THE ENVIRONMENTAL BENEFITS AND IMPACTS OF RED BUTTE GARDEN ON RED BUTTE CREEK: A CASE STUDY OF SUSTAINABLE LANDSCAPE MANAGEMENT

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Civil and Environmental Engineering

The University of Utah

December 2014

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

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ABSTRACT

Red Butte Garden is located on the University of Utah campus in Salt Lake City, UT. It is a nonprofit arboretum and botanical garden. Red Butte Creek runs through the Garden as it transitions from a mainly undeveloped to an urbanized watershed. This study investigates some of the environmental benefits and impacts of the Garden on Red Butte Creek.

In late August 2013, riparian Box elder (*Acer negundo*) foliage samples were collected upstream, downstream, and within the Garden. The natural abundance of total leaf nitrogen isotope ratio was determined to assess nitrogen (N) sources and extent of fertilizer influence downstream. Red Butte Creek water was sampled biweekly from September through December 2013 (total of 7 sampling events) upstream, downstream, and within the Garden. Water samples were analyzed for ammonium, nitrate, chloride, orthophosphate, and dissolved oxygen (DO) concentrations as well as temperature and pH. Total suspended solids (TSS) was measured in Red Butte Creek upstream, downstream, and within the Garden at two flow rates, 0.8 and 1.1 cfs.

The mean total leaf nitrogen $\delta^{15}N$ downstream (1.4 ‰) of the Garden is significantly ($p=0.03$) higher than the upstream mean (-0.1 ‰). Leaf $\delta^{15}N$ in the Garden ranged from -0.2 to 6.7 ‰ ($\mu=2.7$ ‰) and is significantly higher than upstream ($p=0.02$). The mean C:N ratio of leaves upstream, downstream, and within the Garden is 28.8, 20.0, and 20.7, respectively. Both the Garden and downstream leaves are significantly higher than upstream ($p \leq 0.05$).

There was no statistical difference between mean upstream and downstream ammonium ($p=0.95$) and nitrate ($p=0.32$) concentrations. Orthophosphate was below the laboratory reporting limit (0.5 mg/l) for every sample. Average chloride concentrations were slightly higher downstream (14.43 mg/l upstream and 14.62 mg/l downstream) though not significantly ($p=0.59$).

TSS concentrations in Red Butte Creek upstream, downstream, and within the Garden were measured three times throughout this experiment. The average TSS concentration upstream, downstream, and within the Garden is 4.33, 17.47, and 13.35 mg/l, respectively.

The results indicate ^{15}N enrichment in Garden and downstream leaves which is likely caused by the use of organic fertilizer, fish activity, or net N losses. The leaf C:N is higher within the Garden and downstream than upstream, but the source of this increased N cannot be directly associated with Garden activity because of the multiple nonpoint contributors (e.g., urbanization). Ammonium and nitrate concentrations up- and downstream show no change in stream water quality. Overall, the Garden has little impact to Red Butte Creek and is an example of sustainable landscape management.

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ACKNOWLEDGEMENTS

I would like to thank the many individuals who made this work possible, especially Christine Pomeroy for her continuous mentoring, support, and encouragement. The graduate students in the University of Utah's Urban Water Group helped make this project possible by paving the way prior to my matriculation at the University and by providing assistance and advice throughout this processes, particularly Thomas Walsh and Dasch Houdeshel. Griffin Gilbert assisted in much of the field and lab work for this study; I thank him for his contributions. I would also like to acknowledge the Global Change and Sustainability Center and Friends of Red Butte Creek for supporting this research. This project would not have been possible without the support and funding from Red Butte Garden and Arboretum and their director, Greg Lee. Marita Tewes, the Horticultural Director of Red Butte Garden, was also an integral source of information and support for this project. I would also like to acknowledge the guidance I received from my other committee members, Brenda Bowen and Steve Burian. Finally, I wish to thank Sarah, my family, and Scott for their support. Thank you all.

INTRODUCTION

Botanical gardens offer many benefits to society, including biodiversity and land conservation (Shimozono & Iwatsuki, 1986), educational opportunities (Ballantyne, Packer, & Hughes, 2008), green spaces within urban centers (Ward, Parker, & Shackleton, 2010), and a place for recreation, relaxation, and social interaction (Bennett & Swasey, 1996). However, botanical gardens can negatively impact surrounding ecosystems through the introduction of exotic invasive species (Reichard & White, 2001), excess use of fertilizer, and changing the land cover and hydrologic characteristics. Many studies have investigated the environmental impacts of large-scale landscape and agricultural management (Huang et al., 2012; Meissner, Seeger, Rupp, & Balla, 1999; Neely, Baker, & Valk, 1989; Tong & Chen, 2002; Wehmeyer, Weirich, & Cuffney, 2011), but the literature is limited on potential environmental impacts and benefits of botanical gardens.

The addition of synthetic fertilizer is often applied to garden beds and lawns to maintain plant growth by providing essential nutrients (e.g., nitrogen) that are removed through harvest. However, it is estimated that synthetic fertilizer has more than doubled the amount of reactive nitrogen (N) in the biosphere (Vitousek et al., 1997) polluting drinking water sources (Almasri & Kaluarachchi, 2004; Fewtrell, 2004; Ning & Xiaoqi, 1995), leading to deleterious impacts to aquatic systems (Diaz, 2001; Murdoch & Stoddard, 1992; Nixon, 1995; Smith, Tilman, & Nekola, 1999) and economic losses

(Dodds et al., 2008). The timing and rate of fertilizer application has been studied extensively for crops (Ju, Liu, Zhang, & Roelcke, 2004; Melaj et al., 2003; Van Alphen & Stoorvogel, 2000) and turfgrass (Beverly, Florkowski, & Ruter, 1997; Mangiafico & Guillard, 2006) to optimize plant health and minimize export of N to other ecosystems. Since N dynamics and ecosystem processes depend on local factors (e.g., climate, topography, geology), studies at the local scale are needed to understand the effects of synthetic fertilizer application and inform management practices.

This study focuses on the potential impacts and benefits of a small botanical garden on a perennial stream in Salt Lake City, UT. Red Butte Garden is a nonprofit botanical garden and arboretum located on the campus of the University of Utah and serves as a major economic, social, and educational asset to the University and the greater regional community, receiving over 70,000 visitors and 19,000 school groups annually. The 16 acre Garden provides habitat for a range of native and exotic trees, shrubs, perennials, and grasses and is located at the mouth of Red Butte Canyon where Red Butte Creek transitions from an undeveloped to an urbanized watershed. Because of its location, Red Butte Garden offers a unique opportunity to investigate the interactions between human and natural systems.

Red Butte Garden uses best management practices to avoid negatively impacting Red Butte Creek and downstream ecosystems. Synthetic fertilizer is used on average three times per year on lawn space only and organic fertilizer is applied to garden beds closest to the Creek. This study will investigate the N cycling within Red Butte Garden and estimate N export to downstream ecosystems, ultimately providing Red Butte Garden and other landscape managers design and management practices recommendations. This research aims to address the following questions:

1. To what extent does fertilizer used at Red Butte Garden impact plant nitrogen uptake downstream?

    1a. Does the stable isotope ratio of nitrogen in vegetation downstream of the Garden indicate fertilizer influence?

    1b. What other factors may be affecting plant N in and around the Garden?

2. Is Red Butte Garden a source or sink of stream inorganic nitrogen, chloride, and total suspended solids?

The limited literature on the potential environmental impacts or benefits of botanical gardens on surrounding ecosystems motivated the development of this study. The methods and analyses within this thesis are driven by the following three hypotheses:

1. The natural abundance of ^{15}N in Box elder (*Acer negundo*) leaves downstream of the Garden does not vary from the signature of upstream leaves.
2. Red Butte Garden is an inorganic nitrogen sink in Red Butte Creek.
3. Red Butte Garden traps suspended sediment.

Botanical gardens must maintain a vibrant landscape without compromising adjacent ecosystem health. The overarching objective of this research is to provide Red Butte Garden and other landscape managers recommendations. The chapters within this thesis aim to address four specific objectives:

1. Assess Red Butte Garden's impacts on Red Butte Creek.
2. Determine whether Red Butte Garden contributes N to downstream ecosystems.
3. Assess sediment movement through Red Butte Garden to determine any downstream impacts.

4. Provide design and management practice recommendations to Red Butte Garden and similar landscape managers.

REVIEW OF LITERATURE

Botanical Gardens

Botanical gardens have numerous social, economic, and environmental benefits. The International Agenda for Botanic Gardens in Conservation defines a botanical garden as “institutions holding documented collections of living plants for the purposes of scientific research, conservation, display and education” (Jackson & Sutherland, 2000). Most visitors of gardens appreciate the emphasis placed on education and conservation (Ward et al., 2010) as well as providing a place of peace, recreation, social interaction, inspiration, and relaxation (Bennett & Swasey, 1996; Connell & Meyer, 2004). Botanical gardens are also becoming a major venue for educating the public on global environmental change (Ballantyne et al., 2008). In urban settings, where there is a dearth of green spaces and natural environments, botanical gardens provide an important amenity (Ward et al., 2010). Numerous studies have found that the addition of green space in urban settings improves sense of security, human health, and well-being (Groenewegen, Van den Berg, De Vries, & Verheij, 2006; Hussain et al., 2010; Lafortezza, Carrus, Sanesi, & Davies, 2009; Pretty et al., 2007; Takano, Nakamura, & Watanabe, 2002; Tanaka, Takano, Nakamura, & Takeuchi, 1996).

The Botanic Gardens Conservation International estimates that approximately 250 million people visit botanical gardens every year (Jackson & Sutherland, 2000). They attract both local visitors and tourists, which can be a sustainable economic input

(Sharpley, 2007). Studies have shown that the conservation of natural landscapes encouraging healthy ecosystems leads to an improved economy (Balmford et al., 2002; Costanza et al., 1997; Myers, 1988; Rasker & Hackman, 1996). Botanical gardens increase global biodiversity and support endangered species (Shimozono & Iwatsuki, 1986). Along with biodiversity conservation, botanical gardens can act as a conservation buffer. Conservation buffers are locations of "vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services" (Bentrup, 2008). Conservation buffers mitigate water pollution and restore impaired watersheds throughout the U.S. (Cheng & Song, 2009; Lovell & Sullivan, 2006; Qiu, 2009).

Although botanical gardens can have positive environmental impacts, they might also have negative influences on surrounding ecosystems. Since gardens are often highly manicured landscapes, they sometimes require fertilizers and other amendments to improve growth or mitigate pests and plant disease but can cause environmental damage (Graymore, Stagnitti, & Allinson, 2001; Smith et al., 1999). Botanical gardens can also introduce invasive species to sensitive ecosystems (Reichard & White, 2001). Since land use plays an important role in nutrient loading to receiving waters (Heathwaite & Johnes, 1996; Mattikalli & Richards, 1996; Neely et al., 1989; Tong & Chen, 2002), gardens placed in sensitive watersheds and ecosystems should be designed and managed to minimize their impact.

Botanical gardens can be major social, economic, and environmental assets when properly designed and managed. Further research into the specific environmental benefits and impacts of gardens on a local scale is needed to help inform developers and land managers on practices that will mitigate damage and potentially improve watershed and stream health.

Nitrogen Pollution from Botanical Gardens

Nitrogen as a Contaminant

Nitrogen (N) in aquatic systems can be harmful to human and ecosystem health. It is well established that nitrate in drinking water, at concentrations of 10 mg/l and above, can cause methemoglobinemia in infants (Fewtrell, 2004; Walton, 1951). Recent findings suggest that excessive ingestion of nitrate through drinking water may lead to chronic diseases, including some cancers and reproductive impacts (Townsend et al., 2003; Ward, 2005). Nitrogen contamination can also impact aquatic ecosystems by acidifying surface water (Murdoch & Stoddard, 1992) and causing eutrophication (Nixon, 1995; Smith et al., 1999). Eutrophication increases phytoplankton and algal growth, leading to loss of biodiversity (Gong & Xie, 2001; Hautier, Niklaus, & Hector, 2009), depleted dissolved oxygen (DO), causing fish kills (Diaz, 2001), and potential economic losses (Dodds et al., 2008). Nitrogen contamination in water is a major concern and when potential sources lie close to water bodies, care must be taken to mitigate impacts.

Nitrogen contamination to surface water can be placed in two general pollution sources, point and nonpoint. Point source N (e.g., wastewater treatment plants) enters water bodies at a given location whereas nonpoint source N (e.g., runoff) is more difficult to isolate because of the spatial and temporal distribution of the contamination. Anthropogenic activity has increased the amount of nitrogen in the biosphere, dramatically altering the nitrogen cycle (Nixon, 1995; Vitousek et al., 1997) and causing greater N loading to many rivers and receiving waters (Goolsby, 2000; Jaworski &

Hetling, 1996; Pačes, 1982). Widespread synthetic fertilizer is the major contributor to increased N in terrestrial ecosystems and surface and groundwater (Vitousek et al., 1997). Land use (e.g., agricultural, urban) can influence the quantity of water (Huang et al., 2012; Tong, 1990; Wehmeyer et al., 2011) and the quality of water (Halverson, DeWalle, & Sharpe, 1984; Mattikalli & Richards, 1996; Meissner et al., 1999; Tong, 1990; Tong & Chen, 2002) entering water bodies. Land that is fertilized frequently results in increased N concentrations in runoff and, therefore, receiving waters (Camargo & Alonso, 2006; Gburek & Folmar, 1999; Heathwaite & Johnes, 1996; Neely et al., 1989). Average N input from residential lawn fertilization in Baltimore, MD is 97.6 kg/ha/yr (Law, Band, & Grove, 2004). An urban metabolism study of Phoenix, AZ estimates that fertilizer use contributes 20,000 kg of N annually (Kaye, Groffman, Grimm, Baker, & Pouyat, 2006). Fertilizer and urbanization is a major source of anthropogenic N and the use on botanical gardens warrants studies of its impact on a local scale.

Dry and wet deposition of nitrogen has also increased globally due to combustion of fossil fuels and production and use of synthetic fertilizer (Vitousek et al., 1997). Precipitation can be a large N contributor depending on regional climatic characteristics (Nangia, Mulla, & Gowda, 2010) and is typically high in western U.S. urban areas (Burian, Streit, McPherson, Brown, & Turin, 2001; Halverson et al., 1984; Lohse, Hope, Sponseller, Allen, & Grimm, 2008). A report summarizing deposition monitoring data in the western U.S. found that regional N deposition (wet + dry) ranged from 1 to 4 kg/ha/year (Fenn et al., 2003). Most of the deposition monitoring stations are located outside of urban areas and relatively far from N emission sources. Therefore, deposition rates in urban areas are not well understood and are probably higher than the regional averages (Fenn et al., 2003).

Since fertilizer is a major and controllable N source, management should optimize type and amount of fertilizer to maintain a vibrant manicured landscape and mitigate environmental damage (Giri, Nejadhashemi, & Woznicki, 2012; Wigington et al., 2003). Giri et al. (2012) found, through a Soil and Water Assessment Tool (SWAT) model, that reducing fertilizer application rate in subwatersheds nearest drainage outlets led to significant reduction in nitrate loading. Their findings imply that proper land management can help reduce nonpoint source nitrogen pollution.

Botanical gardens are a potential nonpoint source of nitrogen pollution due to the land type and management practices. Successful assessment of local N pollution should include both investigation of sources and examination of the complex and many biogeochemical processes controlling the transport and fate of nitrogen.

Nitrogen Dynamics in Streams and Riparian Ecosystems

A stream system is made up of three distinct ecohydrologic zones: riparian (terrestrial ecosystem directly adjacent to channel), hyporheic (the area just below the stream bed where groundwater and stream water interact), and the stream channel. Nitrogen in riverine systems is constantly being reprocessed and transformed as it moves downstream (Fisher, Grimm, Martí, Holmes, & Jones, 1998). The three ecohydrologic zones are hydrologically connected and therefore exchange nitrogen. These processes and interactions are sensitive to anthropogenic activity (e.g., fertilization), which can change the way N behaves. N pools, fluxes, and the impact of anthropogenic activity on riverine systems are discussed below.

