5-2014

Biogeochemistry of Selenium in Pariette Wetlands, Utah

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BIOGEOCHEMISTRY OF SELENIUM IN PARIETTE WETLANDS, UTAH

by
Colleen P. Jones

A dissertation submitted in partial fulfillment
of the requirement for the degree

of

DOCTOR OF PHILOSOPHY

In

Ecology

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2014

ABSTRACT

Biogeochemistry of Selenium in Pariette Wetlands, Utah

by

Colleen Jones, Doctor of Philosophy

Utah State University, 2014

Co-Major Professors: Dr. Paul Grossl and Astrid Jacobson
Department: Plants, Soils, and Climate

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1) Mass balance and mass water flux of selenium for the Pariette Wetlands were studied. A comparison of inlet and outlet Se fluxes was used to determine the mass of Se stored. Selenium concentrations were higher at the inlet (2.1-16.3 $\mu g\ L^{-1}$) than at the outlet (2.0-14.0 $\mu g\ L^{-1}$). The average amount of Se retention and/or loss was 75%.

2) *Elevated levels of selenium (Se) in water, soil, and biota of the Pariette Wetlands, Utah*. Twelve sample sites were selected to determine the spatial and temporal variation of Se accumulation, concentration and volatilization. At the inlet, concentrations of waterborne Se during low-flow period (winter) were significantly higher than concentrations during high-flow irrigation season (summer). Se concentrations in water at the outlet were lower during the high-flow period ranging from. In contrast, plant tissue Se con-

centration was lower at the inlet and higher at the outlet. Selenium volatilization results indicated that there were spatial and temporal differences among samples sites.

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Knowledge gained about the mass balance, storage of Se, and the associated biogeochemical processes in water, plants, and soils that contribute to the accumulation or loss of Se in the wetlands will be beneficial to future land management decisions to minimize the impact of Se exposure to wildlife.

(115 Pages)

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ACKNOWLEDGMENTS

I would like to express my gratitude to my amazing husband, Kim. I am blessed to share my life with him. I appreciate his love and support in fulfillment of a promise made to my father to complete my degree. Thank you to my wonderful parents, Bill and Lee, who taught me the value of an education and the role of hard work in accomplishing my dreams.

I am grateful for the instruction and mentoring of my co advisors, Dr. Grossl and Dr. Jacobson, whose advice and guidance have helped me become a better researcher. I appreciate the assistance of Henry Allred, Trevor O’Neil, Shannon Babb, John Lawley, and Sarah Leahy in the field and lab. For input that has enhanced my research, I wish to thank my committee of Drs. Mike Amacher, Ben Burger, and Janis Boettinger. Thank you to Drs. Michele Tuttle, Julie Fahy, and Jean Morrison at USGS for help with soil field and analytical assistance. A special thank you to Tim Faircloth and Darren Williams of the BLM and Sandy Wingert of UDWQ for funding and assistance with data collection.

I would also like to express my appreciation to Dennis Shiozawa who encouraged me to complete my degree. Finally, thanks to my friends and colleagues at the Utah State University Uintah Basin campus for believing, supporting, and encouraging me to complete this dissertation.

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CHAPTER 1

INTRODUCTION

In the Western United States, there has been increasing concern over selenium (Se) contamination of public lands and waters resulting from irrigated agriculture and mining activities. Selenium is a naturally occurring element and is an essential trace element required for structure and function of certain proteins in animals (Hoffman, 2002; Winkel et al., 2012). In excess amounts, however, Se is known to cause reproductive failures and abnormalities in egg-laying vertebrates such as birds, fish, amphibians, and reptiles (Hamilton, 2004; Lemly, 1985). Given the increasing occurrence of Se contamination throughout the world, it can be anticipated that this problem will continue to present challenges to land and wildlife managers (Lemly, 2002).

Since the early 1980s, high Se concentrations in agricultural drainage waters have been a major concern in the San Joaquin Valley, California (Seiler, 1995; Tanji et al., 1986). Here, subsurface irrigation drainage water containing high levels of Se was discharged and confined in Kesterson Reservoir, causing deformity of water bird embryos, ultimately leading to the reservoir closure in 1986 (Ohlendorf, 2002; Ohlendorf et al., 1986; Ohlendorf et al., 1988a; Ohlendorf et al., 1988b; Presser, 1994). Similarly, Se contamination has affecting some of Utah’s waters that also serve as wildlife refuges. The Pariette Draw flows into the Pariette Wetlands before reaching the Green River (Stephens et al., 1992). The middle Green River of the Uinta Basin area was identified as an area with significantly high Se contamination, and the Pariette Draw, a tributary to the middle Green River, was identified as one of the three areas of concern (Figure 1-1).

STUDY AREA

Our study area, the Pariette Wetlands, is located approximately one kilometer upstream of the confluence of Pariette Draw watershed and the Green River. The draw is located in the northeastern corner of Utah in the Uintah Basin (Figure 1-1). The Pariette Wetlands, the oasis of the Uinta Basin in Utah (Figure 1-2), encompasses 9,033 acres, 2,529 of which are classified wetlands or riparian zones and is the largest BLM wetlands development in Utah. The wetlands contain diverse vegetation and wildlife in an arid climate. The site was developed in 1975 to improve waterfowl production and provide seasonal habitat for other species including ring-necked pheasant, mourning dove, sandhill and whooping cranes, and peregrine falcon. A wide variety of raptors including the bald eagle, harrier, and prairie falcon also use the area (Stephens et al., 1992; Zalunardo, 1979). Elevated levels of selenium have been measured in the Pariette Draw and Pariette Wetlands, which may be hazardous to wildlife within the drainage (Wingert and Adams, 2011). There is, therefore, a critical need to identify the factors associated with the biogeochemistry of Se and the flux within this aquatic ecosystem.

SELENIUM BIOGEOCHEMISTRY

In the environment, Se is found in five metastable valence states: selenate, SeO_4^{2-}, (Se^{+6}); selenite, SeO_3^{2-}, (Se^{+4}); elemental Se (Se^0); selenides (Se^{-2}) and organic forms of Se (Maher et al., 2010). Under oxidized conditions, it is present as the oxyanions selenate and selenite. Selenate is the primary bioavailable form of Se, and, thus, the form that poses the greatest threat to the environment, especially under alkaline pH and aerobic conditions. As Se is reduced, selenite forms stable complexes with iron and aluminum which are sorbed to soil and sediment particle surfaces and, consequently, are less mobile (Figure 1-3). However, both selenate and selenite, the oxidized form of Se, can occur in the same soil with the same conditions (Goldberg, 2011). Organic matter mineralization is associated with reduced redox potentials. At low redox potentials, Se forms insoluble elemental Se and metal selenides, which are unavailable to biota (Winkel et al., 2012). In its lowest oxidation state, Se forms metallic selenides (CuSe, $FeSe_2$, etc), hydrogen selenide gas (H_2Se) or proteinaceous Se (selenomethionine or selenocysteine) (Presser, 1994). In aquatic ecosystems, cycling of Se occurs within the sediment pore waters, the water column and associated atmosphere (Figure 1-3). The major Se species in aquatic ecosystems can be categorized into four major groups: 1) inorganic Se, 2) volatile and methylated Se, 3) protein and amino acid Se, and 4) biochemical intermediates (Maher et al., 2010).

Geologic processes such as weathering and soil genesis can mobilize sequestered Se from the lithosphere into the hydrosphere and atmosphere, causing Se to be more bioavailable. Selenium is found in many minerals of sedimentary deposits, metamorphic rocks, and hydrothermal veins. Bioalkylation in soils, water and plants can cause Se species such as dimethyl selenide [$(CH_3)_2Se$], dimethyl diselenide [$(CH_3)_2Se_2$], and other volatile organic Se to be released to the atmosphere. When Se volatilization is not accounted for, there is major uncertainty in calculating Se budgets. The underlying mechanism responsible for the mobilization of selenium in the atmosphere is the least understood of the cycling of selenium (Maher, et al., 2010).

Since Se’s chemical forms are similar to sulfur (S), Se can be substituted in the cell as analogues to S containing biomolecules forming organic Se (Unrine et al., 2007).

Once incorporated into biomolecules such as in amino acids, Se then becomes part of proteins. Selenium is essential to the structure and function of some proteins and enzymes (Young et al., 2010). In human health, Se is an important component of several metabolic pathways, which include thyroid hormone metabolism, immune function, and antioxidant defense systems (Levander and Burk, 2006). However, overexposure to Se can cause short-term negative affects in humans such as fatigue and irritability, hair and fingernail changes, damage to peripheral nervous system. Long-term affects of Se are hair and fingernail loss, nervous and circulation system dysfunction, and kidney and liver tissue damage (Ge and Yang, 1993). Se deficiency diseases as well as toxicosis have also been reported in the veterinary medicine literature (Tiwary et al., 2006).

Selenium toxicity to fish and waterfowl are of major concern in aquatic ecosystems. Several investigators have reported bioaccumulation of Se. In Belews Lake, North Carolina and Martine Lake, Texas fish kills were reported as a direct result of Se released into the main basin of these lakes (Hamilton, 2004). Ten other studies were reviewed in which Se was identified as the potential cause of disappearance of several species of fish (Lemly, 1985).Waterfowl are also very sensitive to Se toxicity. Hatchability of eggs was significantly reduced when dietary Se was between 5 $\mu g\ g^{-1}$ and 10 $\mu g\ g^{-1}$. There was also evidence of grossly deformed embryos with missing eyes and beaks, edema of the head and neck, and distorted wings and feet (Ohlendorf, 2002).

OBJECTIVES

The central hypothesis is that concentration of Se in water, soil, and plants influences the biogeochemistry of selenium which, in turn, influences the bioavailability of selenium in the Pariette Wetlands, Utah. Our hypothesis is based on preliminary data as well as the published work of United States Geological Survey USGS reconnaissance study of the 1980's (Stephens et al., 1992) and the TMDL study of the Utah Division of Water Quality (Wingert and Adams, 2011) whose studies suggest that the Se entering into the wetlands is being lost through adsorption, volatilization and/or bioaccumulation. The overall objective of this study, therefore, was to measure levels of Se in water, soil and plants in the Pariette Wetlands. The rationale for our study is to identification the physical, chemical and biological factors associated with the biogeochemistry of Se in the Pariette Wetlands, Utah. Identification of the biogeochemical factors will help land managers make better-informed decisions on how to direct their future management and restoration efforts.

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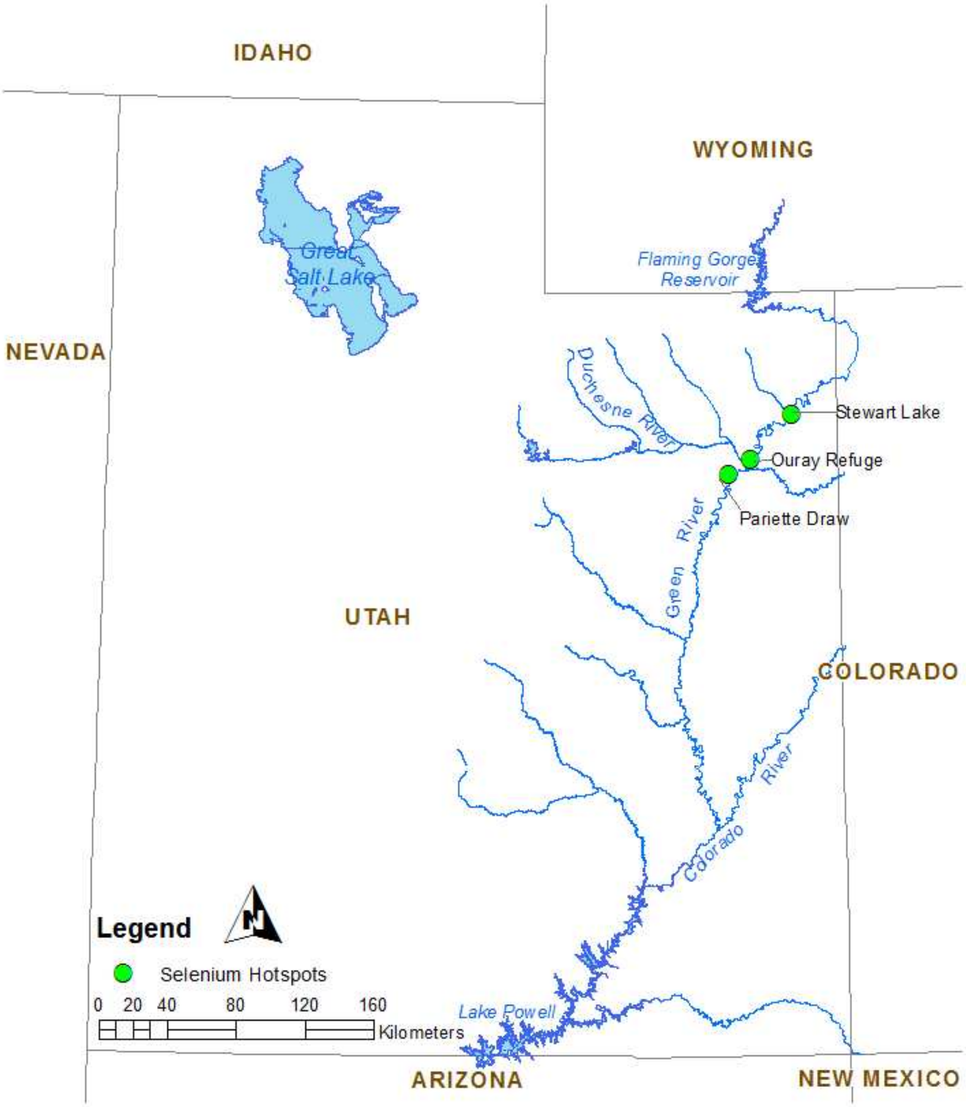

Figure 1-1: Three selenium “hotspots” of the Middle Green River in the Uinta Basin, Utah (green circles).

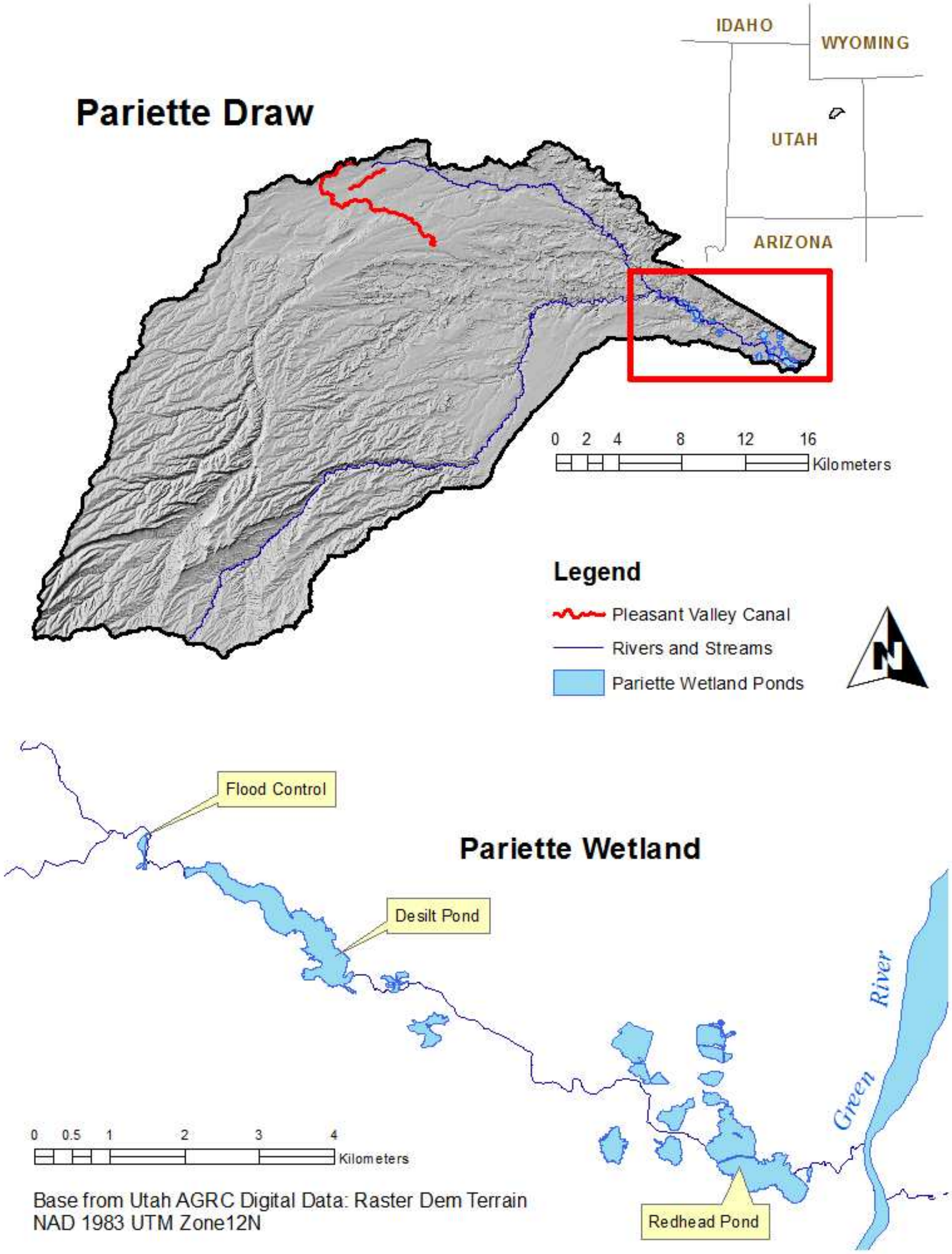

Figure 1-2: Water, and soil sample sites at BLM’s Pariette Wetlands, Utah.

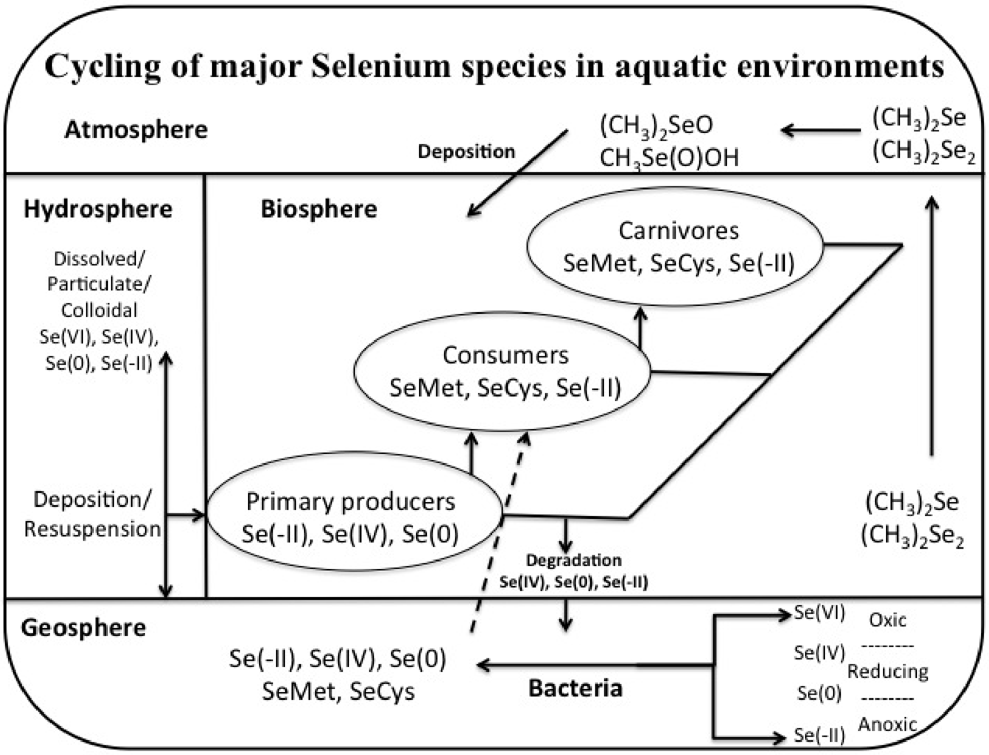

Figure 1-3: Cycling of major Se species in aquatic environments (Maher et al., 2010).

CHAPTER 2

SELENIUM MASS BALANCE AND FLUX IN WATER OF PARIETTE WETLANDS, UTAH

ABSTRACT

Selenium (Se) has potentially deleterious impact on the flora and fauna of aquatic ecosystems. As Se moves through a wetlands system, various processes such as sorption onto sediments, plant uptake, and volatilization into the atmosphere can attenuate Se resulting in its storage in the wetlands. A comparison of inlet and outlet Se fluxes can be used to determine the mass of Se stored in a wetlands system. Inlet and outlet total Se concentrations and water discharge were measured at the Pariette Wetlands and used to calculate Se fluxes. Average flux at the inlet and outlet was compared to the flux occurring during a wetter (2009) and drier (2012) than average year. Average water inflow was between 0.0 and 1.86 $m^3 s^{-1}$, and average water outflow ranged from 0.07 to 0.89 $m^3 s^{-1}$. Selenium concentrations were higher at the inlet (2.1-16.3 $\mu g L^{-1}$) than at the outlet (2.0-14.0 $\mu g L^{-1}$). Retention and/or loss of Se in the Pariette Wetlands were on average 1,147 kg $year^{-1}$. The average amount of Se retention and/or loss in the wetlands ranged from a high of 86.4 % in 2009 to a low of 72.7% in 2012 with an overall retention average of 75%. Most of the Se transported into the Pariette Wetlands is retained by the wetlands. Water movement through the Pariette Wetlands system did not appreciably alter annual Se attenuation rates.

INTRODUCTION

During the past forty years, there has been increasing concern about environmental concentration of selenium (Se) in aquatic ecosystems and its potentially deleterious impact on associated flora and fauna. Sources of Se span from natural (geochemical weathering, wildfires, and volcanic activity) to anthropogenic activities (agriculture, mining, wastewater treatment and coal-fired power plants). In an aquatic ecosystem, water is the most important vector for mobilizing Se from the geosphere (Maher et al., 2010).

During the 1980s, the relationship between selenium concentrations in wetlands and agricultural drain water became an environmental concern (Stephens et al., 1992). For example, in Kesterson Reservoir, California, subsurface agricultural drain water was identified as the source of Se. Selenium was further identified as the cause of embryo abnormalities and mortality for several species of aquatic birds (Ohlendorf et al., 1988).

In 1983, the USFWS reported incidences of waterfowl mortality, birth defects, and reproductive failures in various locations throughout the United States. Irrigation drainage water was identified as the conduit transporting Se to these areas of elevated concentrations. The elevated concentration of Se prompted the United States Department of the Interior (USDOI) to identify the extent and nature of water quality issues introduced by irrigated drainage water in the western United States (Stephens et al., 1992).

In 1985, the USDOI began a program to determine whether irrigation–related contamination problems existed at irrigation projects, national wildlife refuges or wetlands constructed or managed by USDOI. The Pariette Draw flows into the Pariette Wetlands before reaching the Green River (Figure 2-1). The middle Green River of the Uinta

Basin area was identified as having significant high Se contamination. Pariette Draw, a tributary to the middle Green River, was identified as one of three areas of concern.

The Pariette Wetlands was created in 1975 by the BLM to provide wildlife habitat in an arid environment and currently consists of 23 ponds (Zalunardo, 1979). The ponds are filled using water diverted from the Pariette Draw through a series of water diversions structures. These water structures (dikes, dams, outlet pipes and trickle tubes) were designed to maintain constant water levels throughout the summer (D. Williams, personal communication, 2011).

