 AM	15.70	7:30 AM	16.80
7:45 AM	15.7	7:29 AM	15.60	7:45 AM	16.80
8:00 AM	15.7	7:44 AM	15.60	8:00 AM	16.70
8:15 AM	15.7	7:59 AM	15.60	8:15 AM	16.70
8:30 AM	15.7	8:14 AM	15.60	8:30 AM	16.80
8:45 AM	15.8	8:29 AM	15.60	8:45 AM	17.00
9:00 AM	15.9	8:44 AM	15.70	9:00 AM	17.30
9:15 AM	16	8:59 AM	15.80	9:15 AM	17.60
9:30 AM	16.1	9:14 AM	16.00	9:30 AM	17.90
9:45 AM	16.4	9:29 AM	16.20	9:45 AM	18.30
10:00 AM	16.7	9:44 AM	16.40	10:00 AM	18.70
10:15 AM	17.2	9:59 AM	16.70	10:15 AM	19.00
10:30 AM	20	10:15 AM	17.10	10:30 AM	19.30
		10:30 AM	17.40		

ANOVA P-Value: 0.0295

Tukey Test P-Value:

2-1: 0.981425

4-1: 0.044961

4-2: 0.0694304

East Canyon

Downstream				USGS	
Chamber 1		Chamber 3		Background	
Time	Temp (°F)	Time	Temp (°F)	Time	Temp (°F)
12:56 PM	21.50	12:59 PM	23.50	1:00 PM	21.80
12:56 PM	21.60	12:59 PM	23.50	2:00 PM	22.00
12:57 PM	21.60	12:59 PM	23.50	3:00 PM	22.10
12:59 PM	21.70	12:59 PM	23.50	4:00 PM	22.20
12:59 PM	21.70	1:00 PM	23.60	5:00 PM	22.20
1:07 PM	21.90	1:14 PM	24.60	6:00 PM	22.40
1:08 PM	22.00	1:16 PM	24.70	7:00 PM	22.60
1:11 PM	22.10	1:17 PM	24.60	8:00 PM	22.80
1:14 PM	22.10	1:17 PM	24.60	9:00 PM	22.90
1:15 PM	22.20	1:17 PM	24.40	10:00 PM	22.90
1:30 PM	22.40	1:17 PM	24.50	11:00 PM	23.10
1:45 PM	22.60	1:32 PM	24.40	12:00 AM	23.00
2:00 PM	23.00	1:47 PM	24.40	1:00 AM	22.90
2:15 PM	23.20	2:03 PM	25.40	2:00 AM	22.60
2:30 PM	23.30	2:18 PM	25.40	3:00 AM	22.60
2:45 PM	23.70	2:33 PM	25.10	4:00 AM	22.80
4:46 PM	23.50	2:48 PM	25.50	5:00 AM	22.90
10:19 AM	18.90	3:03 PM	25.50	6:00 AM	23.10
		3:18 PM	25.40	7:00 AM	23.00
		3:33 PM	25.50	8:00 AM	22.90
		3:48 PM	25.10	9:00 AM	22.80
		4:03 PM	24.60	10:00 AM	22.70
		4:18 PM	25.50	11:00 AM	22.60
		4:33 PM	25.10	12:00 PM	22.50
		4:48 PM	25.30	1:00 PM	22.30
		5:03 PM	24.90	2:00 PM	22.20
				3:00 PM	22.00
				4:00 PM	21.90
				5:00 PM	21.70

				6:00 PM	21.50
				7:00 PM	21.40
				8:00 PM	21.10
				9:00 PM	21.00
				10:00 PM	20.80
				11:00 PM	20.70
				12:00 AM	20.50
				1:00 AM	20.40
				2:00 AM	20.30
				3:00 AM	20.10
				4:00 AM	20.00
				5:00 AM	19.90
				6:00 AM	19.80
				7:00 AM	19.70
				8:00 AM	19.60
				9:00 AM	19.50
				10:00 AM	19.40
				11:00 AM	19.30
				12:00 PM	19.20
				1:00 PM	19.20
				2:00 PM	19.10
				3:00 PM	19.00
				4:00 PM	18.90
				5:00 PM	18.80
				6:00 PM	18.70
				7:00 PM	18.60
				8:00 PM	18.50
				9:00 PM	18.40
				10:00 PM	18.30
				11:00 PM	18.20
				12:00 AM	18.10
				1:00 AM	18.00
				2:00 AM	18.00
				3:00 AM	17.90
				4:00 AM	17.80
				5:00 AM	17.80
				6:00 AM	17.70
				7:00 AM	17.70
				8:00 AM	17.60
				9:00 AM	17.50
				10:00 AM	17.40