Riparian Zone

The riparian zone is made up of plant species that are often unique to upland species because they have a relatively constant water source. Nitrogen enters a riparian ecosystem through precipitation and runoff, dry deposition, and groundwater discharge (Chapin, Matson, & Vitousek, 2011). The majority of plants assimilate dissolved inorganic nitrogen (ammonium and nitrate); however, some specialized plants can use dissolved organic nitrogen (Chapin et al., 2011). The nitrogen assimilated by plants is converted to organic nitrogen as biomass. As plant tissue dies and returns to the soil, it is decomposed by microbial processes and either stored in microbial biomass or returned to its inorganic form and free for plants to uptake.

The rate of inorganic nitrogen leaving a riparian ecosystem depends on mineralization, nitrification, plant uptake and denitrification rates (Aber et al., 1995; Dodds et al., 2004; Melillo et al., 1989; Vitousek, 1977). Mineralization is the biological processes producing ammonium from the decomposition of organic matter. The carbon and nitrogen content in organic matter is a key factor in determining whether net mineralization or net absorption occurs. When the carbon to nitrogen (C:N) ratio of organic matter exceeds 25, net absorption will occur, removing inorganic nitrogen from the system that would otherwise be available for plant uptake or loss. At C:N ratios below 25, available N exceeds microbial nitrogen demand and therefore, net mineralization will occur, increasing inorganic nitrogen production. Nitrification is the microbial chemoautotrophic process producing nitrate from the oxidation of ammonium. Nitrite (NO_2^-) is an intermediate step in the nitrification process which rapidly oxidizes to nitrate in aerobic conditions and therefore, accumulation of nitrite in riparian ecosystems is uncommon (Vitousek, 1977). Finally, denitrification is a microbial process occurring in anaerobic conditions reducing nitrate and respiring gaseous nitrogen (NO, N_2O, and N_2).

Fertilizer can contribute to excess inorganic nitrogen either directly through runoff of fertilizer or indirectly through the ecosystem processes, such as detritus with low C:N ratios moving downstream to other riparian areas. One study comparing two riparian ecosystems test plots near Red Butte Creek found elevated nitrogen concentrations and reduced C:N ratios in vegetation from a fertilized plot relative to a control plot (Hultine, Jackson, Burtch, Schaeffer, & Ehleringer, 2008). Low C:N ratios and high nitrogen concentration of leaf litter entering an ecosystem can lead to increased mineralization (Dodds et al., 2004; McClaugherty, Pastor, Aber, & Melillo, 1985; Melillo et al., 1989) and, therefore, increased inorganic nitrogen loading to receiving water, creating a positive feedback of increasing inorganic nitrogen (Schade, Marti, Welter, Fisher, & Grimm, 2002).

While riparian ecosystems can release N to water bodies, they can also be effective at removing inorganic nitrogen from streams and rivers (Hill, Labadia, & Sanmugadas, 1998; Lowrance et al., 1984; Peterjohn & Correll, 1984). One study conducted in western Oregon found that a riparian buffer removed nitrate from a stream in a predominantly agricultural watershed (Wigington et al., 2003). The major processes removing nitrogen from streams in riparian zones are denitrification, plant uptake, microbial absorption (Peterjohn & Correll, 1984), and physical adsorption to soil (Triska, Jackman, Duff, & Avanzino, 1994).

The processes occurring in the riparian zone influence N transport to streams and downstream water bodies. A healthy riparian ecosystem can help remove excess inorganic nitrogen from streams; conversely, an N saturated or impaired riparian zone may exacerbate N pollution.

Hyporheic Zone

The hyporheic zone is the space just below the streambed where groundwater and surface water can interact. This zone is often inhabited by many micro and macro organisms, including microbes, algae, and aquatic invertebrates. There is a large collection of research on the hyporehic zone, but historically, little attention has been paid to this habitat by water management professionals. There is growing evidence that when managed properly, the hyporheic zone can potentially provide a large source of water quality treatment (Lawrence et al., 2013).

The organisms living in the hyporheic zone rely on resource input from both groundwater and stream water (Boulton, Findlay, Marmonier, Stanley, & Valett, 1998). Dissolved inorganic nitrogen will be rapidly used by biofilms on the surface of streambed material while organic nitrogen within larger compounds will be physically broken down by macroinvertebrates (Allan & Castillo, 2007). Similar to riparian ecosystems, the net flux of nitrogen from hyporheic zones depends on the biogeochemical processes occurring, the quality of organic matter, and the availability of resources. Streams with heavy canopy often have less algae activity in the hyporheic zone compared to streams exposed to more light (Allan & Castillo, 2007). Often there is a diurnal pattern of ionic nitrogen in water bodies, with increasing concentrations during the night and decreasing during the day (Christensen, Nielsen, Sørensen, & Revsbech, 1990).When algae are present, they will readily use the ionic nitrogen in stream water while actively photosynthesizing. At night when algae are not respiring dissolved oxygen, the aerated zone in streams decreases, correlating with higher denitrification rates and lower uptake (Christensen et al., 1990).

Along with the biological activity controlling N dynamics in the hyporheic zones, physical sorption of ionic N to sediment can be an important storage pool, particularly for ammonium. Ammonium adsorption is controlled by sediment lithology (e.g., size, type) (Triska et al., 1994). The cation-exchange-capacity (CEC) of sediment is a measure of its capacity to adsorb and retain positively charged ions, such as ammonium. CEC can be influenced by sediment lithology, pH, and sediment particle organic coatings. Triska et al. (1994) found that ammonium sorption to sediment ranged from 0.4-1.7 µg NH4/g sediment in a third order stream in Humboldt County, CA. Other studies found higher sorption rates of 1-9 µg NH4/g sediment (Richey, McDowell, & Likens, 1985).

The N dynamic in the hyporehic zone can be very variable across watersheds and even within a single stream reach (Cummins, 1974). It is difficult to predict the rate of nitrogen release or absorption in hyporehic zones without measuring numerous parameters and processes, but it is an important ecosystem to consider in stream N cycling. Just as with the riparian zone, there is great potential to take advantage of the processes occurring in the hyporehic zone to improve water quality and aquatic ecosystem health (Lawrence et al., 2013).

The N dynamics in a stream ecosystem are very complex and controlled by multiple inputs and processes. Successful landscape management that minimizes watershed impacts should incorporate, and when appropriate, utilize these natural systems to improve water quality and ecosystem health.

Nitrogen Isotopes

Isotopic experiments are often used in ecology to investigate nitrogen sources and cycling whereas the conventional approach to N pollution in watersheds relies mostly on mass balance modeling and water quality analyses. With the exception of a few studies (Fogg, Rolston, Decker, Louie, & Grismer, 1998; Harrington, Kennedy, Chamberlain, Blum, & Folt, 1998; Mayer et al., 2002), isotopic analyses have yet to be more broadly utilized in watershed management, though there is growing evidence that these types of experiments, in combination with conventional approaches, can help improve the management of N polluted watersheds (Nestler et al., 2011; Widory et al., 2013).

Nitrogen has two stable isotopes: ^{15}N and ^{14}N. ^{14}N atoms contain seven protons and seven neutrons while ^{15}N atoms contain seven protons and eight neutrons. ^{15}N is 7.14% heavier than ^{14}N. The ^{14}N isotope makes up the vast majority of nitrogen in the biosphere (99.63 %). Diatomic atmospheric nitrogen (N_2) has a $^{15}N/^{14}N$ ratio of 3.6764 x 10^{-3}. The atmospheric N ratio is the standard for which other sources of nitrogen in the biosphere are compared. There are minor variations in the natural abundance of ^{15}N in the biosphere (Mariotti et al., 1981). The differences between compounds can be compared using a mass spectrometer with double ion-collection and double inlet systems to rapidly measure the standard and sample (McKinney, McCrea, Epstein, Allen, & Urey, 1950; Nier, 1947). The relative measure of natural abundance is given as

$$\delta^{15}N\ (‰) = \frac{R_{sample} - R_{standard}}{R_{standard}} * 1000, \qquad [2]$$

where R is the ratio of ^{15}N to ^{14}N:

$$R = \frac{^{15}N}{^{14}N} \cong \frac{^{15}N}{^{15}N + {^{14}N}}. \qquad [3]$$

The $\delta^{15}N$ in plants varies due to its source of nitrogen and the physical and biogeochemical processes taking place in the ecosystem. Biological processes transforming N discriminate against ^{15}N because it is the heavier isotope and thus requires more energy to utilize, leaving the product depleted (Mariotti et al., 1981). Plant $\delta^{15}N$ is influenced by multiple factors, including the signature of the N source, mycorrhizal interactions, plant N demand, and spatial and temporal distribution of N in the ecosystem (Dawson, Mambelli, Plamboeck, Templer, & Tu, 2002).

The measure of a plant's $\delta^{15}N$ can give insight on the nitrogen pools and cycling in its ecosystem. Nitrification results in depleted nitrate, denitrification depletes the gaseous products, and mycorrhizal transfer of N leaves the plant depleted. Studies found that plants assimilating nitrogen through mycorrhizal interactions have 3-8 ‰ lower $\delta^{15}N$ than nonmycorrhizal plants (Michelsen, Quarmby, Sleep, & Jonasson, 1998; Michelsen, Schmidt, Jonasson, Quarmby, & Sleep, 1996). In general, plants that use more ammonium than nitrate are relatively enriched in ^{15}N and plants using more nitrate are depleted (Joseph M. Craine, 2011).

Fertilization also plays a role in the ^{15}N content of plants. Studies have shown that the addition of organic or inorganic fertilizers enriches plant N (Bateman & Kelly, 2007; Bateman, Kelly, & Jickells, 2005; Bol et al., 2005; Högberg, 1990). Bol et al. (2005) found that crops grown with organic fertilizers resulted in higher $\delta^{15}N$ than crops grown with synthetic fertilizers or no fertilizer. Other studies have found that nitrogen saturated ecosystems have ^{15}N enriched soil and vegetation (Hultine et al., 2008; Melillo et al., 1989; Mulholland et al., 2000) and higher losses of nitrogen through denitrification or leaching (Hogberg, 1990; Högberg, 1990).

Nitrogen isotope studies have not been widely used in watershed management (Widory et al., 2013), but their potential to inform professionals on the sources and dynamics of N pollution is vast. Isotopic studies may fill a gap in the future as they become a more accepted method by watershed professionals.

Other Potential Pollutants from Botanical Gardens

Chloride

Increased chloride from anthropogenic activities can affect human health (Calabrese & Tuthill, 1981) and aquatic ecosystems (Bogemans, Neirinckx, & Stassart, 1989; Bollinger, Mineau, & Wickstrom, 2005; Fraser & Thomas, 1982; Panno, Nuzzo, Cartwright, Hensel, & Krapac, 1999; Sanzo & Hecnar, 2006). In a natural ecosystem, chloride is derived from the weathering of parent material. The use of deicing salts on roadways and sidewalks can increase chloride concentrations in runoff (Godwin, Hafner, & Buff, 2003; Hoffman, Goldman, Paulson, & Winters, 1981; Molles Jr & Gosz, 1980; Peters & Turk, 1981). Higher concentrations of chloride can lead to cell osmotic stress on flora and fauna, inhibiting critical biological processes. In the western U.S., the increasing salinity of riparian soils is leading to loss of native vegetation and establishment of the saline tolerant invasive species, *Tamarix* (Ladenburger, Hild, Kazmer, & Munn, 2006; Richardson et al., 2007; Shafroth, Friedman, & Ischinger, 1995).

Phosphorus

Phosphorus pollution is not the focus of this research; however, it is an important pollutant to consider in freshwater systems. Phosphorus is an essential nutrient in terrestrial and aquatic ecosystems. Phosphorus originates from the weathering of rocks and can often be the limiting nutrient in freshwater systems. Excess phosphorus can lead to rapid growth of algae and potentially initiate eutrophication. Phosphorus loading to streams is also greatly influenced by land use. Agricultural land contributes high amounts of phosphorus, typically due to increased soil erosion and animal waste (Dillon & Kirchner, 1975; Johnes, 1996; Osborne & Wiley, 1988; Rupp, Meissner, & Leinweber, 2004). The use of fertilizers has also been correlated to increasing phosphorus concentrations in receiving waters (Secoges, Aust, Seiler, Dolloff, & Lakel, 2013; Xie et al., 2013). Botanical gardens that use fertilizer may contribute phosphorus to receiving waters and should be aware of the processes controlling the fate and transport of phosphorus from their landscapes.

Suspended Sediment

Suspended sediment naturally occurs in stream systems derived from the erosion of stream beds and banks and watershed soils, but increased loading from land use changes (e.g., urbanization, agriculture) can lead to negative impacts to stream biota and overall habitat degradation (Lenat, 1984; Rosenberg & Wiens, 1978; Wood & Armitage, 1997). Suspended sediments can absorb other potentially more toxic contaminants such as metals and organics (Wilber & Hunter, 1977). Metal concentrations can be elevated in urban (Davis, Shokouhian, & Ni, 2001) and agricultural (He et al., 2004) watersheds. Therefore, it is important to consider sediment loading to streams from managed landscapes.

Best management practices (BMP) have been developed to reduce sediment loading to receiving waters and have been shown to be effective at mitigating impacts (Lenat, 1984). Riparian buffer zones are an example of a BMP widely used in agricultural watersheds that help decrease sediment loading to streams (Osborne & Kovacic, 1993). Botanical gardens near streams may act as a buffer zone by trapping sediment in runoff. They may also be a source of sediment loading due to changing hydrologic characteristics such as soil disturbances or addition of impervious surfaces.

BACKGROUND

Site Description

Red Butte Garden is located on the University of Utah campus in Salt Lake City, UT (Figure 1).The entire Garden property is approximately 40.5 ha (100 ac) and includes botanical gardens and walking and hiking trails. The developed and actively managed portion of the Garden is approximately 7.5 ha (18.6 ac), the center of which is approximately 1524 m (5000 ft) above sea level. The Garden is located at the mouth of Red Butte Canyon.

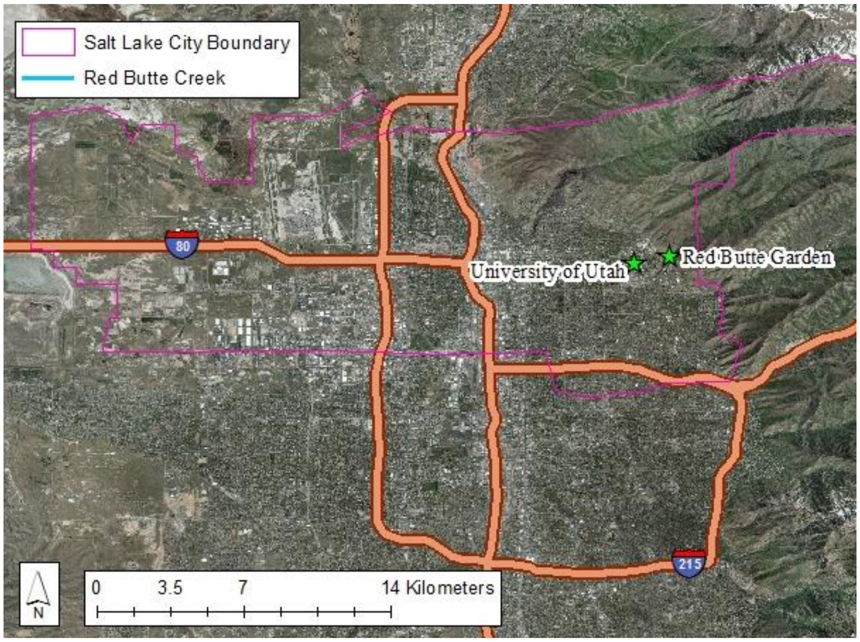

Figure 1. Regional map showing location of Red Butte Creek, Red Butte Garden, and University of Utah

Red Butte Canyon is grasslands at lower elevations and forested at higher elevations. The highest and lowest elevations in the canyon are 2510 and 1530 m, respectively. Red Butte Creek, a perennial third order stream, drains the 20.8 km^2 watershed and is a tributary of the Jordan River. The riparian zone has relatively denser vegetation dominated by Box elder (*Acer negundo*) and river birch (*Betula occidentalis*) (Bond, 1979; Ehleringer, Negus, Arnow, Arnow, & McNulty, 1992). Approximately 1.7 km upstream of the mouth of the canyon, there is a dam and reservoir originally constructed to provide water for the U.S. Army's Fort Douglas (Ehleringer et al., 1992). In 1991, the Army ceased using water from the reservoir and it is currently maintained by the Central Utah Water Conservancy District (CUWCD) providing flood protection and to maintain a population of the endangered June sucker (*Chasmistes liorus*), a fish species endemic to Utah.

