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Abstract approved:

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Concentration ratios are used to determine the transfer of nuclides from soil to biota to fauna. Some nuclides have limited associated data though, this has not prevented predictions from being performed at sites without associated data. These ratios are site specific and are not fully applicable when applied to other locations. A recent literature review for a waste repository performance assessment determined that a significant portion of the environmental data was based on recursively published material. To address this deficiency neutron activation analysis (NAA) was used to determine concentration ratios of certain biota. Three sites, two riparian and one shrub steppe, were sampled in the eastern Washington Columbia basin, near the Hanford site. Two hundred and fifty eight samples of opportunity were collected. This included 15 soil samples, 10 water and sediment samples, 40 different species of biota, and 2 terrestrial animal species and 3 aquatic animal species. These samples were prepared for NAA by drying, weighing, and in certain cases ashing to improve detection efficiency. After activation, the samples were placed in a HPGe detector to perform spectral analysis. The concentration results of 26 elements of interest are presented, along with newly established concentration ratios for all of the species sampled.

Establishment of Concentration Ratios for Riparian and Shrub Steppe Areas of the Eastern Washington Columbia Basin

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Jonathan Bamberger Napier, Author

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Nomenclature

Definitions

Bq	Becquerel
BR	branching ratio
CPS	counts per second
CR	concentration ratio
DE	detection efficiency
DIW	deionized water
HPGe	high purity germanium
IAEA	International Atomic Energy Agency
INAA	instrumental neutron activation analysis
Kcfs	thousand cubic feet per second
Kg	Kilogram
MDC	Minimum detectable concentration
MeV	Megaelectron Volt
mg	milligram
NAA	neutron activation analysis
NIST	National Institute of Standards and Technology
NRC	nuclear regulatory commission
OSTR	Oregon state TRIGA reactor
pCi	picocurie
ppb	parts per billion
ppm	parts per million
SWE	snow water equivalent
TRS	technical report series

Symbols

A	activity
A_o	initial activity
λ	half life (specific to isotope of interest)
M_{Sample}	sample mass
$M_{Standard}$	standard mass
N_1	concentration of an element in a plant or animal
N_2	concentration in the soil associated with N_1
R	Ratio of N_1 to N_2 (N_1/N_2)
σ	error associated with specific number (σ_R is associated error of R)
t	time

Establishment of Concentration Ratios for Riparian and Shrub Steppe Areas of the Eastern Washington Columbia Basin

1.0 Introduction

Radioecology focuses on the mobility and impact of radionuclides throughout the ecosystem. Whicker and Schultz stated that one of the primary subdivisions of radioecology was "radionuclide movement within ecological systems and accumulation within specific ecosystem components such as soil, air, water, and biota" (Whicker and Schultz, 1982). In equilibrium conditions, nuclide movement can be simplified into a ratio of the concentrations between two compartments of an ecosystem, in what is called a concentration ratio (CR).

The movement rate described can be determined during site characterization. Site characterization can be broken down into four stages: background research, field investigation, analysis of samples collected, and data evaluation. The beginning research determines the past and current uses of the site, which in turn, determines locations within the site that would make good sampling areas. After a list of sampling locations has been made, the list is reviewed and often pared down to sites that will not hamper sampling at other locations due to their accessibility restraints or by their potential lack of valuable information. Samples taken at the identified sample sites are then transferred to a central laboratory for analysis. Analysis is completed using one or more chosen techniques to collect data which is then analyzed to draw any pertinent conclusions (HMTRI, 1997). These conclusions can be qualitative or quantitative.

Currently, there are three methodologies for site characterization. The first is to sample multiple species at a single site (KA Higley, 2010), the second is to sample a single species at multiple sites (Sheppard and Evenden, 1990), and the third is to compile data from multiple sources (Beresford et al., 2008).

Software modeling of various sites has been done to characterize exposure to future human inhabitants of those sites. Characterization software is complex and requires multiple steps to prove that the model works. Software models require input data based on the site location to create a model that is robust and represents a location accurately. Qualitative information will build the basis for the model, and quantitative information will allow for calibration of the model. The steps to build such a model were explained by Miller (Miller, 2000):

1) Construction of a conceptual model which describes the system and includes all of the important processes and their couplings

2) Translation of the conceptual model into a mathematical model and coding in the form of a computer program;

3) Verification of the numerical 'correctness' of the code;

4) Validation of the code's 'applicability' to the repository system to assess its predictive capabilities.

A problem arises with the quantitative data required to calibrate the models for accuracy. Nuclide transfer data is element specific, though the use of natural analogues has been used in the absence of data for a desired element (IAEA, 1999). This is an important, but sometimes questionable practice, as one source suggested using cesium-137 data for argon-41 and krypton-85 (Beresford, 2004).

In an analysis of element specific source terms used in a biosphere submodel of a performance assessment for Yucca Mountain, it was determined that of 538 parameters, 139 were sourced from a peer reviewed article, 210 were from institutional publications, 140 had no listed reference, and 49 were derived during the creation of the model by the authors (Higley et al. 2011). Of the data required to build the model, 35% was either not sourced or was inferred by the authors of the performance assessment. When trying to compare data from other locations, it must be considered that CRs from one location are not always appropriate at the other. Whicker and Shultz described this problem by saying that a "problem with concentrations ratios is that they are influenced by many factors associated with the properties of the radionuclide, the organism, and the ecosystem. As a result, individual measurements display a great deal of variability" (Whicker and Schultz, 1982b). Impacting factors are things such as soil type, amount of rain, and weather at the location. This brings to question: how solid are predictions for a location in the absence of site specific data?

The focus of this work is to characterize equilibrium conditions for a number of trace elements at three locations surrounding the Hanford Site so it can be used in any future site assessments. The area is a geological formation that is unique to eastern Washington. During the last ice age, the Purcell Trench lobe of the Cordilleran ice sheet blocked the Clark Fork River. The river blockage caused the formation of the Glacial Lake Missoula, near present day Missoula, Montana. Periodically, the water would build up enough pressure to force liquid water into tiny cracks at the bottom of the ice dam (Clague et al., 2003). Once enough water made it under the bottom of the ice dam it would burst. The water would quickly empty through the opening, flowing in torrents several miles wide in depths of up to 500 feet and at speeds up to fifty miles per hour (Johnson, 2011). There is evidence that this type of flooding occurred up to forty or more times (Clague et al., 2003). The flood waters were impeded at Wallula Gap. The gap created Lake Lewis that contained 250 cubic miles of water, covered 3000 square miles of land, and lasted seven to ten days. The delay allowed sediment to settle out in coarse to fine layers (Johnson, 2011). The current Columbia River channel is the northern and eastern border of the Hanford site.

The Hanford site was established on January 16, 1943 after General Leslie Groves visited the area and determined it met the location requirements set forth by DuPont (Mercer, 2002). As part of the Manhattan Project, the Hanford site was tasked with the creation of plutonium for nuclear weapons. By May 1944 the area had grown from a few thousand residents to over 47,000. B Reactor, the first plutonium production facility in the world, was completed at the end of September of the same year. Eight other reactors were completed at the site in the following years. By 1971, eight of the nine reactors built on the Hanford site had been shut down, due to the decreased demand for plutonium. The ninth reactor, N, ran until 1987 when it too was shut down (*Linking legacies…,* 1997).

The reactors were built near the Columbia River, and are shown in Figure 1.1. The location was chosen based on a list of requirements put forth by DuPont, the main contractor selected by General Leslie Groves of the US Army Corps of Engineers (Williams, 2011):

- A rectangle of land about 12 miles by 16 miles so the plants would be at least 20 miles from any town with a population of more than 1000.
- At least 25,000 gallons per minute of water (for coolant) and 100,000 kilowatts of power (for building purposes).
- No main highway or railroad closer than 10 miles to one of the plants.
- No towns larger than 1000 people.

The Columbia River was an optimal source of coolant due to its size. The proximity of the Grand Coulee and Bonneville dams provided electricity and a local substation aided in accessibility. Additionally, two cities, White Bluffs and Hanford, had sparse populations that allowed for forced relocation and requisition of lands through eminent domain, as defined in the takings clause of the Fifth Amendment (*Linking legacies…,* 1997).

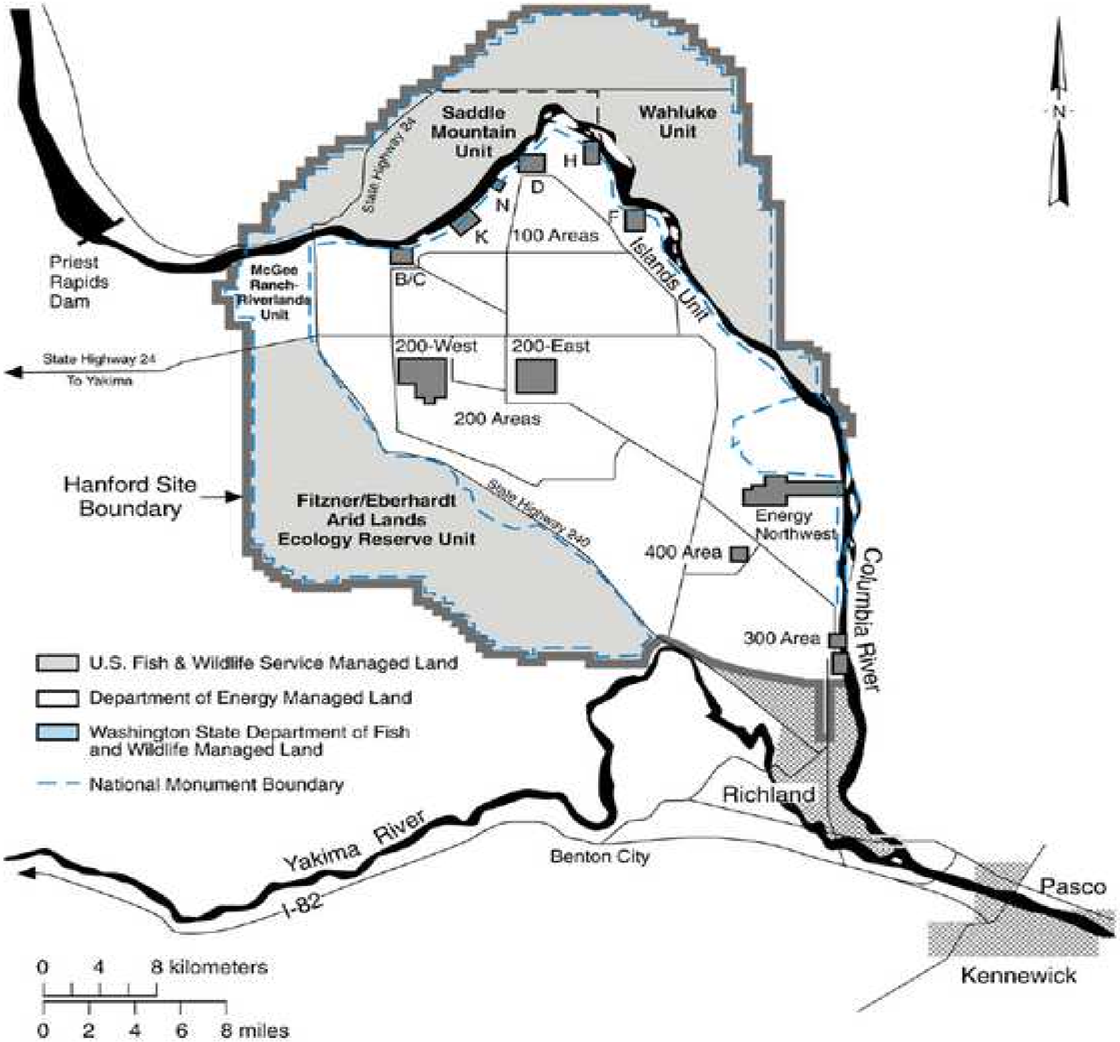

Figure 1.1: Locations of Nuclear Reactors at the Hanford Site and surrounding areas (Fritz et al., 2004)

During plutonium production and reprocessing, waste was also generated. In some instances the waste was discharged straight into the soil, though most of the waste was stored in 149 single shelled tanks and 28 double shelled tanks. Since storage began, some of the older single shelled tanks have leaked and approximately one million gallons of waste has been introduced into the environment. There have also been reports of dumping waste directly into the Columbia River (*Linking legacies…*, 1997).

The samples for this study were collected at three locations in eastern Washington that surround the Hanford site. The three locations were chosen based on their proximity to the Hanford site, along with their ease of access. Two riparian locations were selected along with one inland shrub steppe location. The riparian locations were the primary interest for the study and the inland location was chosen due to the prevalence of the local shrub steppe ecosystem. It was also chosen as a comparison against the nearby riparian areas. The riparian sample locations were on the shoreline; the first in the city of Richland, the second was at Vernita, just north of the Hanford Site. As the Columbia River flows, the Vernita sampling site is up river of the Richland Sampling Site. The third sample site was an arid inland location, just south of the Hanford site.

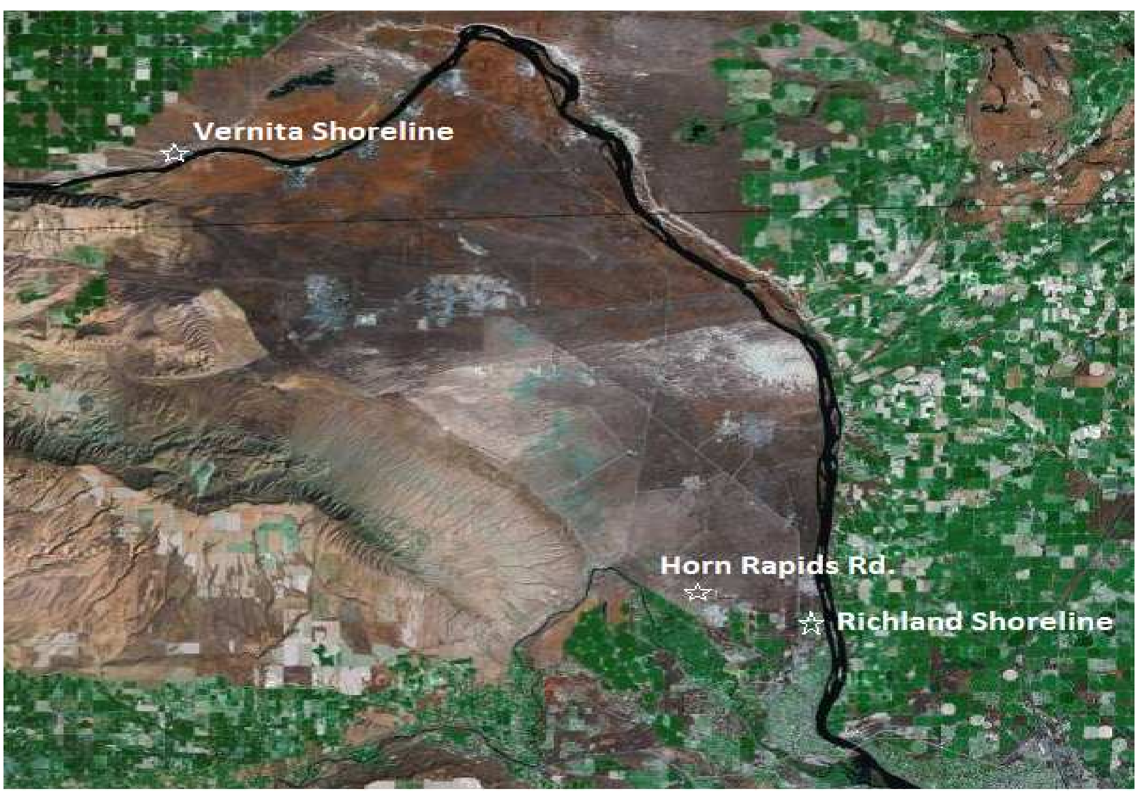

Figure 1.2: Sampling locations

Table 1.1 Coordinates of Sampling Locations

Location	Coordinates
Richland WA	46^{o} 19' 34" N 119^{o} 15' 38" W
Vernita Shoreline	46^{o} 38' 26" N 119^{o} 44' 30" W
Horn Rapids Road Richland, WA	46^{o} 21' 43" N 119^{o} 22' 7" W

This project has specific goals. Concentration ratios will be established irradiation for three sampling locations. The calculated concentration ratios will compare the two riparian locations against each other. Concentration ratios from the riparian locations will be compared against the shrub steppe location. All the concentration ratios will be compared against current and historic concentration ratios from regulatory bodies and determined soil and water concentrations will be compared against known accepted local and national values.

2.0 Literature Review

2.1 Introduction to Concentration Ratios

Plants incorporate what is in the soil into their structure. The amount of each element in plants varies based on the species and environment (Guilizzoni, 1991). Some plants mistake chemical analogues when looking for micronutrients. Examples are: strontium and barium replace calcium (H. J. M. Bowen and Dymond, 2003), and cesium replaces potassium (Korey, 1974). Contaminants in soil can be incorporated into whatever grows on or in it.

A group of stable elements are considered to be trace elements. To be considered present in trace quantities, the concentration of an element must be lower than 10^{-4}g/g and above 10^{-14} g/g (Kruger, 1971). There are seventeen elements that are essential for plant growth (Kabata-Pendias, 2001), and fifteen elements are considered essential for animal life (Sato, 1990).

The general definition of a concentration ratio is defined by the International Atomic Energy Agency (IAEA) as "[t]he ratio of the activity concentration of radionuclide in the plant (Bq kg^{-1} dm) to that in the soil (Bq kg^{-1} dm)" (Beresford et al., 2008; IAEA, 2010). This is shown in equation 1.

$$CR = \frac{\text{Activity concentration in biota } (\frac{\text{Bq}}{\text{Kg}})}{\text{Activity concentration in soil } (\frac{\text{Bq}}{\text{Kg}})} \tag{1}$$

Concentration ratios can also be calculated using concentration instead of activity. This is shown in equation 2.

$$CR = \frac{\text{Concentration in biota } (\frac{\text{mg}}{\text{Kg}})}{\text{Concentration in soil } (\frac{\text{mg}}{\text{Kg}})} \tag{2}$$

A dimensionless constant comes from this number manipulation. It can also be applied in cases that do not us e soil as the growth medium. In this case, the definition slightly changes to "[t]he ratio of the radionuclide concentration in the receptor biota tissue (fresh weight) from all exposure pathways (including water, sediment and ingestion/dietary pathways) mass relative to that in water" (IAEA, 2010). The equation is still the same, but the denominator of equation 1 would be water instead of soil. Both definitions assume that equilibrium has been reached between the environmental medium, be it soil, sediment, or water, and the organism growing in it. However, radionuclide transfer rates vary over time, partly due to elemental availability and partly due to organism ingestion rates (IAEA, 2010).

2.2 Elemental Concentrations in Media

Soil concentrations have been reported by the United States Geological Survey and are listed in Table 2.1. The data is compiled from a multitude of works along with original USGS data (Brooks, 1972; Kabata-Pendias, 2001; Peterson et al., 2007; Rose et al., 1979; Shacklette and Boerngen, 1994). Ranges are used to show the variability that can occur between different sampling locations. Some concentration ranges are very wide, as in the case of silicon, 16,000 ppm to 450,000 ppm, or very narrow as in the case of germanium, 0.1 ppm to 2.5 ppm and is related to the natural abundance of the element (Shacklette and Boerngen, 1994). These wide ranges show that element concentrations are not uniform across the world. This fact would encourage the use of an element specific concentration ratio across all soil types. A method using a single concentration ratio could be true for some elements, but it may only apply in locations with small soil concentration variance.

The riparian samples collected were Burbank loamy sand. The shrub steppe samples collected were Quincy sand. These soil types are relevant as they are two of the most common soil types found on the Hanford site. The soil types were determined using the Web Soil Survey

Table 2.1 Soil concentrations of the World (Brooks, 1972; Kabata-Pendias, 2001; Peterson et al., 2007; Rose et al., 1979; Shacklette & Boerngen, 1994)

	USGS			Rose		Brooks		Peterson	Kabata-Pendias	
Element	Average	Low	High	Low	High	Low	High	mg/kg	Low	High
As	7.20E+00	1.00E-01	9.70E+01	7.50E+00	7.50E+00	5.00E+00	5.00E+00	3.50E+00	7.00E-02	9.30E+01
Ba	5.80E+02	1.00E+01	5.00E+03	3.00E+02	3.00E+02	5.00E+02	5.00E+02		1.00E+01	2.37E+03
Ce	7.50E+01	1.50E+02	3.00E+02						2.12E+01	2.25E+02
Co	9.10E+00	3.00E+00	7.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01		2.00E-01	1.22E+02
Cr	5.40E+01	1.00E+00	2.00E+03	6.30E+00	6.30E+00	2.00E+02	2.00E+02	5.40E+01	3.50E+00	1.50E+03
Cs								1.90E+00	3.00E-01	2.60E+01
Eu								1.80E+00	3.70E-01	7.66E+00
Fe	2.60E+04	1.00E+02	1.00E+05	2.10E+04	2.10E+04	1.00E+04	5.00E+04			
Hf									1.80E+00	2.08E+01
La	3.70E+01	3.00E+01	2.00E+02						4.60E+00	8.97E+01
Lu									1.00E-01	7.20E-01
Na	1.20E+04	5.00E+02	1.00E+05							
Nd	4.60E+01	7.00E+01	3.00E+02						7.90E+00	1.20E+02
Ni	1.90E+01	5.00E+00	7.00E+02	1.70E+01	1.70E+01	4.00E+01	4.00E+01	9.00E+01	2.00E-01	6.60E+02
Rb	6.70E+01	2.00E+01	2.10E+02	3.50E+01	3.50E+01				2.00E+01	2.10E+02
Sb	6.60E-01	1.00E+00	8.80E+00	2.00E+00	2.00E+00	5.00E-01	5.00E-01		5.00E-02	2.32E+00
Sc	8.90E+00	5.00E+00	5.00E+01						5.00E-01	4.64E+01
Sm								6.00E+00	1.89E+00	2.26E+01
Sr	2.40E+02	5.00E+00	3.00E+03	6.70E+01	6.70E+01	3.00E+02	3.00E+02		5.00E+00	1.00E+03
Ta									2.00E-02	4.00E+00
Tb									1.10E-01	1.66E+00
Th	9.40E+00	2.20E+00	3.10E+01			1.30E+01	1.30E+01		4.00E-01	7.60E+01
U	2.70E+00	2.90E-01	1.10E+01	1.00E+00	1.00E+00	1.00E+00	1.00E+00		1.00E-01	1.10E+01
Yb	3.10E+00	1.00E+00	5.00E+01						8.10E-01	5.05E+00
Zn	6.00E+01	5.00E+00	2.90E+03	3.60E+01	3.60E+01	5.00E+01	5.00E+01	5.00E+01	3.50E+00	7.70E+02
Zr	2.30E+02	2.00E+01	2.00E+03	2.70E+02	2.70E+02			1.30E+02	2.00E+01	5.00E+02

tool provided by the US Department of Agriculture Natural Resources Conservation Service website(USDA, n.d.). A soil map shows the relevancy of the samples taken around the Hanford site in Figure 2.1.