				11:00 AM	17.30
				12:00 PM	17.20
				1:00 PM	17.10
				2:00 PM	17.00
				3:00 PM	16.90
				4:00 PM	16.80
				5:00 PM	16.80
				6:00 PM	16.80
				7:00 PM	16.90
				8:00 PM	17.20
				9:00 PM	17.50
				10:00 PM	17.80
				11:00 PM	18.20
				12:00 AM	18.50
				1:00 AM	18.80
				2:00 AM	19.10
				3:00 AM	19.50

ANOVA P-Value: <2E-16

Tukey Test P-Value:

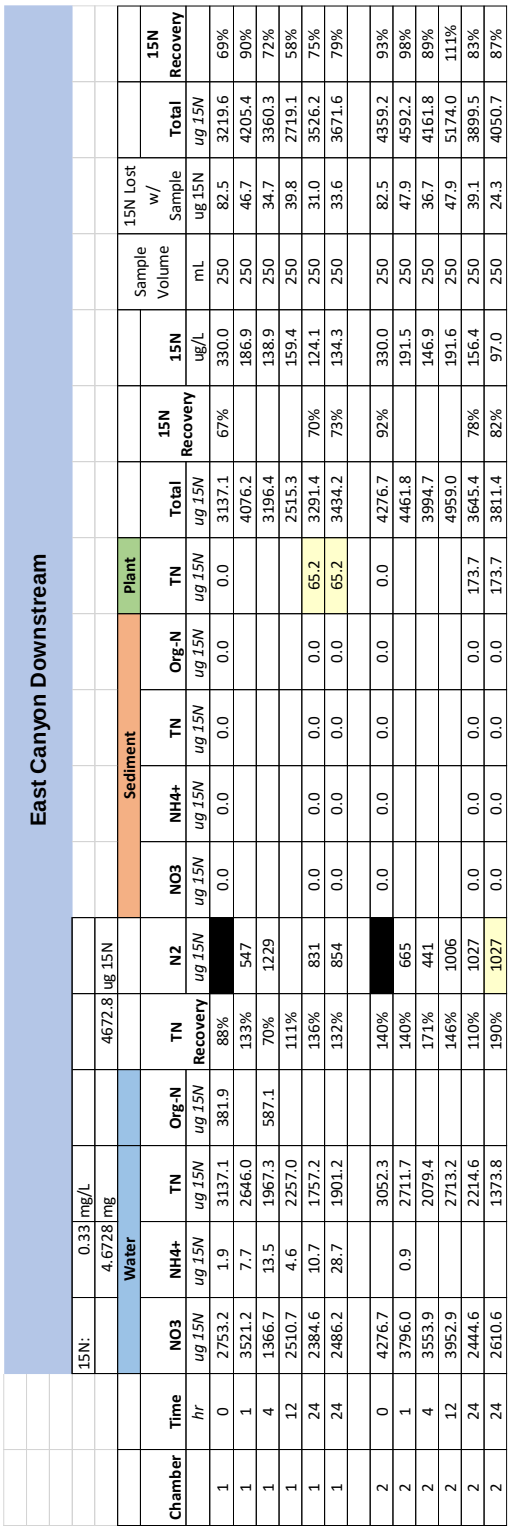
3-1: 3.37E-05

4-1: 2.17E-05

4-3: 0

Appendix G: Mass Balance

(Boxes shaded black signify data points not used. Boxes shaded yellow signify substituted data. Boxes shaded red signify a low recovery.)