Canyon soils above the reservoir are typically about 1 m deep near the stream and much shallower on the steeper slopes. The soil within Red Butte Garden is classified as stony terrace escarpment (NRCS, 2014b). However, it is assumed that the soils within the Garden have been modified by development. Upstream of the Garden and downstream of the dam, the soil is classified as Harkers series (loam) with 6 – 40 % slopes (NRCS, 2014b). Past soil surveys of the area have found most soils in Red Butte Canyon are neutral or slightly basic and range from sandy to loamy clays with a well-developed top soil (Bond, 1979). Bond (1979) found Red Butte Creek to be fairly alkaline (pH 8.0 - 8.4) with high conductivity (550 μS at 21 °C). Average annual precipitation in the canyon ranges from 56.4 cm at 1640 m near the reservoir to 92.1 cm at 2190 m at the top of the watershed (Bond, 1979). The nearest rain gauge to Red Butte Garden is located at the

University of Utah's Biology Growth Site maintained by the Biology Department. Average annual rainfall here for 1997 through 2013 was 35.5 cm (14 in).

There is a U.S. Geological Survey (USGS) stream gauge approximately 350 m upstream of the reservoir. Stream flow follows a seasonal pattern peaking with snowmelt in the spring and experiencing minimum flows in late August and September. Stream flow during summer, autumn, and winter is almost entirely derived from groundwater (Bond, 1979). During spring, stream flow is made up of groundwater, interflow, and snowmelt.

Stream flow data are also available for the reservoir discharge, maintained by the CUWCD. Figure 2 shows a time series of Red Butte Creek daily discharge leaving the reservoir from May 2006 through January 2013. Figure 3 shows a box and whisker plot for each month of the same data set.

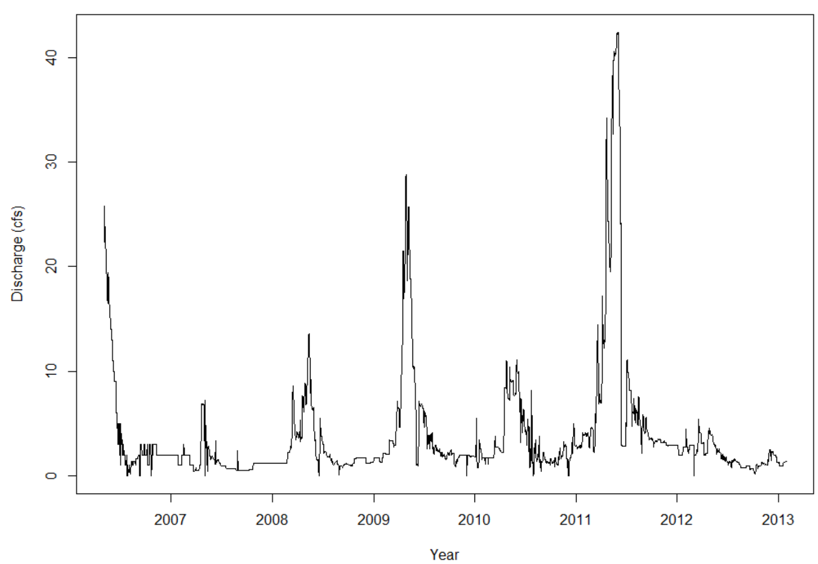

Figure 2. Daily discharge in Red Butte Creek at reservoir release

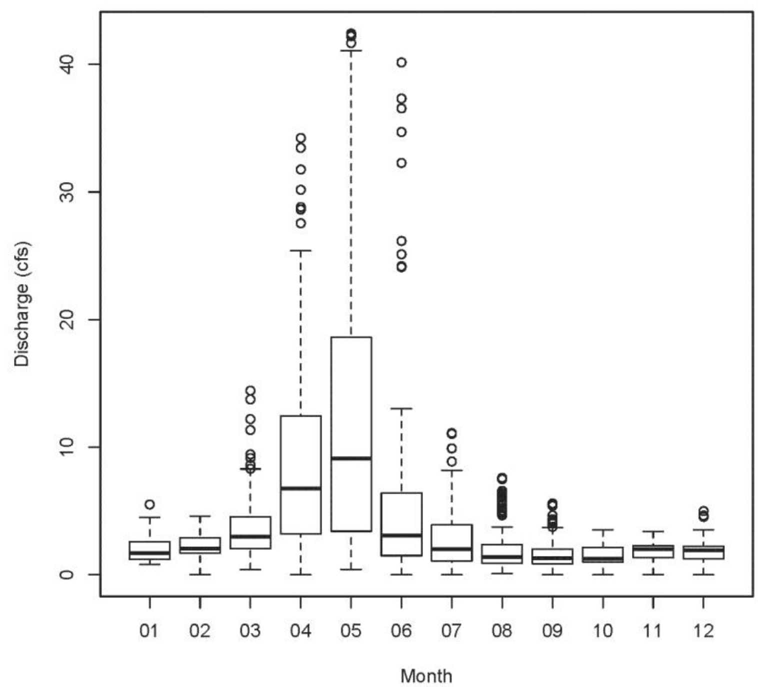

Figure 3. Monthly statistics for daily discharge for Red Butte Creek at reservoir release (May 2006 – January 2013)

Red Butte Garden

Red Butte Garden and Arboretum is a nonprofit organization affiliated with the University of Utah and a member of the American Public Garden Association (APGA). The Garden has native and exotic plants within 7.52 ha (18.6 ac) of actively managed landscape (Figure 4). Approximately 5.5 ha (73%) of this space is cultivated planting beds which include shrubs, trees, perennials, and grasses. Lawns (turfgrass) cover 10% of the total area (0.78 ha) and paved walking paths cover 13% (1 ha), 0.34 ha of which drains directly to Red Butte Creek. There is also a 0.6 ha parking lot which drains to Red Butte Creek.

Over 70,000 people and 19,000 school groups visit the Garden annually. The Garden is a major asset to the University of Utah and greater Salt Lake Metropolitan area.

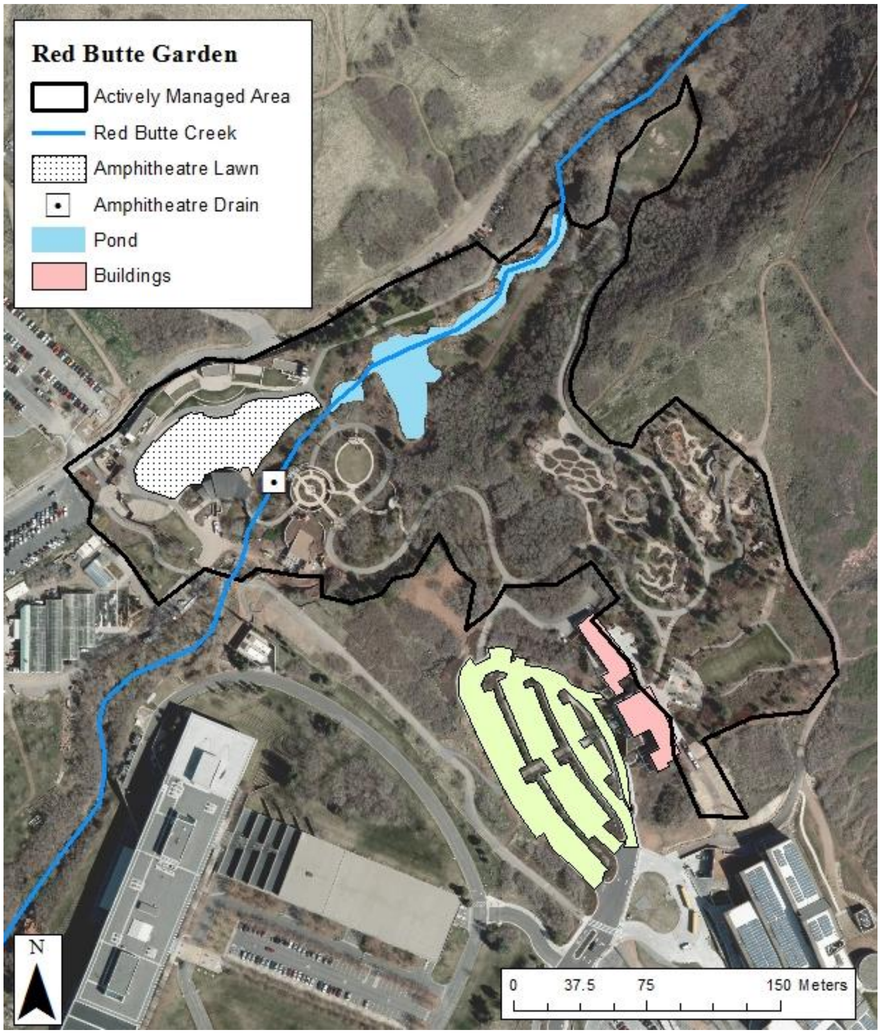

Figure 4. Map of Red Butte Garden actively managed area

There is an amphitheater within the Garden which is a popular venue for multiple events, the largest of which is Red Butte Garden Summer Concert Series with over 72,000 tickets sold every summer.

Red Butte Garden practices sustainable landscape management. The Garden staff are very conscientious of the potential impact on Red Butte Creek and downstream ecosystems from Garden activities (M. Tewes, personal communication, July 14, 2013). Irrigation of garden beds and lawn area occurs during summer months but is monitored to avoid overuse of water. Currently there is one “water-wise” bed and the Garden plans to develop a new 3 acre water conservation plot to demonstrate gardening strategies in a semi-arid climate. Runoff from irrigation is rarely observed (M. Tewes, personal communication, July 14, 2013). The Garden relies on volunteers to hand weed, thereby almost entirely avoiding herbicide use. Precaution is taken in fertilization type, timing, location and rate. All Garden sections directly along the riparian corridor (within 20 m of stream centerline) are amended with organic fertilizer only. This area comprises perennials and native vegetation and is approximately 0.60 ha. The Garden uses Replenish™, a locally sourced compost derived from cow paunch manure, wood shavings, peat, and green waste. The portions of the Garden with turfgrass (0.75 ha), the largest of which is the amphitheater lawn (0.30 ha), are fertilized with synthetic fertilizer. The amphitheater lawn drains to an outfall directly in Red Butte Creek. Lawn clippings are left on the lawn unless a very large growth occurs. All green waste produced in the Garden is placed in an onsite compost and reused in either the green houses or Garden.

During the course of this research which started in mid-August 2013 and concluded in mid-December 2013, the lawns were fertilized once. In early November, three chemicals were applied to the lawns: a 32:3:8 synthetic fertilizer at a rate of 3 lb/1000 ft^2 (total = 36 kg N); Accele-Grow™, a proprietary growth enhancer at a rate of 1.5 ounces/1000 ft^2 (total = 3.59 L); propiconazole 14.3, a fungicide used to prevent mold growth under snow cover, applied at 3 ounces/1000 ft^2 (total = 7.18 L). Previous to this fertilization event, the lawns were amended on June 13, 2013 with the fertilizer and Accele-Grow™. Typically the lawns are fertilized three times per year but were fertilized twice in 2013.

The fungicide propiconazole has been found to be mildly toxic to aquatic organisms. One study found the LC50 of propiconazole for brown trout and crayfish to be 3.3 and 42.0 ppm, respectively (Ciba-Geigy, 1987). The same study found that minimal leaching occurs in most soils, plants readily uptake the fungicide, and the half-life in soils ranges from 30 to 112 days (Ciba-Geigy, 1987).

The Garden also applies deicing salts on their paved walking surfaces. According to Garden staff, on average 2400 lbs of salt are used every year during the winter. The product is 80% potassium chloride and 20% sodium chloride. Assuming that the deicing salt is applied evenly over the 1.6 ha impervious area, 59% of which drains to Red Butte Creek, then 1091 lbs of potassium chloride and 273 lbs of sodium chloride may directly enter the creek annually.

The ornamental pond system within the Garden is directly in-line with Red Butte Creek. As the Creek enters the managed portion of Red Butte Garden, it begins to widen and decrease in velocity and grade. The pond is approximately 2390 m^2 (0.6 ac) and includes a water fall between an upper and lower pond. The largest depth of the upper pond is an estimated 1 m and 0.7 m in the lower pond. The pond is maintained at a relatively constant volume by two water surface diversion. The structures divert an estimated 50% of the flow through a 48 inch corrugated metal pipe that returns flow to the Creek just downstream of the pond.

Suspended sediment can move through the pond system, but bedload sediment is assumed trapped. In 2005, an accidental release of large flows and sediment occurred at dam. This event resulted in a large accumulation of sediment in the Garden pond. The large sedimentation altered stream flow by widening the channel and allowing a greater density of grasses to grow, causing further deposition.

Red Butte Garden Nitrogen Inputs and Outputs

Many past studies investigating stream and riparian N have used a mass balance approach by quantifying inputs and outputs (Groffman, Law, Belt, Band, & Fisher, 2004; Hall Jr & Tank, 2003; Kaye et al., 2006). Figure 5 conceptually illustrates the N inputs to and outputs from Red Butte Garden. The box represents Red Butte Garden and arrows represent fluxes of N. Inputs include Red Butte Creek, deposition, fertilizer, N-fixation, fish food, and animal waste. Outputs include Red Butte Creek, plant harvest, leaching into groundwater, and atmospheric losses from denitrification and volatilization. Nitrogen is cycled within the Garden, transformed by many of the processes discussed above, and may accumulate in aquatic sediment and biota and terrestrial soil and plants.

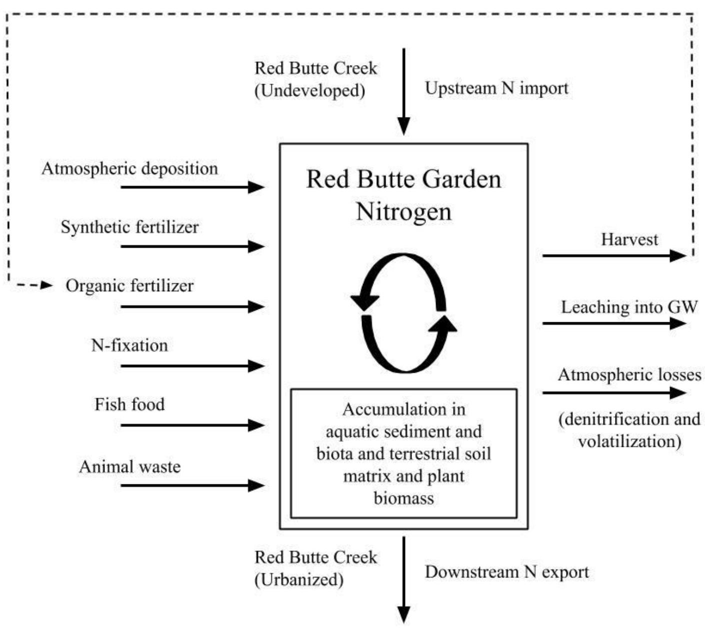

Figure 5. Conceptual model Red Butte Garden nitrogen inputs and outputs

Assuming Red Butte Garden fertilizes their lawn area three times per year at the recommended rate, 107 kg N are added each year. This does not include the Accele-Grow™ product, which is proprietary and thus N content is unknown. Replenish™ is an organic fertilizer derived from cow waste products, wood, and peat is combined with green waste produced from the Garden. A study of various fertilizers found that there is approximately 1920 mg of inorganic N per kg of dry fertilizer and a N:P:K ratio of 0.4:0.12:0.08 in paunch-based fertilizers (B. Fisher, Fleming, Eng, & MacAlpine, 2004). Organic fertilizer has dramatically less ammonium and nitrate than synthetic.