The BLM conducted a Se study in 1978-79 of various sites in Pariette Wetlands. Selenium concentrations ranged from below detection limit (1 μg L^{-1}) at the inlet to 298 μg L^{-1} at the outlet of Redhead Pond (Stephens et al., 1992). The standard Maximum Contaminate Level (MCL) of selenium for drinking water recommended by the United States Environmental Protection Agency (USEPA) is 50 μg L^{-1} (USEPA, 2012). The Utah State Water Quality standard for wildlife is 4.6 μgL^{-1} (Wingert and Adams, 2011). Pariette Draw at Redhead Pond exceeded the USEPA's MCL, and the Utah State Water Quality standard by 500%.

From the 1988 to 1990, USGS and USFWS agencies conducted an extensive reconnaissance study. The water entering Pleasant Valley via the Pleasant Valley Canal (Figure 2-1) met the Utah Water Quality Se standard of less than 1 μg L^{-1}. Selenium levels increased downstream to 9 μg L^{-1} at the inlet to the Pariette Wetlands, and then decreased to 1 μg L^{-1} at the outlet of the wetlands (Stephens et al., 1992).

In 2008 and 2009, a subsequent Total Maximum Daily Load (TMDL) study by the Utah Division of Water Quality (UDWQ) reported similar results to the 1980s studies in which the water entering Pleasant Valley was below the 4.6 μg L^{-1} wildlife water quality standard for selenium. As the water moved through Pleasant Valley, Se increased to 17.4 μg L^{-1} until it reached the Pariette Wetlands. The Se concentration decreased as it moved through the wetlands to 3.9 μg L^{-1}. An inverse correlation to flow was also found. During periods of low flow, the concentration of Se was high, and during periods of high flow concentration of Se was low (Wingert and Adams, 2011). Since little is known, however, about the biogeochemical processes governing Se in the Pariette Wetlands, the specific aim of our study is to estimate the influx, outflux and storage of Se concentration within the wetland, and to establish the association of Se concentration with seasonal changes.

MATERIALS AND METHODS

Surface grab water samples were collected monthly during the irrigation season (April to October) from the inlet and outlet of the Pariette Wetlands as well as from two sample sites within the wetlands (Desilt Pond and Gadwell Pond) from 1993 to 2012 (Appendix A). Clean polyethylene bottles that had been rinsed three times in the field were used to collect water samples. Water samples collected in the field were stored in a cooler on ice until returned to the lab. At the lab, samples were filtered through a 0.45-μm Teflon membrane filter and acidified with trace-metal grade concentrated HNO_3. Water samples were kept refrigerated at 4°C until ready for digestion and then analysis. The water digestion method used was sulfuric acid-potassium peroxydisulfate (Cutter, 1986). The total Se was analyzed by hydride generation atomic absorption spectroscopy (HG-AAS).

Water flow rates into and out of the wetlands were measured using the float method at the inlet below the Flood Control Structure and the outlet below Redhead Pond (Figure 2-1). Multi-probe data loggers were installed at the inlet and outlet to measure water-quality parameters (temperature, conductivity, pH, turbidity and dissolved oxygen) from June to September 2011 and from March to June 2012. Multi-probes were removed once the water levels were too low to take readings (Appendix A).

Selenium fluxes into and out of Pariette Wetlands were calculated with Equation 1:

$$F = Q^{*} C^{*}86{,}400 \quad [1]$$

where F=mass flux, g day^{-1}; Q = inflow or outflow discharge, m^{3} s^{-1}; C = Se concentration, g m^{-3}, and 86,400s day^{-1} converts seconds to days (Stillings et al., 2007). Discharge from three different time periods were analyzed: 2009 (Table 2-1), 2012 (Table 2-2), and averaged data from 1993 to 2012 (Table 2-3).

Since flow data were incomplete due to the closure and discontinued use in 1984 of the USGS gauging stations above and below Pariette Wetlands, data during the operation of the USGS gauging station from 1975 to 1984 were used to estimate the transit time for water and waterborne Se water to move through the wetlands. Average monthly flow data from the USGS station at the inlet and outlet were combined with average monthly precipitation and evapotraspiration data obtained from the Utah Climate Center Myton Station and residence time (Table 2-3). Residence time was calculated with Equation 2:

$$\tau = V / Q * 86{,}400 \quad [2]$$

where τ = residence time, day; V = total volume of wetlands estimated from area and average depth of ponds and canals, m^{-3} (Table 2-4); Q = flow at the outlet, $m^3 s^{-1}$; and 86,400s day^{-1} converts to time to days (Stillings et al., 2007). The total volume and flow of water for the wetlands varied depending on the season and the availability of irrigation return water.

RESULTS AND DISCUSSION

Key factors contributing to discharge were precipitation and irrigation return water. On average, discharge increases in March due to spring runoff and decreases in April until the irrigation season begins. Then, discharge peaks in June and decreases in July and August. At the end of irrigation season, the area has a late rainy season (September through November) when discharge again increases (Figure 2-2). Average annual precipitation between 1993 and 2009 was 15.7 cm (Table 2-3). The total rainfall for 2009 (Table 2-1) was 17.2 cm, and for 2012 (Table 2-2) was 9.6 cm. Most of the water entering the wetlands is diverted from the Duchesne River via the Pleasant Valley Canal (Figure 2-1). Approximately 4.25 $m^3 s^{-1}$ water are diverted during the irrigation season which spans from May to October. A few springs also provided a minimal source of water for the draw (Wingert and Adams, 2011).

On average the Se concentration of water at the inlet was greatest from December to March ranging from 16.6 to 12.4 $\mu g\ L^{-1}$, and lowest during irrigation season (May through October) ranging from 4 to 4.8 $\mu g\ L^{-1}$. At the outlet, the highest Se concentration occurred in December and January at 7.8 and 14 $\mu g\ L^{-1}$ respectively and the lowest during irrigation season ranging from 2 to 2.6 $\mu g\ L^{-1}$ (Figure 2-3).

Selenium concentration and flow were used to calculate flux. On average, the highest influx occurs in March (19.9 kg day^{-1}) and the lowest in August (1.1 kg day^{-1}). The outflux was highest in March (4.1 kg day^{-1}) and lowest in July (0.2 kg day^{-1}) (Figure 2-4).

A mass-balance for Se was created using the mass inflow, mass outflow and the retained components. Discharge at the inflow and outflow were used to calculate the influx, outflux, and stored or lost Se for a year. The amount of Se retained or lost in the wetlands on average was 1,230.8 kg year^{-1}. About 19.8 % of the selenium entering the wetlands exited the wetlands at the outlet. On average, then, 75% of the Se entering was retained within or lost from the wetlands. When the average storage was compared to a wetter than average year (2009, Figure 2-5) and a drier than average year (2012, Figure 2-6), the wetter year retained more Se than a drier year 86.4% and 72.7% respectively. However, the difference in retention was not large enough to be significant.

The estimate total volume of the wetlands is 1,971,377 m^3 (Table 2-4). Residence time is the shortest during spring runoff in March (25.54 days), during peak irrigation season in June (33.99 days), and at the end of irrigation season in October (32.59 days). Residence time is longer during winter [December (313.42 days), January (220.24 days), and February (142.96 days)]. Other potential sources of water loss not accounted for in this study may be evaporation, evapotranspiration, and wetlands recharge, which were not directly measured during the study. Not enough data have been collected to calculate a hydrologic mass balance of the wetlands.

CONCLUSIONS

The mass of Se retained in the Pariette Wetlands is greater (% value of average retention) during wetter than average years, although the difference was not large. Retained Se within the wetlands may be problematic to wildlife feeding in the area depending on the mechanism of removal of Se from the water. If Se is sorbed to sediments as controlled by pH and redox potentials, then Se is not available to wildlife. Also if plants and microbes volatilize Se, then Se will not be available to wildlife. However, if Se is accumulating in plants or in aquatic or benthic organisms that wildlife feed on, there is potential for bioaccumulation of Se to toxic levels detrimental to egg laying organisms such as waterfowl and fish (Lemly, 2002; Ohlendorf, 2002; Presser, 1994). Based on mass-balance calculations, the wetlands received its highest Se loads during spring runoff in March and again during peak irrigation season in June. March could be problematic for waterfowl in the wetlands because it is the beginning their breeding season. Further research is needed to determine fate of Se stored in the wetlands and its mass-balance.

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Table 2-1: Average monthly precipitation (mm) at Myton, Utah Climate Center Station; flow at inlet and outlet ($m^3 s^{-1}$); [Se] measured at inlet and outlet; influx of Se ($g\ day^{-1}$) and outflux of Se ($g\ day^{-1}$) during 2009.

Date	Monthly Precip. (mm)	Flow at Inlet ($m^3 s^{-1}$)	[Se] at Inlet ($\mu g\ L^{-1}$)	Influx ($g\ day^{-1}$)	Flow at Outlet ($m^3 s^{-1}$)	[Se] at Outlet ($\mu g\ L^{-1}$)	Outflux ($g\ day^{-1}$)	Se Storage ($g\ day^{-1}$)
3/10/2009	3.3	0.308	10.8	2,874	0.518	4.1	1,835	1,039
4/21/2009	24.6	0.053	10.2	469	0.028	3.9	94	374
5/11/2009	17.5	0.137	4.1	486	0.028	3.0	73	413
6/22/2009	42.7	5.60	2.5	12,096	1.551	1.3	1,742	10,354
7/20/2009	1.0	0.459	5.4	2,142	0.028	3.4	82	2,060
8/4/2009	19.3	0.468	3.0	1,212	0.028	3.3	80	1,132
9/10/2009	30.9	2.11	3.7	6,731	0.028	3.2	77	6,653
11/3/2009	5.1	0.395	12.5	2,874	0.059	1.7	86	4,177

Table 2-2: Average monthly precipitation (mm) at Myton, Utah Climate Center Station; flow at inlet and outlet ($m^3 s^{-1}$); [Se] measured at inlet and outlet; influx of Se (g day^{-1}) and outflux of Se (g day^{-1}) during 2012.

Date	Monthly Precip. (mm)	Flow at Inlet ($m^3 s^{-1}$)	[Se] at Inlet ($\mu g L^{-1}$)	Influx (g day^{-1})	Flow at Outlet ($m^3 s^{-1}$)	[Se] at Outlet ($\mu g L^{-1}$)	Outflux (g day^{-1})	Se Storage (g day^{-1})
3/05/2012	0	0.703	9.3	5,668	0.413	4.2	1,504	4,164
3/30/2012	2.3	0.388	7.9	2,642	0.265	1.6	376	2,267
5/10/2012	0	0.703	1.8	1,084	0.413	1.8	659	425
6/29/2012	5.8	0.703	2.5	1,535	0.413	1.2	430	1,105

Table 2-3: Average monthly precipitation (mm) and reference evapotranspiration mm d^{-1} during 1993 to 2009 at Myton, Utah Climate Center Station; flow at outlet ($m^3 s^{-1}$); and calculated residence time of water averaged by month from data collected from the USGS gauging station from 1975 to 1984 above and below Pariette Wetlands.

Month	Monthly Pre-cipitation (mm)	ET (mm d^{-1})	Flow at inlet ($m^3 s^{-1}$)	Flow at outlet ($m^3 s^{-1}$)	Residence Time (days)
January	9.84	0.51	0.1204	0.10	220.24
February	8.89	0.98	0.1484	0.16	142.96
March	18.2	2.06	0.8484	0.89	25.54
April	14.77	3.58	0.336	0.20	116.41
May	28.56	4.69	0.5348	0.18	125.37
June	16.67	6.28	1.98	0.69	32.99
July	21.77	6.71	0.3024	0.17	135.81
August	27.37	5.70	0.2632	0.17	138.11
September	27.01	4.14	1.0612	0.25	92.60
October	31.12	2.33	0.4816	0.7	32.59
November	24.4	1.09	0.182	0.19	118.09
December	7.32	0.59	0.196	0.07	313.42

Table 2-4: Area (m^2) and estimated average depth of ponds and canals (m) used to calculate total volume (m^3) of water in Pariette Wetlands.

Pond	Area (m^2)	Average Depth (m)	Volume (m^3)
Flood Control	27,357	0.61	16,677
Desiltation	801,278	0.61	488,459
First	12,302	0.30	3,750
Felters Diversion	23,715	0.46	10,842
First	1,983	0.61	1,209
Felters	100,605	0.76	76,661
Big Island	185,872	1.83	339,923
Avocet	47,955	0.15	7,308
Small Island	43,301	0.61	26,397
Roberts	46,175	0.10	4,644
Horseshoe	22,541	0.46	10,306
Cattail	37,636	0.76	28,678
Mallard	94,373	0.46	43,147
Gadwall	283,604	0.91	259,327
Shoveler	108,092	0.61	65,893
Pintail	86,077	0.61	52,472
Redhead	411,201	1.22	501,337
Two Island Pond	9,105	0.76	6,938
Millet Pond	88,707	0.15	13,519
Swallow Pond	7,244	0.46	3,312
Canal Pond	7,891	0.46	3,608
Raccoon Pond	6,515	0.91	5,958
Canal1	283	0.30	86
Canal2	728	0.30	222
Canal3	243	0.30	74
Canal 4	2,064	0.30	629
Total	2,456,849	15.04	1,971,377

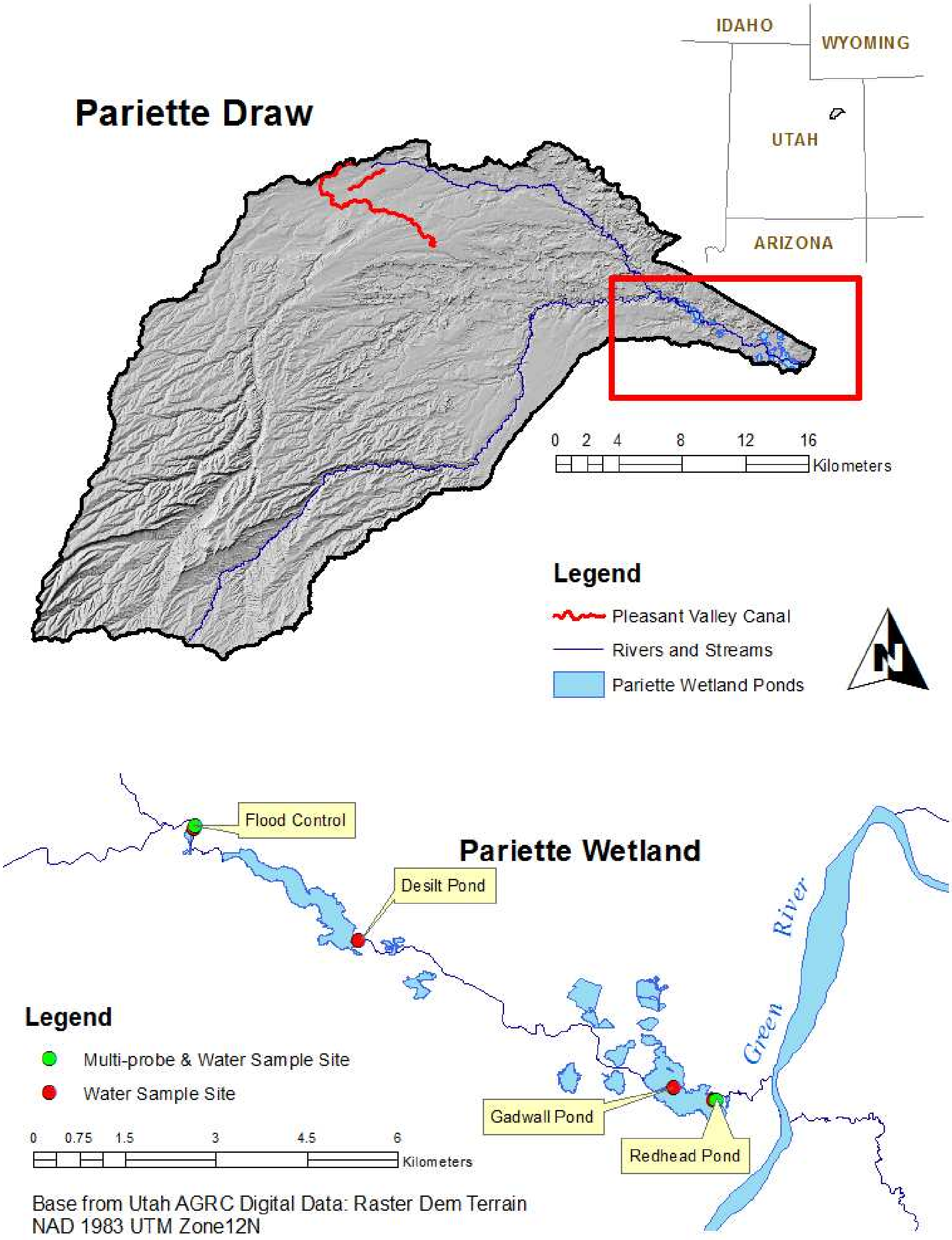

Figure 2-1: Map of Pariette Draw and Wetlands, Utah, with multi-probe and water sample site locations.

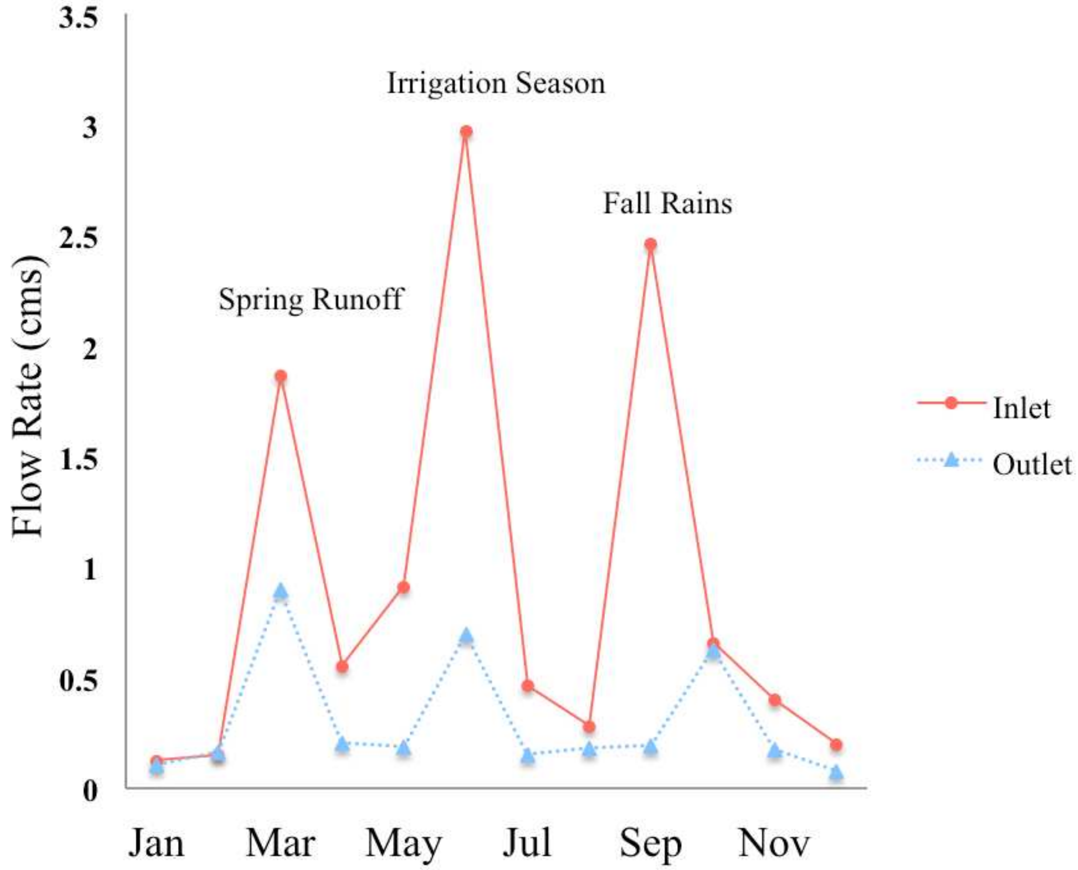

Figure 2-2: Average flow at inlet (red circles) and outlet (blue triangles) of Pariette Wetlands, Utah with peaks represents high flow events during spring runoff, irrigation season, and fall rains (1993-2009).

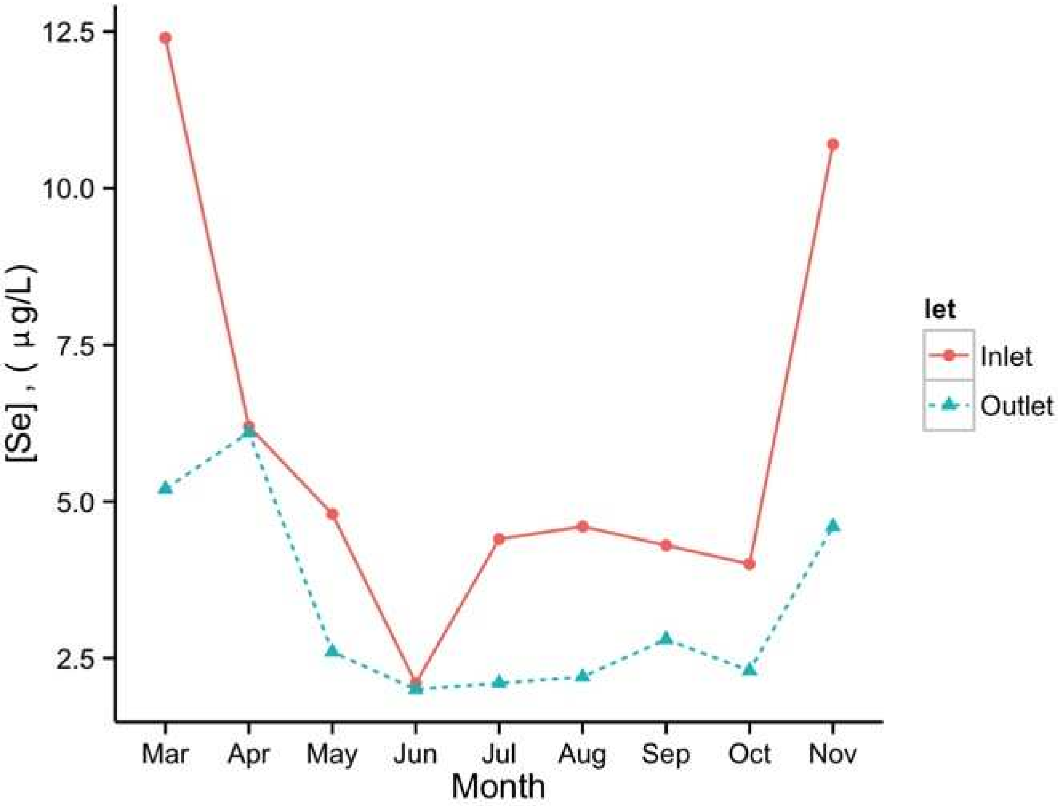

Figure 2-3: Average waterborne Se concentrations at the inlet (red circles) and outlet (blue triangles) of Pariette Wetlands, Utah (1993-2009).