East Canyon Downstream

		15N:	0.33	mg/L			4672.8	ug 15N																
			4.6728	mg																				
			Water						Sediment					Plant										
Chamber	Time	NO3	NH4+	TN	Org-N	TN Recovery	N2	NO3	NH4+	TN	Org-N	TN	Total	15N Recovery	15N	Sample Volume	15N Lost w/ Sample	Total	15N Recovery
	hr	ug 15N	ug 15N	ug 15N	ug 15N		ug 15N	ug 15N	ug 15N	ug 15N	ug 15N	ug 15N	ug 15N		ug/L	mL	ug 15N	ug 15N	
1	0	2753.2	1.9	3137.1	381.9	88%		0.0	0.0	0.0	0.0	0.0	3137.1	67%	330.0	250	82.5	3219.6	69%
1	1	3521.2	7.7	2646.0		133%	547						4076.2		186.9	250	46.7	4205.4	90%
1	4	1366.7	13.5	1967.3	587.1	70%	1229						3196.4		138.9	250	34.7	3360.3	72%
1	12	2510.7	4.6	2257.0		111%							2515.3		159.4	250	39.8	2719.1	58%
1	24	2384.6	10.7	1757.2		136%	831	0.0	0.0	0.0	0.0	65.2	3291.4	70%	124.1	250	31.0	3526.2	75%
1	24	2486.2	28.7	1901.2		132%	854	0.0	0.0	0.0	0.0	65.2	3434.2	73%	134.3	250	33.6	3671.6	79%
2	0	4276.7		3052.3		140%		0.0	0.0	0.0	0.0	0.0	4276.7	92%	330.0	250	82.5	4359.2	93%
2	1	3796.0	0.9	2711.7		140%	665						4461.8		191.5	250	47.9	4592.2	98%
2	4	3553.9		2079.4		171%	441						3994.7		146.9	250	36.7	4161.8	89%
2	12	3952.9		2713.2		146%	1006						4959.0		191.6	250	47.9	5174.0	111%
2	24	2444.6		2214.6		110%	1027	0.0	0.0	0.0	0.0	173.7	3645.4	78%	156.4	250	39.1	3899.5	83%
2	24	2610.6		1373.8		190%	1027	0.0	0.0	0.0	0.0	173.7	3811.4	82%	97.0	250	24.3	4050.7	87%

East Canyon Upstream

15N: 0.167 mg/L

2.36472 mg 2364.72 ug 15N

		Water						Sediment										
Chamber	**Time**	**NO3**	**NH4+**	**TN**	**Org-N**	**TN**	**N2**	**NO3**	**NH4+**	**TN**	**Org-N**	**Total**	**15N**	**15N**	Sample Volume	15N Lost w/	**Total**	**15N**
	hr	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	**Recovery**	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	**Recovery**	ug/L	mL	ug 15N	*ug 15N*	**Recovery**
1	0	1763.4	8.0	1345.5		132%	846	0.0	0.0	0.0	0.0	2617.8	111%	167	250	41.8	2659.6	112%
1	1	1041.3	7.1	873.0		120%	788					1836.1		61.7	250	15.4	1893.3	80%
1	4	565.9	4.1	374.9		152%	793					1362.9		26.5	250	6.6	1426.6	60%
1	12	109.5	3.6	61.1		185%	876					988.9		4.3	250	1.1	1053.8	45%
1	24	0.0	0.0	19.7	19.7	0%	1061	0.0	0.0	360.5	360.5	1441.7	71%	1.4	250	0.3	1506.9	64%
1	24	6.2	2.7	15.3	6.5	58%	998	0.0	0.0	360.5	360.5	1374.3	68%	1.1	250	0.3	1439.4	61%
2	0	1861.8	5.0	1218.3		153%	915	0.0	0.0	0.0	0.0	2781.5	118%	167	250	41.8	2823.2	119%
2	1	1712.8	8.0	1079.0		159%	798					2518.9		76.2	250	19.0	2579.7	109%
2	4	692.6	8.6	829.6	128.3	85%	4264					5094.0		58.6	250	14.6	5169.4	219%
2	12	981.3	11.1	832.4		119%	901					1893.4		58.8	250	14.7	1983.5	84%
2	24	345.2	6.1	248.0			1483	4.5	80.6	189.4	104.3	2024.1	91%	17.5	250	4.4	2118.6	90%
2	24	345.2	7.5	279.6		126%	1483	4.5	80.6	189.4	104.3	2025.5	91%	19.7	250	4.9	2030.5	86%
3	0	1620.6	0.5	1310.3		124%	535	0.0	0.0	0.0	0.0	2156.1	91%	167	250	41.8	2197.8	93%
3	1	1377.0	4.0	855.5	0.0		721					2102.5		60.4	250	15.1	2159.3	91%
3	4	826.6	3.3	546.9		152%	811					1640.6		38.6	250	9.7	1707.1	72%
3	12	325.2	2.2	285.3		115%	859					1186.5		20.2	250	5.0	1258.1	53%
3	24	3.5	0.8	11.0	6.7	39%	859	73.0	159.9	0.0	0.0	1103.3	68%	0.8	250	0.2	1175.1	50%
3	24	12.5	0.0	25.1	12.5	50%	859	73.0	159.9	0.0	0.0	1117.4	69%	1.8	250	0.4	1189.4	50%