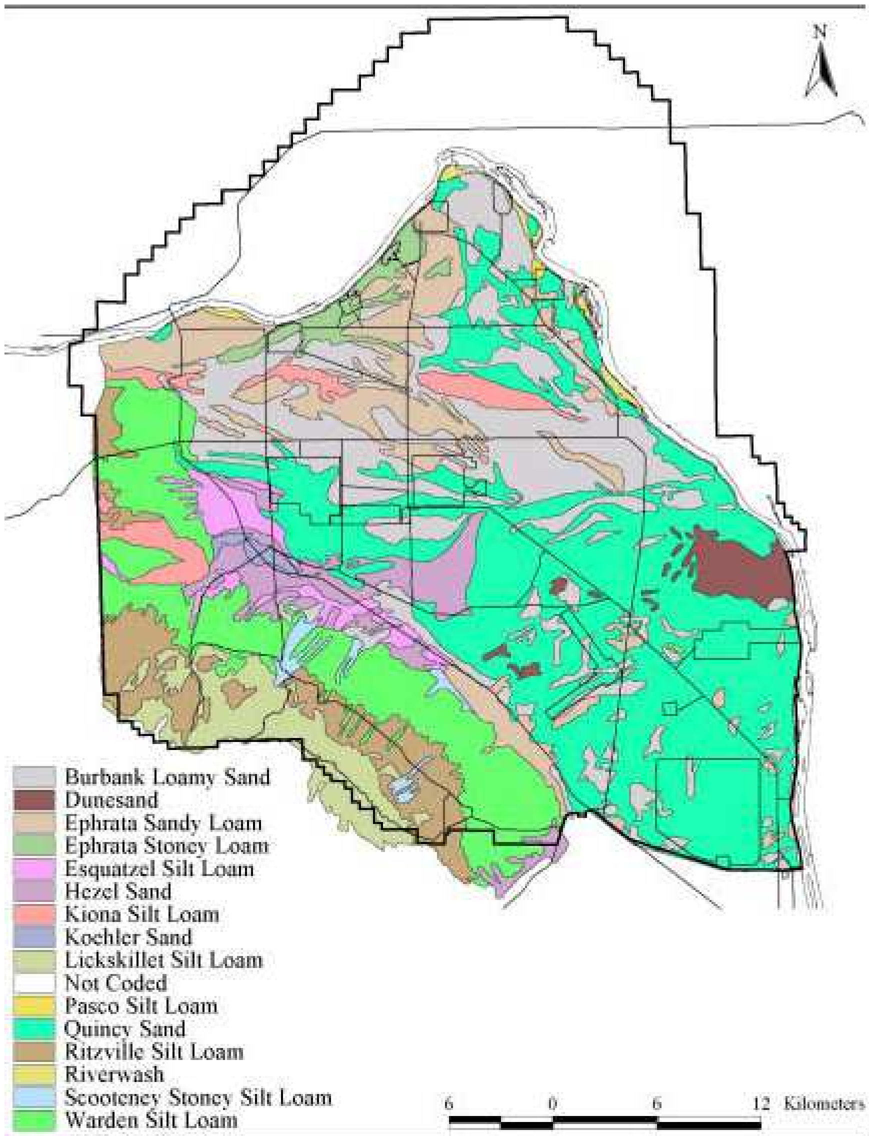

Figure 2.1 Soil map of the Hanford Site. (Sackschewsky and Downs, 2001)

Previously at the Hanford site, water samples have been taken to determine elemental water concentrations. A 1972 study by Cushing and Rancitelli took water samples at a location described as “upstream of the Hanford Atomic Works Project”. The authors took samples five times over ten months. The yearly average, calculated for this project, along with the five samples is shown in Table 2.2. The purpose of separating their data based on date was that each sampling date was chosen as a "biologically significant" time of the year (Cushing and Rancitelli, 1972). There is concentration change reported throughout the year, which is why the yearly average was calculated. The calculated water concentrations are to be compared against both the calculated average and the data from August 14, 1969.

Table 2.2 Columbia River Water Concentration Data (Cushing and Rancitelli, 1972)

Water Concentrations in ppb						
	11/14/1968	2/12/1969	4/24/1969	6/11/1969	8/14/1969	Average
As	2.5	1.4	2.9	2.6	2.4	2.36
Ba						
Ce						
Co	0.02	0.04	0.22	0.06	0.09	0.086
Cr	0.04	0.1	0.1	0.2	0.1	0.108
Cs	0.35	0.03	0.02	0.03	0.03	0.092
Eu						
Fe	13	10	62	24	17	25.2
Hf						
La						
Lu						
Na	2200	1365	2900	1880	2100	2089
Nd						
Ni						
Rb	3.5	0.4	0.9	1.1	1.3	1.44
Sb	0.24	0.43	1.04	0.3	0.43	0.488
Sc	0.002	0.001	0.015	0.003	0.006	0.0054
Sm						
Sr	0.7	0.5	1	1	0.7	0.78
Ta	8	44	6	8	6	14.4
Tb						
Th						
U	0.7	0.5	1	1	0.7	0.78
Yb						
Zn	8	44	6	8	6	14.4
Zr						

In addition to water concentrations, sediment concentrations of the Columbia River have been the subject of research. The USGS took samples over three years ('96-'98) and determined a three year concentration average. Samples were of a range in sizes, from 10 liters to 100 liters, with the intent that with water removal through centrifugation, samples of 1 to 1.25 grams would be obtained. One location sampled during the study was at Vernita Bridge, a location also sampled in this study, and if not the same place then within half a mile. The sediment data is shown in Table 2.3. This table illustrates the gaps that occur in elemental data.

Table 2.3 Available Columbia River sediment concentration information (Horowitz et al. 2001)

Element	ppm	Element	ppm
As		Ni	120
Ba		Rb	
Ce		Sb	3
Co		Sc	
Cr		Sm	
Cs		Sr	320
Eu		Ta	
Fe		Tb	
Hf		Th	
La		U	
Lu		Yb	
Na		Zn	570
Nd		Zr	

The amount of suspended sediment is related to the flow rate of the water. The river has different flow rates throughout the seasons. Generally speaking, the highest flow period should be between late May and early July as the yearly snowpack melts. A year with a colder average temperature during the spring season will affect the spring runoff by shifting the highest flow rates later in the year. A heavy snow year will generally increase the amount of runoff. In this study the sampling year, 2011, had these conditions occur in the same year. The average spring temperature was 4 to 8 degrees Fahrenheit below average temperature for that time period. The average snow water equivalent (SWE), meaning the amount of water that would remain if all the snow suddenly became liquid, ranged from 117% to 159% of the normal average (17% to 59% more snow than normal) on May 3, 2011 (Bond, 2011a). The SWE ballooned to a range of 190% to 256% of normal (90% to 156% above normal average) as of

June 1, 2011 (Bond, 2011b). The increased snowfall and cooler temperatures directly affected the flow rate of the Columbia River (Hardiman et al., 2012). When compared against the average discharge rate of the years 2010, 2009, and the 10 year average, the flow of the Columbia River was abnormally high during the sampling period. The flow rate is shown in Figure 2.2.

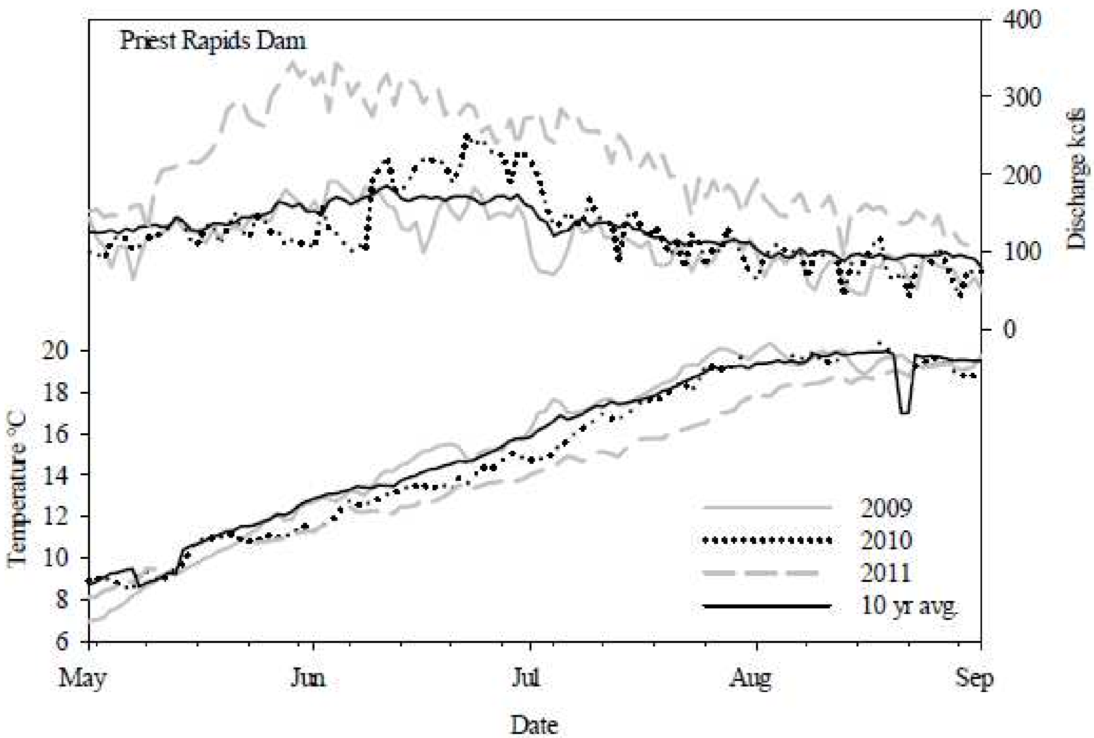

Figure 2.2 Priest Rapids Dam discharge rate in thousand cubic feet per second (kcfs) (Hardiman et al., 2012)

2.3 Review of Published Concentration Ratios

It was expected that equal amounts of absorption data for each element would be available for reference. That is not the case. Analysis of data sources from IAEA Technical Document 1616 (IAEA, 2009) by Higley (Higley, 2011) showed a definitive skewing of data sources towards cesium and strontium. Strontium, the element with the second most sources, only had half the number of references as cesium. Cobalt, the third most studied element, only had a third of the references as cesium. These three elements had fifty percent more references than the thirty other elements listed in IAEA Technical Document 1616 combined (IAEA, 2009). The skewing of the data to those three elements is because they are long lived fission products.

The Nuclear Regulatory Committee uses concentration ratios to determine potential human exposure. The first column of Table 2.4 shows the stable element concentration ratios first used by the Nuclear Regulatory Commission “for the estimation of radiation doses to man from effluent releases.” These numbers were published in Regulatory Guide 1.109 in 1977 (NRC, 1977). The values were calculated as concentration ratios using picocuries per kilogram (pCi/kg in vegetation per pCi/kg in soil) in the same manner as equation 1. The data of Regulatory Guide 1.109 was consolidated from the US Atomic Energy Commission Report UCRL-50163, Part IV from 1968. More data has been published since 1968. A 1983 compilation of data for the Commission of the European Communities and the United Kingdom Ministry of Agriculture, Fisheries, and Food is one such source (Coughtrey et al., 1985). While published in 1985, it is not much more recent than the NRC Regulatory Guide from 1977. In 2009, the IAEA published Technical Document 1616. It was written to support Technical Report Series (TRS) 364 and fill holes left when TRS 364 was written and it represents the most current values internationally (IAEA, 2009). The updated document did not include information on all elements, which is why values from the TERRA computer code (Baes III, 1984) are also listed. The list of TERRA code values represents the most complete table that included all of the necessary values for this study.

Table 2.4 Consolidated Concentration Ratio Data (Baes III et al. 1984; Coughtrey et al., 1985; IAEA, 2009; NRC, 1977)

	NRC 1977	TD-1616		Coughtrey et al.		Baes III et al.	
Element	Average	Low	High	Low	High	NonVegetative Portions (B_r)	Vegetative Portions (B_v)
As						6.00E-03	4.0E-02
Ba	5.0E-03	1.0E-03	3.6E+00			1.50E-02	1.5E-01
Ce	2.5E-03	8.0E-04	3.5E+00	1.0E-03	1.0E-02	4.00E-03	1.0E-02
Co	9.4E-03	2.4E-03	1.6E+00	5.0E-01	5.0E-01	7.00E-03	2.0E-02
Cr	2.5E-04	5.0E-04	2.0E-03	2.0E-03	5.0E-02	4.50E-03	7.5E-03
Cs	1.0E-02	1.6E-02	1.1E+00	5.0E-02	2.5E-01	3.00E-02	8.0E-02
Eu						4.00E-03	1.0E-02
Fe	6.6E-04	2.0E-04	3.0E-01	3.1E-03	1.9E-02	1.00E-03	4.0E-03
Hf						8.50E-04	3.5E-03
La***	2.5E-03	2.0E-05	2.0E-02	1.0E-04	1.0E-01	4.00E-03	1.0E-02
Lu						4.00E-03	1.0E-02
Na	5.2E-02	3.0E-02	1.0E-01	1.0E+01	1.0E+03	5.50E-02	7.5E-02
Nd	2.4E-03	2.0E-02	2.0E-02			4.00E-03	1.0E-02
Ni	1.9E-02	8.5E-03	7.8E-01	1.0E-02	1.0E+00	6.00E-02	6.0E-02
Rb	1.3E-01	6.2E-01	9.0E-01	3.0E-03	3.0E+00	7.00E-02	1.5E-01
Sb		6.6E-05	2.7E-02	5.0E-02	1.0E-01	3.00E-02	2.0E-01
Sc						1.00E-03	6.0E-03
Sm						4.00E-03	1.0E-02
Sr	1.7E-02	1.0E-01	6.2E+00	1.0E-02	2.5E+01	2.50E-01	2.5E+00
Ta						2.50E-03	1.0E-02
Tb						4.00E-03	1.0E-02
Th		2.5E-05	7.8E-02			8.50E-05	8.5E-04
U		1.4E-03	2.7E+00			4.00E-03	8.5E-03
Yb						4.00E-03	1.0E-02
Zn	4.0E-01	3.3E-01	8.8E+00	5.0E-02	7.8E+00	9.00E-01	1.5E+00
Zr	1.7E-04	1.0E-03	1.0E-02	1.0E-03	1.0E+00	5.00E-04	2.0E-03

After a quick look at Table 2.4, it is apparent that transfer factors have changed over the years. There are singular numbers given in Regulatory Guide 1.109 (NRC, 1977) and wide ranges for those listed in IAEA Technical Document 1616 (IAEA, 2009) and Coughtrey and Thorne (Coughtrey et al., 1985). Furthermore, few of the elements have data listed across all three documents. It should be noted, that these values only apply to plants, but does not include trees.

Neutron activation analysis (NAA) is a process that can determine broad spectrum elemental composition. Neutron penetration potential allows for irradiated samples to be completely analyzed (Ayrault, 2005). Sensitivity of NAA is described as being near the parts per billion (ppb) level for reactor irradiators (Soete et al., 1972). Neutron activation analysis uses the interaction of neutrons with atomic nuclei to determine the identity of the decaying atom based on the energy of emitted gamma particles. For analysis, the general reaction that occurs is (n, ɣ), though the now unstable nuclei will also emit alpha or beta particles in addition in an attempt to reach stability.

The neutron source for this project is the Oregon State TRIGA Reactor (OSTR). The OSTR operates at a steady state of 1.1 megawatts. At normal power, the neutron flux used for sample irradiation is $3.0*10^{12}$ neutrons (E > 1 MeV) per square centimeter per second ($n/cm^2/s$). Samples are placed in a rotating rack that allows for uniform irradiation ("OSU TRIGA Reactor," n.d.).

Determination of the activity of each isotope is done using gamma spectroscopy. High purity germanium (HPGe) detectors were used due to their higher energy resolution when compared to other scintillators such as sodium iodide (Knoll, 2010). Connecting an HPGe detector to a multichannel analyzer allows for counting of multiple energies at once. Sorting of pulses emitted by an HPGe is done so that they "are sorted by height in step function of value into a large number of electronic channels (generally ranging from 100 to more than 1000 channels), each counting only those pulses in the narrow pulse-height step" (Kruger, 1971).

2.4 Calculation of Element Concentration

Using a number of equations (Martin, 2006), the original number of atoms of an element can be determined from the activities determined by an HPGe. The total number of counts divided by the live time gives the number of counts per second (cps) and is shown in equation 2.

$$\frac{Total\ Number\ of\ Counts}{Live\ Time} = cps \tag{2}$$

The number of counts per second is equal to the activity and can be plugged into the exponential decay equation 3 where lambda (λ) is the half-life of the specific element and t is the time of decay.

$$A = A_o e^{-\lambda t} \tag{3}$$

Additional factors must be taken into account to correct for the branching ratio (BR) and detection efficiency (DE) of the detector giving equation 4.

$$A = A_o * BR * DE * e^{-\lambda t} \tag{4}$$

Rearrangement of equation 4 gives equation 5. Use of this equation gives the activity at the time of removal from the reactor.

$$A_0 = \frac{A\ (cps)}{(BR * DE * e^{-\lambda t})} \tag{5}$$

The calculated activities in unknowns are derived from standards from the National Institute of Standards and Technology (NIST) included in each batch irradiated within the reactor. A direct comparison on a weight-ratio basis gives the elemental mass of the determined isotope.

$$\frac{M_{Sample}}{M_{Standard}} = \frac{A_{Sample}}{A_{Standard}} \tag{6}$$

From the known isotopic mass, the known percent abundance of each atom allows for determination of the total amount of each element present. This practice works when all other parameters, such as irradiation time, counting time, and detector geometry, are held constant

(Khan et al., 2008; Stancin et al., 2008). Any variation from the known concentrations of NIST standards is corrected for and applied to the unknown samples. The total concentration is reported in µg/g, ppm, or ppb.

2.5 Detection Limits and Elements Below Minimum Detectable Concentration

Natural background radiation occurs in parallel to induced activity during counting, leading to interference. In activated samples, there must be a minimum detectable activity. The detection limit is determined to be when "a given analytical procedure may be relied upon to lead to detection"(Shtangeeva, 2008). These procedures include neutron activation analysis, chemical separation analysis, and others. In optimum circumstances the minimum amount detected will be those shown in Table 2.5.

The conditions used to determine these numbers are superior to those used in this project. Optimum numbers from Ayrault had these conditions: a neutron flux of 10^{14} n/cm^2/s, a decreasing time of 5 minutes, and optimal counting times. Considerations must be made on how to interpret data that is determined in non ideal conditions. This could involve activities that are lower than the minimum detectable concentrations listed above. Non-ideal conditions include the abundance of the target nuclide; the energy of the energy of any emitted gamma particles; the abundance of emitted gamma particles; and the sensitivity and efficiency of the detector.