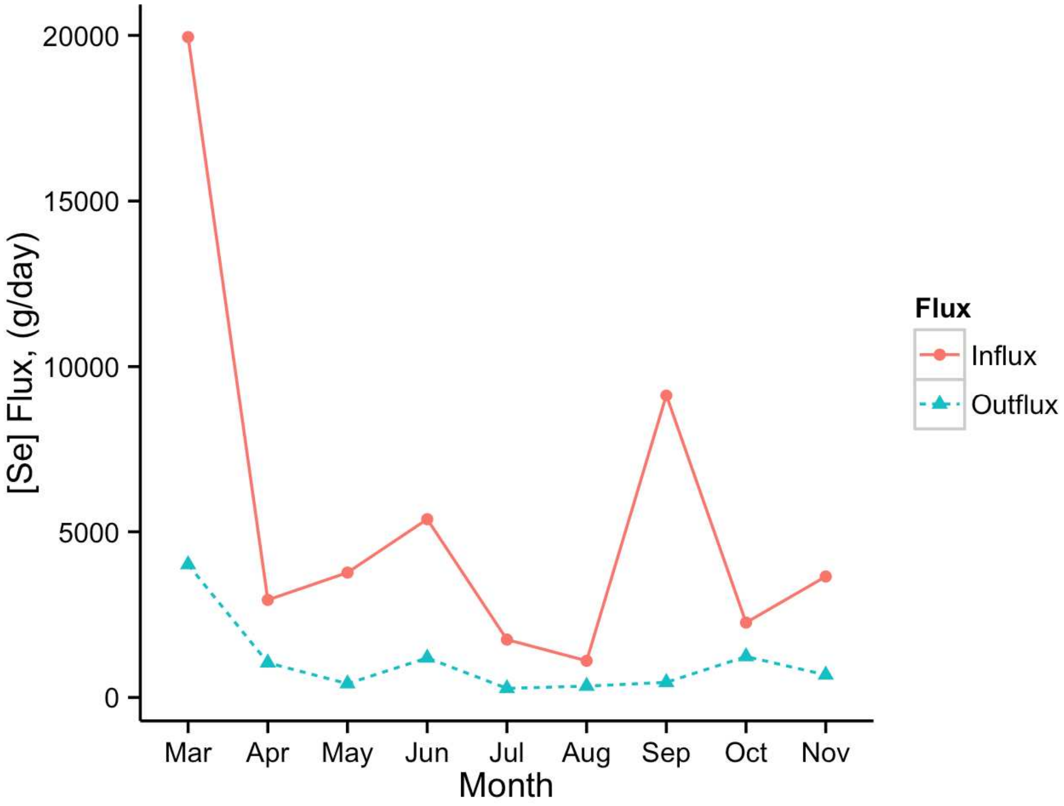

Figure 2-4: Average Se influx (red circles) and outflux (blue triangles) in g day^{-1} with 75% retention of Se within Pariette Wetlands, Utah.

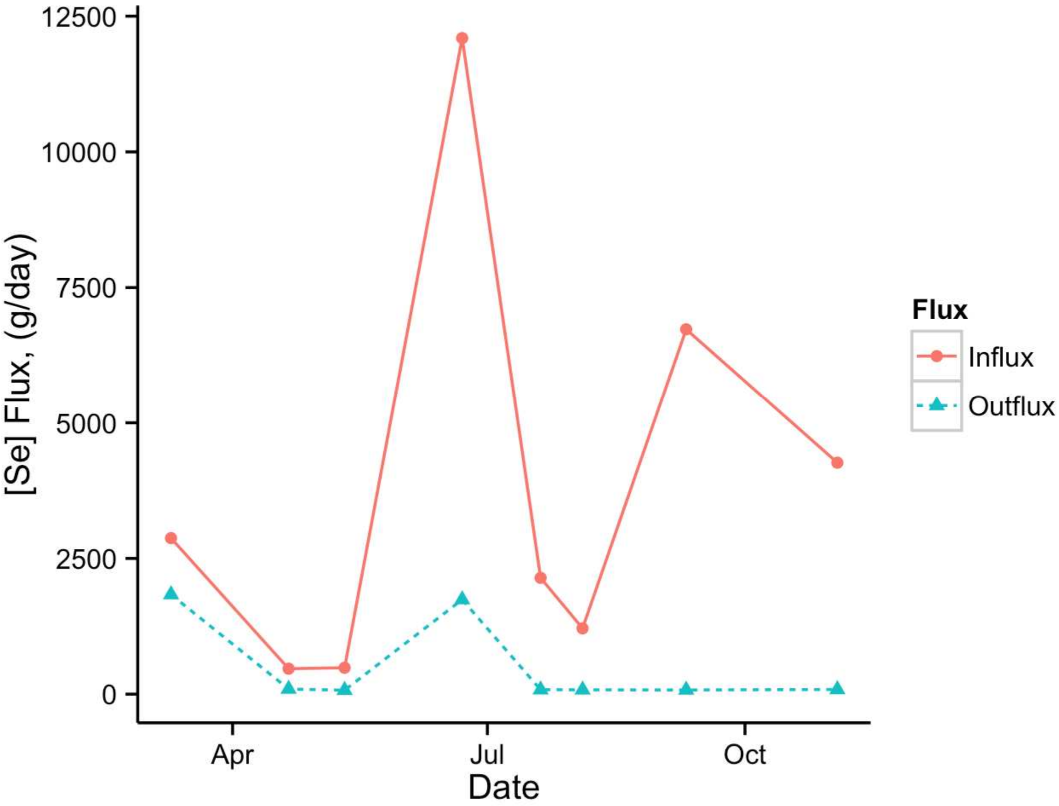

Figure 2-5: Se influx (red circles) and outflux (blue triangles) in g day^{-1} with 86.4% retention of Se within Pariette Wetlands, Utah during a wetter than average year (2009).

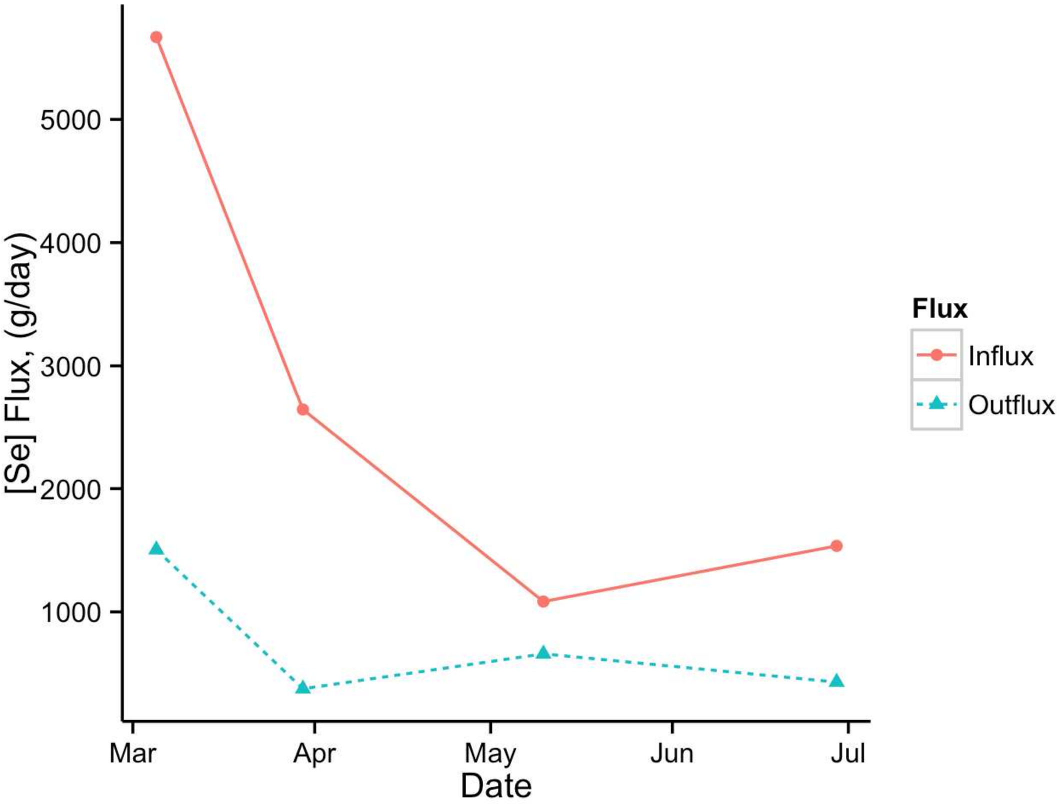

Figure 2-6: Se influx (red circles) and outflux (blue triangles) in g day^{-1} with 72.7% retention of Se within Pariette Wetlands, Utah during a drier than average year (2012).

CHAPTER 3

SELENIUM IN WATER AND PLANT TISSUE AND ITS LOSS THROUGH VOLATILIZATION IN THE PARIETTE WETLANDS, UTAH

ABSTRACT

Elevated levels of selenium (Se) in water, soil, and biota of Pariette Wetlands, Utah may have detrimental effects on local wildlife. Twelve sample sites were selected to determine the spatial and temporal variation of Se concentration, accumulation and volatilization in water and plant tissues from the Pariette Wetlands during the active growing season. At the inlet, concentrations of waterborne Se during low flow period (winter) were between 14.6 and 16.3 µg L^{-1}, significantly higher than concentrations during high flow irrigation season (summer), which ranged from 2.1 to 4.6 µg L^{-1}. Se concentrations in water at the outlet were lower during the high flow period ranging from 7.6 to 14 µg L^{-1}. In contrast, plant tissue Se concentration was lower at the inlet (0.26 ± 0.10 mg kg^{-1}) and higher at the outlet (0.56 ± 0.57 mg kg^{-1}). Selenium volatilization results indicated that there were spatial and temporal differences among samples sites. Rates were highest in the spring (from 0.01 to 0.049 µg day^{-1}) during the peak growing season, and lowest in the fall ranging from 0.004 to 0.01 µg day^{-1} at the end of the growing season. Rates also were spatially different: highest at the wetlands' inlet (0.0069 ± 0.0023 µg day^{-1}) and lowest at its outlet (0.009 ± 0.007µg day^{-1}). Our results indicate that vegetation removal of Se is a significant attenuation process, and that Se volatilization also contributes to the removal of Se from Pariette wetlands from the inlet to the outlet of the wetlands.

INTRODUCTION

Selenium (Se) contamination is an important environmental issue in the western United States. Selenium is a metalloid that exists in five oxidative states; Selenate (Se^{6+}), Selenite (Se^{4+}), elemental Se (Se^0), Selenide (Se^{2-}), and organic Se. Selenate is the major species in an environment that is aerobic and pH from neutral to alkaline. Selenite and elemental Se dominate in anaerobic and lower pH environment. In certain areas, Se occurs naturally in sedimentary rock formations, especially those formed from marine deposits during Tertiary and Cretaceous Ages (Seiler, 1995). Weathering of these formations by natural or anthropogenic causes, such as precipitation, runoff, or irrigation return water can oxidize Se to the two more mobile species, selenate (SeO_4^{2-}) and selenite (SeO_3^{2-}). Once mobilized, Se becomes bioavailable to plants and animals. High concentrations of Se in aquatic ecosystems leads to the accumulation of bioavailable Se by wildlife, causing damage and death (Bañuelos and Lin, 2007).

Kesterson National Wildlife Refuge in the San Joaquin Valley, California, is an example of an environmental disaster caused by Se contamination due to agricultural drainage (Ohlendorf et al., 1986). At the inflow to Kesterson Reservoir, dissolved concentrations of Se exceeding the EPA's Se criterion for toxic waste criterion of 1000 $\mu g\ L^{-1}$ resulted in high rates of embryonic deformity and death of aquatic wildlife (Presser, 1994).

Similarly, the middle Green River area of the Uinta Basin, Utah, has been identified as an area with significantly high Se contamination. Several studies conducted in the 1980's by the USGS, USFWS, and the BLM identified three areas of concern for Se contamination, including Stewart Lake Waterfowl Management Area (SLWM), Ouray National Wildlife Refuge (ONWR), and Pariette Wetlands (Figure 3-2) (Stephens et al., 1992). The concentration of dissolved selenium in irrigation drain water entering SLWM ranged from 14 to 140 μg L^{-1} exceeding the USEPA's chronic criterion of 5 μg L^{-1}. The selenium concentration in sediments collected from drain discharge in the inflow of SLWM ranged from 10 to 85 μg L^{-1} (Stephens et al., 1988). The source of Se contamination was believed to be inflow of shallow ground water and surface water from a sewage lagoon system that flowed through Mancos Shale and was known to be seleniferous (Stephens et al., 1992). Ouray National Wildlife Refuge (ONWR) water samples ranged from 9 to 93 μg L^{-1}. In 1987, ONWR was closed for a short period of time after discovery of deformed American coot embryos. Consequently, the ponds containing elevated levels of selenium were drained and filled in with clean sediments (Stephens et al., 1988). The contaminated irrigation drain water that entered SLWM was diverted around SLWM and into the Green River (Naftz et al., 2005).

The bioavailability of Se depends on the Se species. Selenate and some organic forms of selenium are soluble and available for plant uptake (Zhang et al., 2004). Plant uptake of Se occurs through the roots and is thus influenced by Se species concentration in water and sediment. Plants actively take up selenate through sulfate transport proteins. Selenite is taken up through passive diffusion and can be inhibited by phosphate. Some plants are Se accumulators that preferentially absorb Se over sulfur. However, non-Se accumulators are able to discriminate between selenate and sulfate. Non-Se accumulators will uptake sulfate instead of selenate. Selenium accumulation is determined by Se metabolism of the plant and can be distributed throughout the plant. Distribution of Se species depends on plant development in that selenate generally is concentrated in the older leaves, and organic Se species in younger tissues. Younger leaves are sites of reduction of Se to organic forms.

Loss of Se from plants occurs as a result of volatilization. This occurs when the plant has excess supplies of Se, and typically occurs from the roots (Maher et al., 2010). Plants are able to convert Se to organic forms that bioaccumulate in fish and wildlife (Lemly, 2002). Microbes, plants and animals convert inorganic Se to organic Se through biomethylation. Biomethlyation is an important pathway that converts toxic Se to nontoxic volatile forms of Se such as Dimethylselenide (DMSe) and dimethyldiselenide (DMDSe). Volatilization of Se is considered an effective technique for removing Se from contaminated sites (Hansen et al., 1998; Lauchli, 1993). Volatile Se should be considered, therefore, a component to explain the difference in Se concentrations in water at the input and output of the Pariette Wetlands.

This paper reports the waterborne concentration of Se at the inlet and outlet from the Pariette Wetlands from March 30 to November 17 of 2012. In addition, distribution of Se in plants and volatilization by tissue-type, species, spatial, and season were also reported. Preliminary data of seasonal variability of Se concentration at the inlet, and little to no variability at the outlet of the wetlands, suggests that selenium is being volatized by plants, accumulated by plants and animals or absorbed to sediments.

MATERIALS AND METHODS

Pariette Wetlands was constructed in 1975 by the BLM to provide wildlife habitat in an arid desert (Zalunardo, 1979). Over the last 30 years, various ponds have been added so that there are currently 23 ponds (Figure 3-1). The ponds are filled with water diverted from the Pariette Draw. A series of structures (dikes, dams, outlet pipes and trickle tubes) were designed to maintain constant water levels throughout the summer (D. Williams, personal communication, 2011).

Surface grab water samples were collected monthly during the irrigation season (April to October) from the inlet and outlet of the Pariette Wetlands during 2012. Clean polyethylene bottles that had been rinsed three times in the field were used to collect water samples. Water samples collected in the field were stored in a cooler on ice until returned to the lab. At the lab, samples were filtered through a 0.45-μm Teflon membrane filter, and acidified with metal grade concentrated HNO_3. Water samples were kept refrigerated at 4°C until ready for digestion and then analysis. Digestion method used for water was sulfuric acid-potassium peroxydisulfate (Cutter, 1986). Total Se was analyzed using hydride generation atomic absorption spectroscopy (HG-AAS).

During the active growing season, eleven wetlands and one upland sample sites were selected to determine if emergent plant bioaccumulation and volatilization affect Se retention within the wetlands. Wetlands sample sites were selected based on proximity to water sampling sites (inlet and outlet) and to the three predominant vegetation communities along the edge of the wetlands. Wetlands vegetation communities include common reed (*Phragmites australis* (Cav.) Trin. ex Steud.), cattail (*Typha domingensis* Pres. *and Typha latifolia* L.), and bulrush (*Scirpus acutus* Muhl. ex Bigelow) (Figure 3-1). Upland vegetation consisted of a desert shrub community with tufted hair grass (*Deschampsia cespitosa* (L.) P. Beauv.) as the predominant vegetation nearest the volatile Se passive trap.

Passive trapping of gas-phase Se species was performed with activated charcoal air filters (BULK filter) cut to 15 cm x 9 cm and placed in a fiberglass window screening sleeve to prevent insects and debris from becoming lodged in the filters. Charcoal filters were deployed and collected every six weeks from March 30, 2012 to November 17, 2012. Each passive filter was attached to the top of a PVC pipe that was attached to a five foot metal U-post. The filters were placed level with the top of last year's growth of vegetation. After the six weeks, traps were collected and analyzed for adsorbed Se together with plant and soil samples. Filters were cut into smaller pieces to increase the surface area for extraction and digestion using 6% H_2O_2 in 0.05 NaOH overnight, shaken, and then filtered to remove charcoal (Wu et al., 2003). Samples were then analyzed via inductively coupled plasma mass spectrometry (ICP-MS). The Se concentrations in the extracts were converted from $\mu g\ L^{-1}$ to $\mu g\ day^{-1}$ based on the length of time the filter was deployed.

Plant samples were prepared by soaking them for 30 seconds in 0.3% sodium lauryl sulfate, 1 mM HCL, and deionized water to remove surface contamination (Pilon-Smits et al., 1999). Tissues were dried for 24 hours in a convection oven at 80°C. Dried plant tissue was then finely ground and digested with nitric acid following standard procedures (Zasoski and Burau, 1977). Samples were then analyzed using HG-AAS.

Statistical analysis was performed with Deducer, a GUI interface for R (Fellows, 2012). Multiple comparisons among site, species, tissue type and season were conducted using a generalized linear model.

RESULTS AND DISCUSSION

Surface water samples collected from 1995 to 2012 showed spatial and seasonal variation with yearly average Se concentration at the inlet (5.81 ± 4.22 μg L^{-}1) higher than the outlet (3.71 ± 3.62 μg L^{-1}). Highest Se concentration occurred at low flow during winter months (December, January and February). The lowest Se concentration occurred during peak irrigation season (June, July and August) (Table 3-1), indicating that irrigation water addition to the wetlands tended to dilute soluble Se levels already in the wetlands. A mass balance of Se indicated that on average 75% of Se entering is being retained within the wetlands.

There was a significant difference in Se concentration in parts of all species of sampled plant tissue (flower, vegetative material, and root) collected during the study period (Table 3-2). The lowest mean value was for the flower portion of the plant, (0.28 ± 0.11 mg kg^{-1} (n=18)), and the highest mean value was in the root tissue, (0.76 ± 0.68 mg kg^{-1} (n=23)). The vegetative portion of the plant had a mean Se of 0.34 ± 0.27 mg kg^{-1} (n=6, Figure 3-2). Several studies have shown that Se uptake by plants begins with the roots, and depending on the Se species will determine the rate of translocation of Se from the root to shoot (Zayed et al., 1998).

Bulrush and cattail had similar mean Se concentrations 0.48 ± 0.33 mg kg^{-1} (n=27) and 0.55 ± 0.56 mg kg^{-1} (n=42). Common reed had a mean of 0.25 ± 0.11 mg kg^{-1} (n=27), and tufted hair grass was significantly lower than all other plants sampled 0.16 ± 0.06 mg kg^{-1} (n=6, Figure 3-3). A generalized linear model analysis to examine differences in Se concentration between species, time of sampling, and sampling location indicated that species and date sampled were not significantly different during the sampling period. However, sample site was significantly different with wetlands sites having notably higher concentrations than the upland site (Figure 3-4). The highest mean Se concentration and widest standard deviation was at the outlet to the wetlands and Redhead Pond 0.56 ± 0.57 mg kg^{-1} (n=47). The next highest was at the Desilt Pond 0.41 ± 0.22 mg kg^{-1} (n=25) and the lowest wetlands mean Se concentration was at the inlet at the Flood Control 0.26 ± 0.10 mg kg^{-1} (n=24). The upland sample site was significantly lower than the wetlands sites 0.16 ± 0.06 mg kg^{-1} (n=6).

The Pariette Wetlands covers an area of approximately 3,000 acres. Assuming that the aboveground dry matter (DM) biomass yield ranged from 2.15 to 11.50 kg m^{-2} (Acharya and Adhikari, 2010) and the average aboveground Se concentration of plants in the wetland was 0.4 mg kg^{-1} DM, the total amount of Se accumulated and stored in the aboveground biomass would range from 10 to 60 kilograms, a relatively small fraction of the total amount of Se stored (1,150 kg Se) in the wetland (< 5%).

In San Francisco, Se concentrations in wetlands plants ranged from 5 to 20 mg kg^{-1} in root and shoot material (Hansen et al., 1998). On the lower Colorado River, Mexico, Se concentration in plants ranged from 0.03 to 0.17 mg kg^{-1} (Garcia-Hernandez et al., 2000). A constructed wetlands near Las Vegas, Nevada, reported results of Se concentrations in plant species similar to ours. The highest Se concentrations were in the cattail vegetative material 2.81 ± 0.53 mg kg^{-1} (Pollard et al., 2007). Our study, as well as the San Francisco study cited above, indicated consistently higher concentration of Se in the root than in the vegetative material of the plant (Hansen et al., 1998). Hansen et al. (1998) reported that as much as 30% of the waterborne Se concentration was reduced by the biological volatilization processes of the plant and associated microorganisms.

Among plant species there was no significant difference in volatile Se concentrations collected by charcoal filters during the study period (Table 3-3). Tufted hair grass had the lowest mean of 0.00588 ± 0.00445 μg day^{-1}, and the highest was bulrush with a mean of 0.0114 ± 0.01μg day^{-1}. Common Reed and cattail means were 0.0104 ± 0.00711μg day^{-1} and 0.00871 ± 0.00464 μg day^{-1}, respectively (Figure 3-5).

Spatial differences were significant at a p value of < 0.005. Temporal differences were more significant at a p value of < 0.000005. The upland BLM (0.0059 ± 0.0044 μg day^{-}1) and wetlands Flood Control (0.0069 ± 0.0023 μg day^{-1}) sites were significantly different from one another (Figure 3-6). However, the Desilt Pond (0.014 ± 0.01μg day^{-1}) was significantly different from all other sites except Redhead Pond (0.009 ± 0.007μg day^{-}1) at the outlet of the wetlands. During spring and early summer (May and June) samples are significantly different from the late summer to fall sample periods (Figure 3-7). In early spring (March and April), rising air temperatures, spring run-off, and spring showers contribute to the growth of both the upland and the wetlands plants. By early summer (June) precipitation drops off until late fall (October). In the fall a short rainy season occurs with enough precipitation to increase soil moisture for plant growth which occurs near the end of November before the first frost (Figure 3-8).

Rates of volatilization from vegetation at the Desilt Pond were statistically higher than all other sites except Redhead Pond. Generally, the greatest rate of volatilized Se was produced in the spring and early summer during the peak growing season. In the summer months (July and August), all sample sites decreased in volatilization as water availability decreased, except for the BLM site. After spring run-off during the summer months, the wetlands received only irrigation drainage return water. Occasionally during the dry season, there was insufficient water to fill all the ponds, and some ponds dried. In the fall (September and October), the area had a short rainy season. Temperature and plant available water is significant enough for plants to continue growth. As a result, the November sample period had a slight increase in the rate of Se volatilization. Calderone et al. (1990) reported that volatilization rates were greatly influenced by temperature and organic amendments, and that volatilization was a significant mechanism for removing Se from sediments.