		Box Elder Creek Downstream																
		Water					Sediment				Plant				Sample	15N Lost w/		
		NO3	NH3	TN	Org-N	N2	NO3	NH3	TN	Org-N	TN	Total	15N	15N	Volume	Sample	Total	15N
Chamber	Time	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	Recovery	*ug/L*	*mL*	*ug*	*ug 15N*	Recovery
1	0	2065.4	18.2	2.0	0	1147	0	0	0	0	0.0	3231	104%	220	250	55.00	3286	105%
1	1	2214.3	25.9	1011.9	0	1076								71.5	250	17.87		
1	4	2231.3	341.5	1153.0	0	1171								81.4	250	20.36		
1	12	1965.9	28.0	1140.8	0	1410								80.6	250	20.14		
1	24	851.8	358.2	572.0	0	1701	9	33	155	113	0.0	3066	98%	40.4	250	10.10	3190	102%
1	24	567.6	34.0	281.7	0	1701	9	33	155	113	0.0	2458	79%	19.9	250	4.97	2576	83%
2	0	2858.1	15.9	1535.9	0	911	0	0	0	0	0.0	3785	122%	108.5	250	27.12	3812	122%
2	1	2131.6	17.6	2077.9	0	1109								146.7	250	36.69		
2	4	2076.2	23.7	1391.0	0	1234								98.2	250	24.56		
2	12	2433.7	42.5	1608.1	0	1379								113.6	250	28.39		
2	24	0.0	86.6	48.5	0	2562	0	0	660	681	0.0	3330	107%	3.4	250	0.86	3448	111%
2	24	0.0	83.3	36.1	0	2562	0	0	660	681	0.0	3327	107%	2.6	250	0.64	3444	111%
3	0	2560.4	6.3	967.5	0	907	0	0	0	0	0.0	3474		68.3	250	17.08	3491	112%
3	1	2493.3	7.7	1639.4	0	1166								115.8	250	28.94		
3	4	2296.5	10.7			4515								0.0	250	0.00		
3	12	1957.5	23.6	748.6	0	1412								52.9	250	13.22		
3	24	0.0	37.4	9.1	0	2442	0	64	34	0	0.0	2543	82%	0.6	250	0.16	2602	84%
3	24	0.0	38.2	5.3	0	2442	0	64	34	0	0.0	2544	82%	0.4	250	0.09	2603	84%

		Not Adjusted for N2 Background Only (w/revised N2 data)															
															15N Lost		
		Water					Sediment							Sample	w/		
		NO3	**NH3**	**TN**	**Org-N**	**N2**	**NO3**	**NH3**	**TN**	**Org-N**	**Total**	15N	**15N**	Volume	Sample	**Total**	15N
Chamber	**Time**	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	*ug 15N*	Recovery	*ug/L*	*mL*	*ug*	*ug 15N*	Recovery
1	0	1898	5.86	1048	0	825	0	0	0	0	2728	116%	166	250	41.50	2770	118%
1	1	1501	6.24	1050	0	1523							74	250	18.54		
1	4	1427	5.31	645	0	948							46	250	11.39		
1	12	946	5.04	778	0	1150							55	250	13.74		
1	24	154	6.93	209	48	1271	36	66	0	0	1582	67%	15	250	3.69	1671	71%
1	24	275	2.80	134	0	1271	36	66	0	0	1651	70%	9	250	2.37	1738	74%
2	0	1923	2.12	1175	0	1080	0	0	0	0	3005	128%	166	250	41.50	3046	130%
2	1	1799	6.89	857	0	945							61	250	15.13		
2	4	1382	8.03	892	0	1129							63	250	15.75		
2	12	958	17.08	577	0	967							41	250	10.18		
2	24	214	5	172	24	1271	0	23	0	34	1571	67%	12	250	3.03	1657	70%
3	0	1692	1.48	1017	0	760	0	0	0	0	2453	104%	166	250	41.50	2495	106%
3	1	1364	1.03	409	0	1075							29	250	7.23		
3	4	1052	1.25	476	0	1106							34	250	8.41		
3	12	537	0.54	56	0	884							4	250	1.00		
3	12	535	0.09	272	0	884							19	250	4.81		
3	24	0	0.02	0	0	1044	0	23	0	0	1068	45%	0	250	0.00	1131	48%