When activities are not detected or determined, a nonzero value can, and should, be used to perform calculations. Automatically assuming an amount of zero for non determined activities causes a result bias that is lower than the probable amount. In these instances, a value of half the minimum detectable concentration (MDC) is used. This practice has been shown to be acceptable when up to 70% of the required activities for a specific element are determined to be below the minimum detectable activity (Higley, 2010). When more than 70% of data is

Table 2.5 Optimal INAA Detection Limits in µg. (Ayrault, 2005; Fujingawa and Kudo, 1979; Revel et al., 1984; Theunissen et al., 1987)

Element	Ayrualt (µg)	Theunissen (µg)	Revel and Revel (µg)	Fujingawa (µg)
As	1.0E-07	3.3E-02	1.0E-03	8.0E-03
Ba	1.0E-03	6.0E-02	1.5E+00	
Ce	1.0E-04	9.0E-04	1.0E-01	
Co	1.0E-05	5.0E-03	1.0E-01	1.0E-03
Cr	1.0E-05	2.0E-03	2.0E-02	1.0E-01
Cs	1.0E-04	5.0E-04		
Eu	1.0E-07	7.0E-05	2.0E-03	
Fe	1.0E-03	3.0E-01	4.0E+00	1.6E+00
Hf	1.0E-05	3.0E-04	5.0E-03	
La	1.0E-07	1.5E-04	7.0E-04	
Lu	1.0E-05	4.0E-05		
Na	1.0E-07	5.0E-01	3.0E-01	1.0E-01
Nd	1.0E-04	1.0E-02		
Ni	1.0E-04	1.5E-01		3.0E+00
Rb	1.0E-04	1.0E-02		
Sb	1.0E-06	1.8E-01	2.0E-02	6.0E-03
Sc	1.0E-07	3.0E-04	2.0E-03	
Sm	1.0E-07	3.0E-05	4.0E-04	
Sr	1.0E-05	1.5E-01		
Ta	1.0E-05	5.0E-04	1.0E-02	
Tb		1.0E-04	6.0E-03	
Th	1.0E-06	2.0E-04	1.5E-03	
U	1.0E-06	1.0E-03	2.0E-02	
Yb	1.0E-05	2.0E-04	1.0E-03	
Zn	1.0E-04	1.5E-02	2.0E-01	3.0E-01
Zr	1.0E-03	1.2E-01	2.0E+00	

censored in this fashion, no current analytical techniques provide good estimates of summary statistics (Antweiler and Taylor, 2008). When this technique is applied to more than 70% of values, positive and negative outliers can vary from known values by more than 120%.

2.6 Sources of Error

When dealing with small sample masses, any error in the actual sample will create error in the statistics reported at the end of the project. There are many opportunities to increase the amount of error included in reported values during the entire process.

During sample collection the use of metal collection implements should be avoided. Instead, ceramic scissors or trowels should be used (Ayrault, 2005). During this project, metal trowels were used during sample collection. The trowel was used for collection of soil samples, along with digging out of root balls of select plants. The use of this trowel could increase the amount of certain metals in the samples that were collected while using it. Additionally, during sample cleaning, stainless steel scissors were used to trim larger sample and decrease their size in general. Due to the larger size of most samples, introduction of trace amounts of metal should not affect the overall concentration by an observable amount.

Proper soil sample collection techniques are variable when comparing studies. Generalizations by Ure (Ure, 1995) state that soil samples from arable soils should be taken at 15 to 20 centimeters of soil depth while grassland soils should be collected at 7.5 to 10 centimeters of soil depth. The soil samples were not collected at a standardized depth in this study, and were collected at or near the surface of the soil. The higher organic content of topsoil may bias the samples.

During activation, the neutron flux can vary from sample to sample (Kruger, 1971; Soete et al., 1972). To correct for this, samples are placed on a rotating rack also called a Lazy Susan ("OSU TRIGA Reactor," n.d.). Also, every batch of 25 samples had 5 standards interspersed throughout the batch to asses the impact of neutron flux variance. This prevents error due to samples being compared to standards receiving different neutron fluxes.

There is potential for contamination in laboratory settings. It has been documented that up to 10^{12} atoms of Fe, Cu, Zn, Pb, Ca, Mg, Al, or Si are present per cm^3 of air in laboratory settings (Soete et al., 1972). There is potential for surface contaminants to be left on the activation vials during handling. Use of gloves prevents transference of salt (NaCl) and lead (Pb) found on the skin (Woittiez and Sloof, 1994). Preventative measures such as wiping down the outsides of sample vials with kimwipes and using canned air to blow off surface contaminants can minimize the effect of air contents. The addition of blank sample vials would give an idea of airborne contaminants (Tolg and Tschopel, 1994), though as the vials were stored bagged in a box in a cabinet, the chance of outside contamination is low. Also periodically changing gloves will prevent cross contamination from the samples. This is especially important when preparing standards.

One step included in this project may impact the sensitivity of the results the most. Sample ashing removes most hydrogen, carbon, and oxygen in organic samples. While these elements are invisible during NAA (Kruger, 1971), others elements are lost due to volatilization. Shown in Table 2.6 below, many elements and compounds may be lost during ashing. The

Table 2.6 Elements lost during Ashing (Tolg and Tschopel, 1994)

Element	Gaseous, Te, Sn, Pb, Tl, P, As, Sb, S, Se, Br, I, Zn, Cd, Hg
Oxides of	As, S, Se, Te, Re, Ru, Os, Zn, Cd, Hg
Fluorides of	B, Si, Ge, Sn, P, As, Sb, Bi, S, Se, Te, Ti, Zr, Hf, V, Nd, Ta, Mo, W, Re, Ru, Os, Ir, Hg
Chlorides of	Al, Ga, In, Tl, Ge, Sn, Pb, P, As, Sb, Bi, S, Se, Te, Ti, Zr, Hf, Ce, V, Nb, Ta, Mo, W, Mn, Fe, Ru, Os, Au, Zn, Cd, Hg
Hydrides of	Si, Ge, Sn, Pb, As, Sb, Bi, S, Se, Te

ashing process does not eliminate these elements entirely. An analysis of NIST standards, showed ashing caused variation from the known elemental concentrations certified by NIST. A comparison of the mean observed values of NIST standard 1571 (orchard leaves) showed that arsenic, hafnium, lutetium, and ytterbium had variation greater than 25% of consensus values. In one instance, strontium was shown to vary more than 25% in unashed samples. (Napier et al., n.d.) Another precision metric used is the coefficient of variation. It is the standard deviation from the standard expressed as a percentage of the mean. For unashed samples it showed that most elements had coefficients of variation that were less than 10%, which is more precise than what is listed by NIST . It also showed that hafnium and strontium had coefficients greater than 25%. Variation such as this could impact the calculated concentrations as variation from "known" concentrations will impact calculated unknowns.

2.7 Error propagation

For every sample, concentrations of 28 elements were determined using equations one through seven. Each concentration had error associated with the calculated value. Error cannot be ignored during analysis and is propagated through using certain equations. When taking the arithmetic mean using equation 7,

$$\bar{x} = \frac{1}{n} * \sum_{i=1}^{n} x_i \tag{7}$$

the error associated with each measurement is not carried through. Combination of associated error (σ_{x_i}) is done using a different equation (8) that focuses on error alone.

$$\frac{1}{\sigma_x^2} = \sum_{i=1}^{n} \frac{1}{\sigma_{x_i}^2} \tag{8}$$

Equation 8 is rearranged to Equation 9 for simplicity.

$$\sigma_x = \sqrt{\frac{1}{\frac{1}{\sum_{i=1}^{n} \frac{1}{\sigma_{x_i}^2}}}} \tag{9}$$

Creation of concentration ratios requires a comparison between two numbers with associated error. The average error calculated using equation 9 is brought through using equation 10.

$$\left(\frac{\sigma_R}{R}\right)^2 = \left(\frac{\sigma_{N_1}}{N_1}\right)^2 + \left(\frac{\sigma_{N_2}}{N_2}\right)^2 \qquad (10)$$

In equation 10, R is the calculated average concentration ratio (N_1/N_2), N_1 is the concentration of an element in a plant or animal, and N_2 is the concentration in the soil. Rearrangement of equation 10 for σ_R gives a final equation, equation 11.

$$\sigma_R = R * \sqrt{\left(\frac{\sigma_{N_1}}{N_1}\right)^2 + \left(\frac{\sigma_{N_2}}{N_2}\right)^2} \qquad (11)$$

3. 0 Methods and Materials

3.1 Collection of Samples

The sites were visited in the order of Richland, Horns Rapids Road, and then Vernita. Samples of opportunity were collected at each site. Five replicates of each sample were collected when it was possible. The samples included soil, sediment, water, plant, and invertebrates. A group of fish was obtained from the Northern Pike Minnow Reward Program at the Vernita Bridge Rest Area. This program is put on by the Washington State Department of Fish and Wildlife as a solution to invasive species harming native species of the Columbia River.

The samples were collected by hand. They were then labeled, photographed, and bagged. The plants were stored in plastic Ziploc bags, with larger samples being stored in large plastic trash bags. At each site, crickets and grasshoppers were caught using butterfly nets. At the Richland site, crayfish and spiders were caught by hand. Beetles were collected by hand along Horn Rapids Road. Each group of similar plants was given a number correlated with the photograph taken of each. All of the insects were stored in Glad food storage containers. After collection, all samples were stored on ice until being transferred to a freezer at Oregon State University where they were kept at 20 degrees Fahrenheit.

3.2 Water collection

Water samples were collected in 500 mL polypropylene bottles. The bottles were cleaned using 1 molar nitric acid prior to the trip. For cleaning, the bottles were first rinsed with deionized water (DIW), and then refilled three quarters full with DIW. Next, at least 15.625 mL of 16 molar nitric acid was added. The bottle was then filled the rest of the way with DIW. The bottles were then capped and shaken for 30 seconds. The bottles were emptied into the sink, and then rinsed twice more with DIW. The bottles were then capped and stored until their use at the sample sites. This procedure was taken from the Oregon State University department of Chemical, Biological, and Environmental Engineering (CBEE, n.d.).

Water samples were collected by submerging the capped bottles and then opened with the top facing into the current. The filled bottles were acidified to prevent sorption of trace elements to the inside of the bottles. The samples were acidified using the same acid that was used for cleaning. The samples were acidified to .5 molar by adding 15.625 mL of 16 molar nitric.

3.3 Vegetation Sample Preparation

In the laboratory, the plant samples were washed by hand using DIW to remove any debris on the roots and other parts of the plants. All plant samples were transferred into labeled brown paper bags for drying. To provide better statistics, the samples were separated into five subdivisions, with each subdivision being a replicate of the species. The first four replicates were always whole plants. If there were only five plants, the fifth replicate remained whole. In the case of there being more than five plants, all the remaining plants were labeled as a fifth sample with two parts, an above ground portion, and a below ground portion. In certain instances, larger plants were separated into root/stem/branch portions. This was due to their larger size and the inability to fit them into small paper bags for drying.

Figure 3.1 Paper bag used for sample drying and storage

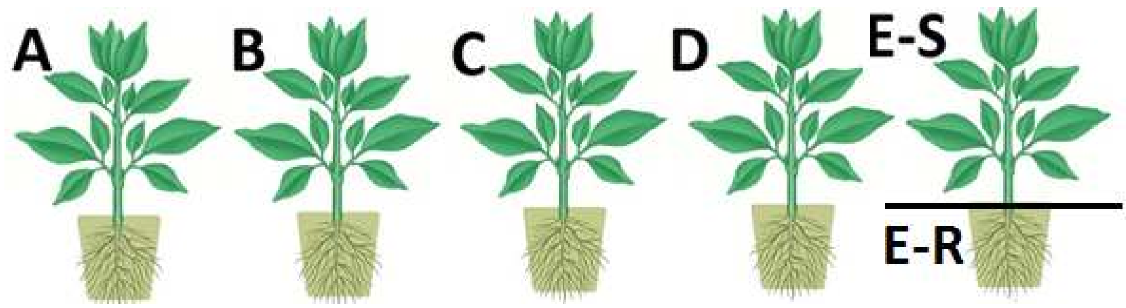

Figure 3.2 Representations of Sample Divisions

The samples were dried in an oven owned by the OSU Forestry Department. The samples were dried in a VWR Model 1390FM oven at 55 degrees Celsius for a minimum of 85 hours to a stable weight. After drying, the samples were massed using an Ohaus Explorer model E 14130 Scale and then homogenized using a Black and Decker BL2100S Blender. The blender was cleaned between each use using a combination of forced air, vacuum cleaner, and dry paper towel. Some samples were too large to be ground using this method and were ground using an industrial grinder also supplied by the OSU Department of Forestry. The grinder was a Wiley Mill grinder that ground the larger samples until they could pass through a 5 millimeter mesh. This grinder was cleaned between uses using a RIDGID shop vac after each use. Each sample was placed back in the bag it was dried in to keep identification simple.

3.4 Soil Preparation

The soil samples were dried using a Fisher Isotemp 200 series drying oven. The Ziploc bags were opened and placed in the oven. The oven was set for 65 degrees Celsius. The samples were heated for a minimum of 24 hours until the all the water in the samples had been removed.

Portions of the dried soil were sent to the Soil Physical Characterization Lab in the OSU Central Analytical Lab in the Department of Crop and Soil Sciences. There, the soil type was determined using a Quick Hydrometer method. Also, the organic matter content was determined using an ashing method. The organic matter determination process was not the same as the sample ashing process that is described in the next section.

3.5 Sample Ashing

To increase detection efficiency, samples over 2 grams were ashed. Portions or entire samples were placed in labeled 100 mL ceramic crucibles with lids. Prior to each use, the crucibles were cleaned using concentrated sodium hydroxide and DIW. The crucibles were rinsed clean with DIW and hung to dry. The lidless crucibles were weighed twice prior to ashing, once empty and once with an arbitrary amount of a sample. Both masses were taken using an Ohaus Explorer model E 14130 Scale and recorded. Lidded samples were placed in a cool muffle furnace. Two furnaces were used for ashing, one a Cole-Parmer StableTemp® furnace, and the other a Thermolyne model CPS-4032P. Each furnace was set for 550 degrees Celsius and the samples were left in the ovens for 23 hours. After 23 hours, the ovens were turned off and the front doors were opened to allow the crucibles to cool enough for handling. Once the crucibles were removed from the ovens, the lids were taken off and the crucibles were massed with the same scale. The ashed samples were transferred into labeled 20 mL liquid scintillation vials for storage. The three crucible masses were used to determine an ashing ratio using the before ashing and after ashing sample masses.

3.6 Water preconcentration

The glassware used for preconcentration was cleaned using the procedure obtained from the OSU Chemical, Biological, and Environmental Engineering website (CBEE, n.d.). The acidified water samples were massed using an Ohaus Explorer model E 14130 Scale. The massed sample was then transferred into 600 mL beaker for concentration. Using two hotplates, one an IKAMAG RCT Basic (*IKAMAG ® RCT Basic Instruction Manual*, 2000) magnetic stir hotplate in combination with an IKATRON ETS-D4 Fuzzy (*IKATRON ® ETS-D4 Fuzzy Instruction*

Manual, 2000) thermometer, and the other a VWR DYLATHERM model 33918-432 hotplate, the water was boiled off. To start, the water samples were boiled on the IKAMAG RCT Basic hotplate, with the target temperature set at 105 degrees Celsius. When the sample had been reduced to near 50 mL, it was transferred into a 150 mL beaker. The smaller beaker was placed on the DLYATHERM hotplate, which was set for maximum heating, and boiled until it was near 700 µL. When the volume reduction was complete, the sample was transferred into a polypropylene 1/20 fluid ounce vial. If the volume reduction had removed too much of the sample, 16 molar OPTIMA pure Nitric Acid was added and reduced until the volume was sufficient. This acid was used based on its known impurities that were listed at the ppt level.

3.7 Animal Sample Preparation

Animal samples were dehydrated using a NESCO American Harvest Food Dehydrator. To obtain a dry weight, the dehydrator was set at the maximum temperature of 71 degrees Celsius. The insects were placed in hexagonal weighing cups. The samples were left for 24 hours, and the mass was recorded once an hour until a consistent weight had been determined. The fish samples were dried individually. Each fish was sliced into smaller pieces so it could fit into the dehydrator. Two levels of the dehydrator were used at a time, the lower with a catch pad. When the pieces reached a consistent mass, all of the pieces with any dripping on the catch pad were weighed and recorded.

Figure 3.3 Dehydration of Northern Pikeminnow

Unlike the plant samples that were homogenized using a blender, the animal samples were crushed by hand. A mortar and pestle was used for this procedure, along with liquid nitrogen. An individual sample was placed in the mortar along with enough liquid nitrogen to cover the sample. The fish were crushed piece by piece. Once the sample was substantially cold, the pestle was used to break the sample into as small of pieces as possible. At this point the insect samples were combined into a single sample of each species from each location. Ten spiders and five cricket or grasshoppers from the Richland site, seven crickets and six beetles from the inland site, and six crickets from Vernita were combined in this manner. The decision for combination was due to the low sample weight of each individual insect. After crushing, the samples were stored in glass liquid scintillation vials. Portions of the fish samples also underwent ashing in the same fashion as the plant samples.

Figure 3.4 Homogenization of Animal Samples Using Liquid Nitrogen

3.8 Encapsulation for Neutron Activation Analysis

To prepare the samples for Neutron Activation Analysis, portions or the entirety of samples were placed in polypropylene 1/20 fluid ounce vials (EP338NAA) made specifically for neutron activation analysis by Emerald Plastics. With gloved hands, the vials were massed and tared. To transfer the samples into the vials, a 5” by 5” piece of weighing paper was folded in half and the desired amount of sample to be transferred was placed into the fold. The tared vial was placed in a mortar, so any sample that missed the vial could be placed back onto the weighing paper. The goal for each vial was 750 mg of each sample. In some cases, this required packing with a cleaned glass stirring rod. Once the desired amount had been transferred, the vial was capped. Any sample on the outside of the vial was wiped off using a combination of forced air and Kimwipes. Cleaned vials were massed and the weight was recorded using a Mettler Toledo AG 285 scale that records to the nearest tenth of a milligram.

Figure 3.5 Sample and weighing paper for transfer (Left) Prevention of sample during transference (Center) Liquid Scintillation Vial and filled sample vial (Right)

Sealing of the polypropylene vials was done using a hand held electric soldering iron. First, excess plastic was trimmed off the vial using wire cutters. Next, the top of the vial was melted using a soldering iron so that the top, when pinched, did not open. Then the sealed vials were placed in larger 1/4 fluid ounce (EP290NAA) polypropylene vials, and the melting/sealing process was repeated with the larger vials.

Figure 3.6 Sealing of sample vial (Left) Sample vial inside secondary containment vial (Center) Sealing of containment vial (Right)

3.9 Neutron Activation Analysis

Standards from the National Institute of Standards and Technology (NIST) are well characterized in their elemental concentrations. NIST standards are certified with 95% confidence intervals to µg/g concentrations. These concentrations are used for calculation of unknown concentrations in samples

Reference standards were included in each batch of samples activated within the reactor. For every 25 samples, there were 5 standards included. Standards were consistently placed in the same order for counting, at positions 1, 8, 15, 22, and 30. Standards 1, 15, and 30 were 200±5 mg of NIST 1633A (coal fly ash) mixed with cellulose binder for suspension of the standard throughout the vial. The cellulose binder (3642 SPEX SamplePrep) was chosen because "of the general inertness of organic matter (C, H, O) to neutron activation" (Kruger, 1971). For all the samples except the soil samples, the standard in position 8 was NIST 1570A (Trace elements in Spinach Leaves) and the standard in position 22 was NIST 1547 (Peach Leaves). The amount of standard used was between 700 and 750 mg. The soil samples were analyzed in 200 mg samples. NIST-1633A was used similarly, but the two other standards were one of 200±5 mg of NIST-688(Basalt Rock) and one of NIST-1633B (Coal Fly Ash).

The samples were irradiated in the OSTR for 21 hours per batch. After removal from the reactor, the samples cooled for one week to allow short lived activation isotopes, that were not looked for in this study, to decay away. After the cool down period, the irradiated samples were counted using a well type HPGe detector for 5000 seconds of live time. Following counting, the samples were allowed to cool for another three weeks, after which a second counting was done using the same detector for 15000 seconds of live time. Counting twice, allows for low activities of longer lived isotopes to be determined after shorter lived isotopes have decayed away. Otherwise they could be lost as noise when samples are highly active from recent irradiation.

4.0 Results and Discussion

4.1 Sample Identification

This section presents the results determined using the methods previously described. The plants of this study are listed and identified in Table 4.2. The plants were identified by Janelle Downs and Jonathan Napier. Janelle Downs is a plant ecologist at Pacific Northwest National Laboratory. The plants were visually identified using her expertise and by comparing sample photos against photos on the USDA Natural Resources Conservation Service website (Agriculture, 2012), the online Burke Museum plant identification tool ("Burke Museum of Natural History and Culture," 2012), and *Vascular Plants of the Hanford Site* (Sackschewsky and Downs, 2001).

One plant sample remains unidentified. Plant 104 is labeled Unidentified Aquatic Plant. It was collected in the water along the Vernita Shoreline. It had a lattice like structure with rhizomes that changed from green to white if it was above or below the sand along the river bottom. In addition to the unidentified plant, a few plants were only identified to genus classification levels. Sample IDs 2, 3, 4, 5, 6, and 29 are a rush of the Juncus genus. Sample IDs 11, 12, and 30 are grasses of the Bromus genus. Sample 22 is a Lupine of the Lupinus genus.

The samples listed in Table 7 with identification numbers 1 through 59 and 113 were collect at the Richland, WA sample site. Samples numbered 60 through 75 were collected along Horn Rapids Road. Samples numbered 79 through 106 were collected at the Vernita, WA sample site. The initial numbering system was streamlined after the first sampling location so that similar species were given the same ID number and labeled A through E instead of giving individual plants a new ID number. This is why the first few samples listed have more than one ID number.