Several researchers have reported similar results that constructed wetlands exposed to Se contamination have higher concentrations at the inlet than at the outlet (Azaizeh et al., 2006; Dicataldo et al., 2010; Hansen et al., 1998; Karlson et al., 1990), indicating that the wetlands act as a sink for Se removal for water entering the wetlands. Most of the Se was immobilized as a result of sorption to sediments, as well as bioaccumulation and volatilization by plants and microbes. Biological volatilization accounted for 10% to 30% of the Se removed from the wetlands (Hansen et al., 1998). In contrast, we calculated that the amount of Se that volatilized from the Pariette Wetland was insignificant (0.02 to 0.03 kg Se year^{-1}) compared to the total of 1,150 kg Se stored in the wetland. The assumptions used to calculate the amount of Se volatilized were 1) the Pariette wetland covered an area of 3000 acres, 2) the volatility flags trapped volatile Se from a 1 m^2 underlying area, 3) plants were active for 200 days of the year, and 4) the average daily volatilization rate was 0.008 μg Se day^{-1}.

Volatilization can occur from the soil, soil/root interface, or even the plant canopy. Volatilization of Se by plants and microbes has been used as a means of bioremediation of Se from impacted sites. Weres et al. (1989) in a study using enclosures placed over plants at Keterson Reservoir, California, concluded that volatilization rates increased over surfaces with the presence of decaying organic matter, increasing temperature, and parallel soil moisture. Zhang and Moore (1997) found in a wetlands system of Benton Lake, Montana, that the major producers of volatile Se were the plants and sediments. The rate of volatilization of Se increased with the increase of temperature, airflow rate, and decomposition of wetlands plants.

The rate of volatilization is greatly influenced by the Se species in the water and soil. Energetically, plants and microbes more easily volatilize selenite and other organic forms of Se than selenate. Although Se species were not differentiated in this study, future work will include speciation of water samples.

Several researchers have demonstrated that the rate of Se volatilization by plants is greater when the available Se is in a more reduced form (selenite or selenomethionine) as compared to selenate (Bañuelos et al., 2005; Zhang and Frankenberg, 2001). Zhang and Moore (1997) suggest that the concentration of dissolved organic Se is a more important factor affecting Se volatilization by plants than dissolved inorganic Se. The data collected during this study was insufficient to determine if volatilization or bioaccumulation is the greatest contributor to Se retention within the wetlands.

CONCLUSIONS

Large seasonal variability of Se concentration in water at the inlet and little to no variability at the outlet of the wetlands suggest that selenium is either being absorbed, volatized by plants, or being stored in the sediments. The main goal of our research was to determine if bioaccumulation and volatilization of Se is a contributing factor in the removal of Se, and if there were significant spatial and temporal differences in Se from the Pariette Wetlands. We conclude that volatilization of Se is occurring, and conditions such as temperature, organic material, and soil moisture influence the spatial and temporal differences. Spatial differences are probably a result of reducing conditions within the wetlands as water saturated soils become anoxic. Anoxic conditions favor the less mobile forms of Se. As inlet water enters the wetlands, Se under oxidized conditions exists as selenate. Then under anoxic flooded conditions Se reduces to selenite, and volatilization may be accelerated. By the time it exits the Desilt Pond, much of the dissolved Se has been reduced, and either sorbed on to sediments or taken up by plants and organisms. By the time the water exits the outlet at Redhead Pond, much of the available Se has been removed. The temporal differences are the result of the seasonal changes in temperature and available water. Once the irrigation season ends, the incoming water to the wetlands are greatly reduced thus reducing the rate of volatilization until more water enters the wetlands during the rainy season in the fall. It may be possible through management practices to remove Se from irrigation return water by manipulating water levels. An understanding of how plants and microbes influence Se volatilization rates ultimately may lead to improved best management practices that significantly reduce the environmental impacts of Se and future the of wetlands for wildlife and waterfowl.

Selenium concentrations in plant tissue analyzed at Pariette Wetlands are near or below typical levels found in the Western United States. Additional studies of other plants and sediments within the wetlands are necessary to determine the extent of ecological risk to local wildlife and to formulate possible mitigation actions.

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Table 3-1: Monthly average of total selenium concentration of surface water collected from the inlet and outlet at Pariette Wetlands from 1995 through 2012.

Month	Inlet n	Inlet [Se] (μg L-1)	Outlet n	Outlet [Se] (μg L-1)
January	0		3	13.97 ± 4.31
February	1	15.7	5	7.64 ± 5.03
March	3	9.34 ± 1.92	8	3.92 ± 2.60
April	2	11.15 ± 0.95	7	6.06 ± 3.59
May	4	3.10 ± 0.84	12	2.53 ± 1.53
June	3	2.44 ± 0.10	8	1.88 ± 0.98
July	4	4.33 ± 2.84	8	1.86 ± 1.01
August	5	3.70 ± 0.74	14	2.05 ± 1.04
September	3	2.78 ± 0.66	7	2.26 ± 1.21
October	0		4	2.33 ± 0.56
November	2	10.15 ± 2.35	6	4.53 ± 1.94
December	1	15.0	2	7.75 ± 5.25

Table 3-2: Selenium concentration of plants (F= flower, S=vegetative material, and R=Root) collected in Pariette Wetlands during 2012.

Emergent Taxa	Part	n	[Se] (mg kg^{-1})
Bulrush	F	5	0.22 ± 0.15
Bulrush	S	17	0.48 ± 0.29
Bulrush	R	9	0.57 ± 0.41
Cattail	F	7	0.32 ± 0.10
Cattail	S	25	0.38 ± 0.32
Cattail	R	10	1.11 ± 0.83
Common Reed	F	6	0.27 ± 0.05
Common Reed	S	19	0.23 ± 0.13
Common Reed	R	4	0.31 ± 0.09

Table 3-3: Se volatilization rates as measured by passive collection of gas-phase Se by charcoal filters in Pariette Wetlands from March 30, 2012, to November 17, 2012.

Site / Species	[Se] µg / day May 10, 1012	[Se] µg / day June 26, 2012	[Se] µg / day August 18, 2012	[Se] µg / day October 6, 2012	[Se] µg / day November 17, 2012
FC / Cattail	0.010	0.008	0.008	0.004	0.010
FC / Bulrush	0.010	0.008	0.004	0.004	0.005
FC / Phragmites	0.010	0.008	0.008	0.004	0.005
DS / Phragmites	0.020	0.008	0.016	0.008	0.010
DS / Bulrush	0.049	0.016	0.012	0.008	0.019
DS / Cattail	0.015	0.016	0.004	0.004	0.010
RH / Cattail	0.010	0.012	0.004	0.008	0.010
RH / Bulrush	0.010	0.008	0.004	0.008	0.010
RH / Cattail	0.024	0.012	0.008	0.004	0.005
RH / Bulrush	0.024	0.012	0.008	0.004	0.005
RH / Phragmites	0.029	0.012	<0.004	0.008	0.005
BLM / Tufted Hair Grass	0.005	0.008	0.012	<0.004	0.005

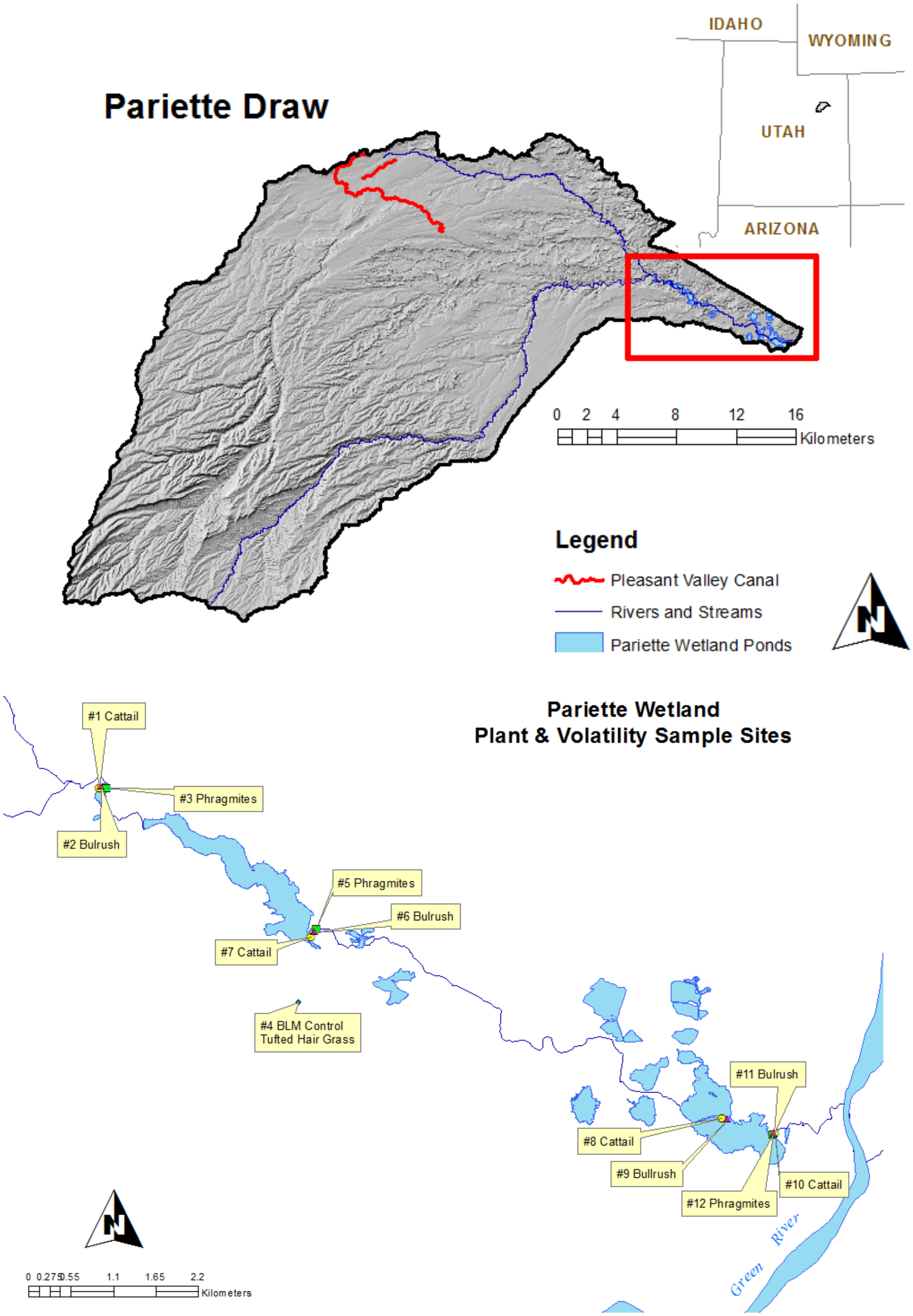


Figure 3-1: Map of Pariette Draw and Pariette Wetlands's Plant and Volatility Flag Sample Sites.

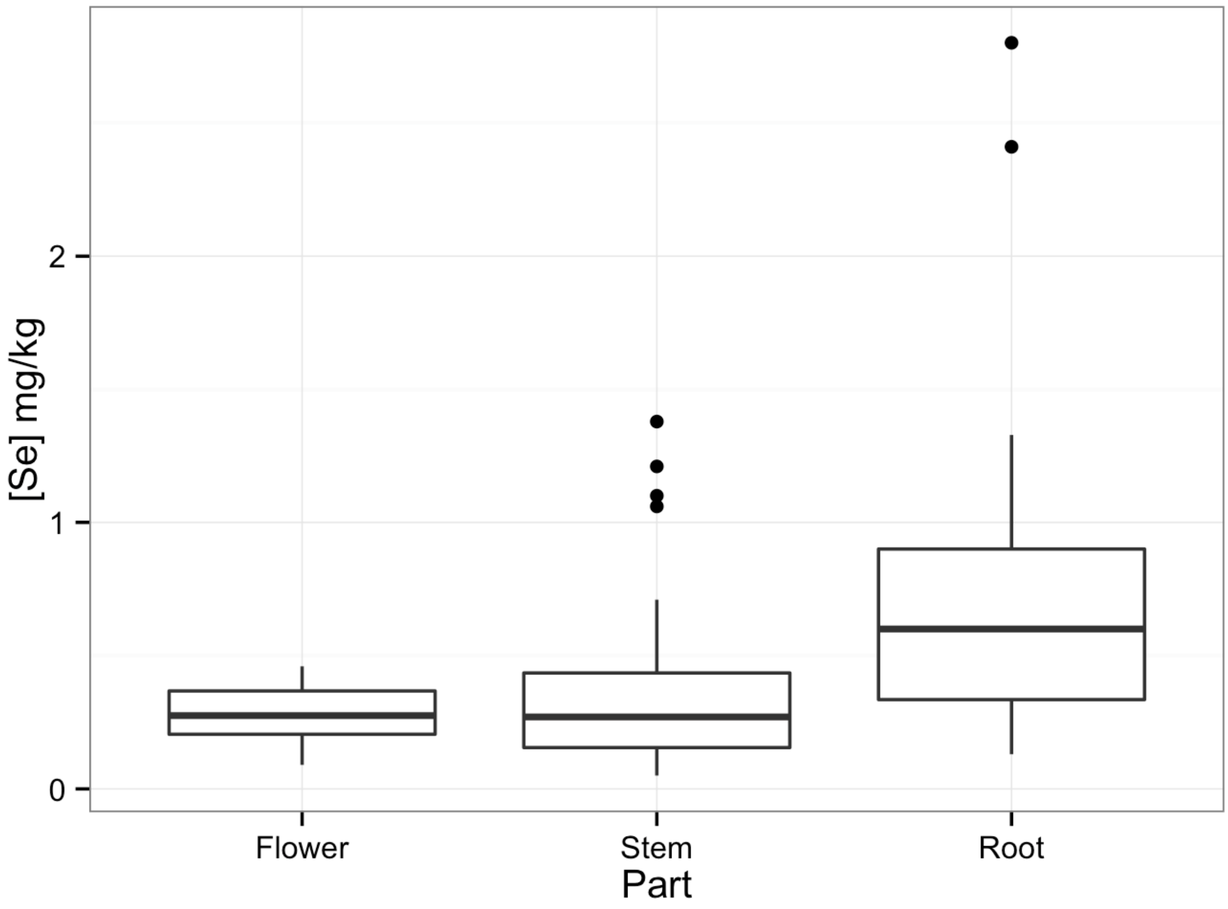


Figure 3-2: Box-and-whisker plot of Se concentration in inflorescence, leaf, root and stem associated with different plants species at twelve sample sites in Pariette Wetlands with upper quartile, lower quartile, and median represent by the box and line inside the box. Whiskers represent the maximum and minimum values of the data excluding the outliners as the black circles outside of the whiskers.

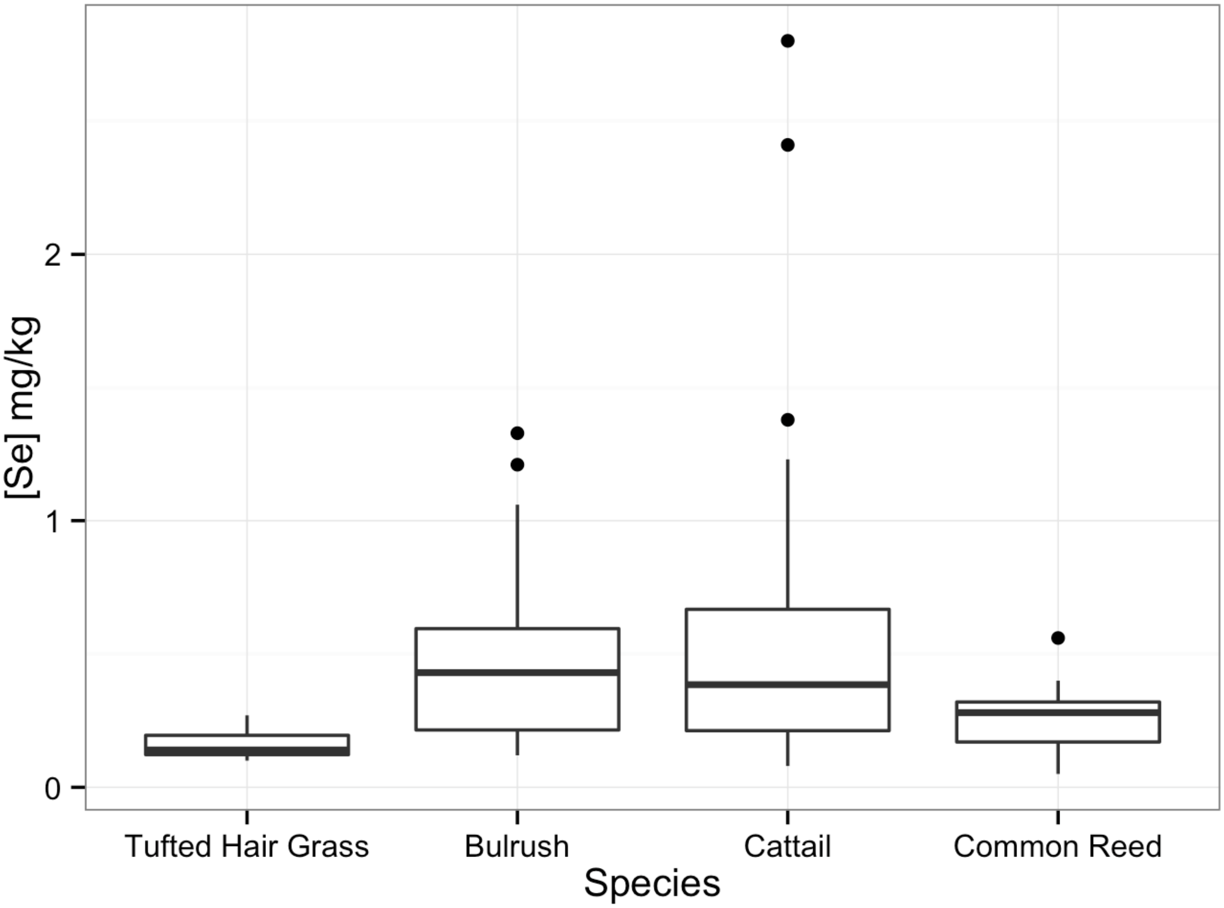


Figure 3-3: Box-and-whisker plot of Se concentration associated with the stems of tufted hair grass, bulrush, cattail, and common reed at twelve sample sites in Pariette Wetlands with upper quartile, lower quartile, and median represent by the box and line inside the box. Whiskers represent the maximum and minimum values of the data excluding the outliners as the black circles outside of the whiskers.

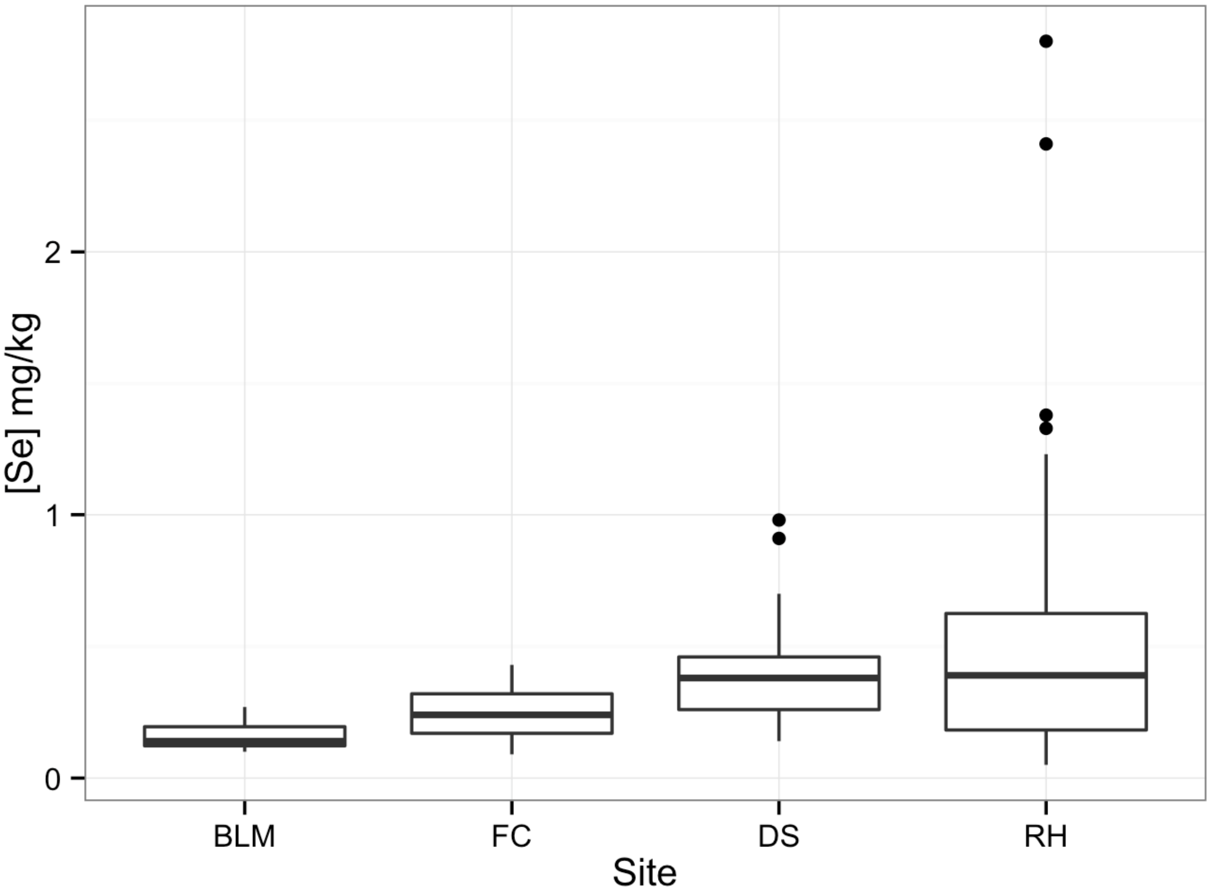


Figure 3-4: Box-and-whisker plot of Se concentration associated with different plant species in the upland (BLM), and wetlands sites Flood Control (FC), Desilt Pond (DS), and Redhead Pond (RH) at twelve sample sites in Pariette Wetlands with upper quartile, lower quartile, and median represent by the box and line inside the box. Whiskers represent the maximum and minimum values of the data excluding the outliners as the black circles outside of the whiskers.