Atmospheric deposition of nitrogen has been modeled and measured in various locations and is often assumed high in semi-arid urban areas (Burian et al., 2001; Halverson et al., 1984; Lohse et al., 2008). Deposition was found to be the second largest N input in Baltimore, MD at 11.2 kg/ha/yr (Groffman et al., 2004). Lohse et al. (2008) estimated that atmospheric N deposition in Phoenix, AZ was 6 kg/ha/year. Assuming this is the rate at which N is deposited at Red Butte Garden then approximately 40 kg of N enters annually.

The N input from N-fixing species is assumed relatively low in Red Butte Garden. There is one Alder (*Alnus incana* spp. *rugosa*) and one Silver buffaloberry (*Shepherdia argentea*) within the riparian area of the Garden. Each of these is classified as a low N-fixer (NRCS, 2014a). One study found that riparian Alder annual nitrogen input was 164 kg N/ha (Klingensmith & Cleve, 1993). However, this study was conducted in a dense native Alder stand in a mesic climate and therefore, the results will not represent N-fixation at Red Butte Garden. Studies of Silver buffaloberry have found that the plant can fix 9.36 kg of N/ha/year (Hendrickson & Burgess, 1989) and add approximately 25 kg of

N/ha/year to surrounding soils (Rhoades, Binkley, Oskarsson, & Stottlemyer, 2008). Again, these findings may not be applicable to Red Butte Garden because there is only one Silver buffaloberry shrub. For this study, N-fixation is assumed negligible.

Fish food can be a substantial N input in some aquatic systems, especially where aquaculture is present (Boaventura, Pedro, Coimbra, & Lencastre, 1997; Foy & Rosell, 1991). Uneaten food and fish feces are likely a large N input in Red Butte Garden. Fish food is available for Garden visitors and therefore, it is difficult to estimate the quantity released into the system, but it is assumed relatively high during the growing season coinciding with high Garden visitation. One study estimated that N release from fish feces is approximately 26 g per fish per month for a trout species in an aquaculture system (Kibria, Nugegoda, Fairclough, & Lam, 1997). Extrapolating this across an estimated fish population of 300 for a year in Red Butte Garden, a total of 94 kg of N is produced from fish feces.

The N inputs presented above are based on past studies and broad assumptions and therefore may not be accurate for Red Butte Garden; however, they provide perspective on the magnitude of inputs, fertilizer being the largest at over 100 kg/year more than three times the amount of the next highest input.

Red Butte Creek and Regional Water Quality

The previous section reviewed the potential pollutant impacting water bodies originating from botanical gardens and provided insight into the processes controlling pollutant fate and transport. This section will discuss the regional watershed concerns in order to provide context to the potential pollutants from Red Butte Garden.

Red Butte Creek is a tributary to the Jordan River which runs north from Utah Lake to the Great Salt Lake. Red Butte Creek enters Liberty Lake in Salt Lake City, UT where it combines with two other tributaries, Emigration and Parleys Creek. From Liberty Lake, the water from the three tributaries is carried through an underground conduit to the Jordan River. Portions of the Jordan River have various designated beneficial uses under the Clean Water Act, including secondary contact, domestic uses, and cold and warm water fisheries. Only the Lower Jordan River (class 3B, protected for warm water fish and aquatic life) is classified as impaired for violating DO regulations. Therefore, the State of Utah is required under the Clean Water Act (EPA, 2002) to develop Total Maximum Daily Loads (TMDL) for total organic matter (OM) in the Jordan River for certain pollutants to address the DO impairment. Four factors have been identified as affecting DO concentration in the Jordan River: physical reaeration from turbulence and the water-atmosphere interface; aerobic decomposition of organic matter and nitrification of ammonium in the water column; aerobic decomposition of organic matter in sediment; and algal growth and decay (UT DWQ, 2013).

Red Butte Creek supplies inorganic nitrogen and nitrogen tied up in larger organic compounds to the Jordan River. Excess nitrogen in the Jordan River can lead to increased algal growth which will increased DO during sunlight and deplete DO during the night, when senesced algae is decomposed (UT DWQ, 2013). Excess organic nitrogen can also lead to release of ammonium and nitrification consuming oxygen.

The Phase I TMDL water quality study found that algae growth in the Jordan River may be nitrogen limited based on the measured N:P ratios (4.90 – 6.22) of sediment (UT DWQ, 2013). This implies that nitrogen is a pollutant of concern because increased nitrogen load would catalyze algae growth and deplete oxygen. This same study found that Red Butte Creek contributes 3.28% (58,000 kg/yr) of the Lower Jordan River's fine particulate organic matter (FPOM) load. This suggests Red Butte Creek may not be a relatively large contributor of nitrogen or organic matter to Jordan River.

There have been a few past studies that looked at water quality of Red Butte Creek. Bond (1979) investigated the nutrient dynamics in Red Butte Creek. The USGS and the UT Department of Water Quality (DWQ) also sampled and analyzed Red Butte Creek for nitrogen. Table 1 summarizes past water quality results of Red Butte Creek for select parameters. The UT DWQ collected water samples in the lower Jordan river from 1978-2005. The average total nitrogen concentration at the North Temple monitoring station, located downstream of the Red Butte Creek outfall, is 2.39 mg/l. Comparing this concentration to those found in Red Butte Creek (Table 1) suggests that the inorganic nitrogen in Red Butte Creek is a minor contributor to the total N in the Jordan River. However, little attention has been paid to the pollutant loading from Red Butte Creek and this may be justified; however, a closer assessment at the impact of the management practices of Red Butte Garden will contribute to an ongoing investigation of a growing urban watershed.

In March 2013, University of Utah students sampled Red Butte Creek at five locations between Red Butte Garden and Liberty Lake. The water was analyzed for ammonium, nitrate, and total N. Table 2 shows the results including the calculated dissolved organic nitrogen concentration and percentage of total N. The sample locations are in order of upstream to downstream. Aside from the most downstream station (Liberty Lake), the majority of the nitrogen in Red Butte Creek was organic.

Table 1. Summary of available water quality data for Red Butte Creek at USGS Stream Gauge from various sources

Variable	Source	Date Range	Average	Standard Deviation	Median	n
			mg/l			
NH_4^+	USGS	1969 - 2013	0.04	0.04	0.03	191
	Bond[a]	1973 – 1974[c]	0.23	-	-	12
	UT DWQ	2004 - 2005	0.07	0.03	0.07	8
NO_3^-	USGS	1971 - 2013	0.01	0.005	0.01	151
	Bond[a]	1973 – 1974[c]	0.18	-	-	12
	UT DWQ	1995 - 2006	0.27	0.27	0.17	39
$O\text{-}PO_4^-$	USGS	1971 - 2013	0.02	0.02	0.02	222
Cl^-	USGS	1964 - 2013	12.44	2.19	12	350
DO	USGS	1967 - 2013	10.09	1.37	9.9	333

a (Bond, 1979)

c Winter months only

Table 2. Results from March 2013 sampling, sites ordered upstream to downstream

Site	NH4	NO3	DON	TN	% ON
	mg/l				
Bonneville Shoreline	0.012	0.007	0.146	0.165	88.3%
Biology Growth Site	0.020	0.036	0.177	0.233	75.9%
Foothill Drive	0.026	0.050	0.235	0.311	75.5%
Upper Miller	0.038	0.084	0.541	0.663	81.5%
Lower Miller	0.023	0.074	0.387	0.484	80.0%
Liberty Lake	0.027	0.740	0.334	1.101	30.4%

METHODS

Acer negundo Leaf Nitrogen

Box elder (*Acer negundo*) leaves were collected along Red Butte Creek. Sampling was divided into three sections, Upstream (control), Garden, and Downstream in order to compare differences between locations. The Upstream leaves were collected between 1.3 and 0.9 km upstream of Red Butte Garden. Downstream leaves were collected between the downstream garden boundary to a distance of 0.75 km downstream. Garden leaves were defined as those collected within the actively managed garden area. Figure 6 shows a map of the sampled trees. A total of 31 leaves were collected from 21 individual trees. Sampling took place August 31 – September 4, 2013. The coordinates of each tree were recorded using a handheld GPS. Leaf location on the tree (i.e., height and aspect) and tree diameter at breast height (DBH) were also recorded. Within an hour of collection, samples were placed in paper bags and dried in an oven at 70 C for 48 hours.

Individual samples were hand ground in liquid nitrogen to homogenize each leaf. Carbon and nitrogen isotopic analysis was conducted at the University of Utah's Stable Isotope Ratio Facility for Environmental Research (SIRFER). SIRFER uses a mass spectrometer with double ion-collection and double inlet system to analyze samples. This method has a ±0.05 ‰ precision.

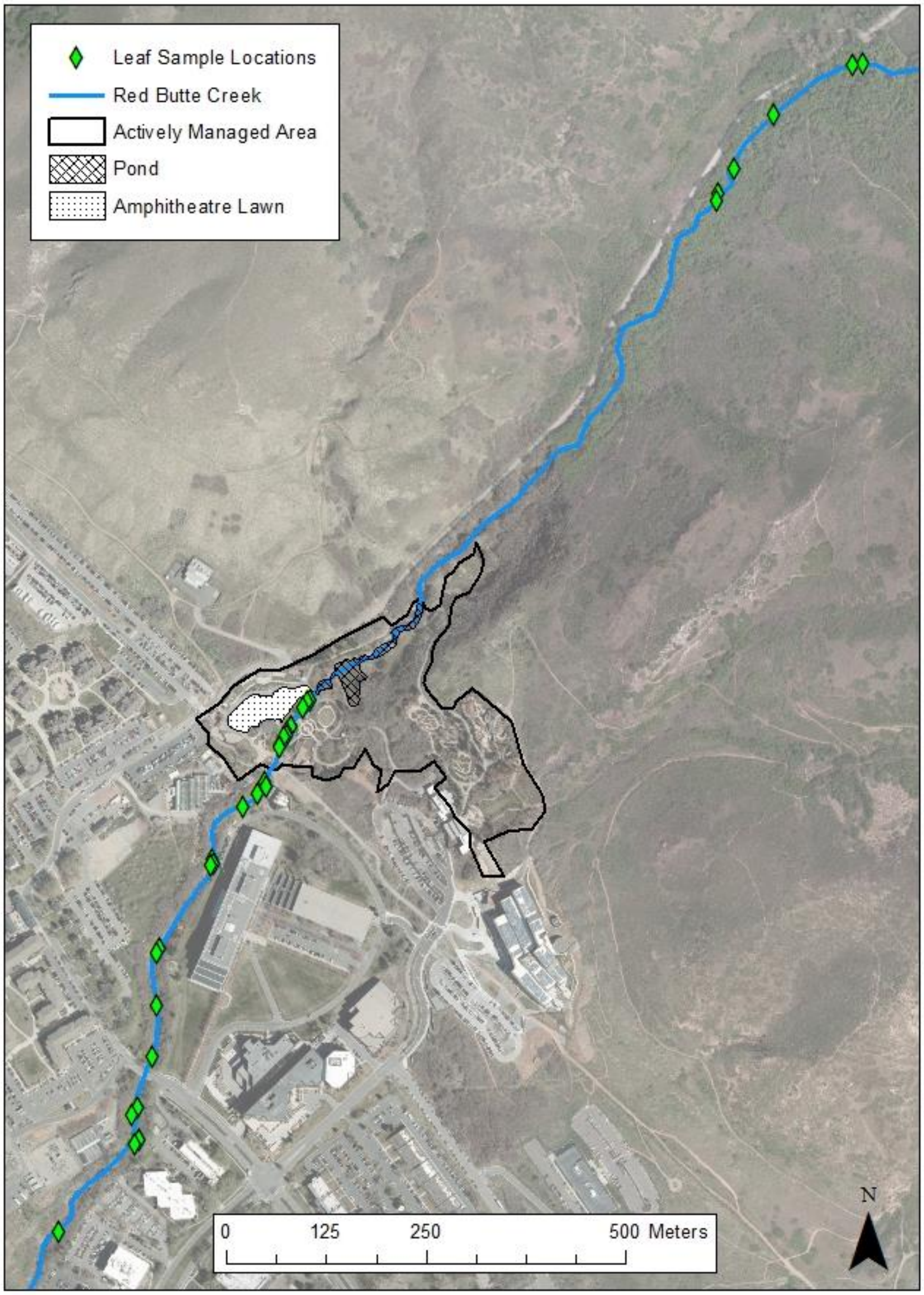

Figure 6. Map of sampled leaf locations

Water Quality

Water quality was assessed upstream, downstream, and within Red Butte Garden. Water samples were collected bi-weekly at three sites from September 5 through December 8, 2013, for a total of seven sampling events. The sites were located upstream, downstream, and within a pond in Red Butte Garden. An auxiliary site within the Garden pond was sampled twice throughout the 14 week sampling period to ensure accuracy of pond water characteristics. The sampling locations are shown in Figure 7. The downstream site was located 15 m downstream of the triple barrel culvert outside of Red Butte Garden. The pond site was located in the upper portion of the large pond. Stream flow here is assumed to be greater than in the southern part of the pond and therefore provides a better representation of water quality characteristics. The upstream site was located at a footbridge approximately 210 m upstream of the pond site.

All samples were collected in the mornings of sampling days between 8:30 and 10:00. The dissolved oxygen (DO) and temperature were measured using a YSI® 55 Dissolved Oxygen Meter. Fifty ml vials (for ammonium, nitrate, and orthophosphate analysis) and 250 ml HDPE bottles (for Cl and TSS analysis) were rinsed three times with sample and then filled. Duplicate samples were collected at each site on each sampling event. The samples were immediately put on ice and brought to the laboratory. The pH of each sample was measured with a Fisher® Mettler Toledo™ FG-2 FiveGo Portable pH meter (± 0.01). The samples to be analyzed for nutrients (50 ml vials) were filtered with 450 µm filter to prevent transformation of nitrogen and phosphorus species.