Table 4.1 Plants of this study with catalog numbers, common and scientific name

ID(s)	Name-Common	Name-Scientific
1,13,14,15	Showy Milkweed	Asclepias speciosa Torr.
2,3,4,5,6,29	Rush	Juncus (sp.)
7,23,33	White mulbery	Morus alba L.
8,9,10	Curly dock	Rumex Crispus
11,12,30	Grass	Bromus (sp.)
16,17,18,19,20	Scouring rush	Equisetum hyemale
21	coyote willow	Salix exigua
22	Lupine	Lupinus (sp.)
24,26,27,31	Purple loosestrife	Lythrum salicaria
25	Field bindweed	Convolvulus arvensis
28	Bladderwort	Utricularia (sp.)
32	Mullein	Verbascum thapsus
37	Reed canarygrass	Phalaris arundinacea
38	Virginia creeper	Parthenocissus quinquefolia
39,49,50	Wood's rose	Rosa woodsii
42	Green algae	
48	Russian knapweed	Centaurea repens
51	siberian elm	Ulmus pumila
52	Eurasian milfoil	Myriophyllum spicatum
53	Curled Pondweed	Potamogeton crispus L.
54	Mimosa	Albizia julibrissin
113	Acorns (oak)	Quercus (sp.)
60	Sand dropseed	Sporobolus cryptandrus
61	Russian thistle	Salsola tragus
67	Rush skeletonweed	Chondrilla juncea
68	prickly lettuce	Lactuca serriola
70	Bluebunch wheatgrass	Agropyron spicatum
71	Mare's tail	Conyza canadensis
72	Sagebrush	Artemisia tridentata
73	snow buckwheat	Eriogonum niveum
74	Russian thistle (Kali)	Salsola kali
75	cheat grass	Bromus tectorum
79	Rush	Juncus (sp.)
80	Columbia River gumweed	Grindelia columbiana
81	Velvet Lupine	lupinus leucophyllus
87	Curly dock	Rumex crispus
88	Thickspike wheatgrass	Agropyron dasystachyum
89	St. Johnswort	Hypericum perforatum
90	Reed Canarygrass	Phalaris arundinacea
91	siberian elm	Ulmus pumila
92	Columbia tickseed	Coreopsis tinctoria
104	Unidentified Aquatic Plant	
105	Eurasin milfoil	Myriophyllum spicatum
106	Green algae	

The animals of this study are listed and identified in Table 4.2. The sample number along with the collection location is listed. Samples 76, 77, 93, and 108 through 111 were initially collected as individual samples. After drying, the mass of each sample was far below the ideal sample mass so an aggregate sample was created. The aggregated samples (except 77) contained more than one species and are identified only by family names. For sample 77, it was only possible to identify the species to the genus.

Table 4.2 Animals of this study

Sample ID(s)	Name-Common	Name-Scientific
76 (Horn Rapids)	Cricket/Grasshopper	Gryllidae and Acrididae
93 (Vernita)	Cricket/Grasshopper	Gryllidae and Acrididae
108 (Richland)	Cricket/Grasshopper	Gryllidae and Acrididae
77 (Horn Rapids)	Black Beetle	Carabid (sp.)
109-111 (Richland)	Wolf and Hairy spiders	Araneidae and Lycosidae
107 (Vernita)	Northern Pikeminnow	Ptychocheilus oregonensis
112 (Richland)	Crayfish	Pacifastacus leniusculus (sp.)
114 (Richland)	Asian Clams	Corbicula fluminea

4.2 Counting Statistics

The counting statistics vary with each element and each sample. The number of samples determined to be below the MDC is listed in Table 4.3. As stated previously, data that is up to 70% below the MDC can still be considered valid when using a value that is half of the MDC. The table shows the total number of values below MDC in six sections: three plant groupings based on location, along with three consolidated groups of soil, water, and animals.

Table 4.3 Number of samples below Minimum Detectable Concentration by element.

Element	Plants			Soils	Animals	Water	Total
	Richland	HRR	Vernita				
Sb	11	3	9	0	5	7	35
Ce	2	2	0	0	8	3	15
Cs	4	3	0	0	2	9	18
Cr	1	2	0	0	10	0	13
Co	0	0	0	0	0	0	0
Eu	2	2	0	0	6	9	19
Hf	2	2	2	0	8	10	24
Fe	0	0	0	0	0	0	0
Nd	48	28	19	0	13	10	118
Ni	77	28	27	17	13	7	169
Rb	1	0	0	0	1	8	10
Sc	0	0	0	0	0	1	1
Sr	1	0	11	0	4	0	16
Ta	21	11	14	0	11	0	57
Tb	31	16	13	0	12	10	82
Th	1	3	0	0	10	10	24
Zn	0	0	0	0	0	0	0
Zr	47	29	24	0	13	10	123
As	10	23	1	2	10	0	46
Ba	1	0	0	0	8	0	9
La	0	0	0	0	6	2	8
Lu	12	11	7	0	12	10	52
Sm	0	0	0	0	7	10	17
Na	0	0	0	0	0	0	0
U	5	21	0	0	12	0	38
Yb	8	10	6	0	12	10	46
Total	83	37	48	25	14	10	217

Table 4.3 shows that most elements were of high enough concentration that the statistics used were viable using half the MDC. Overall the only element that would not be able to be used in this is nickel. Of 217 samples, 169 of them were below MDC, or 77.9%. A division of the samples into groups with similar features shows that the water concentrations were very low and difficult to detect. Eleven of the twenty six elements were below MDC in eight or more of the ten water (80%) samples with two more being below MDC in seven of ten of the water

samples (70%). The results were similar in the animal samples, eleven of the twenty six elements were found to be below the MDC more than 70% of the time. The soil and sediment group was the only group to have none of the elemental concentrations below the MDC more than 70% of the time. This is slightly misleading as nickel was very close to the 70% threshold, being at a 68% occurrence rate in the soil and sediment group. Nickel though, was the only element that was unable to be detected often. Arsenic was the only other element to be below MDC in any soil or sediment sample, occurring only twice in twenty five samples.

The plant samples were separated based on their collection locations. Seven elements were always above the MDC in plants (cobalt, iron, scandium, zinc, lanthanum, samarium, and sodium), while the other elements had samples determined to be below MDC. Nickel, neodymium, and zirconium had occurrence rates over 70%. This occurrence happened twice for nickel, and once for both neodymium and zirconium. This happened for all three elements listed above at the shrub steppe location, with the second occurrence rate of over 70% for nickel appearing at the Richland riparian site. Determining the concentrations of the animals proved problematic as well. Eleven of the twenty six elements were below MDC more than 70% of the time.

4.3 Soil Composition and Concentration

The calculated soil compositions are shown in Figure 4.1. They are shown on a soil triangle that has been slanted into a right triangle. The horizontal axis is percent sand, the vertical axis is percent clay, and the hypotenuse of the triangle is percent silt. The graph shows the average composition of the two sediments and three soils sampled. The Richland sediment, the Horn Rapids soil, and the Vernita soil were classified as sand. The Richland soil was classified as loamy sand, while the Vernita sediment was classified as a sandy loam. The classification was done using the quick hydrometer method by the OSU Soil Physical Characterization Lab in the Department of Crop and Soil Sciences.

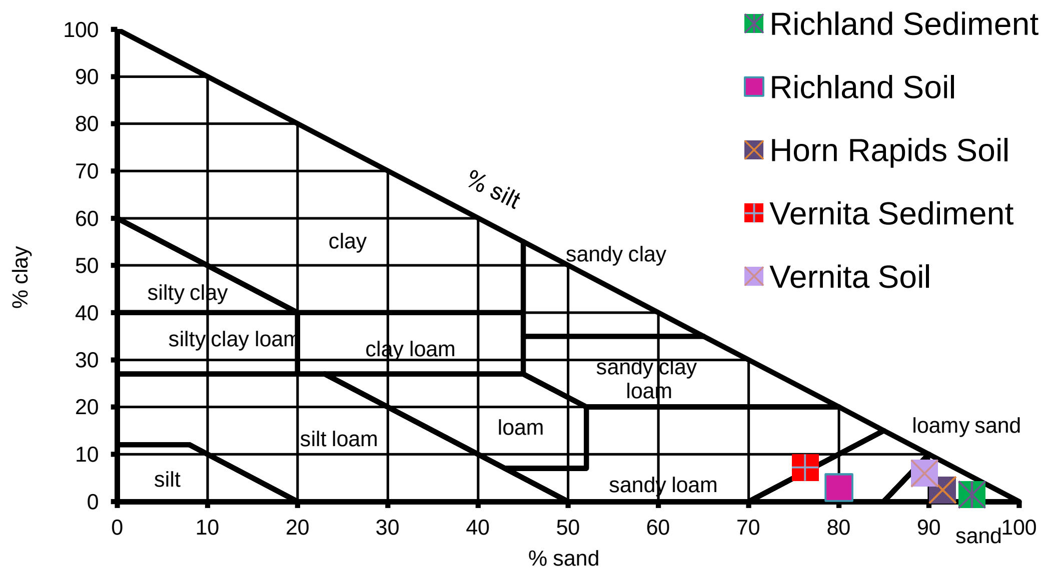

Figure 4.1. Soil compositions of Sediment and Soil at each location.

The amount of sand in each location was high, never dropping below 75% at any location. The variability in the amount of sand however, was noticeable when comparing the soil and sediments at the riparian locations. At Richland, the sediment (94.8%) had a higher amount of sand than the soil (80.0%), but at Vernita the sand percentage in the soil (89.5%) was higher than in the sediment (76.3%). In each instance, the amount of clay remained relatively constant from sediment (1.5%) to soil (3.0%) in Richland, and also at Vernita (7.3% sediment to 6.0% soil).

The variation between sediment and soil may be influenced by the soil sampling technique used and the sample locations. Richland soil samples were taken closer to the historic high water mark while the Vernita soil samples were taken closer to the shoreline. Also, the sediment samples were taken at a period of high flow for the Columbia River. The higher flow rate could change the sediment compositions due to small particles being suspended easier in higher flow. Additionally, the samples taken at Vernita were on a western bank and the

Richland samples were taken on an eastern bank. The microclimates associated with each could vary enough to cause a change in the soil composition.

The elemental concentrations determined in the sediments and soils were compared against average concentrations found in the conterminous United States as determined by the USGS (Shacklette and Boerngen, 1994). Data was available for 19 of the 26 elements in this study, but cesium, europium, hafnium, lutetium, samarium, tantalum, and terbium were not. When the average soil concentration at each location was compared against the average calculated within the US, most elemental concentrations were within 25% (higher or lower) of the average USGS value. Of 95 values, there were 23 that were more than 25% higher or lower and of those, 3 were greater than 50% higher or lower than determined USGS values. Of the elements not reported by Shacklette and Boerngen, cesium, europium, and samarium were compared against values reported by Argonne National Laboratory. The concentrations of these three elements did not show large variance against the ANL concentrations. The 4 remaining elements: hafnium, lutetium, tantalum, and terbium, were compared against a range of determined values throughout the United State (Kabata-Pendias, 2001). Those four elements were within the expected ranges as were the other 20 elements for which data was available (Iron and Sodium were not listed in Kabata-Pendias.)

Those with the highest percentage difference in concentration were arsenic in the Horn Rapids soil being 59.3% lower than average, and zinc in the Vernita soil (58.5%) and sediment (50.8%) higher. The low arsenic levels were only found at the previously mentioned Horn Rapids site. The other four sample averages were not nearly as low, as the next was 24.9% lower than the United States average. In both the soil and sediment at Vernita, chromium, iron, and strontium were higher than the average USGS value for each element. Interestingly, strontium was higher than the national average at each site with more than a 25% difference. Of the 95 samples compared against USGS averages, 73 were higher than the average in the United States. The variance throughout shows how useful site specific data is when used in replacement of universal averages. A complete list of the soil and sediment concentrations can be found in Appendix B.

For use in calculation of the concentration ratios, the average of the sediments and soils were calculated. They were kept location specific so the calculated concentration ratios could be compared as a group against other locations.

4.4 Comparison of Concentration Ratios Between Sample Locations

Figures 4.2 through 4.6 show the ranges of calculated concentration ratios for each element. To form these graphs, the concentration ratios for each plant sample were calculated for each element. Four quartiles are represented on each graph. Also, numbers from Table 5 are included in each graph for comparison. The plants of each location were compared against the soil or sediment from the sample location. Complete tables of concentration ratio by element in each plant species is listed in Appendix A. The numbers used to create Figures 4.3 and 4.5 are not listed in this project, but can be recreated by multiplying the CRs of Appendix A by the soil values Appendix B and dividing the resultant plant concentration by the sediment values listed in Appendix B.