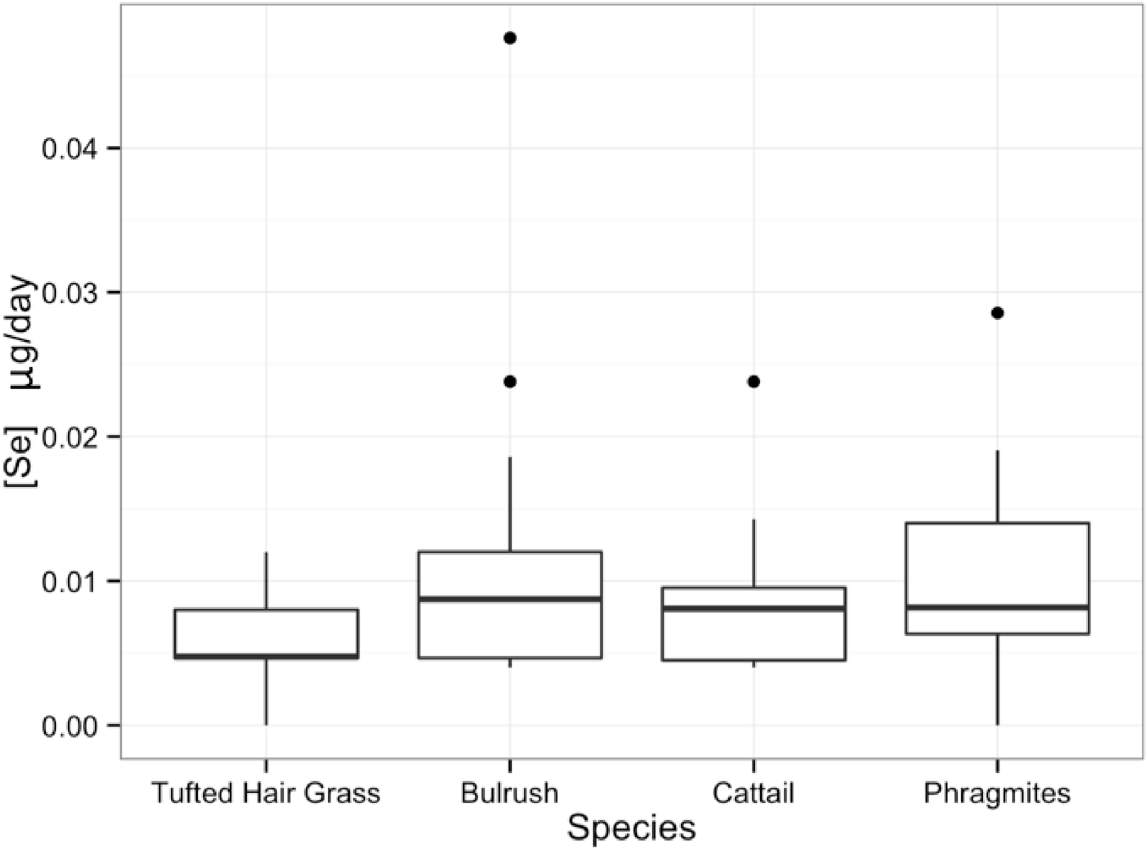


Figure 3-5: Box-and-whisker plot of Se volatilization rates from sites associated with different plants species in Pariette Wetlands with upper quartile, lower quartile, and median represent by the box and line inside the box. Whiskers represent the maximum and minimum values of the data excluding the outliners as the black circles outside of the whiskers.

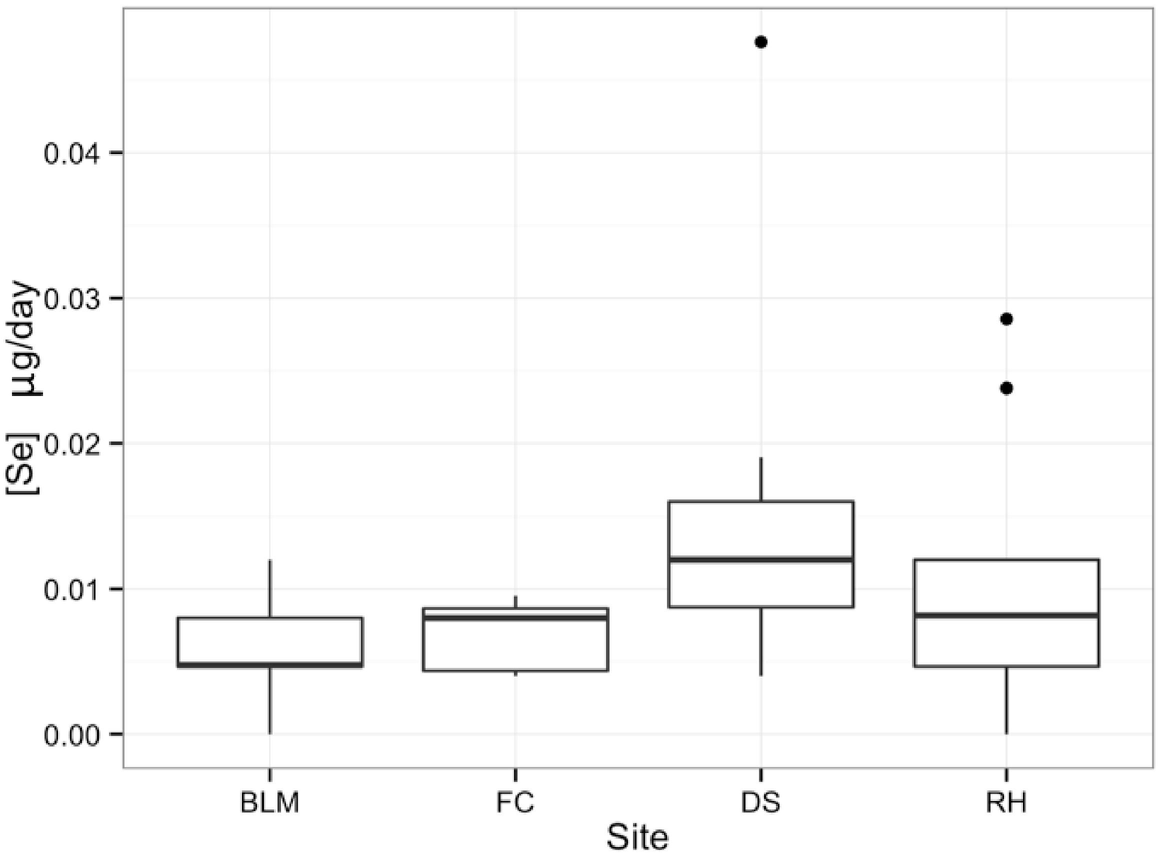


Figure 3-6: Box-and-whisker plot of Se volatilization rates in Pariette Wetlands at upland (BLM) and wetlands (FC = Flood Control; DS = Desilt Pond; and RH = Redhead Pond) sample sites with upper quartile, lower quartile, and median represent by the box and line inside the box. Whiskers represent the maximum and minimum of the data excluding outliners as the black circles outside of the whiskers.

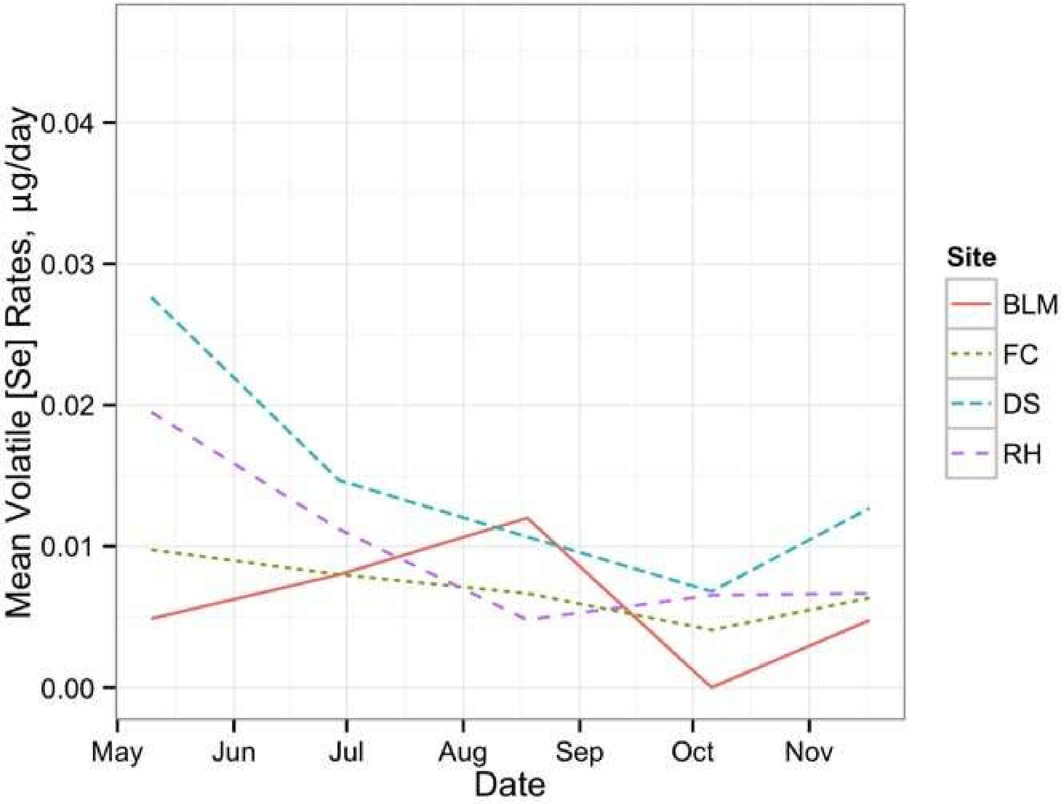
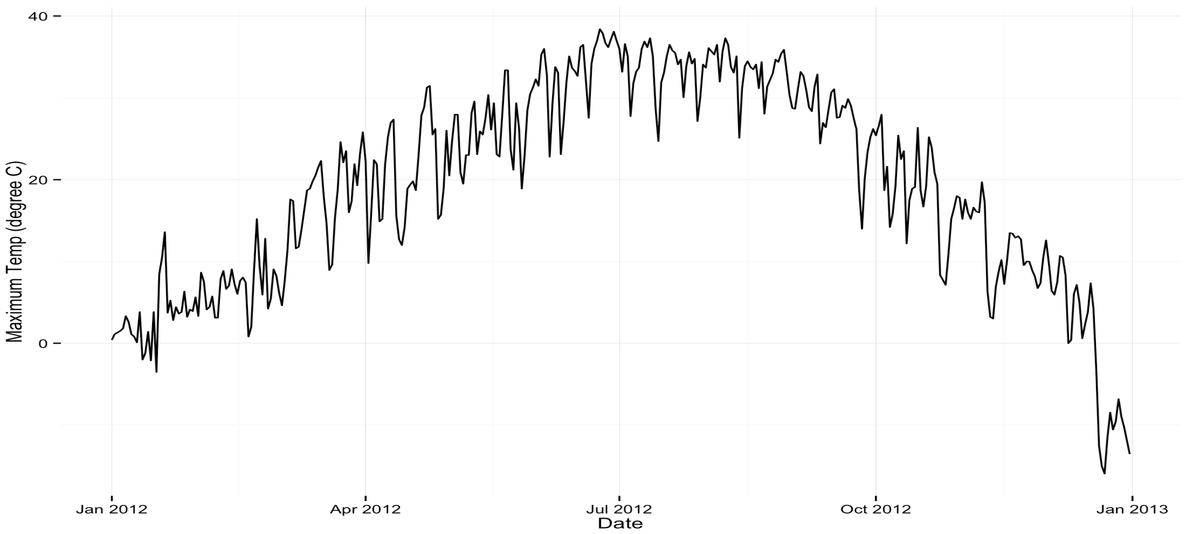
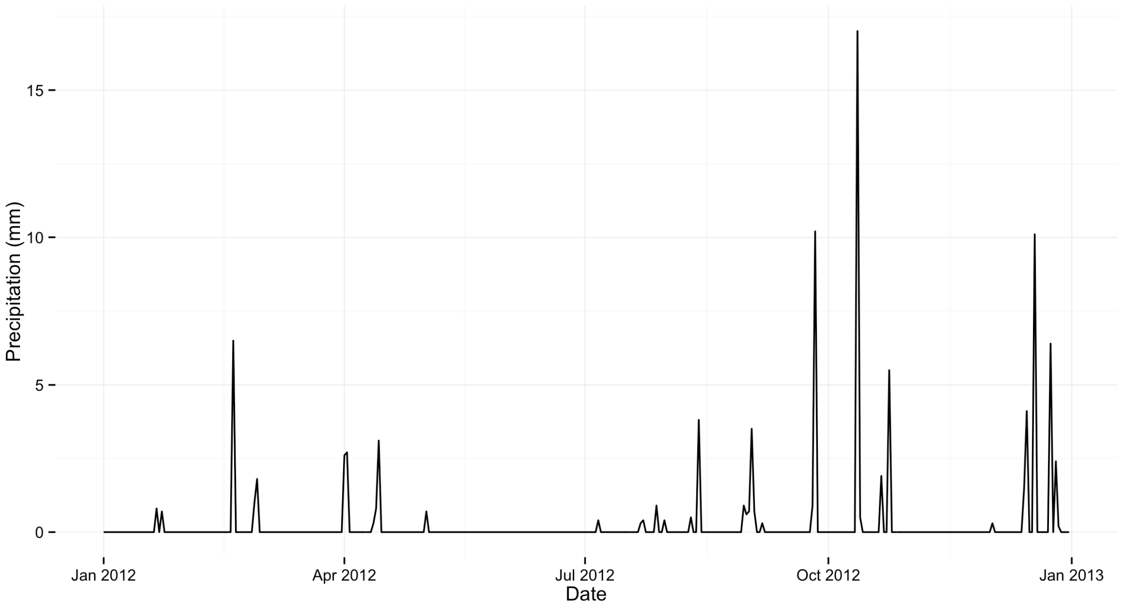


Figure 3-7: Mean volatilization rates of Se at upland (BLM) and wetlands (FC = Flood Control; DS = Desilt Pond; and RH = Redhead Pond) sites during sampling period March 30, 2012 to November 17, 2012.



a)



b)

Figure 3-8: a) Maximum air temperature and b) total precipitation from January 1 to December 31, 2012 from a Utah Climate Center Station Vernal 23 SSE located near Pariette Wetlands http://climate.usurf.usu.edu/.

CHAPTER 4

ASSESSMENT OF SELENIUM MOBILIZATION IN ARID UPLAND AND WETLANDS SOILS OF PARIETTE DRAW, UTAH

ABSTRACT

Selenium (Se) mobilization in the soils of the Pariette Draw and subsequent accumulation into the Pariette Wetlands threaten wildlife. The physical and chemical properties for two soils in the Pariette Draw were compared: one arid soil (elevation 1467 m) and the other a formerly arid soil (elevation 1448 m) inundated by water following creation of wetlands from 1975. The soils were analyzed, and the influence of inundation by irrigation return water of Pariette Draw of Utah was assessed to obtain a better understanding of soil Se and salts in this system. It appears that Se mobility, especially in the wetlands soil, is associated with the distribution of soluble salts in the soil profile. Due to a fluctuating water table caused by inundation of irrigation return water and high evapotranspiration rates coupled with low precipitation, capillary migration is the dominant mechanism driving the distribution and accumulation of salts and soluble Se in the upper horizons (Byz) of the wetlands soil. The distribution of soluble salts and Se in the upland soil is typical of a downward gravity-driven hydrology process. Gypsum solubility regulated sulfate levels within the Byz horizons of the wetlands soil. We surmise that soluble Se is regulated by the solubility of a sodium selenate sulfate coprecipitate. It appears that the relatively low concentration of Se in the local Pariette Wetlands soil is not the source and cause of Se responsible for adversely affecting wildlife in the wetlands.

INTRODUCTION

Selenium (Se) is a naturally occurring trace element associated with various geologic formations throughout the world; it is incorporated into the geosphere in a wide range of geologic sources such as phosphate rocks, black shale, coal, and crustal rocks (de Souza et al., 1999; Maher et al., 2010). The main geologic sources of Se are sedimentary rocks formed from ancient, organic rich, marine basins formed from sediments accumulated during the Upper Cretaceous Period (Pollard et al., 2007). These sedimentary rocks are the parent material for the soils in this study, and they contain Se within their sulfide minerals (Wilber, 1980).

Processes such as physical and chemical weathering and soil genesis can mobilize sequestered Se from the lithosphere into the hydrosphere and atmosphere, causing Se to be more bioavailable in the environment (Maher et al., 2010). Both natural processes and anthropogenic factors mobilize Se. Potential natural processes that mobilize Se include chemical weathering either by snowmelt or rainfall run-off, leaching from saline soils, and upwelling of shallow groundwater. Potential anthropogenic causes include irrigation return flows, animal waste, oil/gas well pads, and non-point sources in the watershed (Wingert & Adams, 2011).

In the Western United States, wildlife deformities at Kesterson Reservoir and other sites led to investigations in the 1980’s of Se environmental contaminations (Presser et al., 1994). Selenium in irrigated return flow waters was identified as the source of contamination in these areas (Presser et al., 1994; Stephens et al., 1992). Similarly, the middle Green River area of the Uinta Basin, Utah, was identified as an area with significantly high Se contamination. Several studies conducted in the 1980’s by the United States Geological Survey (USGS), United States Fish and Wildlife Service (USFWS), and the United States Bureau of Reclamation identified three areas of concern for Se contamination.

The three areas of concern are Stewart Lake Waterfowl Management Area (SLWM), Ouray National Wildlife Refuge (ONWR), and Pariette Wetlands (Figure 4-2) (Stephens et al., 1992). The concentration of dissolved selenium in irrigation drain water entering SLWM ranged from 14 to 140 $\mu g\ L^{-1}$ this exceeds the U.S. Environmental Protection Agency (EPA)'s chronic criterion of 5 $\mu g\ L^{-1}$. The selenium concentration in sediments collected drain discharge in the inflow of SLWM ranged from 10 to 85 $\mu g\ L^{-1}$ (Stephens et al., 1988). The source of Se contamination was believed to be from inflow of shallow ground water and surface water from a sewage lagoon system that flows through Mancos Shale known to be seleniferous (Stephens et al., 1992). The contaminated irrigation drain water that entered SLWM is currently diverted around SLWM and into the Green River (Naftz et al., 2005). Ouray National Wildlife Refuge water samples ranged 9 to 93 $\mu g\ L^{-1}$. In 1987, ONWR was closed for a short period of time after discovery of deformed American coot embryos. Consequently, the ponds containing elevated levels of selenium were closed, drained and filled in with clean sediments (Stephens et al., 1988). Pariette Wetlands water samples ranged from 1 to 7 $\mu g\ L^{-1}$. Biota sampled during the same time contained Se concentrations intermediate between ONWR and SLWM. No deformed embryos were observed. However, the bioaccumulation factor of Se for Pariette Wetlands ranged 300 to 2,200 times the Se concentration between the water samples and biota (Stephens et al., 1992).

Selenium has been measured over the last 20 years in the Pariette Draw and Pariette Wetlands at levels known to be hazardous to wildlife (Stephens et al., 1992;

Wingert and Adams, 2011). Maximum allowable concentrations in aquatic ecosystems for water borne Se was 2 μg L^{-1}, and for sediment was 2 μg g^{-1} dry weight, according to Lemly (2002). High levels of Se exposure can cause reproductive failure and teratogenic deformities in oviparous organisms, such as birds and fish (Lemly, 1985).

Pariette Wetlands is the United States Department of the Interior Bureau of Land Management's (USDI BLM) largest wetlands development in Utah, and was created to provide wildlife habitat in a semi-arid desert of Pariette Draw. The Pariette Wetlands is an arid land oasis in the Uinta Basin located in northeastern Utah (Figure 4-1). The primary land uses within the draw (about 35 miles southwest of Vernal, Utah) are irrigated hay, pasture, and livestock grazing. Used as rangeland, the earea is also impacted by the oil and gas industry (Wingert and Adams, 2011). Pariette Wetlands was developed to improve waterfowl production and provide seasonal habitat for migratory birds. The area contains diverse vegetation and wildlife in an arid climate (average annual precipitation - 14.3 cm; mean annual air temperature 7.9°C). The wetlands comprises 23 ponds (Figure 4-1), mainly filled with water diverted from the Duchesne River into the Pleasant Valley Canal from May to October for irrigation of farmland in Pleasant Valley. A few springs also provide a minimal source of water for the draw. As each pond fills, excess water flows over water control structures. After the last pond (Redhead Pond), approximately one kilometer upstream from the mouth of the Pariette Draw, the draw flows into the Green River (Stephens et al., 1988; Wingert and Adams, 2011).

The Uinta Basin is a geologic structural basin, part of the physiographic region known as the Colorado Plateau. Formation of the Basin began during the Late Cretaceous Period, 70 to 80 million years ago, when the Uinta Arch rose slowly causing the Uinta

Basin to subside. Then during the Eocene Epoch, 55 to 34 million years ago, a large saline lake call Lake Uinta helped form this basin (Stokes, 1986).

Sediment deposits during the Eocene Epoch formed the Uinta and Green River Formations (Stokes, 1986). These two formations compose most of the surface of Pariette Draw, and are known to be seleniferous in areas (Stephens et al., 1992). Following this formation, a system of great interior lakes was formed, and Lake Uinta was one of these lakes. Next, the Green River Formation accumulated fine clastic sediments. After the deposition of the Green River Formation, a sharp uplift of the Uinta Mountains occurred (Fike and Phillips II, 1983). Then during Late Pleistocene Epoch, approximately 24,000 years ago, glacial retreat of the Unita Mountains caused alluvial deposits of the Uinta Formation (Laabs et al., 2009).

Soil surveys completed in 1995 by the Natural Resources Conservation Service (NRCS) indicate that the soils at and near the wetlands are classified within the Aridisol and Entisol Soil Orders (Leishman et al., 2003). Soil parent material originates from lacustrine, fluvial and volcanic deposits. The area is a broad intermittent drainage with northwest to southeast descending slope. Unique landforms, considerable topographic relief, and deeply incised stream channels and washes characterize this area. The descriptive local topography is badlands, and the plant community is a mixture of desert shrub in the upland with cattails and rushes within the wetlands (Leishman et al., 2003). Map units from Soil Survey indicate that both sites are of the Motto-Rock outcrop complex. Motto series taxonomic classification is loamy, mixed, superactive, mesic, Lithic Natrargids (Leishman et al., 2003). The landform is a structural bench with well-drained soils formed from slope alluvium over residuum derived from shale and sandstone. Natrargids are Aridisols that have a natric horizon and do not have a pertrocalcic horizon within 100 cm of the soil surface (Soil Survey Staff, 2010). To date, NRCS has no detailed information listed about the salts and their association with each horizon.

After the 1980’s studies (Stephens et al., 1992), most of the Se research in the Uinta Basin focused on SLWM and ONWR. Not much has been added to help understand the complex interaction involved with mobilization and accumulation of Se in Pariette Wetlands. There is no detailed information pertaining to salinity and selenium dynamics of the soils in the Pariette Draw. The objective of this study was to provide detailed physical and chemical properties of two soils, one from the arid upland and the other from the margin of the wetlands in the Pariette Draw. Our goal was to obtain a better understanding of the processes that regulate the distribution of Se in a typical arid soil compared to a soil affected by water in the Pariette Wetlands. Insight into how inundation by water has impacted the Se distribution and form in the soil will be essential to understanding these processes. The information gained will lead to management strategies that will mitigate Se, thus minimizing the risk of Se toxicity to wildlife in the Pariette Wetlands.

MATERIALS AND METHODS

Description of Study Area

Two different pedons of the Pariette Draw (Figure 5-1) were examined on September 17, 2011: one somewhat poorly drained pedon inundated by irrigation return flow at the margin of the wetlands (Flood Control), and a second pedon on an arid upland just south of the wetlands (BLM Compound). Sites were selected in stable undisturbed areas with representative native vegetation. The wetlands margin pedon was located downstream of the inlet to Pariette Wetlands below the Flood Control structure. The upland pedon was located upslope of the BLM compound building, and was not influenced by the inundation of water that created the current wetlands. The mean annual air temperature was 7.9°C, and the maximum monthly average temperature for June, July and August was 30.5°C. The minimum monthly average temperature for December, January, and February was -14.0°C (Prono, 2008). The soil moisture and soil temperature regime was aridic and mesic.