The samples were shipped overnight on ice to the Utah State University Analytical Laboratory where they were analyzed for orthophosphate, ammonium, nitrate,

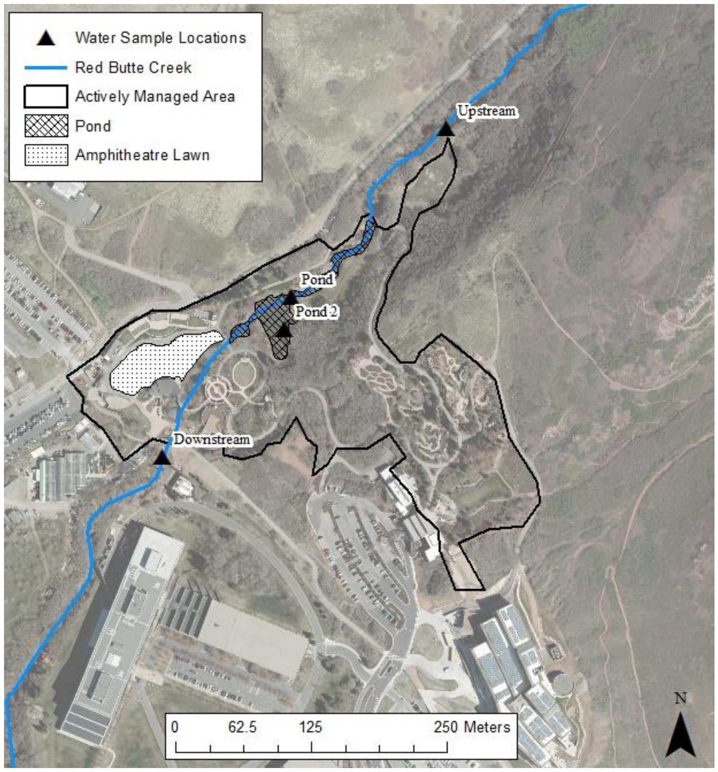

Figure 7. Water sampling locations and important Red Butte Garden features

and chloride concentrations. Orthophosphate was measured using LACHAT® QuikChem Method 10-115-01-1-A flow injection analysis following EPA Method 365.3 (0.01 – 2.00 mg/L, MRL = 0.50 mg/l). Ammonium was measured using LACHAT® QuikChem Method 12-107-06-1-B, following U.S. EPA method 350.1 (0.01 – 2.00 mg/l, MRL = 0.07 mg/l) (NTIS, 1979). Nitrate was measured using LACHAT® QuikChem Method 12-107-04-1-B, following the U.S. EPA method 353.2 (0.05 – 10.00 mg/l, MRL = 0.25 mg/l) (NTIS, 1979). Chloride was measured using LACHAT® QuikChem Method 10-117-07-1-C flow injection analysis (6.0 – 300.0 mg/L). Along with these water quality parameters, total suspended solids (TSS) were measured once per month using the American Public Health Association method 2540D (4.00 to 20,000.00 mg/L) (APHA, 1994).

Statistical Analyses

Comparison of means was conducted using Students *t* test for all water quality parameters and leaf variables. Multivariate correlations for both the leaf and water results were computed using the Pearson Product-Moment method. These statistical analyses were carried out using JMP® 11.0 (SAS Institute Inc., Cary, NC, 1989-2007). Regression analysis was used to test the relationships between variables using analysis of variance (ANOVA) in R: A Language and Environment for Statistical Computing (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013). Statistical significance level was set at $p \leq 0.05$ for all analyses.

RESULTS

Acer negundo Leaf Results

The leaf total N δ^{15}N is plotted against distance downstream of Red Butte Garden in Figure 8. Leaves in the garden are relatively enriched. As distance from the Garden increases, there is a mix of enriched and depleted leaves ranging from -1.0 to 6.0 ‰ (μ=1.53 ‰, σ = 2.31 ‰). Mean δ^{15}N for the Garden and upstream is 2.91 and -0.17 ‰, respectively (Figure 9). The mean δ^{15}N of Garden leaves is significantly higher than upstream leaves (p=0.02). The mean for downstream leaves is also significantly higher than upstream (p=0.03). There is no significant difference between leaf δ^{15}N in the Garden and downstream (p=0.26). These data can also be visualized on a map showing leaf locations with point size representing δ^{15}N (Figure 10).

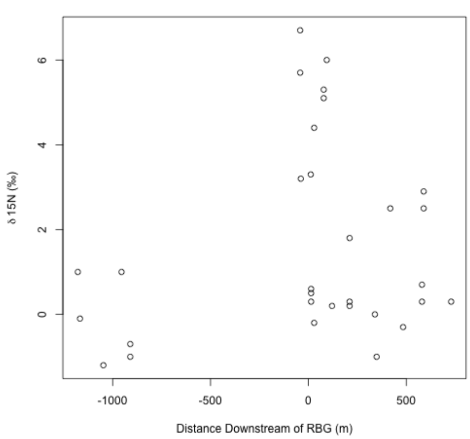

Figure 8. δ^{15}N (‰) vs. distance downstream of Red Butte Garden, where negative distance indicates upstream direction

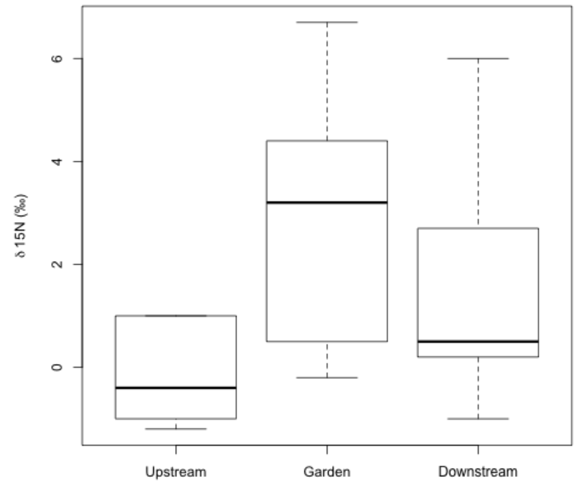

Figure 9. Box plot of leaf $\delta^{15}N$ by location

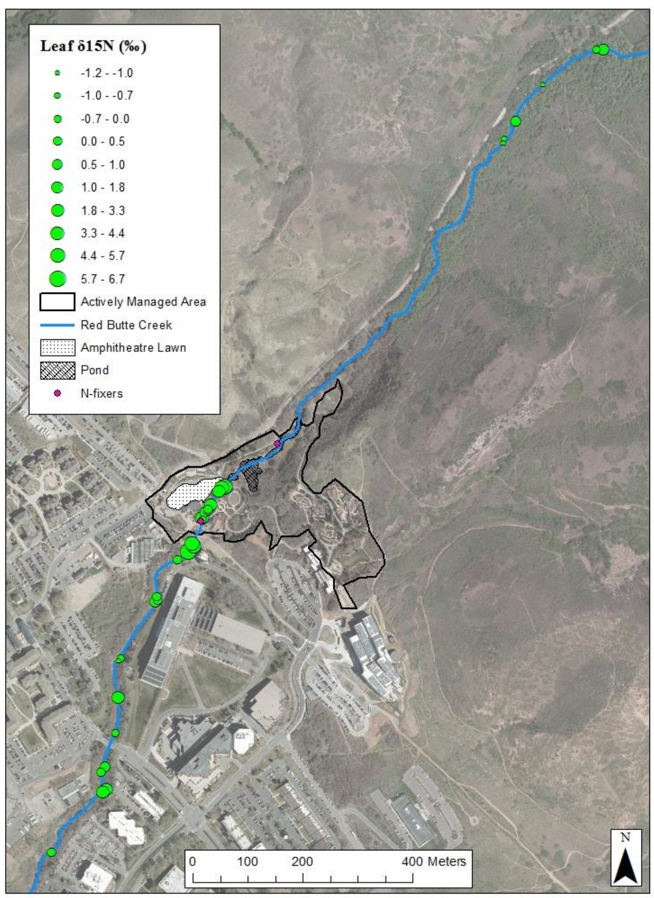

Figure 10. Map showing leaf sample location and $\delta^{15}N$ values

Leaf C:N is plotted against distance downstream of Red Butte Garden (Figure 11). Figure 12 shows the same data in a box plot. There is a cluster of trees downstream with markedly lower C:N. The average C:N for upstream, Garden, and downstream leaves is 28.8, 20.0, and 20.7, respectively. Mean leaf C:N downstream and in the Garden are significantly higher than upstream (p=0.02 and 0.02). There is no significant difference between C:N in the Garden and downstream (p=0.62).

Table 3 shows Pearson product-moment correlation values between variables measured in the leaf experiment. The bold correlation values indicate significance, where $p \leq 0.05$. These correlation values indicate certain relationships may exist. For example, leaf $\delta^{15}N$*C:N (ρ = -0.57), C:N*DBH (ρ= -0.35), and $\delta^{15}N$*DBH (ρ = 0.40) are found to have significant relationships. Figures 13-15 show scatter plots with linear regressions for each of these relationships.

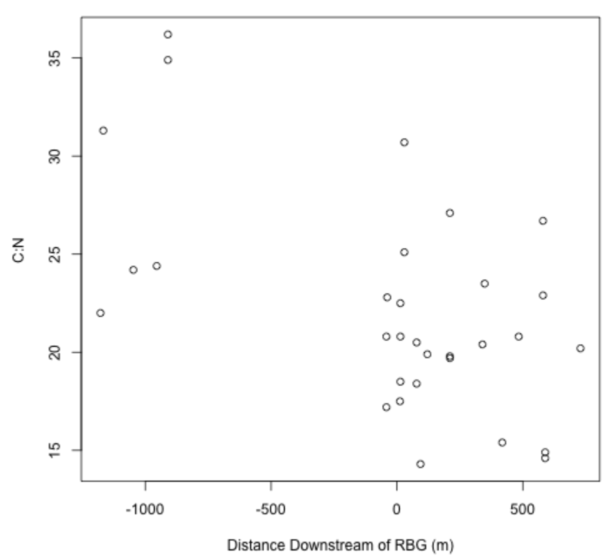

Figure 11. C:N vs. distance downstream of Red Butte Garden, where negative distance indicates upstream direction

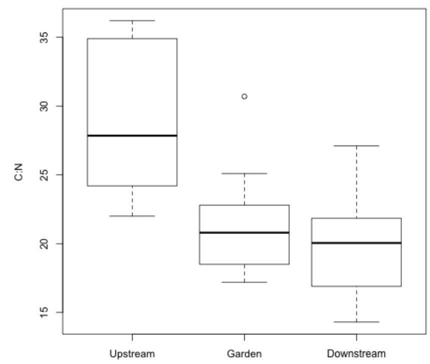

Figure 12. Box plot of leaf C:N by location

Table 3. Pearson product-moment correlations (ρ) between leaf experiment variables, bold indicates significance (p≤0.05)

	d15N	d13C	Wt% N	Wt % C	C:N ratio	DBH
d15N	1	-0.22	**0.59**	-0.30	**-0.57**	**0.40**
d13C		1	-0.11	**0.56**	0.24	-0.11
Wt% N			1	0.01	**-0.94**	0.35
Wt % C				1	0.20	-0.08
C:N ratio					1	-0.35
DBH						1

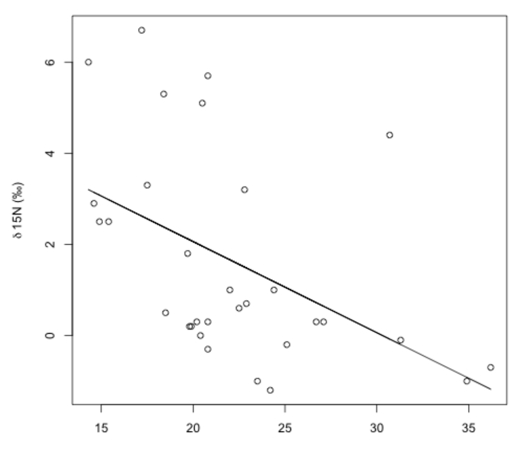

Figure 13. Linear regression model for leaf δ^{15}N vs. C:N (r^2=0.23, p=0.006, F=8.61)

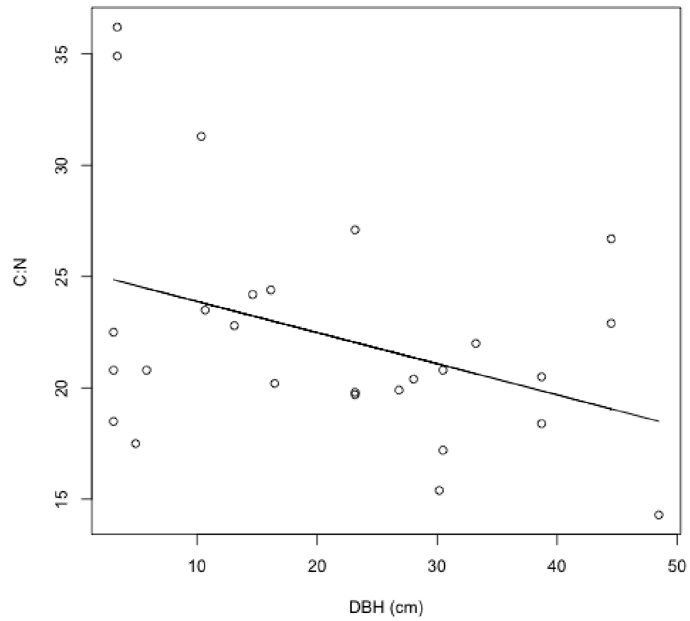

Figure 14. Linear regression for leaf C:N vs. tree diameter (r^2=0.15, p=0.046, F=4.40)

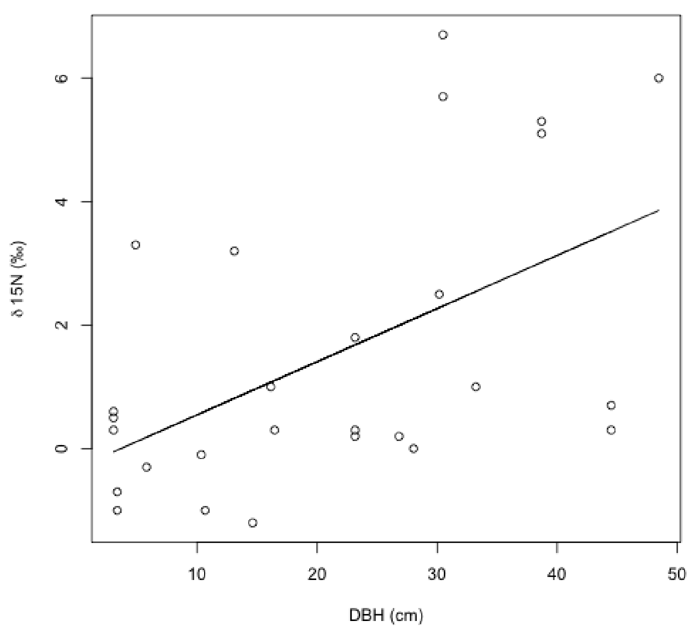

Figure 15. Linear regression for leaf δ^{15}N vs. tree diameter (r^2=0.28, p=0.005, F=9.69)

Water Quality

Table 4 summarizes the results from the water sampling and analysis. The majority of the nitrate measurements (34 out 39) were below the laboratory's minimum reporting limit of 0.25 mg/l. Orthophosphate was also measured but all results were below the laboratory reporting limit (0.5 mg/l) and therefore are not included. The mean ammonium and chloride concentrations were slightly higher downstream than upstream, though not significantly (p=0.95 and 0.59 for ammonium and chloride, respectively). Dissolved oxygen was slightly higher upstream than downstream (p=0.89) and mean pH were virtually equal (μ=8.14).

Figure 16 shows a series of box and whisker plots for ammonium, chloride, and TSS for the three sampling locations. There is no statistical difference between upstream and downstream ammonium (p=0.95) and nitrate (p=0.32) concentrations. The ammonium concentration in the pond is marginally larger than upstream (p=0.17) and downstream (p=0.17). TSS was significantly higher within the pond (p=0.02) and downstream (p=0.002) compared to upstream.