Appendix H: ^{15}N Raw Data

East Canyon Downstream

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
Background		57.3	5.0	56.2	0.4	0.5	0.4
1	0	45.8	5.4	61.1	13.2	0.6	11.2
1	1	59.4	5.6	55.5	12.9	0.8	10.5
1	4	24.7	5.4	42.1	12.6	1.0	10.4
1	12	45.6	3.0	52.5	12.2	1.2	9.5
1	24	44.7	5.0	44.1	11.4	1.0	8.6
1	24	43.0	5.3	49.4	12.3	1.6	8.3
2	0	66.0	3.2	59.3	14.1	0.5	11.3
2	1	61.5	5.1	53.8	13.0	0.6	10.7
2	4	56.8	3.4	43.6	12.2	0.6	9.5
2	12	53.3	4.8	48.5	11.5	0.5	8.8
2	24	39.3	3.6	50.0	9.1	0.6	6.5
2	24	43.7	4.7	33.9	8.7	0.5	6.1
3	0	60.2	3.8	55.0	5.3	0.8	4.1
3	1	57.7	5.7	55.4	6.7	0.5	5.2
3	4	52.3	4.0	44.4	9.3	0.6	6.6
3	12	48.1	4.9	51.2	9.7	0.6	6.6
3	24	28.2	5.3	35.2	7.5	0.7	4.2
3	24	27.5	6.9	43.5	8.0	0.6	3.5

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
1	0	7.1	5.3	155	0.47	0.51	0.37
1	24	7.4	3.6	110	0.41	0.62	0.38
2	0	13.1	14.4	127	0.44	0.40	0.38
2	24	12.7	9.2	89	0.42	0.45	0.39
3	0	14.7	8.5	103	0.42	0.42	0.38
3	24	10.3	10.4	127	0.45	0.48	0.40

		Sample	Sample	Sample	15N Abundance
Chamber	**Time**	*mg plant*	*g plant*	*ug N*	*%15N*
	hr				TN
1	0	12.777	0.012777	353.266	0.372
1	24				
2	0	27.84	0.02784	303.2782	0.372
2	24	8.01	0.00801	153.5135	0.984
3	0	18.63	0.01863	362.0019	0.371
3	24	10.263	0.010263	393.2755	0.645

East Canyon Upstream

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
Background		12.6	2.7	25.9	0.42	0.51	0.38
1	0	21.1	2.5	26.0	17.96	1.22	11.33
1	1	15.2	4.0	23.9	14.90	0.73	8.14
1	4	17.9	3.0	20.8	6.98	0.75	4.30
1	12	19.6	4.0	23.2	1.45	0.53	0.98
1	24	11.5	2.6	24.7	0.40	0.49	0.57
1	24	16.6	4.0	21.8	0.39	0.49	0.60
2	0	18.9	3.4	25.7	21.10	0.72	10.44
2	1	22.5	5.5	27.5	16.39	0.56	8.67
2	4	11.5	3.8	23.8	13.27	0.84	7.80
2	12	20.8	5.3	27.0	10.25	0.71	6.89
2	24		2.9	23.0		0.92	2.71
2	24	17.7	4.5	22.0	4.43	0.67	3.15
3	0	17.5	2.7	24.4	19.87	0.55	11.77
3	1		4.1	20.1		0.54	9.50
3	4	15.8	2.8	20.6	11.40	0.76	6.11
3	12	19.0	2.7	25.1	3.91	0.68	2.81
3	24	13.7	3.3	18.3	0.44	0.48	0.67
3	24	18.5	2.2	24.5	0.43	0.52	0.62