Field Methods

Soils were exposed by backhoe excavation to a depth of at least 150 cm. Genetic horizons were identified based on morphological features including color, texture, structure, effervescence with HCl, and visible salt crystals. Soils were described in the field and samples were collected from each genetic horizon (Soil Survey Staff, 2009) (Appendix B).

Laboratory Analysis

Soil samples were air-dried, crushed and passed through a 2-mm sieve to remove coarse fragments. Saturated paste extracts were obtained using an automatic vacuum extractor. Saturation percentages were measured before extraction by weighing and oven-drying part of the saturated paste and measuring the mass water content. Saturated paste extracts were analyzed for pH and electrical conductivity (ECe) (Soil Survey Staff, 2009). Soil ground to <0.25 mm was analyzed for calcium carbonate equivalent (CCE) (Fonnesbeck et al., 2013).

A spl sample was taken from each saturated paste extract and submitted to the United States Geological Survey (USGS) in Denver for elemental analysis using inductively coupled plasma-mass spectrometry (ICP-MS), inductively coupled plasma-atomic emission spectroscopy (ICP-AES), and hydride generation atomic absorption spectrometry (HG-AAS) (Taggert, 2002). Sodium Adsorption Ratio (SAR) was calculated using the elemental analysis results (Soil Survey Staff, 2009). The chemical equilibrium model PHREEQC (v. 3) (Parkhurst and Appelo, 1999) was used to predict ion activities in the extracts solutions at 25°C, saturated paste pH values, and redox potential associated with dry aerated ($pe = 20.66 – pH$) or wet, aerobic soils ($pe = 15 - pH$) (Azaizeh et al., 2003). Additionally, the USGS laboratory measured the total iron in the samples collected from each soil horizon. Pearson’s correlation test was used to test for significant correlation of ion concentration of the extract paste and ECe. Salts collected from the soil surface as well as clearly present white solids within the flood plain soil profile were analyzed by x-ray diffraction (XRD). The XRD was done using a Panalytical X’Pert Pro X-ray Diffraction Spectrometer with monochromatic Cu K-alpha radiation. High Score software was used to index peaks and identify minerals.

RESULTS AND DISCUSSION

Morphological and Physical Properties

The deep, somewhat poorly drained, wetlands-margin soil near the flood control structure was formed from alluvium and colluvium overlying colluvium derived from sandstone and mudstone of the Uinta Formation. This pedon occurred on an east-northeast-facing toeslope of a cliff with a slope gradient of 6%. The upland soil near the BLM Compound occurred on a south-southwest backslope of a ridge with a slope gradient of 8%. Based on climate data collected from a nearby Utah Climate Center Station at Myton, the mean annual precipitation was 14.3 cm, and mean annual air temperature was 8.0 °C. Soil moisture regime was typic aridic, and the soil temperature regime was mesic. The upland site supported a desert shrub community composed of native vegetation dominated by Indian rice grass (*Achnatherum hymenoides*), saltgrass (*Distichlis spicata*), greasewood (*Sarcobatus vermiculatus)* and rabbit brush (*Ericameria nauseosa*). The wetlands-margin site in the riparian and flood plain zone consisted primarily of graminoids; common reed (*Phragmites australis*), cattails (*Typha domingensis and T. latifolia*), and rushes (*Scirpus acutus, S. maritimus, Eleocharis palustris, Juncus arcticus and S.pungens*).

Soil color is the most obvious feature of a profile, and can indicate chemical composition. The near-surface horizons of the wetlands-margin soil have a hue of 10YR and lower value, indicating the accumulation of organic matter turnover from the wetlands vegetation. At about 28 cm depth, chromas change from 3 to 2 (Table 5-1); change in chroma in the lower part indicated that the soil may be subject to saturation, facilitating the reduction and removal of Fe. Saturation of soils and sediments in the wetlands has caused the soluble salt to dissolve and mobilize, ultimately, precipitating in the horizons with visible gypsum veins (Byz1, Byz2, Byz3 and Byz4). The soils were moderately developed with subangular blocky structure in the solum, whereas the regolith was structureless single grain weathered sandstone (below 113 cm). The texture was sandy loam throughout the pedon except for sandy clay loam in the Byz4 horizon.

All horizons of the upland soil were 7.5YR and had chromas of 3, indicating that organic matter was low and the soil had not been subject to saturation. Several horizons had gravel lenses (Bk2 and Bk3), and alternating light and dark colored 1-cm thick sediment bands (2Bk4 and 2BCk). Carbonate coats around rock fragments and finely disseminated carbonates were present throughout profile (Table 4-1).

Soil Forming Processes and Classification

The epipedon for the wetlands (Flood Control) pedon was ochric, and the diagnostic subsurface horizons were gypsic (41-131 cm) and sodic (6-152 cm). There were no other diagnostic characteristics, and the family particle size was fine-loamy (control section 25-100 cm). Based on these diagnostic characteristics, the family classification was fine-loamy, mixed, superactive, mesic Sodic Haplogypsids (Soil Survey Staff, 2010).

The diagnostic epipedon for the upland pedon (BLM Compound) was ochric, and the diagnostic subsurface horizons were cambic (14-86 cm), calcic (86-109 cm), and sodic (14-154). A genetic characteristic was a lithologic discontinuity of gravel lens with alternating light and dark sediment bands that occur at 86 to 109 cm. The family particle size was sandy-skeletal over loamy (control section 25-100 cm). The family classification was sandy-skeletal over loamy mixed, superactive, mesic Sodic Haplocalcids (Soil Survey Staff, 2010).

Chemical Properties

The chemical properties of the upland and wetlands soils, especially with regard to the quantity and distribution of soluble salts in each profile, differed considerably. Hydrology was the main factor responsible for the difference in accumulation and distribution of soluble salts between the two soil profiles. The upland soil profile was typical of a well-drained, arid soil, where soluble salts and carbonate concentrations increased with depth due to a downward translocation of these materials transported via a gravity-driven hydrology. The ECe for the upland soil ranged from 0.54 to 2.62 dSm^{-1}, which is not extraordinarily high (Table 4-2 and Figure 4-5).

In contrast, the ECe values of the wetland-margin soil were one order of magnitude higher than the upland soil ranging from 3.27 to 27.4 dSm^{-1} (Table 4-2 and Figure 4-4). The wetland-margin had the highest ECe in mid layers of the soil profile (28 to 131 cm), indicating an upward translocation and accumulation of soluble salts via capillary migration due to alteration of the water table associated with inundation of irrigation return flow into the wetlands. The migration of the soluble salts to the surface was also influenced by the seasonal high evapotranspiration rates and low annual precipitation. The predominate ions of the saturated paste extracts were sodium (Na^+), calcium (Ca^{2+}), sulfate (SO_4^{2-}), and chloride (Cl^-). A significant correlation ($p<0.01$) existed between ECe and the soluble ions in the saturated paste extract, especially SO_4^{2-} ($r^2 = 0.96$). The extract SO_4^{2-} content in the Byz horizons of the wetlands soil was two orders of magnitude higher than in the upland soil. During soil genesis, soluble salts dissolve when in contact with water, translocate, and then precipitate as water recedes or evaporates. Carbonates will precipitate first, followed by gypsum and then sodium salts (Boettinger and Richardson, 2001). This distribution of salts in the wetlands soil profile as related to hydrology followed a predicted sequence as proposed by the Hardie-Eugster model (Hardie and Eugster, 1970). The model predicts the following order of mineral formation upon concentrating the saline pore water solutions: calcite, gypsum, glauberite, thenardite, and halite. First Ca is partially removed from solution with the formation of calcite. Additional Ca is removed along with sulfate when gypsum precipitates. Due to increasing Na levels, Ca and sulfate continue to precipitate in the form of glauberite, and ultimately nearly complete removal of Ca favors the formation of thenardite, followed very closely by halite. In the wetland soil, we were able to measure the presence of calcium carbonate, gypsum, glauberite, and thenardite, but not detect halite. Calcium carbonate levels were lower in the Byz horizons (28 to 131 cm) (Figure 4-4) but higher (>5% CCE) in the adjacent layers above and below the Byz horizons. A white precipitate could clearly be observed in the Byz horizons in the wetland profile, which was gypsum as identified by XRD. Likewise, the geochemical modeling indicated that gypsum ($CaSO_4*2H_2O$) solubility regulated the SO_4^{2-} levels in the Byz horizons of the wetlands soil. With the exception of the topmost surface soil layers, the pH values for both soils exceeded 8.5 and were most likely buffered by sodium carbonate. The upland soil on average had higher pH values than the wetlands soil. Surface salt crusts, which can be seen throughout the Pariette Draw, were collected and identified via XRD as being the mineral thenardite (Na_2SO_4).

Iron solubility in both profiles also appeared to be regulated by hydrology, where the percent of total Fe demonstrated a similar distribution and accumulation pattern as the soluble salts (Figures 4-4 and 4-5). The fluctuating high water table in the wetland-margin soil resulted in fluctuating soil redox conditions and, subsequently, a dynamic zone of Fe dissolution and precipitation of ferric oxides in the Byz horizons. The high surface area ferric oxides were loosely able to retain selenite and sulfate. Whereas in the upland profile the percent total Fe peaks lower in profile. The patterns in the Figures 4-4 and 4-5 gave valuable insight into effects of translocation of these salts, and the mobilization of selenium in these soils. The upland soil had higher total Se levels (87 to 217 μg kg^{-1}) than the wetlands soil (48 to 139 μg kg^{-1}), and both soils had a lower value than 440 μg kg^{-1}, which is the estimated mean total Se content of soils worldwide (Kabata-Pendias, 2011). Soluble Se concentrations measured in the saturated paste extracts for the each of the soil horizons differed between the two soils. In the upland soil, soluble Se could be detected only in the deepest horizons (86 to 154 cm) and ranged from 5.54 to 15.12 μg kg^{-1}, whereas in the wetlands soil soluble Se was present in all of the horizons, except the surface 6-cm horizon, and ranged from 14.6 to 57.1 μg kg^{-1}. The wetlands profile had two to four times higher soluble Se concentrations than the upland profile (Figure 4-3). The lack of intense and prolonged reducing conditions allow for Se to become oxidized. Oxidized Se became soluble and translocated from lower horizons to the Byz horizons in the wetland soil. Although the total Se concentrations measured in the wetland soil were nearly half that of the upland soil, a much greater proportion (21 to 52%) of the Se was soluble and thus bioavailable in the wetlands soil (Table 4-2).

In contrast, soluble salts concentrations increased with depth in the upland soil due to infiltration of water and dissolution and leaching of salts to lower horizons (Figure 4-5) (Berger and Cooke, 1997). Several researchers have reported similar differences in soluble salts as a result of changes in water table as well as season. Berger (1997) examined three similar alluvial fans in salar basins of northern Chile. The calcium sulphate distribution and other soluble salts were influence by a combination of groundwater, surface flow and wind (Berger and Cooke, 1997). Eghbal (1989) investigated an alluvial fan in Carrizo Plain, California, where the overall salt concentrations were highest in the lower part of the profile away from Soda Lake due to leaching. The profiles closer to Soda Lake had higher salt concentrations towards the surface due to movement of groundwater (Eghbal et al., 1989).

We surmise that soluble Se was most likely regulated by the solubility of a sodium selenite-sulfate coprecipitate, due to the relatively low concentration of Se in the Pariette Wetlands soil. Background concentration of Se in California soils averaged 0.06 ± 0.084 mg/kg (Bradford et al., 1996). The soil of Pariette Wetlands does not appear to be the source of Se that is negatively impacting wildlife in the wetlands. Nor were soil Se levels high enough to result in significant Se bioaccumulation from plants growing in these soils, or to the organisms that feed on them. The high soil salinity levels in the wetlands would have a greater impact on vegetative growth than Se. The high soluble sulfate content in the wetlands soils would inhibit Se uptake by plants (Mackowiak and Amacher, 2008). Most likely it is the exposure of water containing elevated levels of Se flowing through the wetlands that is the source of Se negatively impacting local wildlife.

CONCLUSIONS

Significant physical and chemical properties of the upland and wetlands soils differ as a result of alteration of the water table due to irrigation return water. Soluble Se concentrations were associated with soluble salt, and soluble salts levels were more than one order of magnitude greater in the wetlands profile than the upland profile. Capillary migration was responsible for the translocation and accumulation of salts in the upper horizons (Byz horizons; 28 to 131 cm) of the wetlands soil, while lack of soluble salt and the distribution of CCE in the upland soil reflected downward translocation, typical of soils formed in arid climates. Within the Byz horizons of the wetlands soil, soluble salts were composed mostly of sulfates. Gypsum solubility regulated sulfate levels within the Byz horizons. Surface salt crusts within the wetlands soil were identified as thenardite (XRD and geochemical modeling). We surmised that soluble Se was most likely regulated by the solubility of a mixed sodium selenite-sulfate coprecipitate. It appears that the relatively low concentration of Se in the Pariette Wetlands soil was not the source and cause of Se responsible for adversely affecting wildlife in the wetlands. Instead, it is the exposure of water containing an elevated level of Se flowing through the wetlands that most likely is the source of Se negatively impacting animals.

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Table 4-1: Physical properties of wetland and upland soil profiles from Pariette Draw, Utah.

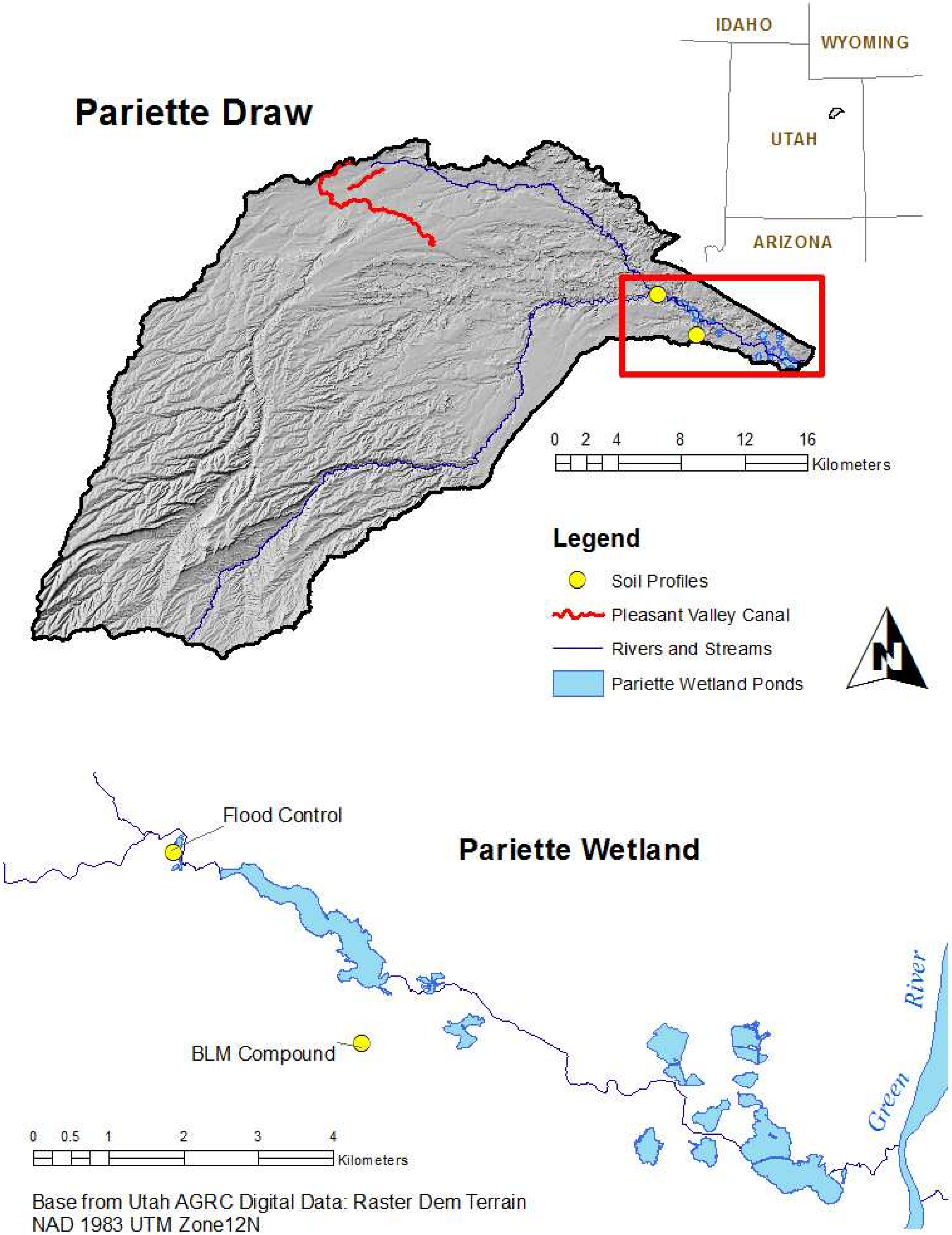
Horizon	Depth (cm)	Munsell Color		Texture			Structure
		Dry	Moist	%RF	Class	%Clay	
Wetland Profile							
A	0-6	10YR 6/2	10YR 4/3	-	SL	8	SBK
Bw1	6-18	10YR 6/2	10YR 4/3	-	SL	18	SBK
Bw2	18-28	10YR 6/3	10YR 4/2	-	SL	17	SBK
Bkz	28-41	7.5YR 7/2	7.5YR 7/2	-	SCL	22	SBK
Bz1	41-62	7.5YR 6/2	7.5YR 4/2	1GR	SL	19	SBK
Bz2	62-101	7.5YR 6/2	7.5YR 5/2	1GR	SL	19	SBK
Bz3	101-113	7.5YR 6/2	7.5YR 4/2	3GR	SCL	23	SBK
Bz4	113-131	7.5YR 7/2	7.5YR 4/2	1GR	SL	17	SBK
2C	131-152	7.5YR 6/2	7.5YR 4/2	10GR & 60ST	STXSL	11	SGR
Upland Profile							
A	0-4	7.5YR 7/3	7.5YR 4/3	2GR	SL	10	PL
Bw	4-14	7.5YR 6/2	7.5YR 5/3	25GR	GRCOSL	12	SBK
Bk1	14-41	7.5YR 5/3	7.5YR 4/3	35GR	GRVLCOS	6	SBK
Bk2	41-54	7.5YR 6/2	7.5YR 4/3	50GR	GRVLCOS	6	SBK
2Bk3	54-86	7.5YR 6/3	7.5YR 5/4	35GR	GRVLCOS	8	SBK
2Bk4	86-109	7.5YR 7/3	7.5YR 5/2	-	L	25	SBK
2BC	109-125	7.5YR 6/3	7.5YR 5/3	-	SIL	21	SBK
2C	125-154	7.5YR 6/4	7.5YR 5/3	-	FSL	12	MA

Notes -
Texture: GR = Gravelly, ST = stony, SL = sandy loam, SCL = sandy clay loam, STXSL = extremely stony sandy loam, GRSOSL = gravelly coarse sandy loam, GRVLCOS = very gravelly coarse sandy loam, L = loam, SIL = silt loam, FSL = fine sandy loam.
Structure: SBK = subangular blocky, SGR= single grain, PL = platy, MA = massive.

Table 4-2: Chemical properties of soils from Pariette Draw, Utah.

Horizon	Depth (cm)	pHp	ECe (dS m^{-1})	$CaCO_3$ Equiv. %	Fe_{Total} %	SAR	Ca^{2+} (mg/kg)	K^+ (mg/kg)	Mg^{2+} (mg/kg)	Na^+ (mg/kg)	SO_4^{2-} (mg/kg)	Se_e (µg/kg)	Se_{Total}	Se_e / Se_{Total}
Wetland														
A	0-6	8.10	3.27	4.64	1.4	10.60	27.60	11.67	2.74	218.69	172.49	<3.50	34.5	0.10
Bw1	6-18	8.90	11.7	5.07	1.9	83.25	15.06	9.56	1.77	1,284.84	1,524.83	14.58	48.2	0.302
Bw2	18-28	9.10	18.2	4.93	1.8	144.36	10.51	9.31	2.95	2,062.02	2,552.97	30.22	76.5	0.39
Bkz	28-41	9.05	24.3	4.41	2.1	100.75	54.35	10.43	11.43	3,138.98	4,869.33	52.17	80.4	0.65
Byz1	41-62	8.59	25.5	3.31	2.0	62.96	126.85	7.98	16.15	2,839.24	4,775.60	46.64	91.5	0.51
Byz2	62-101	8.71	27.4	3.37	2.0	59.37	179.44	8.40	36.30	3,344.13	6,076.54	57.09	113.4	0.50
Byz3	101-113	8.74	27.4	3.56	1.9	52.79	169.15	7.85	39.59	2,943.90	5,722.25	43.19	115.6	0.37
Byz4	113-131	8.72	24.1	3.96	1.7	40.40	150.98	5.71	24.79	2,037.44	5,110.18	27.94	71.6	0.39
2C	131-152	8.71	20.5	5.11	1.8	43.51	160.36	5.95	37.79	2,364.88	4,714.31	27.17	66.0	0.41
Upland														
A	0-4	8.06	0.54	11.94	1.4	1.66	11.65	1.75	1.40	22.51	15.08	<3.50	119.6	0.029
Bw	4-14	8.84	0.77	14.66	1.5	8.58	2.58	0.27	0.32	55.07	13.97	<3.50	131.4	0.026
Bk1	14-41	8.83	1.19	9.25	1.3	19.52	1.51	0.29	0.32	101.46	85.35	<3.50	97.8	0.036
Bk2	41-54	9.19	1.18	7.75	1.3	21.03	1.34	0.24	0.29	103.28	96.40	<3.50	95.8	0.037
2Bk3	54-86	9.39	1.01	8.83	1.3	22.35	0.91	0.33	0.24	93.03	29.84	<3.50	56.7	0.061
2Bk4	86-109	9.16	2.19	21.89	2.2	39.45	2.69	0.35	1.23	312.32	312.32	12.26	175.6	0.070
2BC	109-125	9.02	2.40	12.37	2.6	42.36	3.87	0.66	2.18	421.92	502.78	15.12	126.4	0.11
2C	125-154	9.03	2.62	6.92	1.9	30.31	4.17	0.47	2.06	303.94	409.34	5.54	70.5	0.08

Note: < indicates that the concentration is below detection limit of the ICP-MS.



Base from Utah AGRC Digital Data: Raster Dem Terrain
NAD 1983 UTM Zone12N

Figure 4-1: Map of Pariette Draw and Pariette Wetlands study area (red box, expanded below), and locations of soil pedons (yellow circles).