Table 4. Summary of water quality results (mean ± 1 standard deviation)

	Range	Upstream	Pond	Downstream
NH4 (mgl^{-1})	0.07 - 2.00	0.147 ± 0.074	0.193 ± 0.085	0.149 ± 0.079
NO3 (mgl^{-1})	0.25 - 10.00	0.35*	0.30*	0.28*
Cl (mgl^{-1})	6.00 – 300.00	14.42 ± 0.99	14.55 ± 1.10	14.63 ± 1.07
DO (mgl^{-1})	0.0 - 20.0	10.49 ± 1.24	6.23 ± 1.34	10.42 ± 1.03
T (C)	-5.0 - 45.0	5.9 ± 4.4	7.6 ± 4.6	5.7 ± 4.0
pH	0.00 - 14.00	8.14 ± 0.09	7.92 ± 0.12	8.13 ± 0.12
N		13	11	15

* Less than 3 samples above detection limit

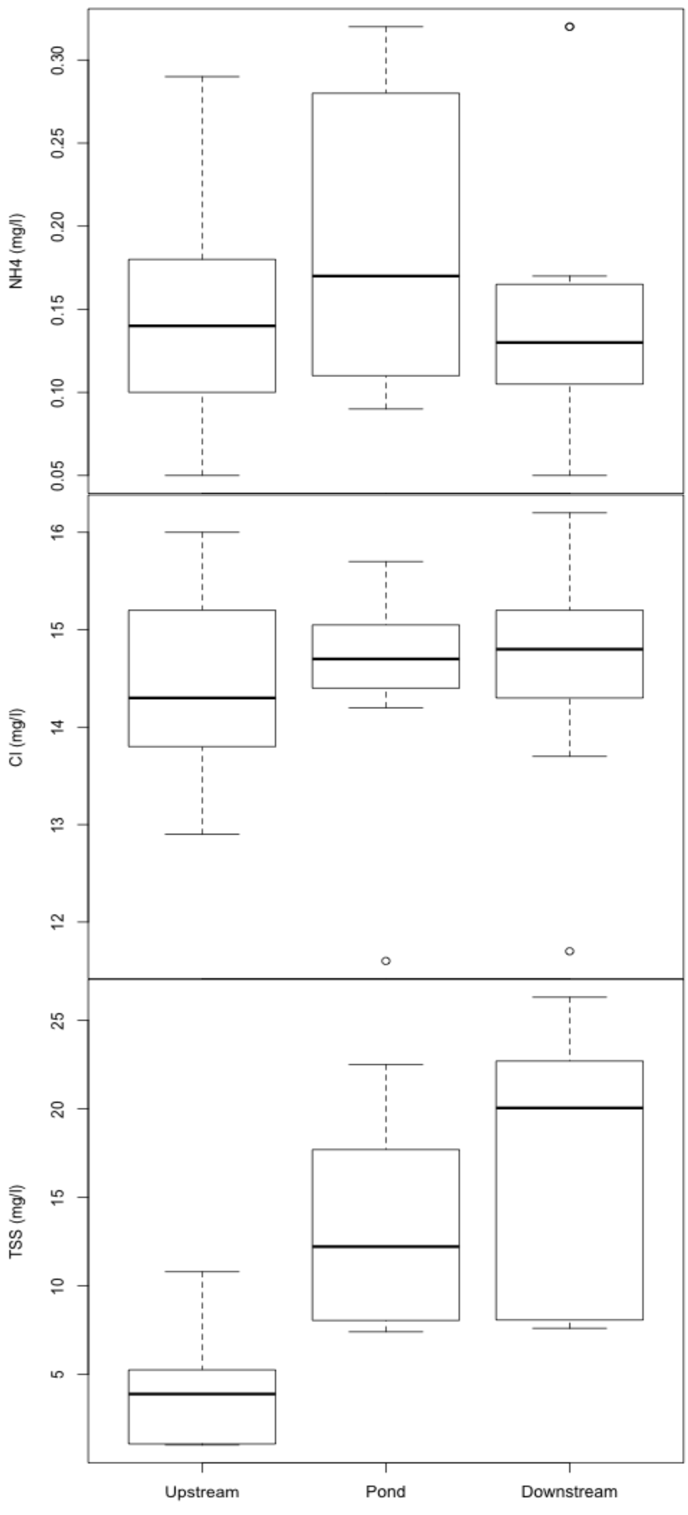

Figure 16. Water quality parameters

Table 5 shows the correlations determined by the Person product-moment method for the variables measured in the water quality experiment. The expected relationships are present in the data, for example date*temperature, temperature*DO, and pH*DO. Ammonium is significantly, though weakly, correlated with DO (ρ=-0.36), T (ρ=0.39), and discharge (ρ=-0.44). These relationships are further analyzed by applying linear regression (Figure 17 and 18).

Table 5. Pearson product-moment correlations for water quality experiment variables, bold indicates significance ($p \leq 0.05$)

	Date	NH4	Cl	DO	T	pH	Discharge
Date	1.00	**-0.41**	0.16	**0.58**	**-0.96**	**0.50**	0.30
NH4		1.00	-0.20	**-0.36**	**0.39**	-0.31	**-0.44**
Cl			1.00	-0.02	**-0.23**	0.03	-0.01
DO				1.00	**-0.60**	**0.87**	**0.38**
T					1.00	**-0.47**	**-0.39**
pH						1.00	**0.60**
Discharge							1.00

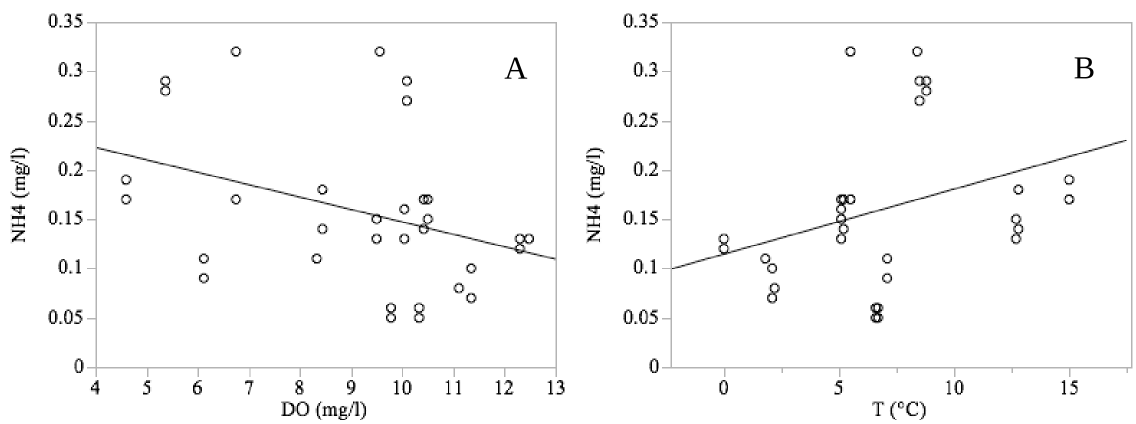

Figure 17. Linear regressions for [A] NH4*DO (r^2=0.12, p=0.04, F=4.78) and [B] NH4*T (r^2=0.12, p=0.04, F=4.66)

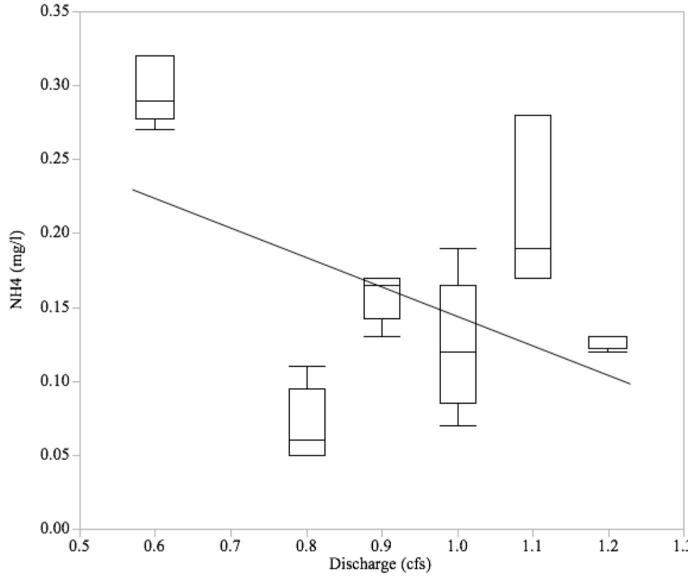

Figure 18. Linear regression for NH4*discharge (r^2=0.19, p=0.005, F=8.97)

Figure 19 shows precipitation and discharge time series for the sampling period and Figure 20 shows a time series of precipitation and ammonium concentrations. Fertilizer was applied to the lawn the week of November 8. Mean upstream and downstream ammonium directly after the chemical application (Nov 15) are higher than the previous and subsequent sampling event. Sampling on November 15 coincided with a precipitation event. The highest measured ammonium concentrations (0.32 mg/l) occurred at the downstream site on October 6, two days after a precipitation event lasting two days and producing 9.14 mm (0.36 in) or rain.

An additional two downstream samples were collected on November 15 because this sampling event occurred during a storm and took place directly after the application of lawn fertilizer. Ammonium ranged from 0.13 to 0.17 mg/l downstream; however, the mean concentration of the event is not significantly greater than the mean of the remaining samples at the downstream location (p=0.85). Figure 21 shows a hydrograph

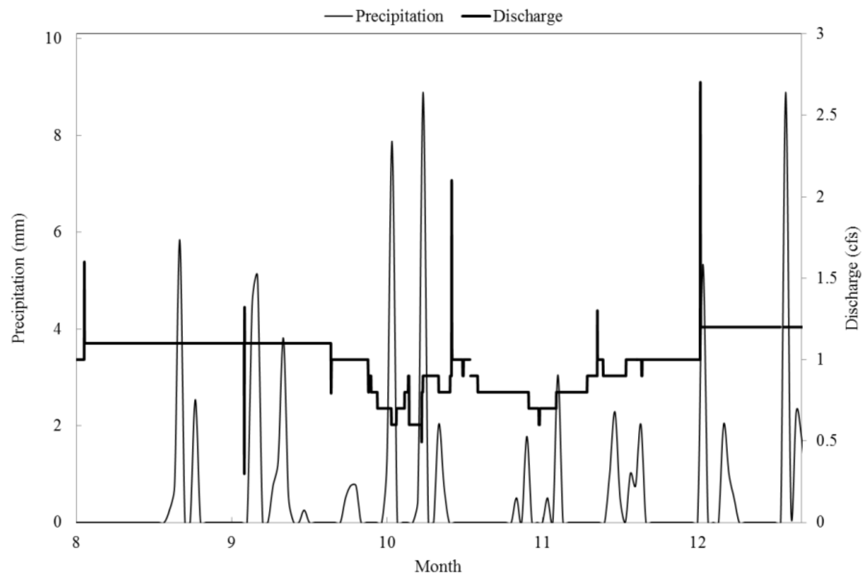

Figure 19. Relationship between precipitation and discharge for sampling period

of the November 15 precipitation event and ammonium concentrations. The upstream and downstream concentrations increased slightly during the second pulse of precipitation.

Chloride concentrations are plotted with precipitation (Figure 22) and discharge (Figure 23). Concentrations are fairly temporally and spatially consistent. The Garden uses 2400 lbs of deicing salt a year on their 1.6 ha (4.0 ac) sidewalk and parking surfaces, approximately 55% of which is directly connected to storm drains discharging to Red Butte Creek though no deicing salts were used at the Garden during this experiment.

Figure 24 shows a time series plot of stream stage from a newly installed gauge approximately 500 m downstream of Red Butte Garden and discharge from the reservoir outlet. The downstream gauge is part of a large stream monitoring network developed by the innovative Urban Transition and Aridregion Hydro-Sustainability (iUTAH) project. This purpose of this figure is to visualize differences in discharge upstream and downstream of the study site.

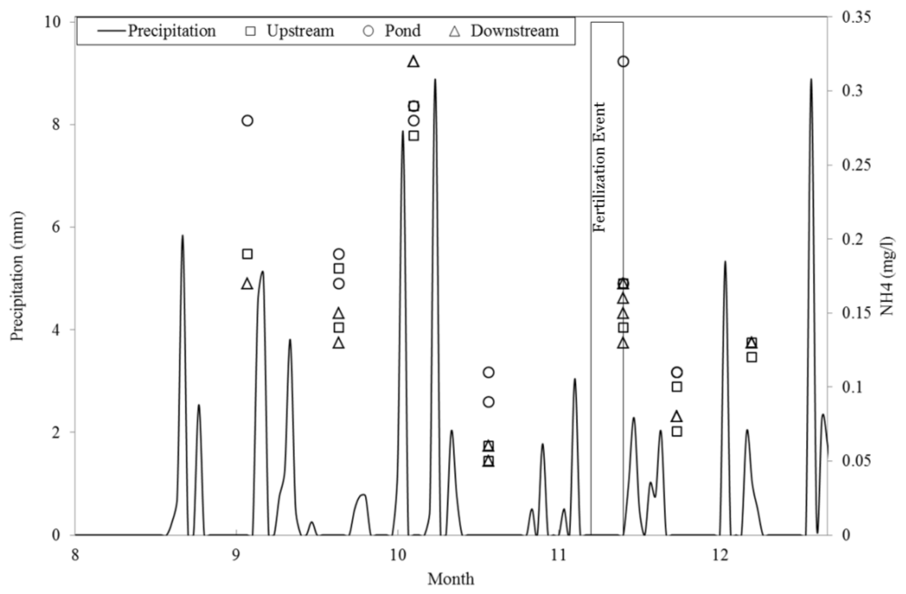

Figure 20. Precipitation (left y-axis) and ammonium concentrations (right y-axis) 2013

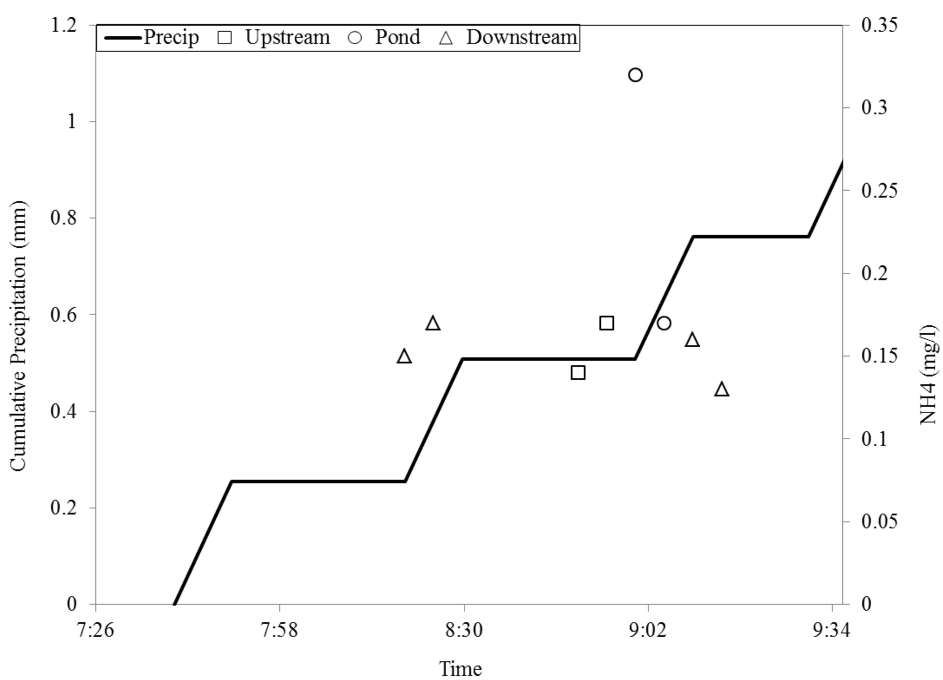

Figure 21. November 15, 2013 precipitation (left axis) and ammonium measurements (right axis)

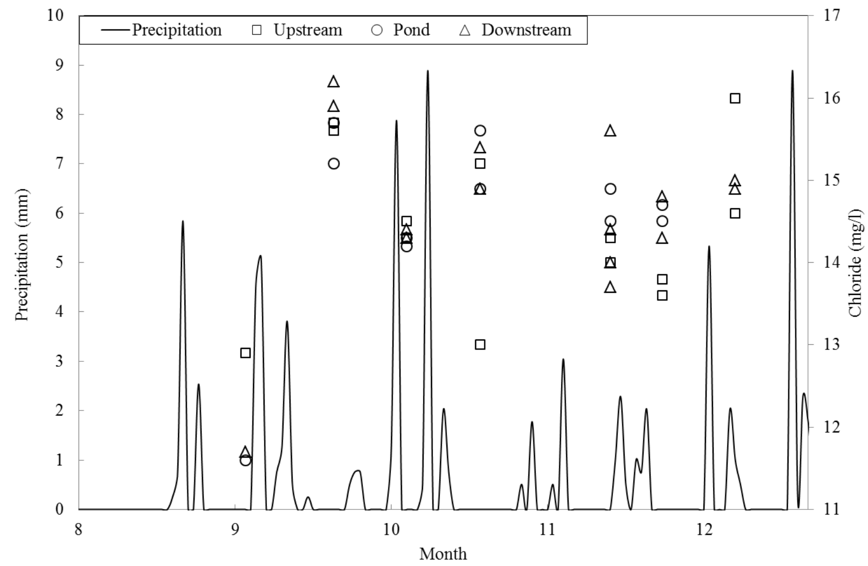

Figure 22. Precipitation (left y-axis) time series and chloride concentrations (right y-axis)