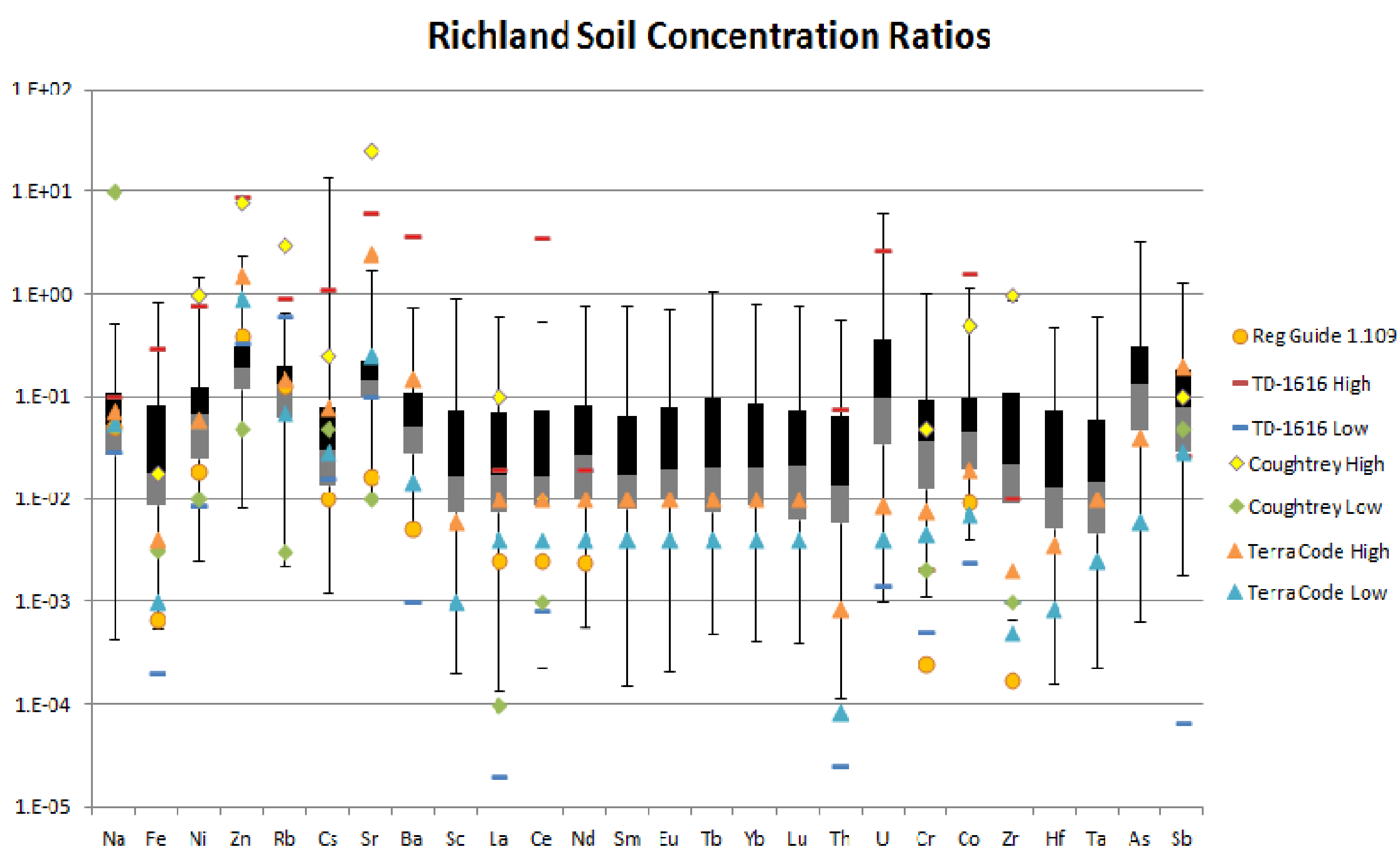

Figure 4.2 Range of Concentration Ratios (Plant vs. Soil) at Richland

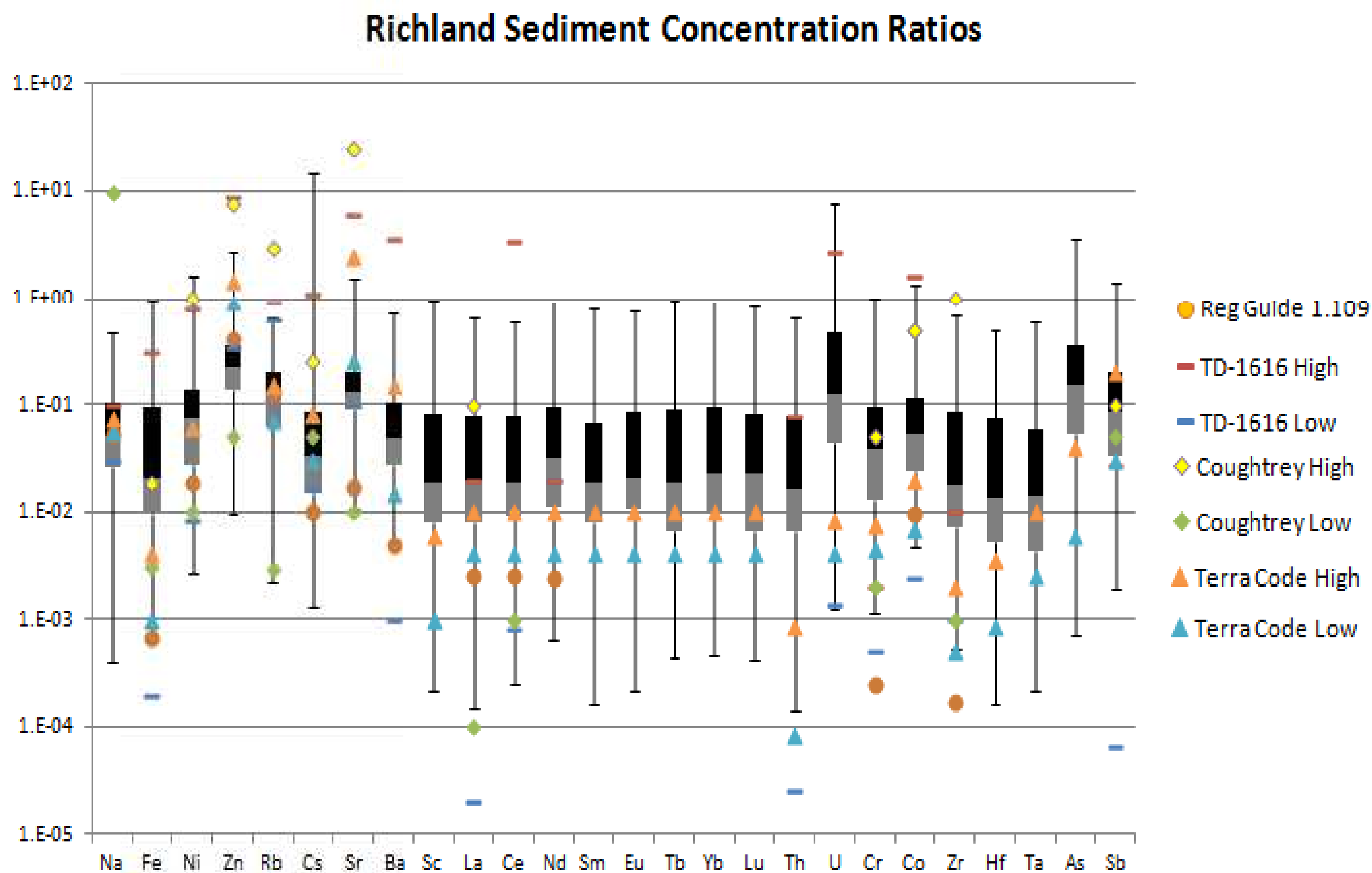

Figure 4.3 Range of Concentration Ratios (Plant vs. Sediment) at Richland

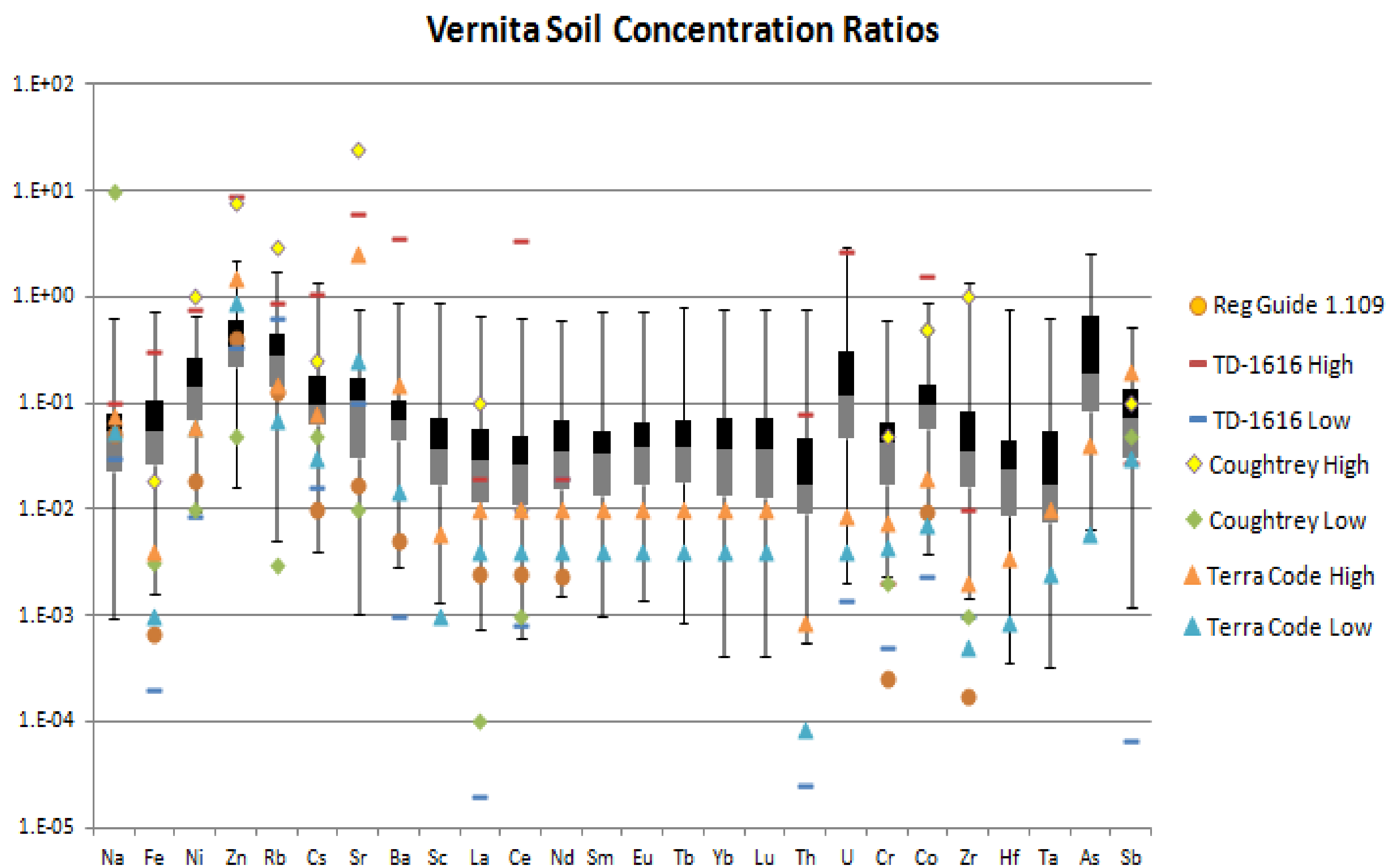

Figure 4.4 Range of Concentration Ratios (Plant vs. Soil) at Vernita

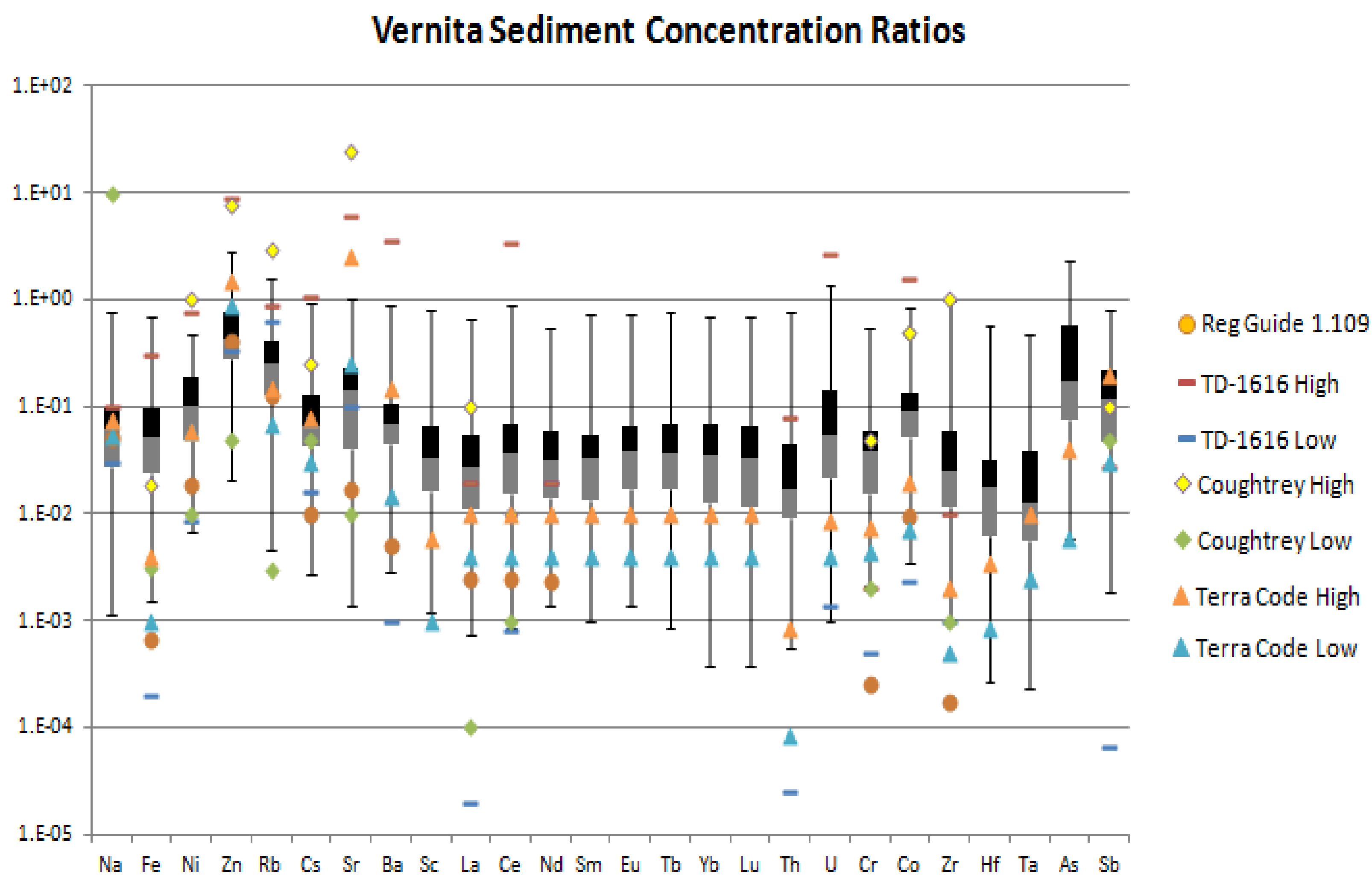

Figure 4.5 Range of Concentration Ratios (Plant vs. Sediment) at Vernita

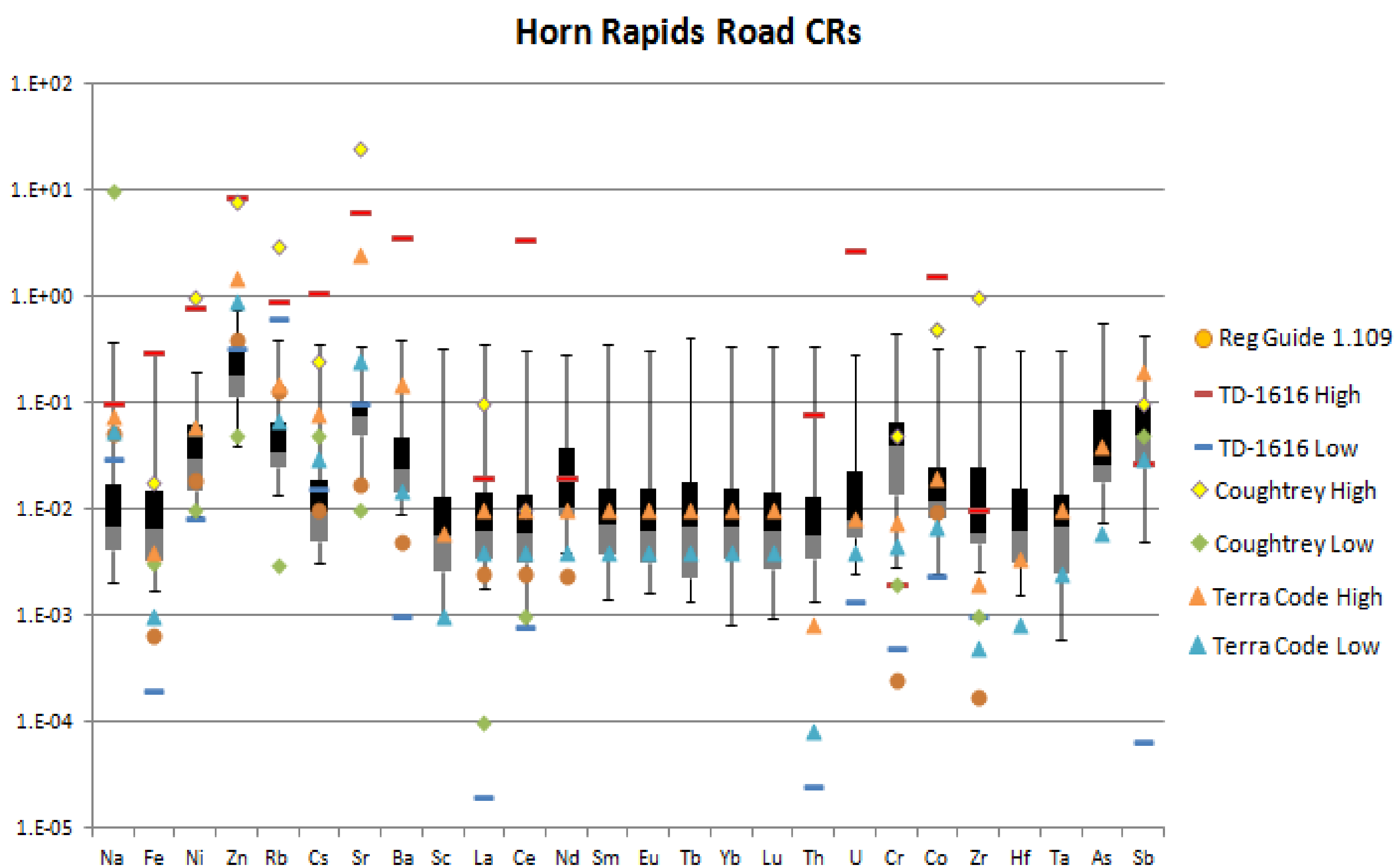

Figure 4.6 Range of Concentration Ratios (Plant vs. S) at Horn Rapids

At first glance it is apparent how inaccurate the values listed in Regulatory Guide 1.109 would be for the two riparian sites. The inaccuracies could be due to Regulatory Guide 1.109 not being specific enough for the sampled locations or the concentration ratios could not be conservative enough for adequate public protection. At Richland, the listed values for sodium and rubidium were equal to the calculated medians, while for zinc the value was slightly high. For every other value, the number was lower than the 25th percentile of calculated values. In certain instances the listed value was lower than any value calculated in this study. The values determined for Vernita were similar in their differences from Regulatory Guide 1.109 values.

The use of ranges, as was done in Technical Document 1616 and Coughtrey and Thorne, is a better practice than listing singular numbers. However, certain CRs did not fall within these ranges. When the Richland CRs were compared with the most current data in TD-1616, zinc, rubidium, lanthanum, neodymium, chromium, and antimony had 50% of calculated CRs outside of the TD-1616 Ranges. This occurred for values of rubidium, lanthanum, chromium, zirconium, and antimony calculated for Vernita. Calculated Horn Rapids Road CRs fell outside the ranges of sodium, zinc, rubidium, cesium, neodymium, chromium, and antimony for more than 50% of the samples. In fact, none of the rubidium CRs calculated from Horn Rapids Road data was within the ranges listed in TD-1616. It should be noted that neodymium has only a single CR value listed in TD-1616.

Older data from Coughtrey and Thorne was more in line with what was determined in this study. A first point of difference is the CRs for sodium are listed as ranging between 10 and 1000. It is noted that for sodium "no best estimate can be assigned due to wide variation recorded within and between plant species" (Coughtrey et al.). At Richland, iron, cesium, and cerium, had more than 50% of calculated values outside the ranges listed by Coughtrey and

Thorne. At Vernita, only iron and cerium were outside the ranges more than 50% of the time. The only element to be outside of the Coughtrey and Thorne ranges at Horn Rapids was cesium.

The Terra Code had two values listed, one for NonVegetative portions of plants, and one for Vegetative portions. In the graphs, these are listed as Terra Code Low (NonVegetative) and Terra Code High (Vegetative). When considered as ranges, these values are much more acceptable, but even then they do not correlate well with the calculated data. The values worked well for sodium, rubidium, cesium, barium, and antimony at Richland and Vernita. The other values were all too low for the riparian sites. At Horn Rapids Road, the values listed for the actinides and antimony were accurate.

Comparing the sediment and soil graphs, Figure 4.2 against Figure 4.3 and Figure 4.4 against Figure 4.5, shows that there is basically no difference when using soil or sediment for concentration ratios. The ranges shown do not change much from graph to graph. Considering the only thing that changed is the denominator of the concentration ratio, this makes sense. From the small differences in elemental concentration between soil and sediment, it is probable that CRs for aquatic shoreline plants can be created using soil concentrations. Shorelines should be considered homogenous enough for this premise to be correct. Other factors must be considered, such as proximity of collection points. If no major differences between the foundations of the shore and river are found, then the practice of using shore samples to calculate aquatic CRs can be considered acceptable.

The soil concentrations of chromium, iron, neodymium, thorium, antimony, zinc, and zirconium are higher at Vernita than at Richland. The change in concentration did not lead to a change in the range of CR values. The soil ranges narrowed at Vernita, but the median generally stayed the same. This pattern was observed for chromium, iron, neodymium, antimony, and zirconium. Zinc and thorium had similar medians, but as the lowest values increased, the logarithmic scale of the graphs makes the increase appear larger than it truly is as the differences are of the order of 10^{-4}.

The ranges of concentration ratios are much narrower from the data of the Horn Rapids samples as shown in Figure 4.7. The CR ranges were skewed closer to 10^{-2} rather than 10^{-1} that was observed at Richland and Vernita. The availability of water for desert plants is much lower than those in riparian areas. The proximity of the water table in riparian areas allows for replenishment of the vadose zone of the soil by capillary action. In drier areas, the water table can drop significantly during periods of low rainfall (Rockhold, Waichler, Saunders, Clayton, and Strickland, 2009). Unfortunately, the amount of water in each soil sample was not determined before the samples were dried. This could have been done simply by massing the samples before and after placing in the oven.

The two similar sample sites, Richland and Vernita, had variation in the soil elemental concentrations. There were a few species that were collected at each site. The species collected at both Richland and Vernita were Juncus (sp.), Myriophyllum spicatum, Rumex Crispus, Ulmus pumila, green algae, and Phalaris arundinacea.

Concentration ratios were calculated for each species at each location to allow for comparison between sample sites. Division of the Richland CRs by the Vernita CRs was done to compare similar species. An arbitrary comparison factor of 4 was used to determine if values were in agreement. This is too allow for some variation between sites. Of the 26, elements only 2 were not in agreement for Juncus (sp.). Terbium and thallium had calculated CRs higher at Richland. Rumex Crispus had only 13 of 26 elements in agreement. All 13 were determined to be higher at Richland. Concentration ratios of each element were determined to be in agreement for Green algae. Three of 26 were determined to be in agreement for Ulmus pumila. Barium and sodium CRs were found to be higher at Richland while the CR for nickel was higher at Vernita. Phalaris arundinacea concentration ratios corresponded in 22 of 26 elements. Arsenic, cesium, rubidium, and zinc had concentration ratios calculated as much lower at Vernita than Richland. Concentrations could not be compared for Myriophyllum spicatum, as the Richland sample was compromised during activation in the reactor and could not be analyzed without spreading contamination.

Differences in the soil concentration should not be the cause of the changes in the calculated CRs but there were differences as noted before. One not mentioned, is the difference in antimony. This may have caused the differences in the Rumex Crispus CRs. This is also considered for arsenic, cerium, chromium, lanthanum, strontium, and zirconium, but is more likely due to other factors rather than only soil concentration. Other factors that could affect the plant growth are the direction of the slope of the growing location and the land use near the sample sites. Richland has an east facing slope and is a residential neighborhood, while Vernita was a west facing slope and is used as a boat launch.

Certain elements were compared against others in this study based on their chemical properties. These comparisons were done using the median concentration ratio at each location. The alkali metals, sodium, rubidium, and cesium, showed no patterns based on concentration. The alkali earth metals, strontium and barium, were consistent in that the strontium median was always higher than the barium median. The transition metals showed no apparent trends. The lanthanides and actinides were consistent at each location. At Richland, the median CRs were near 2.0E-02 for each element. At Vernita, the CRs were near 3.0E-02, except for uranium, which was noticeably higher at 1.2E-01. At Horn Rapids, the median CRs were much lower, but all near 6.5E-03. The metalloids, arsenic and antimony, showed higher median CRs at Richland and Vernita, but this was reversed at Horn Rapids. This could be due to the lower soil concentration of arsenic determined at Horn Rapids.

4.5 Comparison of Roots and Shoots Concentration Ratios

Certain samples were either large enough to be separated into above (shoots) and below (roots) ground samples, or had enough individuals included to create a fifth sample that was split into above and below portions. The species collected in Richland were Morus alba L., Phalaris arundinaceae, Utricularia (sp.), Juncus (sp.), Rosa Woodsii, and Centaurea repens. The species collected at Vernita were Juncus (sp.), Rumex crispus, Agropyron dasystachyum, Hypericum perforatum, Phalaris arundinacea, and Ulmus pumila. The species collected along Horn Rapids Road were Sporobolus cryptandrus, Lactuca serriola, Agropyron spicatum, Artemisia tridentate, and Bromus tectorum. There were a total of 10 samples from Richland, 6 from Vernita, and 5 from Horn Rapids Road. The samples were of 17 different plant species.

The data shown in Figures 4.7 through 4.12 are consistent with the data shown in Figures 4.2, 4.4, and 4.6. The consistency is shown by being within the ranges shown in the previous figures without large outliers.

The roots and shoots were compared by species against each other to determine which was higher. The results for each element were tabulated and are shown in Table 4.4.

Table 4.4 The number of occurrences of shoots CR being higher than root CR

Element	**Antimony**	**Arsenic**	**Barium**	**Cerium**	**Cesium**	**Chromium**
Occurrence	3	7	8	5	10	8
Element	**Cobalt**	**Europium**	**Hafnium**	**Iron**	**Lanthanum**	**Lutetium**
Occurrence	4	6	6	4	6	4
Element	**Neodymium**	**Nickel**	**Rubidium**	**Samarium**	**Scandium**	
Occurrence	6	12	11	6	7	
Element	**Sodium**	**Strontium**	**Thallium**	**Terbium**	**Thorium**	
Occurrence	7	11	8	6	6	
Element	**Uranium**	**Ytterbium**	**Zinc**	**Zirconium**	**Total Species**	
Occurrence	4	3	8	4	17	

When there was more than one plant taken at the same location, an average was taken for analysis. The data shows that cesium, nickel, rubidium, and strontium are concentrated more in the shoot portions of plants than the root portions. Barium, chromium, thallium, and zinc are concentrated equally in the roots and shoots of the plants sampled.