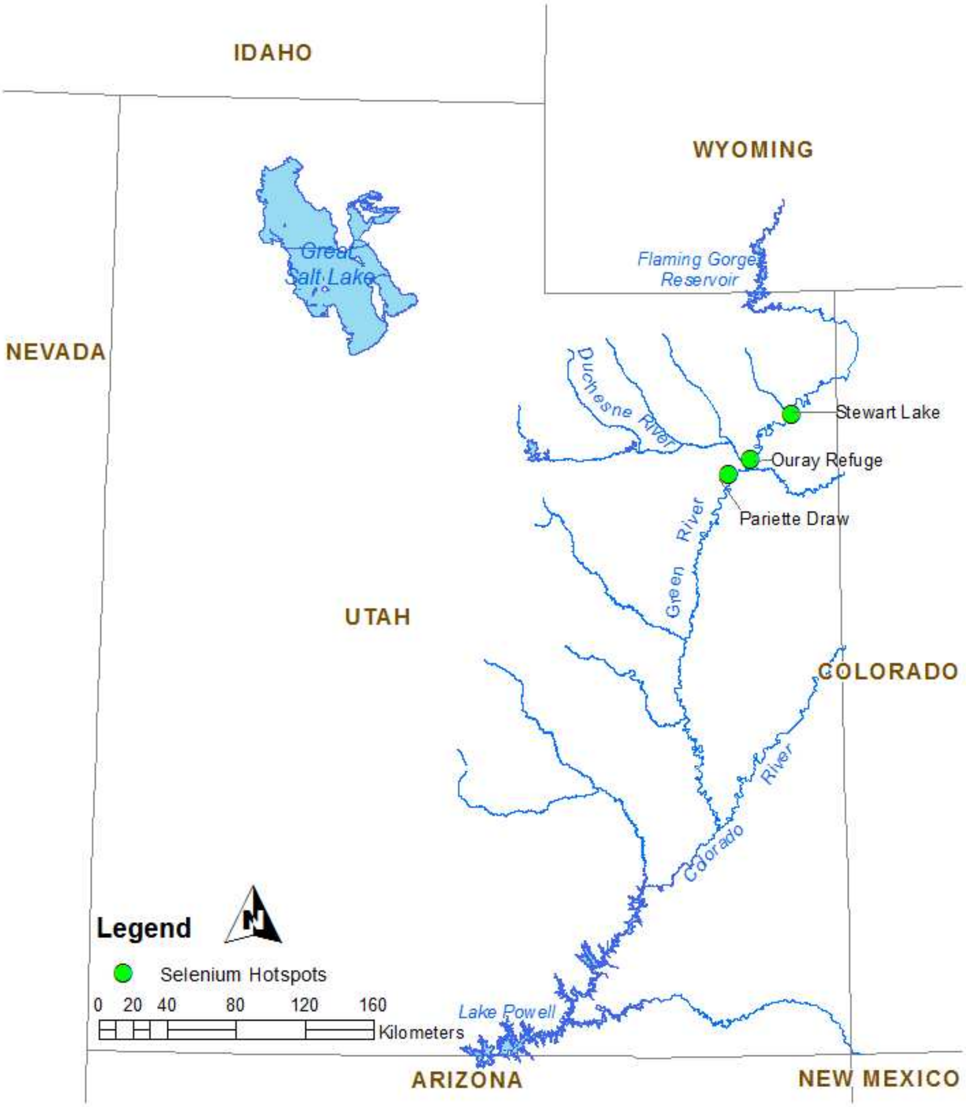


Figure 4-2: Map of Selenium “hotspots” identified during the 1980’s studies.

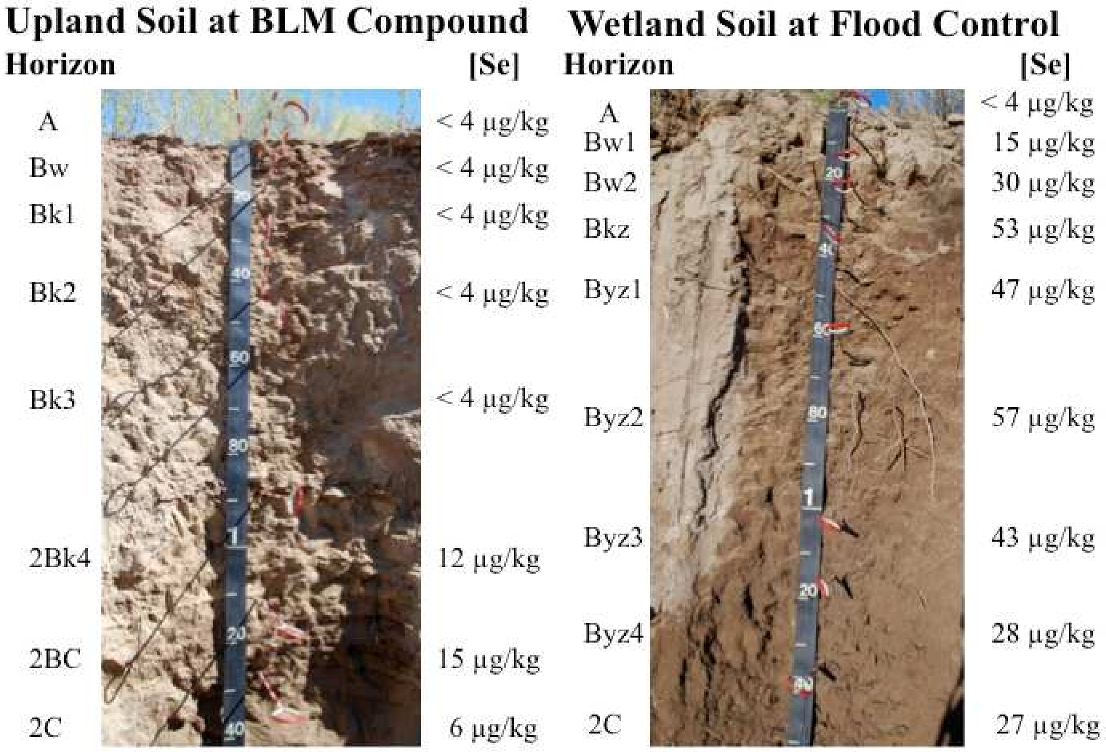
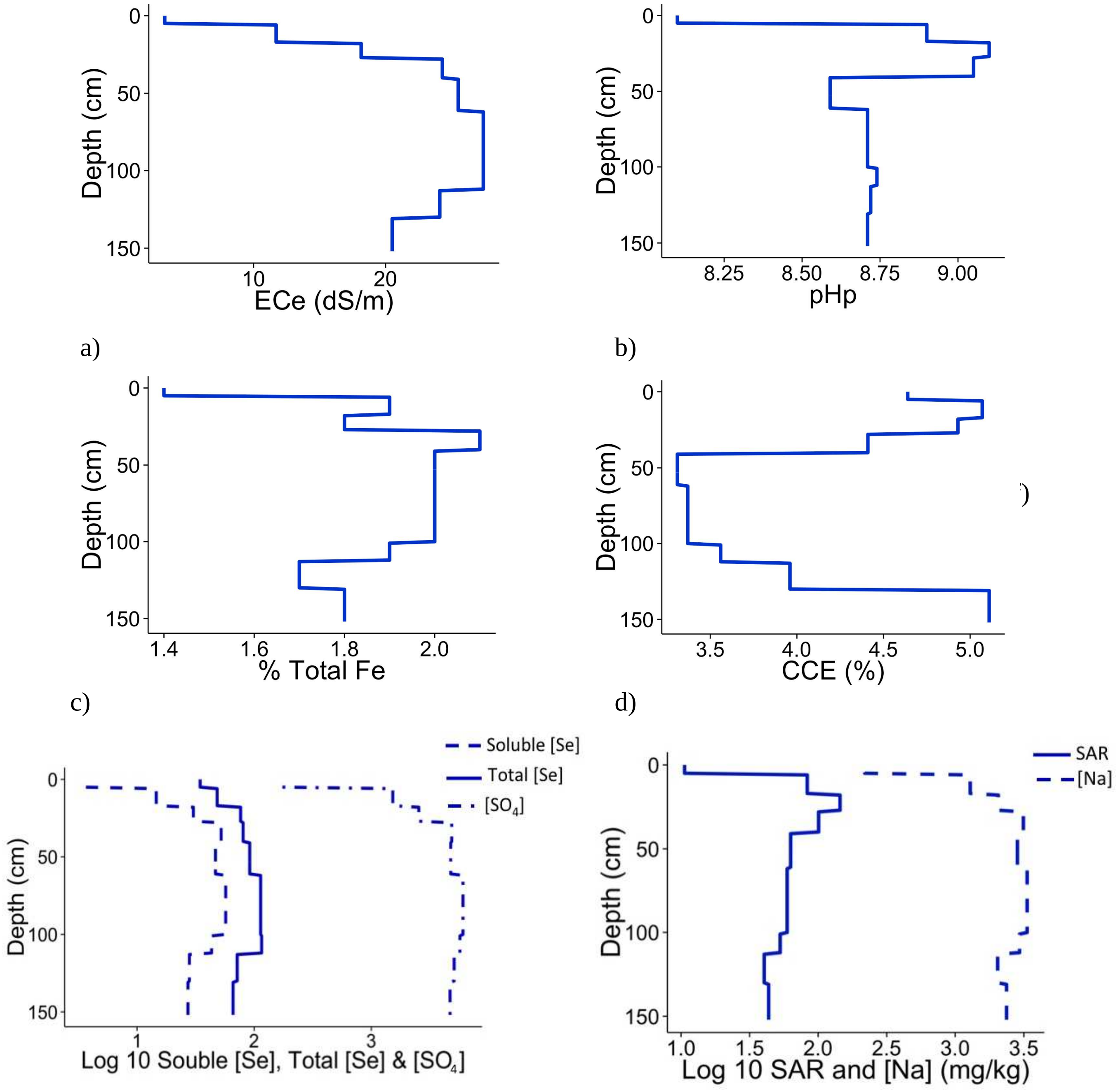


Figure 4-3: Photos of soil profiles of Wetlands and upland soils of Pariette Draw, Utah.



a)

b)

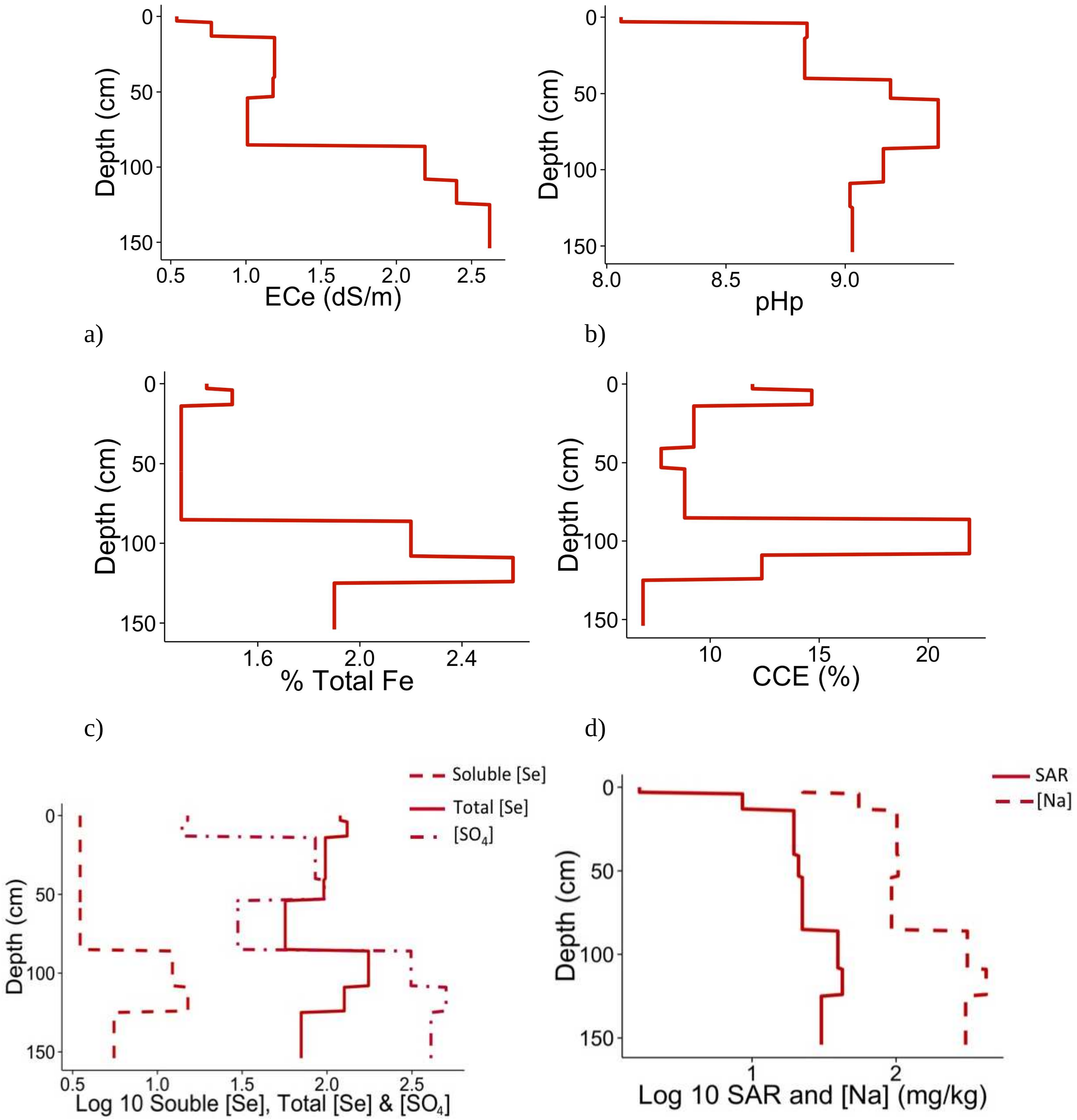
c)

d)

e)

f)

Figure 4-4: Relationship to soil depth of wetland profile’s chemical properties: a) electrical conductivity (dS m^{-1}), b) pH of extract paste, c) % Total Fe, d) Calcium Carbonate Equivalent (%), e) Log 10 transformation total [Se] (µg kg^{-1}), soluble [Se] (µg kg^{-1}) and [SO$_4$] (mg kg^{-1}), and f) Log 10 transformation SAR and [Na] (mg kg^{-1}).



a)

b)

c)

d)

e)

f)

Figure 4-5: Relationship to soil depth of upland profile's chemical properties: a) electrical conductivity (dS m^{-1}), b) pH of extract paste, c) % Total Fe, d) Calcium Carbonate Equivalent (%), e) Log 10 transformation total [Se] (µg kg^{-1}), soluble [Se] (µg kg^{-1}) and [SO_4] (mg kg^{-1}), and f) Log 10 transformation SAR and [Na] (mg kg^{-1}).

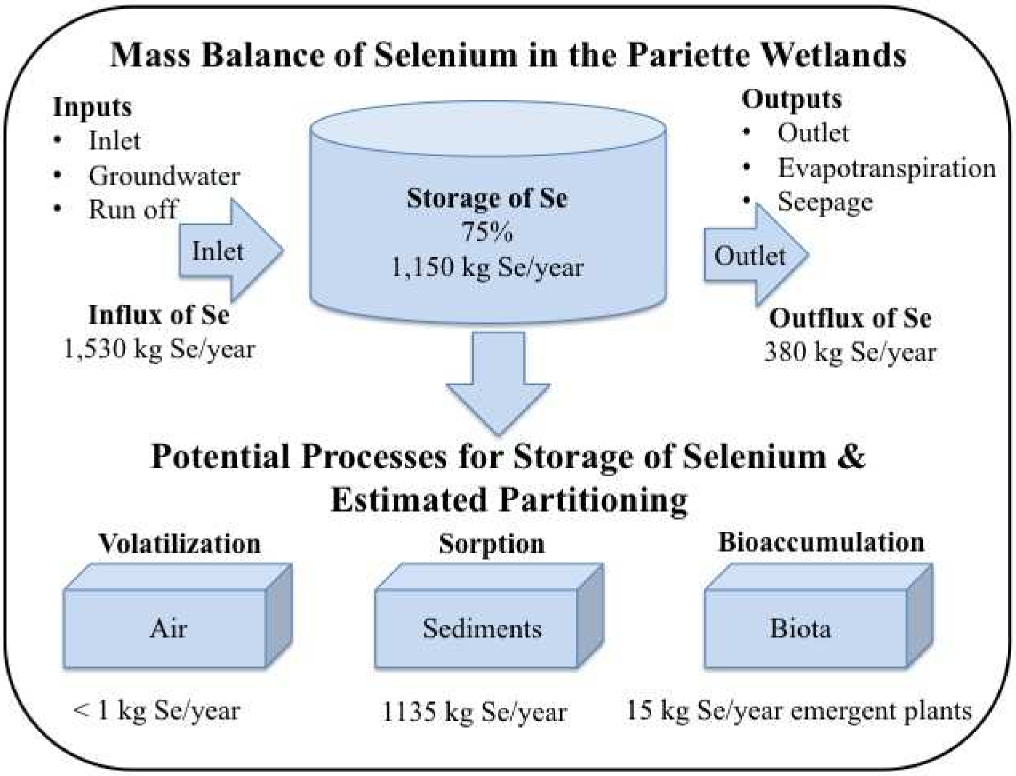
CHAPTER 5

SUMMARY AND CONCLUSIONS

We examined the biogeochemical partitioning of selenium (Se) in water, plant, air and sediments in the Pariette Wetlands. From this information we calculated a mass balance for Se in the Pariette Wetlands (Figure 5-1). The difference between inputs and output or flux gave great insight to how much Se was being retained or stored in the wetlands. The average influx of Se was 1,530 kg year^{-1} and outflux was 380 kg year^{-1}. On average 75% (1,150 kg year^{-1}) of Se entering the wetlands was retained or stored by some biogeochemical process. Processes associated with Se retention included bioaccumulation into the biota, volatilization by plants and animals, and sorption to sediments. In the Pariette Wetlands, Se sorption to sediments accounted for 95 to 99 % (1090 to 1140 kg Se) of the Se retained. Accumulation into plants only accounted for 10 to 60 kg Se retained (< 5%) and volatilization was insignificant with less than 1 kg Se lost (Figure 5-1).

The amount of Se being stored from year to year, the potential of bioaccumulation to local wildlife exposed, and the timing of exposure during their life history stage should be of great concern to stakeholders. Waterfowl exposed to high concentration of Se during their reproductive stage will have a higher rate of reproductive failure and teratogenic deformities than any other life history event. Sources of exposure to wildlife include the water and food sources of their diet. Vegetation eaten in their diet was a significant cause of wildlife exposure to Se.

Future work should include continued collection of Se concentration in sediments, water, submergent vegetation, emergent vegetation, benthic macroinvertebrates, plankton, fish tissue and bird eggs. The data collected from these five ecosystem components could be used to develop a risk assessment to determine the extent of toxicological effects in fish and birds. Assessment of risk will compare hazard profiles using a Spatially Explicit Exposure Model (SEEM). The SEEM model can be used to predict potential risk in aquatic birds breeding in Pariette Wetlands.



5-1: Mass balance of selenium in the Pariette Wetlands, Utah.

APPENDIX

Appendix A

This appendix includes raw data collect by the Utah Division of Water Quality (1993-2009) and Utah State University (2011-12). Water temperature was measured in degrees Celsius, pH in standard units, dissolved oxygen (DO) in mg/L, specific conductance (SpC) in µS/cm, flow in cubic meters per second, Total Dissolved Solids (TDS) in mg/L, Turbidity in NTU, and selenium (Se) concentration in µg/L.

Pariette Wetlands inlet below Flood Control Structure

Date	**Water Temp. (°C)**	**pH**	**DO (mg/L)**	**SpC (µS/cm)**	**Flow (cms)**	**TDS (mg/L)**	**Turbidity (NTU)**	**[Se] (µg/ L)**
8/28/06	17.0	8.5	8.04	1,795	0.15	1,272		4.2
2/26/07	1.0	8.3	11.92	5,040		1,630		15.7
6/4/07	15.5	8.5	8.3	1,175	1.70	754		2.3
8/6/07	30.0	8.7	6.3	2,450	0.221	1,732		4.9
11/5/07		8.5		5,930		4,662		7.8
12/3/07		8.6		5,630		4,710		15.0
4/14/08	11.4	8.3	8.9	6,240	1.36	5,376		12.1
5/19/08	16.3	8.3	8.2	1,580	1.70	1,162		3.4
7/7/08						1,030		8.5
8/11/08						1,046		3.4
3/10/09	37.3	7.8	5.5	3,520	0.311	3,692		10.8
4/21/09	22.9	8.3	7.0	6,575	0.054	5,414		10.2
5/11/09	20.5	8.7	7.5	2,397	0.139	1,708		4.1
6/22/09	17.0	8.2	8.1	1,093	5.6	754		2.5
7/20/09	27.7	8.4	6.5	2,738	0.464	2,062		5.4
8/4/09	25.0	8.5	6.9	1,192	0.473	816		3.0
9/10/09	17.7	8.4	7.9	1,271	2.14	908		3.69
11/3/09	4.8	7.4	10.57	4,744	0.399	3,880		12.5
5/31/11					15.2*			3.1
7/20/11					0.703*			1.8
8/24/11	21.6	7.6	7.3	2,416	0.358*	1,789*	48.71	3.1
9/9/11	16.7	7.3	8.1	1,260	0.703*	933*	1,241	2.5
3/5/12	7.5	8.5	9.9	4,580	0.703*	3,391*	3.8	9.33
3/30/12	7.88	7.5	9.8	5,410	0.703*	4,005*	1.53	7.88
5/10/12	15.42	8.3	8.3	1,180	1.78*	874*	56.1	1.78
6/29/12	21.69	8.6	7.2	4,410	2.53*	3,265*	20.04	2.5

***** Flow was calculated using 2009 trend data correlation between precipitation and flow. TDS was calculated by multiplying specific conductivity by a conversion factor of 0.74.