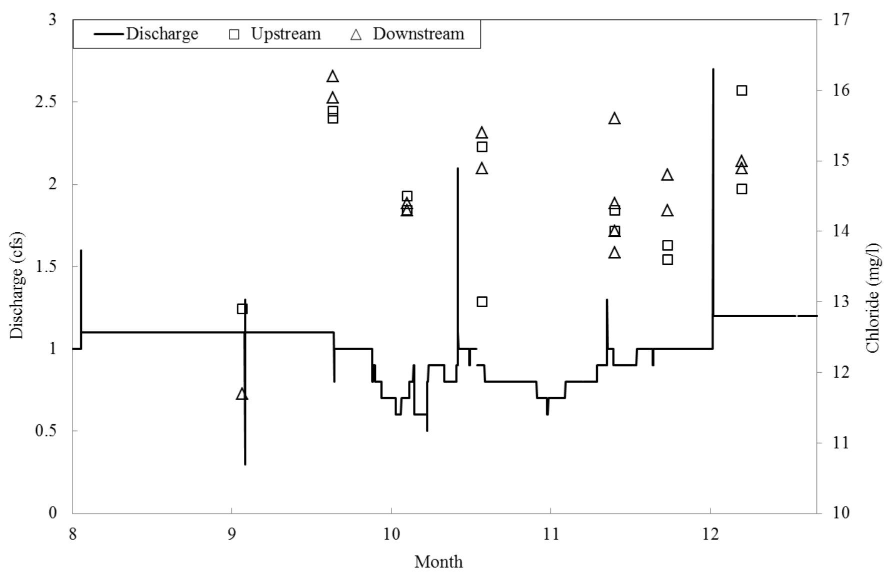

Figure 23. Discharge (left y-axis) and chloride concentration (right y-axis)

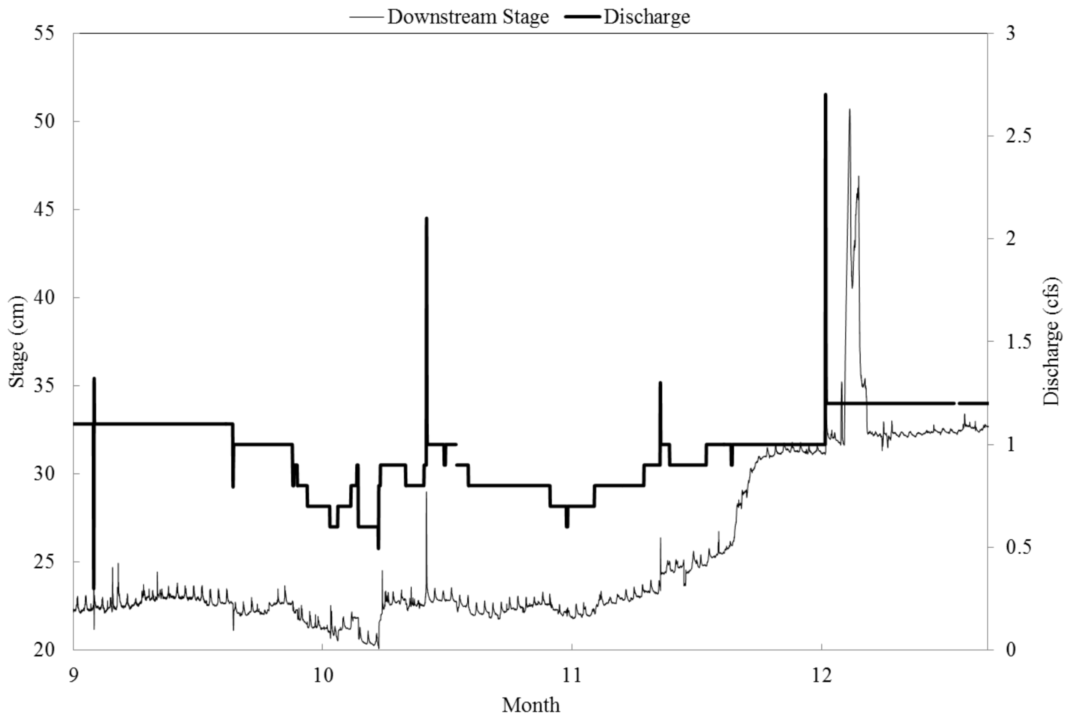

Figure 24. Reservoir outlet discharge and stream stage from a site downstream of Garden

DISCUSSION

Acer negundo Leaves

Natural Abundance of N Isotopes

The nitrogen isotopic signature of *Acer negundo* leaves downstream of the Garden is significantly higher than the signature of upstream leaves. The relatively large range of $\delta^{15}N$ in leaves downstream (-1.0 – +6.0 ‰, σ = 2.24 ‰) indicates that there are many factors influencing the isotopic signature here and in the Garden. The leaf ^{15}N enrichment observed in and just downstream of the Garden may be caused by one of three possible factors or a combination of more than one: (1) the application of organic fertilizer; (2) net ecosystem nitrogen losses; and (3) the incorporation of organic material from the pond into riparian soils.

Organic fertilizer derived from animal products typically enriches soils and plants in ^{15}N (Bol et al., 2005; Freyer & Aly, 1974; Yoneyama, Kouno, & Yazaki, 1990) because of the increase in the heavy isotope with the increase in trophic level (Minagawa & Wada, 1984). It is possible that the relatively high $\delta^{15}N$ is a consequence of the use of organic fertilizer (derived from cow waste) on the beds nearest the creek.

Net ecosystem nitrogen losses can also enrich soils and plants (Garten, 1993; Högberg, 1990; Johannisson & Högberg, 1994; Vitousek, Shearer, & Kohl, 1989). Johannisson and Hogberg (1993) found that increasing long-term addition of urea and ammonium-nitrate (synthetically produced) to forest plots resulted in increased foliar

$\delta^{15}N$. Soil retention of ^{15}N is a result of gaseous, nitrification, and leaching losses. Similarly, Craine et al. (2009) found that, globally, ecosystems with greater N availability (i.e., more soil N) have ^{15}N enriched vegetation. Denitrification can be a major process leading to enrichment (Clément, Holmes, Peterson, & Pinay, 2003) and is typically high in riparian zones (Groffman & Crawford, 2003). It is possible that the soils within the Garden receive excess N from fertilizer and as a result experience net N losses (e.g., denitrification, leaching) causing enrichment.

The pond within the Garden provides habitat for two species of fish and many birds. The known fish species present are an intentionally stocked koi and June sucker (*Chasmistes liorusor*); there may also be some Cutthroat trout (*Oncorhynchus clarkia*) (J. Baker, personal communication, January 29, 2014) and Brown trout (*Salmo trutta*). A very rough estimate of 300 individual fish live in the 0.24 ha (0.6 ac) pond (F. Kollmann, personal communication, February 1, 2014). The nitrogen within fish feces and carcasses is enriched in ^{15}N (Checkley & Entzeroth, 1985; Checkley & Miller, 1989; Minagawa & Wada, 1984; Montoya, Horrigan, & McCarthy, 1990; Steele & Daniel, 1978), therefore potentially leading to enrichment in Garden soils. Studies in northwestern U.S. watersheds have found relatively high ^{15}N in plants and soils near portions of streams experiencing salmon spawning (Bilby, Fransen, & Bisson, 1996; Reimchen, Mathewson, Hocking, Moran, & Harris). Without further isotopic analysis of N sources (e.g., soils, aquatic particulate organic matter, stream water), it is difficult to discern the exact processes contributing to the foliar enrichment observed in and around the Garden.

The large range of $\delta^{15}N$ values in the downstream trees suggests various N sources. Moving downstream of Red Butte Garden, Red Butte Creek becomes increasingly urbanized with adjacent lawns and development. Potential factors influencing plant N downstream of the Garden include adjacent lawn fertilization and urban runoff.

There are two stormwater outfalls in Red Butte Creek between the downstream boundary of the Garden and the furthest downstream sample location. One outfall is on the west and one is on the east side of the Creek. The west-side outfall drains the upper portion of the University of Utah campus, a predominantly developed catchment (55% directly-connected impervious). The east-side outfall drains a less developed catchment (15% directly-connected impervious). There is also 1.34 ha (3.31 ac) turf grass lawn (Williams Building, Research Park) downstream of the Garden which drains as overland flow directly to the Creek. The application of synthetic fertilizer at this location may also explain the lower δ^{15}N values. There is a distinct difference between the leaves in the downstream category that are near the garden and those that are further downstream. This may indicate a difference in N source. Further investigation of N sources and leaves in the urbanized portion of Red Butte Creek should be carried out.

Many studies have characterized nitrogen content in urban runoff (Dietz & Clausen, 2005; Hunt, Jarrett, Smith, & Sharkey, 2006; Sharkey, 2006; Taylor, Fletcher, Wong, Breen, & Duncan, 2005). All but one of these studies found notably higher nitrate and nitrite concentrations than ammonium in urban stormwater runoff. If this trend applies to the Red Butte Creek urbanized watershed, this may provide some explanation for the depleted foliage downstream. In general, nitrate has lower δ^{15}N than ammonium because of the fractionation occurring during transformation processes (Craine, 2011; Dawson et al., 2002).

Nitrogen entering ecosystems through atmospheric deposition is typically depleted in ^{15}N because of the discrimination against the heavy isotope during gaseous N production. Studies have correlated depleted ^{15}N in foliage to ecosystems relying mainly on deposited and fixed N (e.g., early successional ecosystems) (Garten, 1993; Vitousek et al., 1989). The depleted signatures in the control group and downstream of the Garden could indicate these plants rely on deposited N, potentially transported via urban runoff.

Leaf C:N

Results indicate that leaf N enrichment is associated with decreasing leaf C:N (r^2=0.23, p=0.006, F=8.61) (Figure 13). Leaf C:N is lower in the downstream grouping and markedly low just outside of the Garden. A study conducted in a mesic watershed in Tennessee found that foliar $\delta^{15}N$ is negatively correlated with C:N and positively correlated with net mineralization and net nitrification (Garten, 1993). Garten (1993) measured soil characteristics as well as foliar N content to draw these conclusions. Due to the high nitrogen content in the littler just downstream of the Garden, it is possible that net mineralization and nitrification rates are elevated here leading to a positive feedback of increasing inorganic nitrogen (Garten, 1993; Hultine et al., 2008; Schade et al., 2002). This could lead to a net positive transport of inorganic nitrogen to downstream receiving waters (i.e., Jordan River and Farmington Bay). It is likely though that the inorganic nitrogen leaving these systems will be used by downstream biota prior to the Jordan River as water quality results indicate low levels of stream ammonium and nitrate concentrations.

If net mineralization and nitrification are occurring near the Garden, as suggested by low C:N and high $\delta^{15}N$, this may be another cause of the depleted signature in leaves further downstream. During nitrogen losses, the product is left depleted and substrate enriched. Therefore, any inorganic nitrogen transported downstream will be relatively depleted. Further ^{15}N analysis within Red Butte Creek and other watersheds may help elucidate the potential inorganic nitrogen loading to the Jordan River originating from mineralization and nitrification in riparian zones. Unfortunately, no riparian soil samples were analyzed from Red Butte Creek and therefore, these conclusions drawn based on foliar N cannot be confirmed.

Plant Physiology

Acer negundo is a dioecious species (i.e., male and female plants). Plant physiology is different between male and female trees. A study conducted on *Acer negundo* trees in Red Butte Canyon and the vicinity found that the streamside communities are female dominated while more drought-prone areas are male dominated (Dawson & Ehleringer, 1993). The authors also found that female trees had significantly higher leaf nitrogen concentration than male trees but did not investigate the nitrogen isotopic signature. Unfortunately, tree gender was not noted during sampling. It has been hypothesized that little or no fractionation of nitrogen occurs within a plant; that is, once assimilated, the isotopic signature remains constant as nitrogen moves through plant tissue (Dawson et al., 2002).

Some studies have investigated water use in riparian Box elder trees and shown that younger trees with shallow root systems use stream water more than mature trees (Blasius & Oberwinkler, 1989; Dawson & Ehleringer, 1991, 1993). One of these studies investigated water source in *Acer negundo* trees in Red Butte Canyon and found that young trees along the stream (within 2 m of stream banks) used stream water, while more established stream-side trees used deeper water (Dawson & Ehleringer, 1991). Our data may support these past findings. There is a significant relationship between δ^{15}N and tree diameter ((r^2=0.28, p=0.005, F=9.69) (Figure 15). Larger trees have more enriched foliage. This observation could be supported by the findings in Dawson and Ehleringer (1991). The younger (i.e., smaller) trees may be accessing shallow water, while mature trees may be using deeper groundwater, each source having a unique nitrogen isotopic signature. It has been found that increasing soil depth is correlated with increasing δ^{15}N due to greater long-term N losses (Evans & Ehleringer, 1993). In general, nitrate is more depleted in ^{15}N than ammonium (Craine, 2011); therefore, it is possible that young trees have more nitrate available and mature trees have more ammonium. If we assume that the depletion observed in young trees is due to nitrate present in stream water, it may indicate that nitrifying bacteria populate the stream and hyporheic zone with high rates of nitrification. However, the water quality results show low levels of nitrate (<0.25 mg/l).

Plants relying on mycorrhizal fungi for N uptake tend to have depleted foliage (Dawson et al., 2002). Studies have found that the fungi community associated with tree roots changes with tree age, thereby changing tree nitrogen assimilation (Blasius & Oberwinkler, 1989; Dighton & Mason, 1985). Trees in and just downstream of the Garden have a sufficient supply of inorganic nitrogen and rely less on mycorrhizae. A study of fertilized forest plots found that increasing N input by fertilization led to decreasing soil respiration (an indicator of mycorrhizae activity) (Adesemoye & Kloepper, 2009)

Nitrogen fixation by microorganisms living symbiotically with certain plant species increases available nitrogen in ecosystems. This fixed nitrogen has an isotopic signature near 0‰ since it is derived from atmospheric N_2. If non-N-fixing plant species are living in a community with N-fixers, it is possible that their isotopic signature will have a relatively low $\delta^{15}N$. There are a few N-fixing species living in Red Butte Canyon, Silver buffaloberry (*Shepherdia argentea*) and Alder trees, mainly *Alnus incana*. There is one *Alnus incana* individual in the riparian zone within the Garden and one *Shepherdia argentea* (see Figure 10). *Alnus incana* and *Shepherdia argentea* are associated with low nitrogen fixation according to the Natural Resource Conservation Service (NRCS, 2014a). It has also been established that nitrogen fixation occurs more in dry and nitrogen depleted ecosystems (Chapin et al., 2011) so there may be little N-fixation associated with the two individual plants in Red Butte Garden where N is assumed abundant. A plant's energetic cost of nitrogen fixation is two to four times higher than absorbing ionic nitrogen in the soil (Lambers, Chapin, & Pons, 2008). When nitrogen is not limiting, N-fixation will be minimal.

One study found that riparian Alder annual nitrogen input is 164 kg N/ha (Klingensmith & Cleve, 1993). Assuming the lawns (0.75 ha) are fertilized three times a year at 36 kg of N per application, the total annual N addition is 107 kg. The addition of nitrogen from the Garden fertilizer is almost double the amount fixed from a dense native Alder stand. This, along with the results discussed above, suggest N-fixation is minimal.