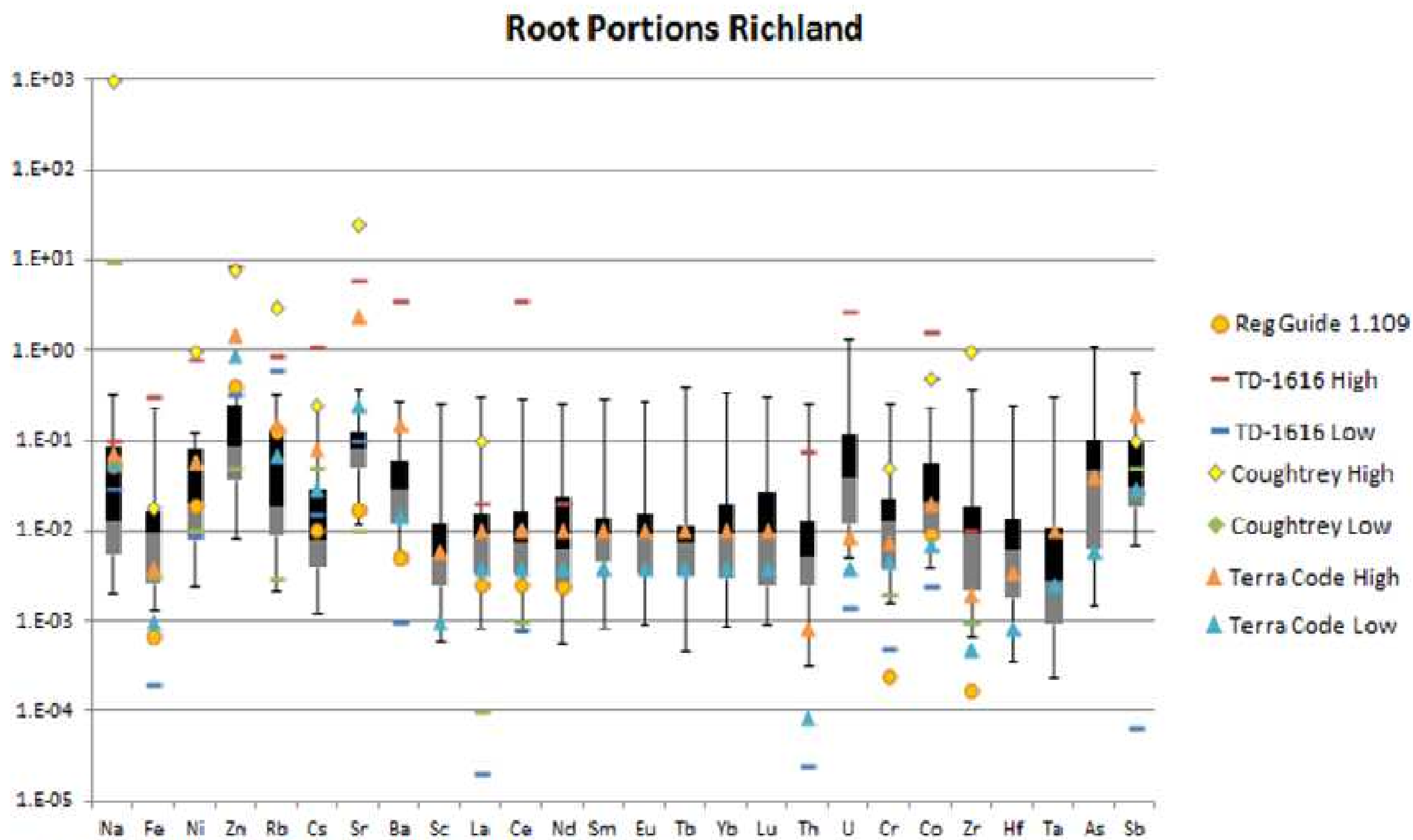

Figure 4.7 Range of Root Concentration Ratios (Richland)

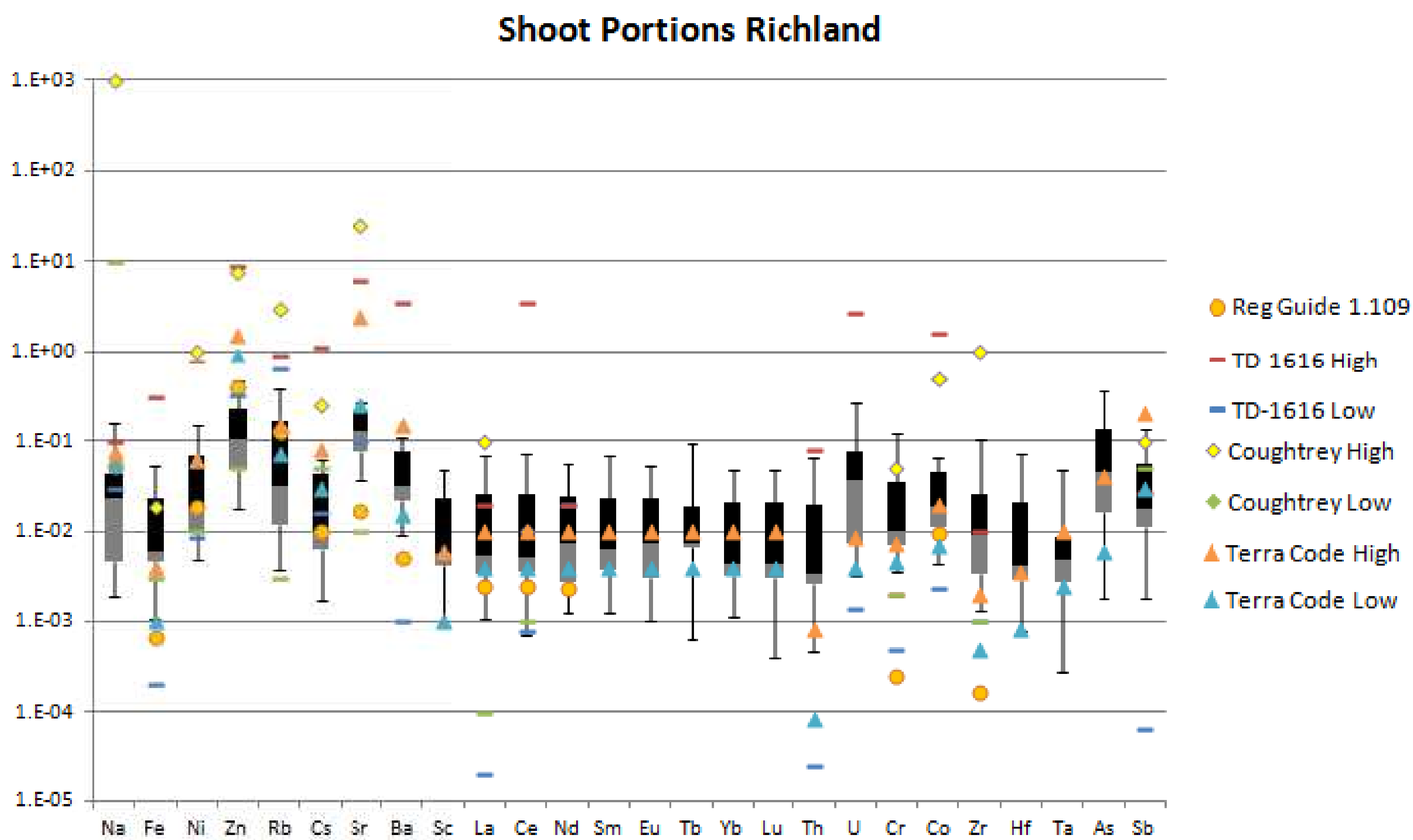

Figure 4.8 Range of Shoot Concentration Ratios (Richland)

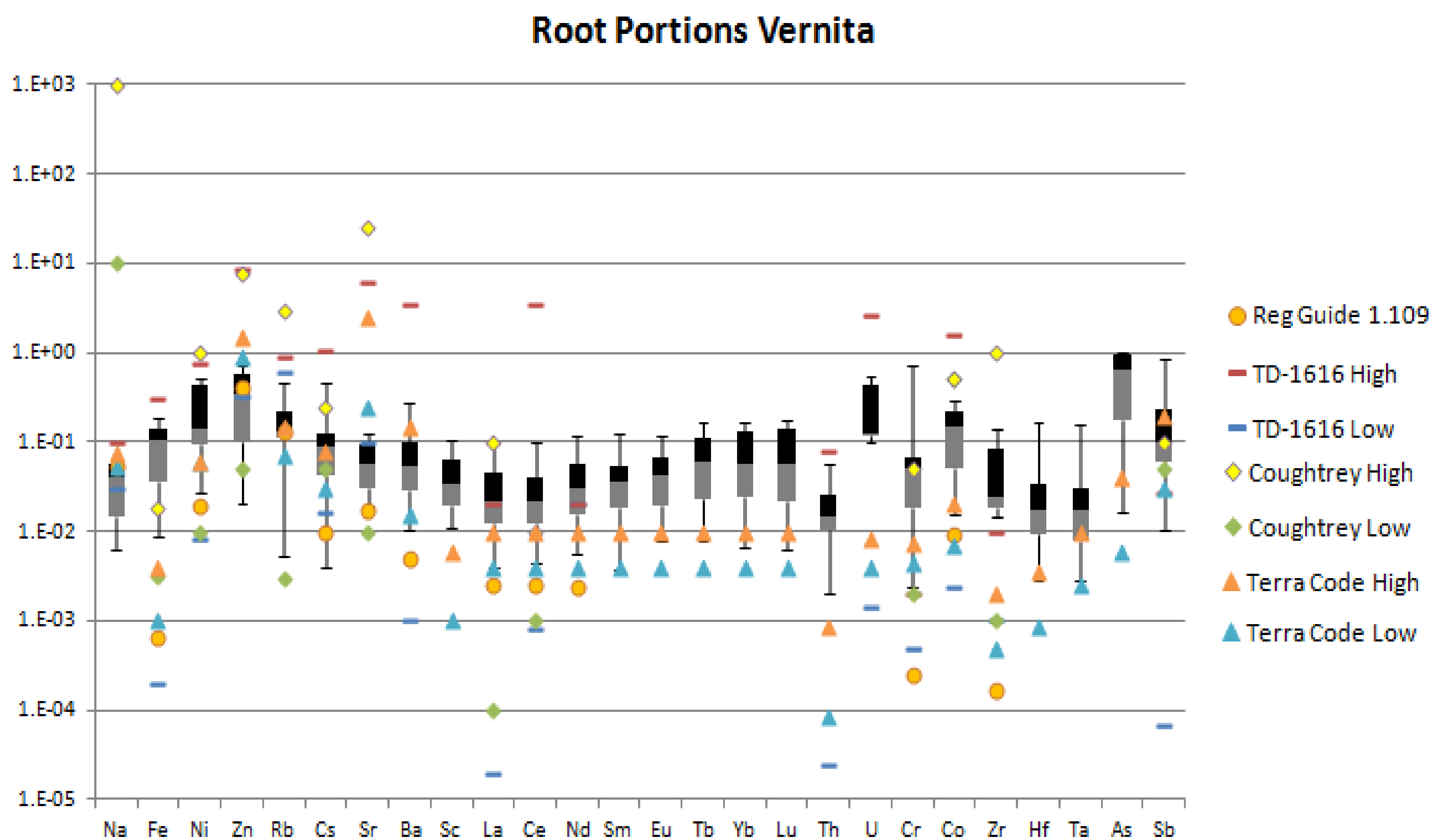

Figure 4.9 Range of Root Concentration Ratios (Vernita)

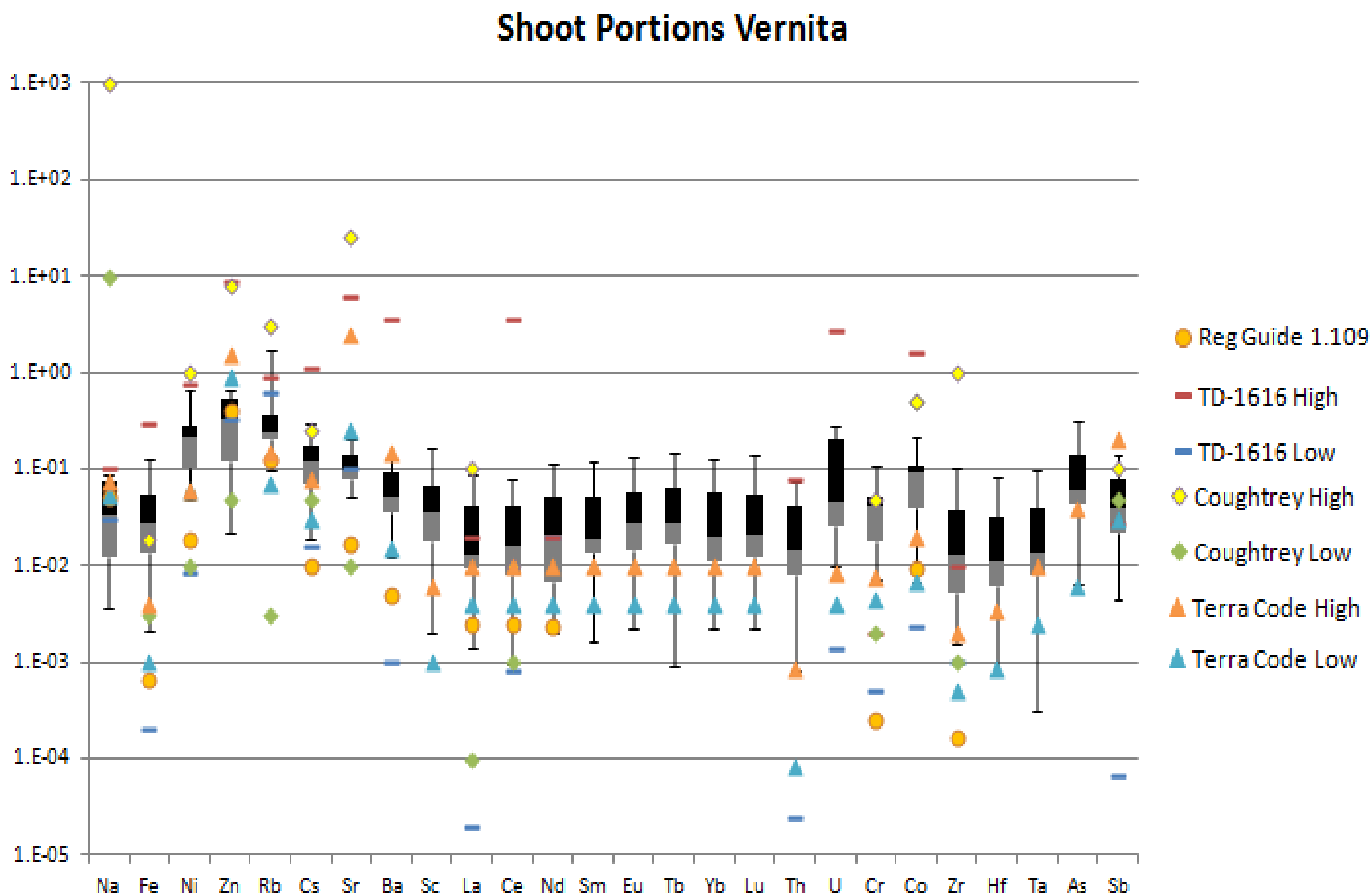

Figure 4.10 Range of Shoot Concentration Ratios (Vernita)

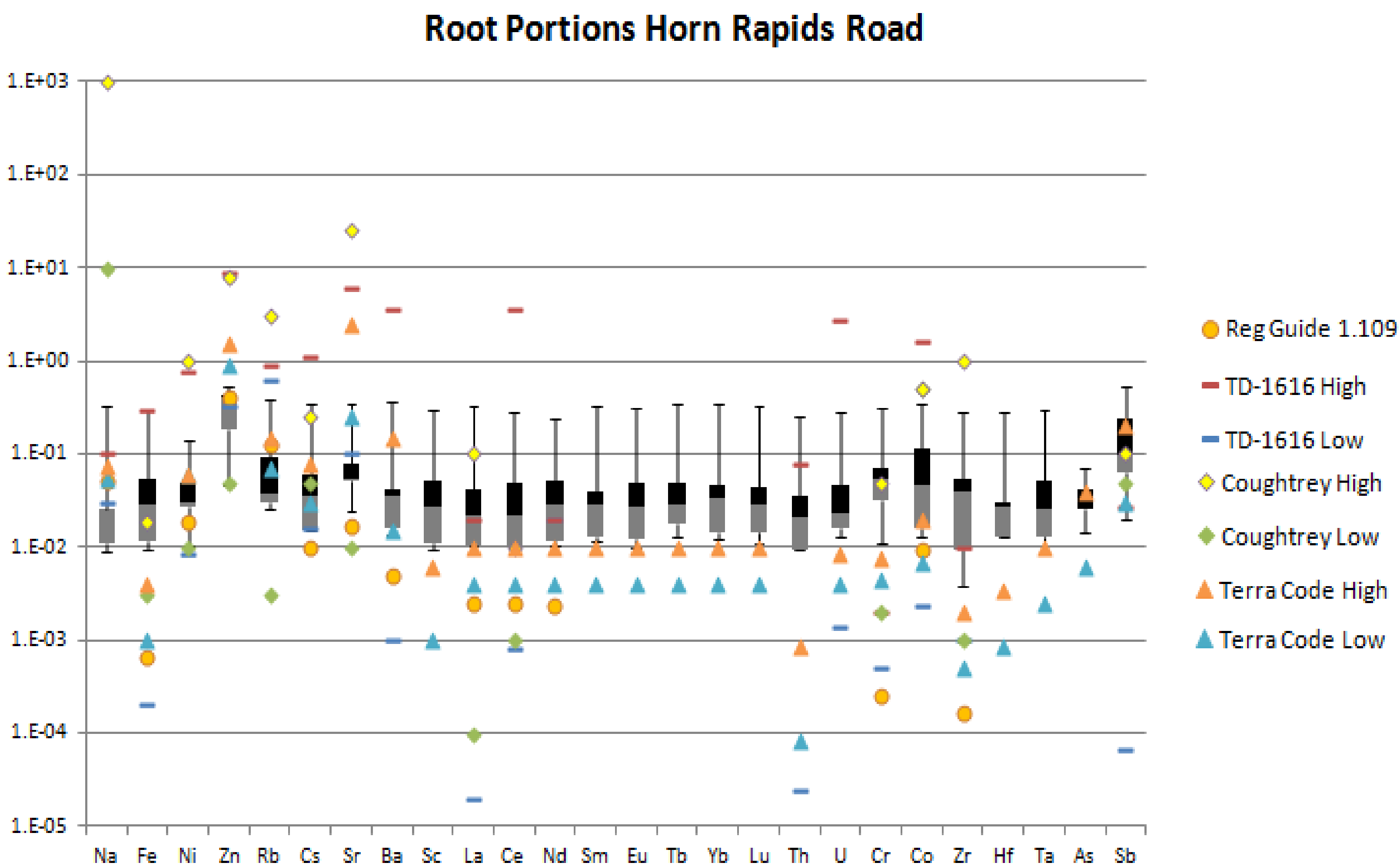

Figure 4.11 Range of Root Concentration Ratios (Horn Rapids)

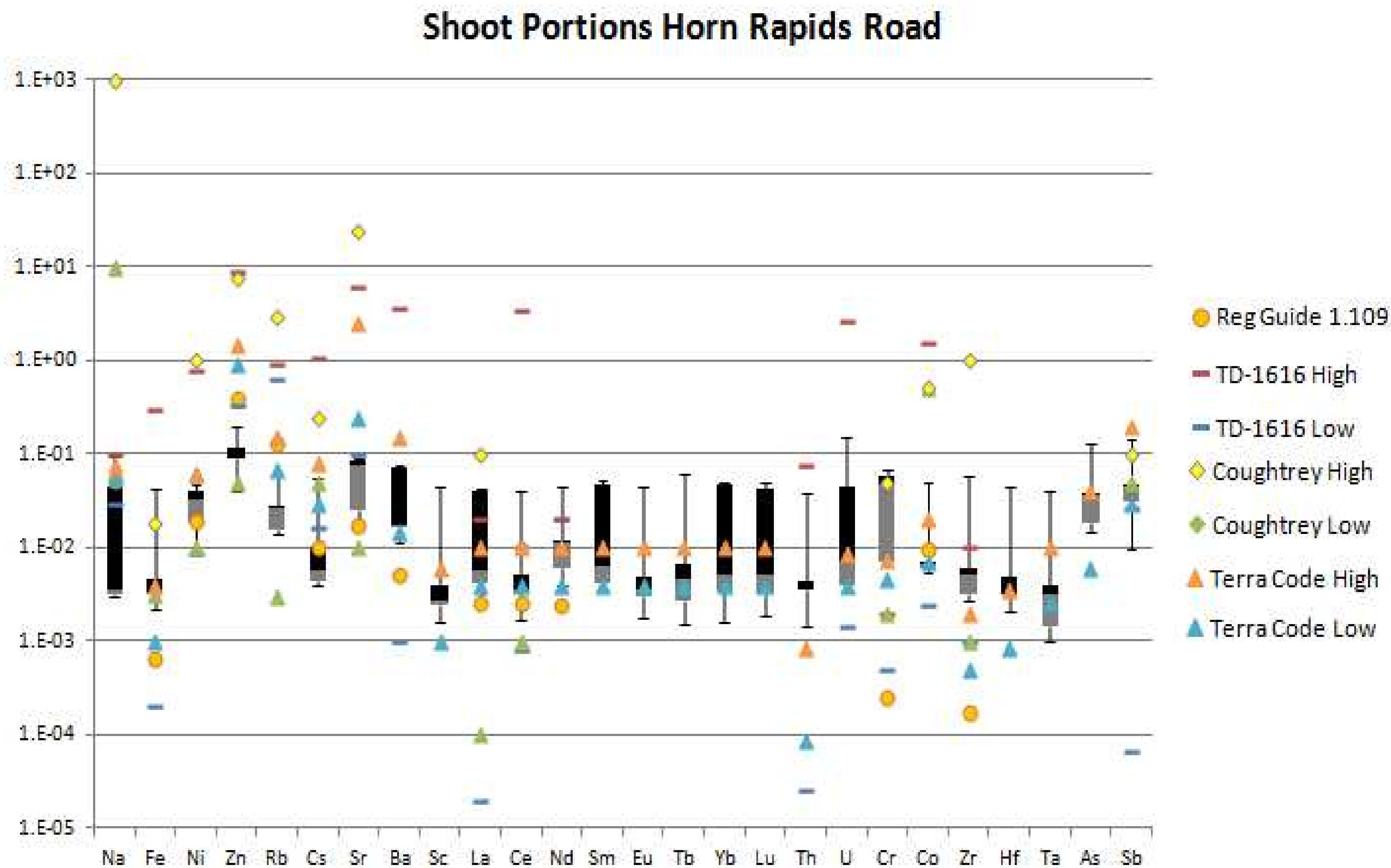

Figure 4.12 Range of Shoot Concentration Ratios (Horn Rapids)

4.6 Animal Concentration Ratios

The analyzed water samples were averaged and compared against available historical data. As the samples were acidified, the maximum amount of listed contaminants in the acid was subtracted from each sample before analysis. The two sites were averaged based on the assumption that because one site was upriver of the other, they should be considered contiguous. There are no major inflow sources between the two sample points other than ground water inflow and farm runoff, but these inputs are minor when compared to the initial flow. Historical data for only 11 of 26 elements was found. Arsenic, antimony, and cesium were determined to be an order of magnitude lower than the historical data. Chromium was determined to be higher than historical data. The rest of the elements were determined to be consistent with available historical data.