Pariette Wetlands at Desilt Pond outlet

Date	Water Temp. (°C)	pH	DO (mg/L)	SpC (µS/cm)	Flow (cms)	TDS (mg/L)	Turbidity (NTU)	[Se] (µg/ L)
12/8/08	3.0	8.3	9.2	2,961	0.037	4,084		7.7
3/10/09	2.9	7.8	13.1	3,520	0.31	2,660		5.1
4/21/09	16.0	8.2	8.5	5,078	0.068	3,986		5.4
5/11/09	17.0	8.3	8.5	3,520	0.36	2,526		2.9
6/22/09	20.9	8.1	10.1	1,380	1.36	958		1.3
7/20/09	26.6	9.1	8.3	2,650	0.053	1,910		2.3
8/4/09	26.3	9.1	8.6	2,938	0.31	2,118		2.2
9/10/09	20.4	8.8	8.1	1,773	0.079	1,318		1.6
11/3/09	8.6	7.0	10.4	3,937	0.17	2,974		3.6
8/24/11								1.1
8/24/11								1.3
9/9/11								2.6
9/9/11								2.9
3/5/12								5.4
3/30/12								2.3
5/10/12								1.3
6/29/12								1.0
11/17/12								2.1

Pariette Wetlands outlet below Redhead Pond

Date	Water Temp. (°C)	pH	DO (mg/L)	SpC (µS/cm)	Flow (cms)	TDS (mg/L)	Turbidity (NTU)	[Se] (µg/ L)
7/22/93				3,440	0.028	2,574		<0.5
8/17/93				2,350		1,780		1.0
5/24/94	20.3		7.5	3,745	0.039	2,890		0.5
6/22/94				3,335	0.037	2,430		0.5
7/18/94				4,880		3,966		1.0
8/17/94				6,036		4,664		<0.5
9/20/94				4,978	0.028	4,092		2.0
10/5/94				2,768	0.84	2,094		2.0
10/18/94				2,279	2.83	1,578		2.0
11/21/94				4,154	0.45	3,416		2.0
3/2/95				4,925	0.028	4,224		4.0
3/20/95				4,948	0.057	4,018		2.0
4/20/95				5,922		4,886		0.5
5/2/95				5,930	0.14	4,914		0.5
5/23/95				2,580	0.42	1,904		1.0
6/20/95				2,096	1.33	1,622		1.0
8/4/95	22.2		7.2	1,738	0.18	1,172		<0.5
10/24/95	8.8		9.7	1,962	0.99	1,436		2.0
11/27/95	6.6		10.1	3,588	0.22	2,808		3.0
1/24/96	1.0		11.7	5,152	0.11	4,378		8.0
2/27/96	1.1		11.7	3,458	0.19	2,624		2.0
4/10/96	6.1		10.2	4,577	0.028	3,656		2.0
5/7/97	15.6		8.3	2,268	0.19	1,624		3.7
5/20/96	14.4		8.5	2,732	0.057	2,020		3.8
6/18/97	20.0		7.6	1,011	0.25	662		2.4
7/17/97	24.4		6.9	2,833	0.028	2,032		2.4
7/19/97	22.2		7.2	2,390	0.19	1,742		2.7
8/25/97	21.0		7.4	2,550	0.14	1,088		2.3
9/23/97	16.7		8.1	1,050	0.34	1,018		2.8
4/20/98				5,350	0.028	1,448		11.0
6/22/98	20.0		7.6	1,400	1.98	1,018		3.6
7/20/98	16.7		8.1	2,048	0.028	1,448		2.4
8/17/98	17.8		7.9	1,850	0.057	1,338		2.2
9/21/98	16.7		8.1	1,479	0.057	1,054		2.1
11/30/98	11.1		9.1	4,080	0.14	3,136		8.0
1/20/99	7.2		9.9	5,540	0.057	4,140		18.0
2/16/99	0.0		12.1	4,100	0.14	3,170		8.2
3/15/99	10.0		9.3	4,180	0.028	3,280		9.4
4/27/99				2,190	0.14	1,514		3.2
5/11/99	13.3		8.7	1,500	0.17	1,064		2.1

7/12/99	26.1				0.14	1,272		2.6
8/21/00	16.7		8.1	1,490	0.14	2,294		3.0
10/29/00	5.2				0.22	1,568		3.3
11/18/00	2.5				0.14	2,574		4,8
12/16/00	0.2				0.14	3,869		13.0
1/19/01	0.0				0.14	4,815		15.9
2/10/01	0.0				0.14	4,688		16.9
3/23/01	12.7				0.19	2,582		6.4
4/27/01	20.0				0.042	3,244		11.7
5/25/01	22.5				0.028	1,886		2.9
7/17/01	27.1			2,520	0.059	1,792		<0.5
9/14/01								4.3
11/15/01	2.0	9.0	7.7	4,830	0.014	4,510		4.9
8/28/06	22.0		7.2	2,720	0.17	1,928		1.9
2/26/07	1.0		11.8	3,550		2,614		5.8
6/4/07	16.9		8.0	3,990	0.15	2,836		2.8
6/25/07				3,380	0.099	2,394		2.3
8/6/07	21.5		7.3	4,810	0.0028	3,588		3.2
11/5/07				4,940		3,788		4.8
4/14/08	13.5		8.6	4,720	0.068	3,562		6.6
5/19/08	20.2		7.4	6,020	0.71	4,872		5.5
7/7/08				2,350		1,606		2.0
8/11/08				4,210		6,146		3.2
10/28/08	10.6	8.6	11.4	3,179	0.6	2,632		2.0
12/8/08	0.4	7.9	8.1	3,328	0.0057	4,926		2.5
2/24/09						4,476		5.3
3/10/09	-0.2	7.9	11.0	4,476	0.52	3,504		4.1
4/21/09	21.7	8.0	8.3	5,717	0.028	4,178		3.9
5/11/09	19.5	8.2	12.9	5,947	0.028	4,686		3.0
6/22/09	21.4	8.3	8.9	2,216	1.57	1,616		1.3
7/20/09	24.3	7.9	8.6	4,216	0.028	2,876		3.4
8/4/09	21.8	8.1	7.0	4,733	0.028	3,472		3.3
9/10/09	23.8	8.0	7.7	4,774	0.028	4,172		3.2
11/3/09	9.3	8.4	14.5	3,215	0.059	2,282		1.7
5/31/11	21.4	8.5	7.4	3,610	0.53*	2,671*	0.158	1.5
8/24/11	23.8	7.8	7.1	2,170	0.26*	1,606*	356	0.92
9/9/11	19.0	7.9	7.7	2,440	0.70*	1,806*	462	0.7
3/5/12	6.0	7.3	10.3	5,160	0.38*	3,818*	130	4.2
3/30/12	15.5	7.5	8.2	4,490	0.38*	3,323*	80	1.6
5/10/12	18.3	7.5	7.7	6,100	0.70*	4,514	381	1.8
6/29/12	18.7	7.0	7.7	5,720	0.70*	4,233*	99	1.2

***** Flow was calculated using 2009 trend data correlation between precipitation and flow. TDS was calculated by multiplying specific conductivity by a conversion factor of 0.74.

Appendix B

Soil Description: Upland Soil at BLM Compound

The Upland Soil at BLM Compound sample site is a dry location on a backslope of a ridge of the Pariette Wetlands, Utah. The soil consists of deep, well-drained soil formed from alluvium over sandstone and mudstone of the Uinta Formation. This pedon occurs on a south-southwest backslope of a ridge with a slope gradient of 8%. The average annual precipitation is 14.3 cm, and mean annual air temperature of 8.0°C. Soil moisture regime is aridic, and temperature regime is mesic. The presumed native vegetation is desert shrub. (Colors are for dry soil unless otherwise noted).

A - 0 to 4 cm; pink (7.5YR 7/3) sandy loam, brown (7.5YR 4/3) moist; moderate thin platy structure; soft, loose, slightly sticky, non-plastic; few fine and few very fine roots, common fine and common very fine pores; few carbonate coats around rock fragments; violently effervescent, moderately alkaline (pH 8.2); clear smooth boundary.

Bw – 4 to 14 cm; pink (7.5YR 6/2) gravelly coarse sandy loam, brown (7.5YR 5/3) moist; weak fine subangular blocky parting to equal very fine subangular blocky structure; very hard, very friable, slightly sticky, non-plastic; few fine and few very fine roots, few fine and few very fine pores; few carbonate coats around rock fragments; violently effervescent, strongly alkaline (pH 8.6); clear smooth boundary.

Bk1 – 14 to 41 cm; brown (7.5YR 5/3) very gravelly coarse sandy loam, brown (7.5YR 4/3) moist; weak fine subangular blocky parting to equal very fine subangular blocky structure; soft, very friable, non-sticky, non-plastic; few fine and few very fine roots, few very fine pores; few carbonate coats around rock fragments, faint carbonate coats infused into the matrix adjacent to pores; violently effervescent, strongly alkaline (pH 8.8); clear smooth boundary.

Bk2 – 41 to 54 cm; pinkish gray (7.5YR 6/2) very gravelly coarse sandy loam, brown (7.5YR 4/3) moist; weak fine subangular blocky parting to equal very fine subangular blocky structure; slightly hard, friable, non-sticky, non-plastic; common fine and few very fine roots, few very fine pores; few carbonate coats around rock fragments, faint carbonate coats infused into the matrix adjacent to pores; gravel lens at bottom of horizon; violently effervescent, strongly alkaline (pH 8.9); clear smooth boundary.

Bk3 – 54 to 86 cm; light brown (7.5YR 6/3) very gravelly coarse sandy loam, brown (7.5YR 5/4) moist; weak fine subangular blocky parting to equal very fine subangular blocky structure; slightly hard, very friable, non-sticky, non-plastic; f few very fine roots, few very fine pores; few carbonate coats around rock fragments, 3 cm gravel lens at bottom of horizon; strongly effervescent, very strongly alkaline (pH 9); abrupt smooth boundary.

2Bk4 – 86 to 109 cm; pink (7.5YR 7/3) loam; weak fine subangular blocky parting to equal very fine subangular blocky structure; soft, friable, slightly sticky, moderately plas-

tic; few fine and few very fine roots, common fine and few very fine pores; finely disseminated carbonates 1cm alternating light and dark sediment bands; violently effervescent, strongly alkaline (pH 9); clear smooth boundary.
2BC – 109 to 125 cm; light brown (7.5YR 6/3) silt loam, brown (7.5YR 5/3) moist; moderate medium subangular blocky parting to weak fine subangular blocky structure; slightly hard, friable, slightly sticky, moderately plastic; few very fine roots, common fine and common very fine pores; finely disseminated carbonates,1 cm soils band at bottom of horizon; violently effervescent, very strongly alkaline (pH 9); clear smooth boundary.
2C – 125 to 154 cm; light brown (7.5YR 6/4) fine sandy loam, brown (7.5YR 5/3) moist; structureless massive; slightly hard very friable, non-plastic; few fine and few very fine roots, few fine and few very fine pores; finely disseminated carbonates,1 cm sediment band at 154 cm, few relic redox features at 139 cm; violently effervescent, very strongly alkaline (pH 9).
TYPE LOCATION: Uintah County, Utah; within the BLM's Pariette Wetlands 35 miles southwest of Vernal, Utah; adjacent to the middle Green River; N 40.04675 W 109.82999; elevation 1467 m. The current vegetation is desert shrub community with rice grass, salt grass, greasewood and rabbit brush.
SMR: Aridic
STR: Mesic
Diagnostic epipedon: Ochric
Diagnostic subsurface horizons: Cambic (14-86 cm), Calcic (86-109cm), and Sodic (14-154 cm)
Other diagnostic characteristics: Lithologic discontinuity of gravel lens with alternating light and dark bands 86 to 109 cm
Soil subgroup: Typic Haplocalcids
Family particle size: sandy-skeletal over loamy (25-100 cm)
Family Name: Sandy-skeletal over loamy, mixed, superactive, mesic, Sodic Haplocalcids

Soil Description: Wetlands Soil at Flood Control

The Pariette Wetlands flood control sample site consists of deep, somewhat poorly drained soil formed from alluvium and colluvium over colluvium sandstone and mudstone of the Uinta Formation. This pedon occurs on an east-northeast toeslope of a cliff with a gradient of 6%. Moisture regime is aridic, and temperature regime is mesic. The average annual precipitation is 14.3 cm, and mean annual air temperature is 8.80°C. The presumed native vegetation is desert shrub community with rice grass, salt grass, greasewood and rabbit brush. (Colors are for dry soil unless otherwise noted.)
A - 0 to 6 cm; light brownish grey (10YR 6/2) sandy loam, brown (10 YR 4/3) moist; weak very fine subangular blocky structure; soft, very friable, slightly sticky and non-

plastic; few very fine roots; few very fine pores; no rock fragments; strongly effervescent, moderately alkaline (pH 8.1); clear smooth boundary.

Bw1 – 6 to 18 cm; light brownish grey (10YR 6/2) sandy loam, brown (10YR 4/3) moist; strong very coarse subangular blocky structure; hard, firm, slightly sticky and non-plastic; common very fine, few fine and few moderate roots; few very fine and few fine pores; strongly effervescent, strongly alkaline (pH 8.9); clear smooth boundary

Bw2 – 18 to 28 cm; pale brown (10YR 6/3) sandy loam, dark grayish brown (10YR 4/2) moist; weak fine parting to equal very fine subangular blocky structure; slightly hard, very friable, slightly sticky and non-plastic; few very fine, few fine and few moderate roots; few very fine pores; strongly effervescent, strongly alkaline (pH 8.9); clear smooth boundary.

Bkz – 28 to 41 cm; pinkish gray (7.5 YR 7/2) sandy loam, brown (7.5YR 4/2) moist; moderate medium parting to equal fine subangular blocky structure; slightly hard, very friable, slightly sticky and moderately plastic; few coarse and few fine roots; few very fine and few fine pores; few coarse salt veins; strongly effervescent, strongly alkaline (pH 9.0); clear smooth boundary.

Byz1 – 41 to 62 cm; pinkish gray (7.5YR 6/2) sandy loam, brown (7.5YR 4/2) moist; moderate medium parting to equal fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; few very fine and fine roots; few very fine and fine pores; common coarse salt veins with weathered sandstone; slightly effervescent, strongly alkaline (pH 8.8); clear smooth boundary.

Byz2 – 62 to 101 cm; pinkish gray (7.5YR 6/2) sandy loam, brown (7.5YR 5/3) moist; moderate medium parting to equal fine subangular blocky structure; slightly hard, very friable, slightly sticky and moderately plastic; common coarse, few very fine and few fine roots; few very fine and fine pores; common coarse salt veins with weathered sandstone; slightly effervescent, moderately alkaline (pH 8.4); clear smooth boundary.

Byz3 – 101 to 113 cm; pinkish gray (7.5YR 6/2) sandy clay loam, brown (7.5YR 4/2) moist; weak fine parting to equal very fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; few very fine roots; few very fine pores; common coarse salt veins with weathered sandstone; slightly effervescent, moderately alkaline (pH 8.4); clear smooth boundary.

Byz4 – 113 to 131 cm; pinkish gray (7.5 YR 7/2) very stony sandy loam, brown (7.5YR 4/2) moist; moderate medium parting to equal fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; few very fine, fine, medium roots; few very fine pores; common coarse salt veins with weathered sandstone; slightly effervescent, moderately alkaline (pH 8.4); clear smooth boundary.

2C – 131 to 152 cm; pinkish gray (7.5YR 6/2) very stony sandy loam, brown (7.5YR 4/2) moist; structureless single grain; soft, very friable, slightly sticky and non-plastic; few very fine and fine roots; few fine and medium pores; common weathered sandstone; strongly effervescent, strongly alkaline (pH 8.6); clear smooth boundary.

TYPE LOCATION: Uintah County, Utah; within the BLM’s Pariette Wetlands 35 miles southwest of Vernal, Utah; adjacent to the middle Green River; N 40.06969 W 109.85906; elevation 1448 m. The presumed native vegetation is desert shrub community with rice grass, salt grass, greasewood and rabbit brush.
SMR: Aridic
STR: Mesic
Diagnostic epipedon: Ochric
Diagnostic subsurface horizons: Gypsic (41-131 cm) and Sodic (6-152 cm)
Other diagnostic characteristics: none
Soil subgroup: Sodic Haplogypsid
Family particle size: Fine loamy (25-100 cm)
Family Name: Fine-loamy, mixed, superactive, mesic, Sodic Haplogypsid

Curriculum Vitae

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Education

Ph.D., Ecology - Utah State University, Department of Plants, Soils & Climate, Logan, Utah. Dissertation Title: *Biogeochemistry of Selenium in Pariette Wetlands, Utah* - Advisor: Paul R. Grossl - Spring 2010 - August 2014

B.S., Science Composite – Summa Cum Laude**,** Utah State University, Department of Secondary Education - December 2003

M.S., Zoology, Brigham Young University**,** Department of Zoology, Provo, Utah Thesis Title: *Genetic Variation Among and Within Native and Non-native Trout (Oncorhynchus) Populations of the Sheep Creek Drainage, Utah -* Advisor: Dennis Shiozawa - Fall 1996 – Winter 1999

B.S., Zoology Brigham Young University, Department of Zoology, Provo, Utah **-** Summer 1987

Related Employment

2013-present	Postdoctoral Research Associate (assessment of environmental toxins in water, soils and biota), Utah State University – Uintah Basin, Vernal, Utah
2011-2013	Graduate Research Assistant (biogeochemistry of selenium in a wetland), Utah State University – Uintah Basin, Vernal, Utah
2012-2013	Earth Systems Science Teacher, Vernal Junior High School, Vernal, Utah
2010-2011	Health Teacher, Uintah High School, Vernal, Utah
2004- present	Adjunct Professor (Biology 1010, Chemistry 1010 and USU 1360), Utah State University, Uintah Basin Vernal, Utah
1996-1999	Biologist Assistant (fish population and habitat data) Utah Division of Wildlife Resources, Vernal, Utah
1989-1991	Project Coordinator (oil refinery engineering projects) Chemical Design Company, Point Richmond, California
1987-1989	Assistant Property Manager, Som and Associates, San Francisco, California

Teaching Experience

2004-present	**Adjunct Professor,** Utah State University, Uintah Basin, Vernal, Utah (Biology 1010 - Biology and the Citizen, Chemistry 1010 - Introduction to Chemistry & USU 1360 – Integrated Physical Science)

Experienced and comfortable with the use of distance education delivery methods.

Developed and organized lectures, labs, demonstrations, and instructed courses ranging from 20 to 200 students using distance education delivery up to 18 different sites.

2012-2013 **Earth Systems Science Teacher,** Vernal Junior High School**,** Vernal, Utah.
Developed curriculum, lectures, labs, demonstrations, and writing assignments to challenge students to be more aware of human impact on the environment.

2010-2011 **Health Education II Teacher,** Uintah High School, Vernal, Utah.
Taught high school students how to be aware and involved in their physical, mental, and social health.

Manuscripts in Preparation

Jones, C.P., M.C. Amacher, P.R. Grossl, A.R. Jacobson and S. Wingert. Selenium Mass Balance and Flux in Water of Pariette Wetlands, Utah. (Manuscript in preparation, to be submitted to Journal of Environmental Quality)

Jones, C.P., P.R. Grossl, and M.C. Amacher. Selenium in Water and Plant Tissue and Its Loss Through Volatilization in the Pariette Wetlands, Utah. (Manuscript in preparation, to be submitted to Journal of Environmental Quality)

Jones, C.P., P.R. Grossl, M.C. Amacher, Boettinger, A.R. Jacobson, and J. Lawley. Assessment of Selenium Mobilization in Arid Upland and Wetlands Soils of Pariette Wetlands, Utah. (Manuscript in preparation, to be submitted to Journal of Environmental Quality)

Jones, C. P., D. K. Shiozawa, R. P. Evans, and L. K. Hatfield. Genetic Variation Among and Within Native and Non-native Trout (*Oncorhynchus*) Populations of the Sheep Creek Drainage, Utah.

Presentations and Posters

Jones, C.P. L. Boyd. May 2014. Water Quality and Its Measurements of the BLM's Pariette Wetlands, Utah. Community Outreach to Altamont High School Earth Systems Students for the BLM.

Jones, C.P., P.R. Grossl, A.R. Jacobson, J.L. Boettinger, M.C. Amacher and B.J. Burger. April 2014. Biogeochemistry and Hazard Assessment of Selenium in the Pariette Wetlands, Utah. Uintah Basin Research Conference. Vernal, Utah.

Jones, C.P., C. Hall, M. Mansfield and S. Lyman. April 2014. Ozone Formation in the Uintah Basin: A Box Model. Uintah Basin Research Conference, Poster Session. Vernal, Utah

Jones, C.P., P.R. Grossl, A.R. Jacobson, & C. Cline. September 2013. Hazard Assessment of Selenium in Pariette Wetlands Complex, Utah. Stakeholder Meeting. Roosevelt, Utah.

Jones, C.P. and P.R. Grossl. April 2012. Introduction to Selenium Biogeochemistry of Pariette Wetlands, Utah. Uintah Basin Research Conference, Vernal, Utah.

Allred, H., **Jones, C.P.** and P.R. Grossl. April 2012. Methods for Selenium Accumulation Detection in Pariette Wetlands, Utah. Uintah Basin Research Conference, Vernal, Utah.

O'Neil, T., H. Allred, **Jones, C.P.** and P.R. Grossl. April 2012. Selenium Biogeochemistry in the Pariette Wetlands, Utah. Uintah Basin Research Conference, Poster Session. Vernal, Utah.

Jones, C.P., and P.R. Grossl. October 2011. Selenium Biogeochemistry in the Pariette Wetlands. 2011 International Annual Meetings of American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. San Antonio, Texas.

Jones, C.P., L.K. Hatfield, R.P. Evans, and D.K. Shiozawa. April 1997. A Cutthroat Trout Metapopulation Study in Sheep Creek: An Overview of mtDNA Investigations. Meeting of fisheries biologist from Region 4 of the U. S. Forest Service. Vernal, Utah.

Jones, C. P., D.K. Shiozawa, R.P. Evans, and L.K. Hatfield. November 1997. Genetic Variations of Colorado River Cutthroat Trout (*Oncorhynchus clarki pleuriticus*) Populations of the Sheep Creek Drainage in the Uinta Mountains near Vernal, Utah. Desert Fishes Council, 29th Annual Meeting. Death Valley, California.

Jones, C. P., L. K. Hatfield, R. P. Evans, and D. K. Shiozawa. March 1998. A Cutthroat Trout Metapopulation Study in Sheep Creek: An Overview of mtDNA Investigations. Joint meeting of the Colorado/Wyoming and Bonneville Chapters of the American Fisheries Society. Grand Junction, Colorado.

Jones, C. P., D. K. Shiozawa, R. P. Evans, and L. K. Hatfield. November 1999. Genetic Variation Among and Within Native and Non-native Trout (*Oncorhynchus*) Populations of the Sheep Creek Drainage, Utah. Uintah Mountain Club, Monthly Meeting Vernal, Utah.

Research and Field Experience

2013-present	Postdoctoral Fellow – Air Quality Research Group, Utah State University, Vernal. Supervisor: Dr. Seth Lyman. Duties: field collection, analytical work and modeling of data.
2013-present	Postdoctoral Fellow – Plants, Soils & Climate, Utah State University, Vernal. Supervisor: Dr. Astrid Jacobson. Duties: field collecting, processing, and prepping samples of aquatic bird eggs, fish tissue, benthic macroinvertebrates, plants, sediments, and water samples. Samples are then analyzed for selenium concentration to be used in a spatially explicit

	exposure model. The model can then be used to quantify the potential risk of effects in aquatic birds breeding at Pariette Wetlands.
2010-present	Graduate Research Assistant - Plants, Soils & Climate, Utah State University, Vernal. Advisor: Dr. Paul Grossl. Duties: field collection, analytical work and modeling of data to assess the mobilization of selenium in a created Wetlands of the soil, water, air and biota. Research includes examining variability of pH, redox reactions, temperature, salinity, and soil composition. Techniques such as ICP-MS and HG-AAS will also be used to assess mobilization of selenium.
1996-1999	Graduate Research Student - Zoology Department, Brigham Young University. Advisor: Dennis Shiozawa. Duties: Planned, conducted, and reported results of mt DNA research and analysis of Colorado River cutthroat trout using PCR and RFLP analysis.

Future Research

- Development of instrumentation to measure mercury compounds in the atmosphere.
- Investigation of reclamation options for threatened and endangered species.
- Reclamation of abandoned oil and gas well pads in arid environments.
- Measurement of hydrocarbon emissions from several source categories in the Uintah Basin.

Awards and Scholarships

2013	Graduate Researcher of the Year, Utah State University – Uintah Basin
2011-2013	Research Assistantship – Selenium Grant – Bureau of Land Management
2008	Outstanding Faculty Member - Utah State University
2006	Webelos Den Leader Award – Boy Scouts of America
2003	Utah State University – Graduated with Honors - Summa Cum Laude
2003	Service Scholarship Award - AmeriCorps
2002	Salute to Volunteer Award - Utah State University Extension
2000-2003	Certificate of Achievement Award – 4-H Uintah County Program
1997	Young Careerist Award- Business and Professional Women's Club
1996	Performance Award -Utah State Division of Wildlife Resources
1983-1985	Dean's List - University of Texas Arlington
1984	Grace Thorton Scholarship - University of Texas Arlington

Professional Society Membership

2011	Soil Science Society of America
2010	Society of Wetlands Scientists

2004-present	Sigma Alpha Lambda
1998, ’99, 2010	American Fisheries Society
1997	Desert Fishes Council