Water Quality

Nitrogen

Based on the data found in this study, Red Butte Garden neither contributes nor removes inorganic nitrogen from Red Butte Creek. The data suggest that the production and input of inorganic nitrogen is balanced by the uptake by plants and absorption by soil and biota, which is often the case in relatively undisturbed streams and riparian zones (Allan & Castillo, 2007). Ammonium concentrations in the pond are marginally higher ($p=0.17$) than both upstream and downstream. This is likely caused by increased sediment biological activity and retention time. The N inputs from fish and birds is assumed high in the pond and the cycling of N more complex because of sediment biological activity (e.g., algae) both consuming and producing inorganic N at higher rates relative to upstream and downstream hyporheic zones.

Nutrient loading (mass per time) is more commonly used than concentration (mass per volume) in water resources management because it provides a more accurate measurement of the total mass of the pollutant. For this particular study, loadings are not reported because discharge is assumed to be consistent throughout the system (i.e., every sampling site). However, this is a broad assumption that may lead to inaccuracies since it is likely that there are gaining or losing portions of Red Butte Creek within the study site. Future investigation should include discharge measurements at sampling locations.

Two stream gauges within Red Butte Creek were analyzed in order to assess discharge continuity throughout the study site. Figure 24 shows the discharge from the reservoir outlet and stream stage from a monitoring station downstream of the Garden. [N.B. At the time of this study, discharge measurements were not available at the downstream monitoring station]. The largest peaks in reservoir discharge coincide with increases in downstream stage, as expected. However, there are certain dates (e.g., October 10) when downstream stage increases and reservoir discharge decreases; a result of a precipitation event. Currently, there is not a stage-discharge relationship for the downstream monitoring station and therefore, this analysis can only provide anecdotal evidence of discharge consistency. Future work should include additional discharged measurements throughout the study area.

Organic N was not measured in this experiment and there may be greater dissolved organic nitrogen (DON) concentrations in the Creek downstream of the Garden. A group of University of Utah students for a class project found that DON:TN at the downstream sampling location was 0.9 in March 2013. With the relatively dense population of fish and birds within the Garden pond, it is likely the Garden contributes organic N to the Creek. There are complex interactions occurring within the Garden and while these past and current studies do not provide an entire picture of the interactions, they do provide some evidence that Red Butte Garden is neither a sink nor source of inorganic N. Organic nitrogen in Red Butte Creek may be a more practical parameter to assess since currently a TMDL is being developed for total organic matter in the lower Jordan River to address dissolved oxygen impairment (UT DWQ, 2013).

Precipitation and stream nitrogen did not relate in this study (Figure 20), contrary to what is known about nitrogen content in runoff. The temporal extent and spacing of water sampling limit these analyses and conclusions. Extending water sampling for an entire year with a more frequent interval may show a relationship between nitrogen and precipitation. Ammonium and nitrate concentrations are relatively high in precipitation in arid urban centers (Bond, 1979; Burian et al., 2001) and therefore, it is possible that stream inorganic nitrogen concentrations will increase during and following precipitation especially in the spring when discharge, precipitation, and biological activity are high.

Most precipitation in Red Butte Garden infiltrates and or is lost through evapotranspiration (ET) because it is a mostly pervious (75%) catchment with abundant vegetation. Inorganic nitrogen in precipitation will be assimilated by plants or absorbed by microorganisms. However, in a nitrogen saturated system, inorganic nitrogen may leach to groundwater or enter the Creek through interflow. Future investigation should include analyzing soil and sediment within the pond for nitrogen and carbon content to determine whether the system is nitrogen limited or saturated.

Figure 17 and 18 show the linear regression models for NH4*DO, NH4*temperature, and NH4*discharge. Increasing dissolved oxygen results in decreasing NH4, which may be occurring due to greater photosynthetic biological activity increasing oxygen and consuming nutrients. Increasing temperature is correlated with increasing ammonium, which also may be a result of greater biological activity. As temperatures rise, soil respiration increases, potentially increasing mineralization and nitrification rates (Chapin et al., 2011). Decreasing ammonium is observed with increasing discharge, which could be a result of increased dilution and mixing. However, the samples collected at a discharge of 0.6 cfs may be considered an outlier and therefore, an increasing trend of ammonium with discharge would be observed (Figure 18). The highest ammonium concentrations were observed at the lowest flow, which, as mentioned above, occurred two days after a relatively large rain event (October 7). There may have been factors other than discharge which had a greater influence on ammonium concentrations for this sampling event. Bond (1979) found a weak negative correlation between discharge and ammonium at the USGS stream gauge during 1973.

Stream discharge did not vary greatly during this study. Flow exiting the reservoir is controlled by the Central Utah Water Conservancy District in order to mitigate flooding and preserve the fish habitat within the reservoir. Flows during this study ranged from 0.6 to 1.1 cfs. In the past 8 years, the peak discharge leaving the reservoir was 43 cfs occurring in June 2011. As shown in Figure 3, stream discharge peaks in spring (May and June). Continuing water quality sampling or monitoring through an entire year would help show any relationships between stream discharge and nutrient concentrations.

Figure 19 shows the precipitation and discharge time series for the duration of this experiment. Since discharge is controlled at the reservoir, 2 km upstream of Red Butte Garden, there is not a consistent relationship between precipitation and discharge. In early October, there were two relatively large rain events (8 mm and 9 mm) which coincided with low discharge (0.5 cfs). One of the purposes of the reservoir and dam is to mitigate flooding in Salt Lake City and therefore, discharge from the dam is decreased prior to predicted large rain events. In other cases, discharge from the dam may increase prior to a rain event to increase capacity in the reservoir. This human influenced relationship between precipitation and discharge makes it difficult to predict downstream hydrology and its influence on water quality. However, these relationships were still examined.

Chloride

Average downstream chloride concentrations (14.63 mg/l) are not significantly higher than upstream (14.42 mg/l). No dicing salts were used during the sampling period. The observed concentrations are assumed background levels. The USGS measured chloride concentration at the stream gauge above the dam between 1964 and 2013 (μ=12.44 mg/l, σ=2.19 mg/l, n=350) (Table 1). Bond (1979) found that chloride concentrations in Red Butte Creek increase with discharge, indicating runoff is higher in chloride concentrations than ambient Creek levels. The innovative Urban Transitions and Aridregion Hydro-sustainability (iUTAH) project has recently established a monitoring network in Red Butte Creek called Gradients Along Mountain to Urban Transitions (GAMUT). One of these monitoring stations, located approximately 0.5 km downstream of Red Butte Garden, has been monitoring conductivity among other variables since early autumn. The conductivity data show a strong relationship with precipitation. GAMUT provides continuous stream monitoring, which in the future will help provide insight into the interactions occurring upstream and downstream of the Garden.

Total Suspended Solids

The mean TSS concentration downstream of the Garden is significantly higher than upstream (p=0.002). The concentration in the pond within the Garden is also significantly higher than mean upstream concentration (p=0.02). In 2005, there was an accidental release at the CUWCD dam. A large amount of fine sediments (<2mm) accumulated in the upper portion of the Garden pond as a result of this incident. The accumulation altered the hydraulics of the Creek by widening and decreasing velocities.

A nonnative variety of *Phragmites* invaded this upper pond area, further compounding the hydraulic alterations. The results of this study suggest that the sediment accumulated in the upper pond is gradually being transported to downstream reaches and eventually may be removed altogether, allowing the pond to return to its designed form. Red Butte Garden will also be removing some of the invasive *Phragmites* which should accelerate the transport of fine sediment. From a management perspective, these changes are improvements; however, the impact of this sediment to downstream reaches should be considered. Further analysis of sediment transport upstream, through the Garden, and downstream should be completed.

CONCLUSIONS

The potential environmental impacts and benefits of Red Butte Garden on Red Butte Creek have been studied and the results and analyses are presented in this thesis. The experiments focused on the nitrogen dynamics within and around the Garden to determine whether the Garden contributes or removes N from the Creek system. Water quality results suggest Red Butte Garden is neither a sink nor source of inorganic nitrogen to Red Butte Creek. Leaf results, though inconclusive, suggest the Garden may contribute N to vegetation downstream.

Total Box elder leaf nitrogen $\delta^{15}N$ is significantly higher in the Garden (p=0.02) and downstream (p=0.04) compared to upstream. This is likely a result of increased organic N or net N losses. The pond provides habitat to many fish and birds, potentially exporting organic N downstream and enriching soils. The application of organic fertilizer derived from cow waste on Garden beds nearest the Creek may also be a source of enriched N. Further analysis of soils in the riparian corridor and trufgrass area should be conducted to determine mineralization, nitrification, and denitrification rates. If net N loss is the cause of enrichment, it is important to determine the dominant pathway, whether leaching of nitrate or denitrification as the former is a greater concern to downstream ecosystems.

Box elder leaf C:N results indicate significantly higher nitrogen in the Garden (p=0.02) and downstream (p=0.02) compared to upstream. This is likely due to increased

N inputs from fertilization and urban runoff. The increased N in leaf litter can lead to net mineralization and nitrification producing a positive feedback of increasing inorganic N in Red Butte Creek. Again, more analyses are needed to understand all of the processes occurring within this complex human built and natural landscape.

The water quality results indicate no significant difference between upstream and downstream conditions for all measured parameters ($p \geq 0.05$), with the exception of TSS. However, the sampling temporal spacing and extent cannot provide a clear picture of overall stream quality. Expanding sampling to include an entire year on a more frequent interval will likely provide more insight. Additionally, dissolved organic nitrogen and total nitrogen should be included in future analyses. It has been hypothesized that organic nitrogen is high in Red Butte Creek and the leaf data from this study corroborate that hypothesis. Furthermore, total organic matter is the pollutant currently under scrutiny in the TMDL development for the lower Jordan River (UT DWQ, 2013).

TSS concentrations are higher in the pond and downstream, indicating the Garden is a source of sediment, though likely as a result of the accidental dam release in 2005. From the Garden's perspective, the transport of sediment downstream is positive since the accumulation has altered the pond system, leading to more stagnant flows and the introduction of an invasive *Phragmites* species. However, the impacts from increased TSS to downstream reaches should be assessed.

Engineering Applicability

The water quality results suggest the Garden neither contributes nor removes inorganic nitrogen or chloride. Given this conclusion, no change in management practices is required by Red Butte Garden to mitigate impacts. Conversely, leaf results suggest that there is increased N within the Garden and downstream, as expected due to the anthropogenic inputs from fertilizer and urban runoff. This increased nitrogen content in vegetation alters the natural N cycling in Red Butte Creek and may lead to a positive feedback of increasing nitrogen. To minimize N contribution, the Garden should continue to use organic fertilizer in riparian garden beds and minimize their use of synthetic fertilizer on the lawn space. Since Red Butte Garden is upstream of the dense urban zone it cannot serve as a buffer zone; however, placing native riparian vegetation between lawns and Red Butte Creek will help remove excess N in runoff and interflow. Finally, the fine sediment, which accumulated in the pond in 2005, will likely diminish gradually. Removal of the invasive *Phragmites* will accelerate the transport of these sediments.

Shortcomings

There are multiple shortcomings in this research that limit the conclusions. Leaf samples were collected in the late part of the growing season when plants begin to transition nitrogen from leafs to branches, which resulted in lower than normal leaf N concentrations. *Acer negundo* is a dioecious species and the gender of the sampled trees was not recorded. While there is no isotopic fractionation of N across tree gender, there may be a difference in leaf N content (Dawson & Ehleringer, 1993). It may be safe to assume that the majority of the sampled trees are female since Dawson and Ehleringer (1993) found that female to male ratio is much higher in riparian than upland areas. Mycorrhizae interaction can play a large role in fractionation of N isotope and was not measured in this experiment. Strong mycorrihaze activity will supply depleted N to plants

(Craine et al., 2009).

Water sampling was limited by time and funding and therefore only covered September through December. Water analysis did not include total nitrogen, which was an oversight, given that previous work has found high concentrations of dissolved organic nitrogen in Red Butte Creek. The methods used for nitrate and orthophosphate were not rigorous enough to measure small concentrations. It is recommended that ionic chromatography be used in place of colorimetric methods in the future.

Concentrations are reported in this thesis rather than the more appropriate loading rates because accurate discharge observations were not available for each sampling site. Analyses in this thesis using discharge are limited since all discharge is from the reservoir outlet 1.7 km upstream of the study site. There are likely gaining and losing stream sections between the reservoir and the Garden. As mentioned above, future work should include additional discharge measurement locations. The iUTAH monitoring network will be a valuable resource for in-stream measurements.

Lastly, total suspended solids were measured in grab samples using 250 ml bottles. This sampling method does not provide a reliable way to collect a suspended sediment sample because it does not account for the influence of channel shape and changes in discharge that greatly affect sediment load. A sampling fish is common apparatus used to collect suspended sediment samples and is recommended for any future work.

Recommendations

Technical Recommendations for Further Research

Red Butte Garden offers a unique site for multidisciplinary research. The Garden is a place where human and natural systems interact and is located at the nexus between an undeveloped and urbanized watershed. The use of Red Butte Garden as a research site should be expanded. Numerous additional potential research efforts have been identified while addressing the research questions laid out for this project. Prioritized future research efforts include:

1. Analyze riparian soil and pond sediment to determine N dynamics
    a. Mineralization, nitrification, and denitrification rates
    b. Nitrogen and carbon content
2. Determine whether lawn soils and riparian areas are N saturated
3. Monitor water quality through spring and growing season to investigate relationships between precipitation and increased Garden activities
    a. Establish the baseline conditions of Red Butte Creek for which to compare specific management practices
    b. Use ionic chromatography to detect low concentrations of constituents
    c. Include total nitrogen and dissolved organic nitrogen analyses to address potential high organic loads and investigate influence on Jordan River
4. Investigate nitrogen input from fish and their food
5. Measure sediment transport during higher spring flows and determine impacts from a net export of sediment from the Garden to downstream reaches

Garden Management Recommendations

Based on the results and analyses in this study, the primary suggestion to Red Butte Garden is to maintain similar practices with minor alterations and more specific investigation into areas of improvement. Water quality results indicate no negative impact and the leaf data suggest greater N in downstream riparian zones, but the source of this increased N cannot be directly associated with Red Butte Garden. Suspended solids data suggest that the accumulation of fine sediment in the upper portion of the pond will likely be naturally removed over time and therefore, no action is required.

The Garden should consider reducing fertilizer application since synthetic fertilizer is estimated to be the greatest nitrogen input (>100 kg annually). Excess N may lead to net export downstream, impacting other ecosystems. The elevated N in downstream leaves may lead to net mineralization and nitrification, potentially resulting in a positive feedback.

Maintaining a buffer zone of native riparian vegetation at the downstream end of the Garden will help remove inorganic nitrogen from stream water. The harvested litter from these areas should be recycled into the organic fertilizer.

And finally, the Garden should consider a consistent and regulated fish feeding protocol to eliminate excess input of fish food; further research into fish activity could more specifically inform any management changes. Fish activity is estimated to contribute approximately 90 kg of N annually and the leaf results and past studies suggest high organic N content in riparian zones downstream of the pond, possibly as a result of excess feeding or fish activity.

These recommendations should be understood and considered within the context and limitations of this research. Natural abundance of leaf N stable isotopes does not provide a quantitative method for determining N inputs and outputs. Water quality monitoring occurred during autumn and may not be an indication of the general trends during the growing season. Additionally, total N was not measured, which is strongly recommended for any future work to determine organic nitrogen concentrations.

Broader Impacts

The results of this study will support future research in Red Butte Garden and Red Butte Creek. The ongoing research and outreach activities by iUTAH and Friends of Red Butte Creek can capitalize form this work and improve future efforts. This works has shown there are complex interactions between human and natural systems and provides justification for further research.

This study is an initial step toward quantifying baseline conditions for which to compare management practices. Other landscape managers should follow similar steps to help optimize alternatives to maintain vibrant land without damaging the surrounding natural environment.

Finally, this study shows that there is potential for botanical gardens to couple as green infrastructure by mitigating the impacts from urbanization (e.g., stormwater treatment). This is an innovative opportunity with limited literature and great potential given the numerous urban botanical gardens nationally and abroad.

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