Of the eleven elements with available data, eight were calculated above the MDC more than 30% of the time and were not questionable. The other three, antimony, arsenic, and cesium were not. It was observed that these values were determined to be lower than historical data. If this tendency continues, the values of barium, cerium, lanthanum, strontium, and thallium should be considered correct. Conversely, the values of europium, hafnium, neodymium, nickel, samarium, lutetium, terbium, thorium, ytterbium, and zirconium should be considered as conservatively low. A complete list of water concentrations for Richland, Vernita, and an average of both is listed in Appendix E. At one point, calculation of Kd values were considered between water and sediment, but the values showed a lack of equilibrium between the sediment and soil and were off of comparable numbers by three orders of magnitude or more.

To create concentration ratios for the animals of this study, the insects and arachnids were compared against their local soils. The aquatic animals were compared against the water concentrations. They are shown in Figures 4.13 and 4.14. Concentration ratios by element can be found in Appendix D for the insects and arachnids and Appendix E for aquatic species. The number of crickets and grasshoppers varied in each group, along with the ratio of crickets to grasshoppers. In every case, the number of individuals did not matter, as one aggregate sample was created. The low mass of an individual would have interfered with the counting statistics. The aggregate CRs were higher for the desert samples in almost every instance. For rubidium, cesium, strontium, uranium, and antimony, the Vernita aggregate CRs were higher. At Richland, neodymium and terbium had the highest calculated aggregate CRs. The CRs never varied by more than one order of magnitude. Interestingly, the CRs for zinc were near one for all species.

Concentration ratios for the spider and beetle samples are also shown on Figure 4.13. They are an aggregate sample for the same reasons as the cricket/grasshopper samples. The aggregate beetle sample showed the overall lowest CRs in rubidium and cesium. Of the five groups, the arachnids had the highest overall CR of sodium, rubidium, neodymium, and arsenic. Conversely, the arachnid group also had the lowest CRs of iron, scandium, lanthanum, samarium, cobalt, and hafnium. The arachnid CR for samarium was lowest by more than one order of magnitude. The aggregate cricket/grasshopper sample from Horn Rapids Road showed the highest CRs of the three locations. This is opposite of the trend observed in the plants and it could mean that a lack of water increases CRs in insects.

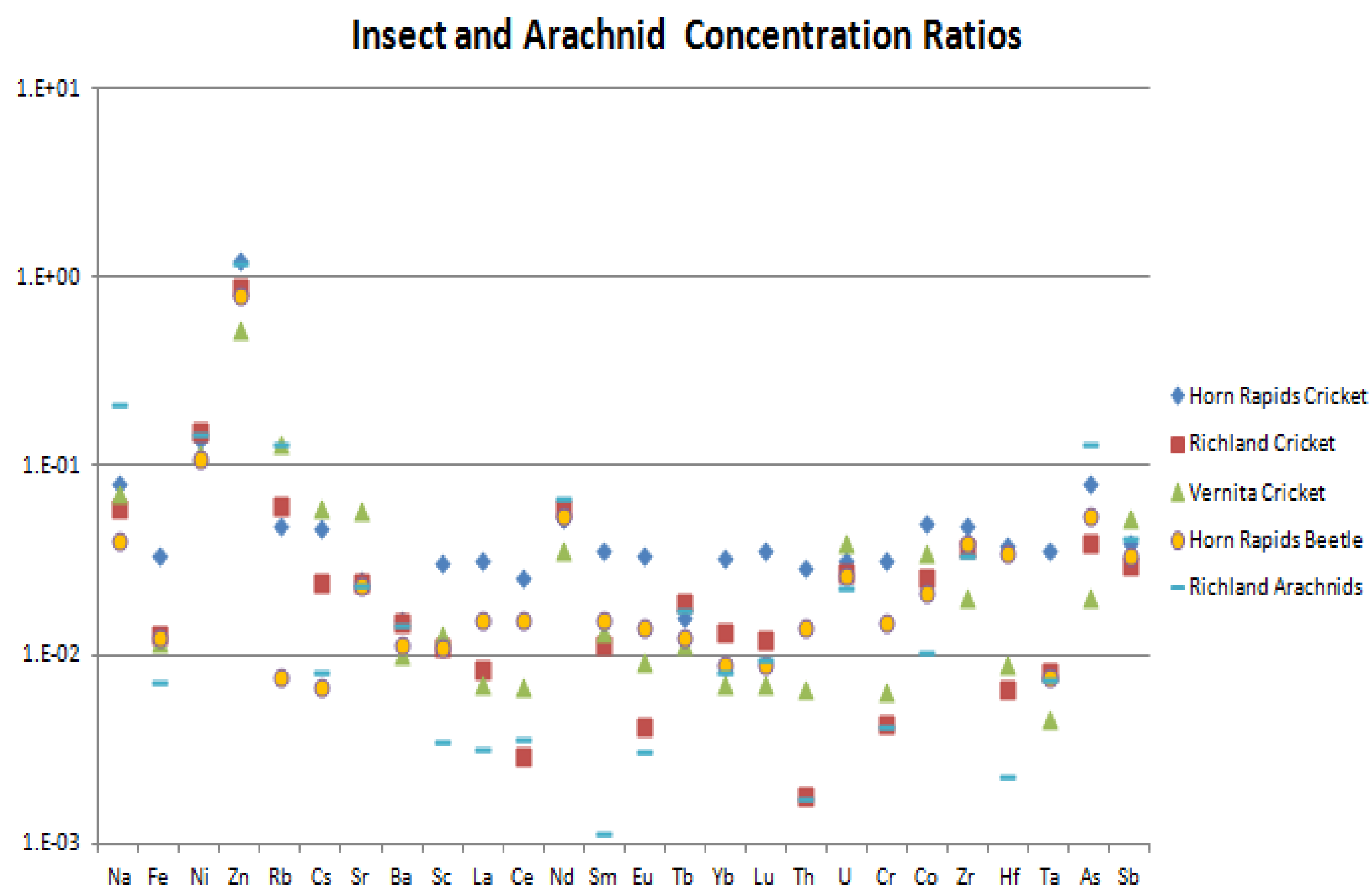

Figure 4.13 Concentration ratios for insects against the soil they were collected over.

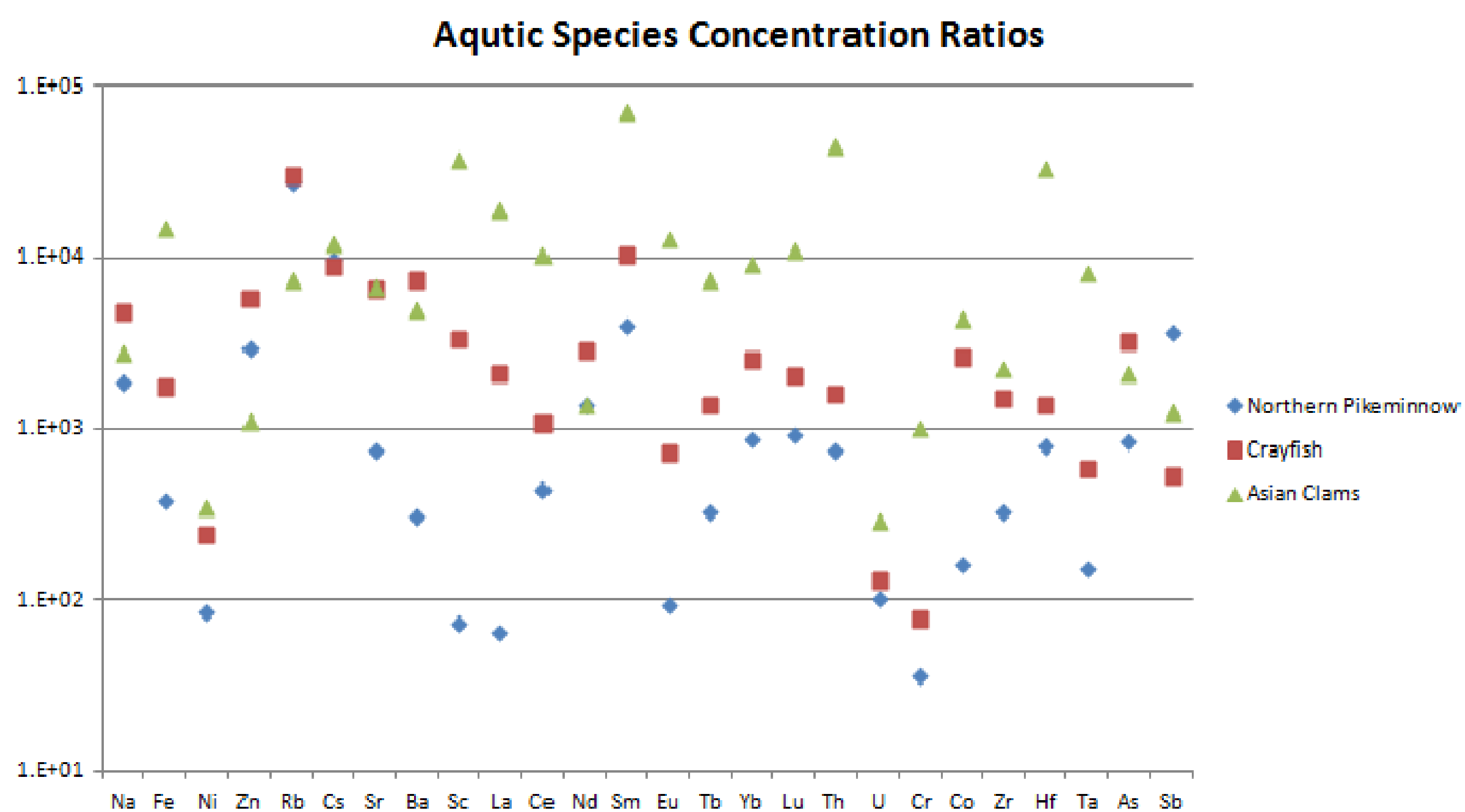

Figure 4.14 Concentration ratios of aquatic species against water concentration.

The low elemental concentrations of the water samples caused all of CRs to be greater than one in all of the aquatic species. The clam and fish samples were aggregated samples. The fish were not cleaned before processing and the clams were crushed whole. No parts were removed during the drying phases either. Asian clams showed the highest CRs overall. The Asian clam CRs for iron, scandium, lanthanum, cerium, samarium, thorium, chromium, hafnium, and thallium were all higher than crayfish CRs by an order of magnitude. The fish samples had the lowest concentration ratios for every element except for zinc, rubidium, cesium, and antimony. The CRs for all three species were widely spread for every element, except for cesium where the CRs were tightly bunched around 10^4. While offset, the patterns observed graphically are consistent between species. Because of the inclusion of the shells in the clam samples and the exoskeletons of the crayfish, it is assumed that they represent the elemental sinks which caused the CRs to be so much higher than those of the northern pikeminnow.

5. 0 Conclusions

The primary goal of this work was to establish concentration ratios for specific areas surrounding the Hanford site. Forty species of plants were analyzed over three locations, along with two types of insects, arachnids, two types of shellfish, and a species of fish. When compared to available concentration ratios, it is readily apparent why the NRC regulatory guide 1.109 was replaced with current IAEA standards listed in IAEA Technical Document 1616. This study shows that there are concentration ratios outside of accepted values, so site specific values should be used or created whenever possible.

A secondary goal was to create site specific elemental data for water, soil, and sediment. A search for site specific data turned up available data that was limited in scope to elements of interest at that time. A prime example is the elemental concentrations of sediment shown in Table 2.3. Concentrations for only four of the 26 elements in this study were determined previously. Gaps left in data for soil, water, and sediment for rarer elements are filled by this project.

Compared against each, the drier shrub steppe environment produced concentration ratios lower than those of the riparian areas. The fewest number of samples were collected at Horn Rapids Road, but that would not be a cause for lower concentration ratios. Instead, it is thought that lower water availability for the plants caused this. Water is not the limit for growth at these areas. Analogous elements may be absorbed by plants when a lack of specific elements required for growth occurs. This proves that concentration ratios for certain elements are dependent on soil composition.

Shorelines create a convergence area between terrestrial and aquatic ecosystems. This study suggests that terrestrial soil medium can be used in place of the aquatic soil medium, as one is eroded into the other. This practice is probably limited by the proximity of the desired aquatic sampling point to the sampled shoreline.

Compared between riparian and shrub steppe, concentration ratios for plants are higher in riparian areas. The sampled insects showed the opposite. The aggregate cricket and grasshopper sample showed higher concentration ratios for nonessential elements in drier areas.

The procedures followed by this project can be used for other locations of interest for the creation of site specific data. Results from data that are not site specific can cause calculations to show plant concentrations that are too high or too low. Best practices must include site specific data. Calculation of this data can be done using NAA to characterize element of interest quickly.

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Appendix A Concentration Ratios by Element (Plant/Soil)

All numbers are in ppm.

Table A-1 Average, Min, and Max Concentration Ratios by plant species for Antimony

Antimony						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	3.8E-02	2.0E-03	2.2E-02	1.4E-03	5.5E-02	4.5E-03
Rush	2.8E-01	1.5E-03	3.0E-02	2.0E-03	6.6E-01	5.1E-02
White Mulbery	3.5E-02	1.7E-03	1.8E-03	5.4E-04	1.8E-03	5.4E-04
Curly Dock	4.5E-01	2.3E-02	8.2E-02	5.6E-03	1.2E+00	7.4E-02
Grass	2.1E-01	7.9E-03	7.8E-02	1.0E-02	3.7E-01	2.7E-02
Scouring Rush	3.7E-01	2.3E-02	1.6E-01	2.3E-02	7.8E-01	5.9E-02
Coyote willow	1.4E-01	1.0E-02	1.4E-01	1.0E-02	1.4E-01	1.0E-02
Lupine	6.6E-02	4.7E-03	6.6E-02	6.6E-02	6.6E-02	4.7E-03
Purple Loosestrife	7.2E-02	3.6E-03	9.3E-03	6.1E-04	1.2E-01	1.0E-02
Field Bindweed	6.7E-02	1.1E-02	6.7E-02	1.1E-02	6.7E-02	1.1E-02
Bladderwort	2.7E-01	1.4E-02	9.0E-02	9.4E-03	5.7E-01	3.5E-02
Mullein	4.0E-01	2.0E-02	3.0E-02	2.0E-03	6.6E-01	5.1E-02
Reed canarygrass	6.8E-02	1.1E-03	1.8E-02	1.2E-03	1.0E-01	8.1E-03
Virginia Creeper	5.7E-02	3.9E-03	5.7E-02	3.9E-03	5.7E-02	3.9E-03
Wood's Rose	2.4E-02	1.2E-03	4.4E-03	6.9E-04	4.9E-02	3.7E-03
Green Algae	1.3E+00	8.9E-02	1.3E+00	8.9E-02	1.3E+00	8.9E-02
Russian knapweed	2.7E-02	1.4E-03	6.1E-03	4.0E-04	5.4E-02	4.7E-03
Siberian elm	2.8E-02	2.7E-03	2.8E-02	2.7E-03	2.8E-02	2.7E-03
Curled Pondweed	7.0E-02	3.7E-03	5.7E-02	3.1E-03	8.3E-02	1.4E-02
Mimosa	1.8E-01	1.2E-02	1.8E-01	1.2E-02	1.8E-01	1.2E-02
Acorns (oak)	2.1E-03	1.4E-04	2.1E-03	1.4E-04	2.1E-03	1.4E-04
Horn Rapids						
Sand dropseed	5.2E-02	4.4E-03	2.4E-02	3.8E-03	7.4E-02	7.2E-03
Russian thistle	7.8E-02	5.8E-03	4.9E-03	4.2E-04	3.1E-01	3.7E-02
Rush skeletonweed	1.2E-01	9.3E-03	2.9E-02	4.9E-03	3.6E-01	5.9E-02
Prickly lettuce	5.1E-02	3.9E-03	2.6E-02	3.6E-03	9.8E-02	1.0E-02
luebunch Wheatgras	6.4E-02	4.7E-03	9.7E-03	8.3E-04	1.1E-01	1.1E-02
Mare's tail	2.1E-02	2.0E-03	1.3E-02	2.0E-03	2.9E-02	2.0E-03
Sagebrush	3.4E-02	2.9E-03	2.0E-02	2.5E-03	4.8E-02	4.2E-03
Snow buckwheat	9.6E-02	9.4E-03	9.6E-02	9.4E-03	9.6E-02	9.4E-03
Russian thistle (Kali)	2.5E-02	3.6E-03	2.5E-02	3.6E-03	2.5E-02	3.6E-03
Cheat grass	2.7E-01	2.1E-02	1.4E-01	1.5E-02	4.3E-01	5.3E-02
Vernita Shoreline						
Rush	1.2E-01	4.3E-03	2.6E-02	1.5E-03	2.8E-01	1.7E-02
lumbia river gumwe	2.0E-01	7.1E-03	9.0E-02	5.3E-03	5.2E-01	2.8E-02
Velvet Lupine	4.7E-02	1.6E-03	7.4E-03	4.0E-04	7.6E-02	4.3E-03
Curly Dock	4.3E-02	1.8E-03	2.1E-02	1.8E-03	1.0E-01	7.0E-03
Riparian Wheat Grass	3.9E-02	2.9E-03	1.2E-03	6.6E-05	1.0E-01	1.3E-02
St Johns wort	8.9E-02	3.1E-03	1.0E-02	6.8E-04	1.2E-01	6.8E-03
Reed Canarygrass	1.6E-01	5.6E-03	3.1E-02	1.7E-03	3.3E-01	1.5E-02
Siberian elm	2.5E-02	9.8E-04	4.5E-03	5.5E-04	4.6E-02	2.4E-03
Columbia tickseed	3.8E-02	1.3E-03	5.6E-03	3.0E-04	5.6E-02	3.4E-03
identified Aquatic Pl	4.5E-01	3.6E-02	4.5E-01	3.6E-02	4.5E-01	3.6E-02
Eurasin milfoil	4.7E-01	3.2E-02	4.7E-01	3.2E-02	4.7E-01	3.2E-02
Green Algae	5.2E-01	3.6E-02	5.2E-01	3.6E-02	5.2E-01	3.6E-02

Table A-2 Average, Min, and Max Concentration Ratios by plant species for Arsenic

Arsenic						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	4.4E-02	1.9E-03	4.3E-03	2.3E-04	6.6E-02	7.6E-03
Rush	4.2E-01	4.1E-03	6.7E-02	5.4E-03	9.9E-01	8.4E-02
White Mulbery	8.0E-02	3.5E-03	1.5E-03	7.7E-05	3.6E-01	1.7E-02
Curly Dock	1.3E+00	5.5E-02	1.4E-01	8.3E-03	3.3E+00	2.1E-01
Grass	2.4E-01	7.3E-03	9.0E-02	7.6E-03	3.6E-01	2.9E-02
Scouring Rush	7.6E-01	4.1E-02	3.5E-01	4.3E-02	1.5E+00	1.0E-01
Coyote willow	1.6E-01	9.8E-03	1.6E-01	9.8E-03	1.6E-01	9.8E-03
Lupine	8.0E-02	1.4E-02	8.0E-02	1.4E-02	8.0E-02	1.4E-02
Purple Loosestrife	1.3E-01	6.1E-03	6.7E-02	6.4E-03	1.9E-01	1.7E-02
Field Bindweed	1.4E-01	1.4E-02	1.4E-01	1.4E-02	1.4E-01	1.4E-02
Bladderwort	5.3E-01	2.5E-02	2.0E-01	1.7E-02	1.1E+00	7.7E-02
Mullein	5.5E-01	2.7E-02	1.5E-01	1.6E-02	9.9E-01	8.4E-02
Reed canarygrass	5.3E-02	2.8E-03	3.7E-02	3.5E-03	7.7E-02	6.1E-03
Virginia Creeper	6.5E-02	4.5E-03	6.5E-02	4.5E-03	6.5E-02	4.5E-03
Wood's Rose	1.8E-02	8.3E-04	4.2E-03	3.5E-04	5.4E-02	3.4E-03
Green Algae	2.1E+00	2.6E-01	2.1E+00	2.6E-01	2.1E+00	2.6E-01
Russian knapweed	3.4E-03	1.6E-04	1.8E-03	1.2E-04	5.4E-03	2.8E-04
Siberian elm	1.7E-02	2.2E-03	1.7E-02	2.2E-03	1.7E-02	2.2E-03
Curled Pondweed	1.4E-01	6.1E-03	5.7E-02	2.6E-03	2.2E-01	2.9E-02
Mimosa	2.6E-02	1.3E-03	2.6E-02	1.3E-03	2.6E-02	1.3E-03
Acorns (oak)	6.4E-04	3.3E-05	6.4E-04	3.3E-05	6.4E-04	3.3E-05
Horn Rapids						
Sand dropseed	3.1E-02	3.7E-04	1.7E-02	4.6E-04	6.3E-02	5.7E-03
Russian thistle	3.3E-02	3.2E-04	1.1E-02	2.9E-04	5.8E-02	1.7E-03
Rush skeletonweed	1.2E-01	1.1E-03	2.1E-02	5.5E-04	2.8E-01	4.0E-02
Prickly lettuce	2.4E-02	3.3E-04	1.5E-02	4.1E-04	4.0E-02	3.4E-03
luebunch Wheatgras	5.1E-02	5.1E-04	1.9E-02	5.5E-04	1.7E-01	1.9E-02
Mare's tail	1.8E-02	3.0E-04	1.4E-02	4.0E-04	2.0E-02	5.6E-04
Sagebrush	1.6E-02	3.3E-04	1.5E-02	4.1E-04	1.8E-02	5.1E-04
Snow buckwheat	1.4E-01	1.7E-02	1.4E-01	1.7E-02	1.4E-01	1.7E-02
Russian thistle (Kali)	7.7E-03	2.2E-04	7.7E-03	2.2E-04	7.7E-03	2.2E-04
Cheat grass	2.7E-01	5.5E-03	1.3E-01	1.8E-02	5.7E-01	1.0E-01
Vernita Shoreline						
Rush	4.9E-01	3.3E-02	3.6E-02	2.6E-03	1.0E+00	7.6E-02
lumbia river gumwe	8.3E-01	5.7E-02	3.2E-01	2.3E-02	2.6E+00	1.8E-01
Velvet Lupine	8.8E-02	6.4E-03	6.9E-02	7.0E-03	1.1E-01	9.5E-03
Curly Dock	2.4E-01	1.7E-02	4.2E-02	7.3E-03	6.3E-01	4.5E-02
Riparian Wheat Grass	2.4E-01	1.7E-02	9.2E-03	9.2E-04	6.9E-01	5.0E-02
St Johns wort	1.0E-01	6.9E-03	1.7E-02	1.4E-03	1.6E-01	1.5E-02
Reed Canarygrass	1.1E+00	7.4E-02	3.1E-01	2.8E-02	1.6E+00	1.1E-01
Siberian elm	2.5E-02	1.8E-03	6.6E-03	7.5E-04	4.5E-02	4.2E-03
Columbia tickseed	3.4E-01	2.4E-02	3.8E-02	2.8E-03	7.4E-01	5.2E-02
identified Aquatic Pl	1.6E+00	1.3E-01	1.6E+00	1.3E-01	1.6E+00	1.3E-01
Eurasin milfoil	1.0E+00	9.3E-02	1.0E+00	9.3E-02	1.0E+00	9.3E-02
Green Algae	1.2E+00	9.8E-02	1.2E+00	9.8E-02	1.2E+00	9.8E-02