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
1	0	17.9	15.9	85.9	0.38	0.38	0.37
1	24	13.1	14.1	115.0	0.37	0.40	0.37
2	0	11.4	18.3	80.5	0.38	0.39	0.37
2	24	11.8	19.6	96.0	0.38	0.49	0.37
3	0	13.4	42.8	75.4	0.37	0.37	0.38
3	24	19.2	21.5	74.6	0.38	3.03	0.38

Box Elder Creek Downstream

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
Background		24.2	23.1	46.9	0.41	0.38	0.37
1	0	25.7	24.5	6.9	17.44	0.52	2.58
1	1	25.6	25.7	33.3	18.69	0.56	6.96
1	4	26.9	22.3	37.0	17.24	3.51	6.81
1	12	27.4	20.5	41.2	14.98	0.71	6.06
1	24	16.2	16.1	33.6	10.91	4.90	3.84
1	24	12.4	15.7	21.3	9.77	0.98	3.37
2	0	25.6	26.1	39.7	24.07	0.47	8.64
2	1	20.9	25.4	50.9	21.21	0.49	8.65
2	4	19.5	24.1	39.3	22.22	0.57	7.64
2	12	25.2	26.9	47.6	19.34	0.64	6.98
2	24	8.7	26.0	40.0	0.53	1.00	0.67
2	24	9.8	25.6	36.6	0.45	0.99	0.66
3	0	27.9	23.9	31.1	19.78	0.43	7.15
3	1	26.5	23.6	46.7	19.63	0.44	7.56
3	4	27.1	20.9		17.69	0.53	
3	12	24.2	19.5	26.9	16.38	0.69	6.13
3	24	10.0	15.7	30.9	0.48	1.02	0.61
3	24	10.8	16.4	30.4	0.42	0.99	0.60

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
1	0	9.5	12.1	71.0	0.45	0.42	0.38
1	24	8.8	13.9	80.1	0.51	0.43	0.39
2	0		18.1	83.2		0.38	0.37
2	24	8.8	15.1	123.2	0.39	0.44	0.40
3	0	7.7	5.6	25.3	0.43	0.38	0.42
3	24	7.9	10.5	27.2	0.38	0.38	0.42

		Sample	Sample	Sample	15N Abundance
Chamber	**Time**	*mg plant*	*g plant*	*ug N*	*%15N*
	hr				TN
1	0	8.009	0.008009	240	0.42
1	24	8.349	0.008349	216	0.43
2	0	5.923	0.005923	251	0.39
2	24	6.599	0.006599	229	0.43
3	0	5.894	0.005894	235	0.40
3	24	6.53	0.00653	155	0.42

Box Elder Creek Upstream

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
Background		15.3	4.5	15.1	0.4	0.44	0.39
1	0	18.7	5.2	21.1	21.8	0.62	10.81
1	1	14.0	5.4	20.1	22.3	0.60	10.94
1	4	15.0	5.4	15.9	19.0	0.56	8.30
1	12	12.9	5.3	18.4	14.2	0.56	8.24
1	24	4.6	5.4	16.3	6.7	0.59	2.48
1	24	9.0	4.1	13.9	5.7	0.59	2.01
2	0	20.2	5.1	18.9	20.5	0.48	13.46
2	1	20.1	5.7	18.4	18.5	0.59	9.77
2	4	17.9	5.5	20.2	15.4	0.65	8.91
2	12	11.7	7.2	20.7	15.8	0.74	5.49
3	0	17.8	4.5	20.4	20.5	0.51	10.86
3	1	15.3	3.6	14.2	18.6	0.59	6.27
3	4	14.7	3.5	14.1	14.4	0.63	6.98
3	12	9.0	3.4	7.8	11.9	0.59	2.08
3	12	9.4	3.4	13.0	11.4	0.57	4.38
3	24	5.8	3.6	6.6	0.7	0.53	0.54

		Mass N			15N Abundance		
Chamber	**Time**	*ug N*			*atom %15N*		
	hr	NO3	NH3	TN	NO3	NH3	TN
1	0	6.2	4.5	26.5	0.39	0.45	0.40
1	24	8.1	9.3	21.0	0.43	0.43	0.43
2	0	7.3	6.9	42.8	0.69	0.43	0.35
2	24	4.8	8.6	39.0	0.41	0.43	0.35
3	0	8.4	4.4	43.7	0.39	0.39	0.39
3	24	4.5	4.8	21.9	0.43	0.50	0.40