Table A-3 Average, Min, and Max Concentration Ratios by plant species for barium

Barium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	3.2E-02	1.6E-03	2.4E-02	2.0E-03	4.0E-02	5.0E-03
Rush	1.7E-01	5.3E-04	1.6E-02	5.6E-04	5.5E-01	1.8E-02
White Mulbery	2.9E-02	5.9E-04	7.8E-03	2.9E-04	4.9E-02	1.9E-03
Curly Dock	2.1E-01	4.4E-03	3.4E-02	2.1E-03	5.5E-01	2.4E-02
Grass	1.3E-01	2.9E-03	3.2E-02	4.2E-03	2.3E-01	8.7E-03
Scouring Rush	3.0E-01	7.6E-03	1.5E-01	1.1E-02	5.4E-01	1.8E-02
Coyote willow	6.4E-02	3.1E-03	6.4E-02	3.1E-03	6.4E-02	3.1E-03
Lupine	9.2E-02	3.2E-03	9.2E-02	3.2E-03	9.2E-02	3.2E-03
Purple Loosestrife	4.4E-02	1.3E-03	2.7E-02	2.9E-03	9.1E-02	8.7E-03
Field Bindweed	6.7E-02	4.9E-03	6.7E-02	4.9E-03	6.7E-02	4.9E-03
Bladderwort	1.2E-01	3.1E-03	3.6E-02	4.7E-03	2.8E-01	9.6E-03
Mullein	2.6E-01	6.2E-03	8.8E-02	7.6E-03	5.5E-01	1.8E-02
Reed canarygrass	4.0E-02	9.3E-04	1.9E-02	1.5E-03	6.5E-02	4.4E-03
Virginia Creeper	4.2E-02	1.7E-03	4.2E-02	1.7E-03	4.2E-02	1.7E-03
Wood's Rose	1.8E-02	4.0E-04	5.1E-03	2.9E-04	2.7E-02	1.2E-03
Green Algae	7.6E-01	2.7E-02	7.6E-01	2.7E-02	7.6E-01	2.7E-02
Russian knapweed	2.3E-02	5.9E-04	9.9E-03	5.3E-04	2.8E-02	2.2E-03
Siberian elm	1.1E-01	3.5E-03	1.1E-01	3.5E-03	1.1E-01	3.5E-03
Curled Pondweed	1.3E-01	5.0E-03	1.1E-01	6.8E-03	1.4E-01	6.4E-03
Mimosa	2.7E-02	1.2E-03	2.7E-02	1.2E-03	2.7E-02	1.2E-03
Acorns (oak)	1.5E-02	9.5E-04	1.5E-02	9.5E-04	1.5E-02	9.5E-04
Horn Rapids						
Sand dropseed	2.1E-02	8.8E-04	9.1E-03	1.7E-03	3.5E-02	1.8E-03
Russian thistle	3.1E-02	1.2E-03	1.7E-02	1.8E-03	4.9E-02	5.0E-03
Rush skeletonweed	4.1E-02	1.1E-03	1.8E-02	1.2E-03	7.8E-02	1.2E-02
Prickly lettuce	1.5E-02	5.4E-04	1.2E-02	1.1E-03	2.0E-02	1.5E-03
3luebunch Wheatgras	2.8E-02	8.6E-04	1.3E-02	1.4E-03	5.8E-02	2.4E-03
Mare's tail	1.3E-02	7.4E-04	1.1E-02	1.1E-03	1.5E-02	1.4E-03
Sagebrush	1.4E-02	5.3E-04	1.1E-02	6.9E-04	1.6E-02	7.4E-04
Snow buckwheat	2.3E-01	7.1E-03	2.3E-01	7.1E-03	2.3E-01	7.1E-03
Russian thistle (Kali)	6.9E-02	2.9E-03	6.9E-02	2.9E-03	6.9E-02	2.9E-03
Cheat grass	2.3E-01	4.7E-03	7.3E-02	2.8E-03	4.0E-01	1.4E-02
Vernita Shoreline						
Rush	7.0E-02	3.2E-03	3.8E-02	1.1E-02	1.5E-01	7.3E-03
olumbia river gumwee	1.5E-01	3.1E-03	6.4E-02	2.8E-03	4.1E-01	1.5E-02
Velvet Lupine	1.6E-01	3.8E-03	1.3E-01	4.1E-03	2.1E-01	6.7E-03
Curly Dock	7.5E-02	1.8E-03	5.6E-02	2.5E-03	1.1E-01	4.8E-03
Riparian Wheat Grass	2.6E-02	6.5E-04	2.9E-03	4.4E-04	4.5E-02	2.2E-03
St Johns wort	7.9E-02	1.5E-03	1.0E-02	4.0E-04	1.0E-01	3.7E-03
Reed Canarygrass	8.5E-02	2.7E-03	4.9E-02	9.8E-03	1.4E-01	9.6E-03
Siberian elm	2.3E-02	6.2E-04	1.2E-02	5.9E-04	3.1E-02	1.4E-03
Columbia tickseed	4.5E-02	8.7E-04	5.4E-03	2.2E-04	6.5E-02	3.0E-03
identified Aquatic Pla	4.4E-01	2.2E-02	4.4E-01	2.2E-02	4.4E-01	2.2E-02
Eurasin milfoil	5.4E-01	2.0E-02	5.4E-01	2.0E-02	5.4E-01	2.0E-02
Green Algae	8.7E-01	2.9E-02	8.7E-01	2.9E-02	8.7E-01	2.9E-02

Table A-4 Average, Min, and Max Concentration Ratios by plant species for Cerium

Cerium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.6E-02	5.0E-04	1.1E-02	5.9E-04	2.1E-02	2.2E-03
Rush	1.3E-01	1.5E-04	1.3E-02	1.6E-04	4.2E-01	5.5E-03
White Mulbery	3.6E-03	3.7E-05	7.1E-04	7.4E-05	6.7E-03	3.1E-04
Curly Dock	8.4E-02	6.4E-04	1.1E-02	4.6E-04	2.1E-01	4.8E-03
Grass	1.4E-01	8.6E-04	2.0E-02	1.1E-03	2.8E-01	3.4E-03
Scouring Rush	2.7E-01	2.7E-03	1.6E-01	3.8E-03	4.2E-01	5.9E-03
Coyote willow	3.7E-02	7.7E-04	3.7E-02	7.7E-04	3.7E-02	7.7E-04
Lupine	3.1E-02	4.8E-04	3.1E-02	4.8E-04	3.1E-02	4.8E-04
Purple Loosestrife	1.5E-02	2.9E-04	5.7E-03	7.5E-04	3.1E-02	1.5E-03
Field Bindweed	5.8E-02	2.1E-03	5.8E-02	2.1E-03	5.8E-02	2.1E-03
Bladderwort	1.2E-01	1.1E-03	8.9E-03	1.7E-03	2.9E-01	3.2E-03
Mullein	2.1E-01	1.8E-03	3.3E-02	2.7E-03	4.2E-01	5.5E-03
Reed canarygrass	2.2E-02	2.4E-04	9.7E-03	3.7E-04	3.7E-02	6.2E-04
Virginia Creeper	1.6E-02	2.9E-04	1.6E-02	2.9E-04	1.6E-02	2.9E-04
Wood's Rose	3.9E-03	5.7E-05	7.4E-04	6.5E-05	8.3E-03	2.5E-04
Green Algae	5.4E-01	7.2E-03	5.4E-01	7.2E-03	5.4E-01	7.2E-03
Russian knapweed	3.1E-03	8.0E-05	1.7E-03	2.8E-04	4.7E-03	4.9E-04
Siberian elm	9.0E-03	3.3E-04	9.0E-03	3.3E-04	9.0E-03	3.3E-04
Curled Pondweed	2.2E-02	1.4E-03	1.6E-02	2.1E-03	2.8E-02	1.8E-03
Mimosa	1.3E-02	2.0E-04	1.3E-02	2.0E-04	1.3E-02	2.0E-04
Acorns (oak)	2.3E-04	3.6E-06	2.3E-04	3.6E-06	2.3E-04	3.6E-06
Horn Rapids						
Sand dropseed	1.0E-02	2.6E-04	1.7E-03	4.7E-04	2.2E-02	6.2E-04
Russian thistle	3.3E-03	4.1E-05	8.0E-04	5.4E-04	8.0E-03	1.9E-03
Rush skeletonweed	7.9E-03	9.7E-05	5.3E-03	3.4E-04	1.4E-02	5.2E-04
Prickly lettuce	5.3E-03	1.5E-04	3.0E-03	3.7E-04	1.0E-02	6.3E-04
3luebunch Wheatgras	1.4E-02	2.4E-04	3.2E-03	5.9E-04	4.4E-02	8.0E-04
Mare's tail	2.8E-03	2.1E-04	2.4E-03	4.0E-04	3.2E-03	3.5E-04
Sagebrush	7.6E-03	1.6E-04	5.1E-03	2.1E-04	1.0E-02	2.2E-04
Snow buckwheat	4.7E-02	7.2E-04	4.7E-02	7.2E-04	4.7E-02	7.2E-04
Russian thistle (Kali)	3.2E-03	4.8E-04	3.2E-03	4.8E-04	3.2E-03	4.8E-04
Cheat grass	1.8E-01	1.5E-03	4.0E-02	8.5E-04	3.2E-01	4.6E-03
Vernita Shoreline						
Rush	3.5E-02	6.3E-04	1.2E-02	2.3E-03	1.0E-01	1.7E-03
olumbia river gumwe	7.8E-02	5.1E-04	3.2E-02	5.3E-04	2.0E-01	2.8E-03
Velvet Lupine	3.0E-02	3.0E-04	8.8E-03	6.6E-04	4.7E-02	6.2E-04
Curly Dock	1.3E-02	2.0E-04	7.9E-03	4.7E-04	2.4E-02	7.4E-04
Riparian Wheat Grass	1.6E-02	4.1E-04	6.0E-04	7.6E-05	2.0E-02	1.3E-03
St Johns wort	4.9E-02	2.8E-04	4.4E-03	7.8E-05	6.8E-02	8.6E-04
Reed Canarygrass	5.3E-02	5.9E-04	2.1E-02	2.2E-03	1.1E-01	2.2E-03
Siberian elm	6.1E-03	8.0E-05	9.8E-04	8.7E-05	1.0E-02	1.8E-04
Columbia tickseed	9.7E-03	6.2E-05	1.4E-03	3.2E-05	1.6E-02	3.9E-04
identified Aquatic Pl	2.9E-01	5.1E-03	2.9E-01	5.1E-03	2.9E-01	5.1E-03
Eurasin milfoil	6.3E-01	6.8E-03	6.3E-01	6.8E-03	6.3E-01	6.8E-03
Green Algae	5.4E-01	6.1E-03	5.4E-01	6.1E-03	5.4E-01	6.1E-03

Table A-5 Average, Min, and Max Concentration Ratios by plant species for Cesium

Cesium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	4.3E-02	1.8E-03	2.4E-02	3.3E-03	6.3E-02	7.3E-03
Rush	1.6E-01	5.5E-04	1.2E-02	5.8E-04	6.3E-01	2.9E-02
White Mulbery	5.7E-03	1.9E-04	1.2E-03	1.2E-04	1.0E-02	1.3E-03
Curly Dock	8.3E-02	2.5E-03	1.2E-02	1.1E-03	2.1E-01	1.4E-02
Grass	1.6E-01	4.0E-03	5.4E-02	5.4E-03	2.7E-01	1.4E-02
Scouring Rush	5.1E+00	1.4E-01	2.7E-01	2.1E-02	1.4E+01	4.7E-01
Coyote willow	6.1E-02	3.6E-03	6.1E-02	3.6E-03	6.1E-02	3.6E-03
Lupine	1.1E-01	4.4E-03	1.1E-01	4.4E-03	1.1E-01	4.4E-03
Purple Loosestrife	2.2E-02	6.5E-04	3.8E-03	1.8E-04	4.0E-02	4.6E-03
Field Bindweed	1.4E+00	4.8E-02	1.4E+00	4.8E-02	1.4E+00	4.8E-02
Bladderwort	1.0E-01	2.9E-03	6.0E-03	2.8E-04	2.4E-01	1.1E-02
Mullein	2.5E-01	8.4E-03	4.9E-02	7.8E-03	6.3E-01	2.9E-02
Reed canarygrass	2.8E-02	9.1E-04	1.2E-02	1.2E-03	4.6E-02	2.7E-03
Virginia Creeper	2.3E-02	1.3E-03	2.3E-02	1.3E-03	2.3E-02	1.3E-03
Wood's Rose	5.2E-03	2.2E-04	2.2E-03	2.2E-04	8.6E-03	1.0E-03
Green Algae	1.3E+00	5.4E-02	1.3E+00	5.4E-02	1.3E+00	5.4E-02
Russian knapweed	1.1E-02	4.1E-04	2.9E-03	3.5E-04	1.5E-02	1.4E-03
Siberian elm	1.8E-02	1.4E-03	1.8E-02	1.4E-03	1.8E-02	1.4E-03
Curled Pondweed	2.3E-02	7.1E-04	1.4E-02	4.8E-04	3.3E-02	8.2E-03
Mimosa	3.1E-02	1.5E-03	3.1E-02	1.5E-03	3.1E-02	1.5E-03
Acorns (oak)	3.9E-03	5.6E-04	3.9E-03	5.6E-04	3.9E-03	5.6E-04
Horn Rapids						
Sand dropseed	1.6E-02	7.0E-04	4.0E-03	7.1E-04	3.5E-02	2.2E-03
Russian thistle	4.5E-03	1.8E-04	3.2E-03	7.5E-04	6.0E-03	3.0E-04
Rush skeletonweed	1.2E-02	5.2E-04	7.6E-03	7.6E-04	1.9E-02	1.6E-03
Prickly lettuce	7.7E-03	3.9E-04	4.3E-03	5.1E-04	1.5E-02	1.8E-03
3luebunch Wheatgras	2.1E-02	8.5E-04	5.8E-03	1.2E-03	5.8E-02	3.2E-03
Mare's tail	5.0E-03	4.1E-04	3.2E-03	7.0E-04	8.1E-03	8.4E-04
Sagebrush	1.3E-02	5.9E-04	1.0E-02	6.3E-04	1.5E-02	8.6E-04
Snow buckwheat	5.3E-02	2.8E-03	5.3E-02	2.8E-03	5.3E-02	2.8E-03
Russian thistle (Kali)	3.8E-03	8.0E-04	3.8E-03	8.0E-04	3.8E-03	8.0E-04
Cheat grass	2.0E-01	6.6E-03	5.6E-02	3.8E-03	3.7E-01	1.8E-02
Vernita Shoreline						
Rush	8.9E-02	5.3E-03	4.2E-02	1.2E-02	1.6E-01	1.4E-02
olumbia river gumwe	1.6E-01	6.7E-03	7.5E-02	5.3E-03	4.1E-01	2.3E-02
Velvet Lupine	2.6E-01	1.0E-02	2.3E-01	1.1E-02	3.1E-01	1.4E-02
Curly Dock	1.4E-01	5.7E-03	5.7E-02	3.3E-03	2.2E-01	9.9E-03
Riparian Wheat Grass	7.5E-02	4.4E-03	4.7E-03	6.4E-04	5.9E-02	1.0E-02
St Johns wort	8.2E-02	3.2E-03	4.0E-03	5.4E-04	1.2E-01	6.2E-03
Reed Canarygrass	1.6E-01	7.5E-03	7.2E-02	1.6E-02	2.9E-01	2.2E-02
Siberian elm	4.1E-02	1.7E-03	1.9E-02	1.0E-03	6.5E-02	3.1E-03
Columbia tickseed	6.1E-02	2.3E-03	8.7E-03	4.4E-04	1.0E-01	5.4E-03
identified Aquatic Pl	6.3E-01	4.5E-02	6.3E-01	4.5E-02	6.3E-01	4.5E-02
Eurasin milfoil	8.0E-01	4.4E-02	8.0E-01	4.4E-02	8.0E-01	4.4E-02
Green Algae	1.3E+00	6.7E-02	1.3E+00	6.7E-02	1.3E+00	6.7E-02

Table A-6 Average, Min, and Max Concentration Ratios by plant species for Chromium

Chromium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	3.4E-02	8.7E-04	1.8E-02	8.6E-04	6.0E-02	3.6E-03
Rush	1.7E-01	4.9E-04	2.1E-02	5.5E-04	4.8E-01	1.4E-02
White Mulbery	8.0E-03	1.3E-04	1.8E-03	7.4E-05	1.5E-02	6.0E-04
Curly Dock	1.5E-01	2.3E-03	2.5E-02	8.9E-04	3.8E-01	1.2E-02
Grass	2.0E-01	2.5E-03	8.9E-02	3.1E-03	3.1E-01	8.5E-03
Scouring Rush	3.0E-01	6.2E-03	1.3E-01	9.3E-03	5.6E-01	1.7E-02
Coyote willow	5.1E-02	1.9E-03	5.1E-02	1.9E-03	5.1E-02	1.9E-03
Lupine	4.9E-02	1.4E-03	4.9E-02	1.4E-03	4.9E-02	1.4E-03
Purple Loosestrife	2.8E-02	5.9E-04	1.0E-02	1.3E-03	7.9E-02	3.0E-03
Field Bindweed	6.1E-02	3.9E-03	6.1E-02	3.9E-03	6.1E-02	3.9E-03
Bladderwort	1.3E-01	2.5E-03	2.5E-02	3.3E-03	2.6E-01	9.0E-03
Mullein	2.5E-01	4.5E-03	4.2E-02	4.1E-03	4.8E-01	1.4E-02
Reed canarygrass	5.1E-02	7.5E-04	2.4E-02	2.1E-03	6.8E-02	1.9E-03
Virginia Creeper	1.7E-02	5.9E-04	1.7E-02	5.9E-04	1.7E-02	5.9E-04
Wood's Rose	6.8E-03	1.3E-04	1.6E-03	1.0E-04	1.1E-02	3.6E-04
Green Algae	1.0E+00	2.7E-02	1.0E+00	2.7E-02	1.0E+00	2.7E-02
Russian knapweed	7.8E-03	1.8E-04	2.6E-03	1.7E-04	1.2E-02	8.8E-04
Siberian elm	1.1E-02	6.5E-04	1.1E-02	6.5E-04	1.1E-02	6.5E-04
Curled Pondweed	5.3E-02	2.7E-03	4.5E-02	3.3E-03	6.0E-02	4.3E-03
Mimosa	1.7E-02	6.4E-04	1.7E-02	6.4E-04	1.7E-02	6.4E-04
Acorns (oak)	1.1E-03	2.7E-04	1.1E-03	2.7E-04	1.1E-03	2.7E-04
Horn Rapids						
Sand dropseed	4.7E-02	1.1E-03	4.0E-02	1.3E-03	5.3E-02	1.8E-03
Russian thistle	1.8E-02	3.3E-04	2.8E-03	1.1E-04	3.8E-02	1.3E-03
Rush skeletonweed	5.6E-02	1.1E-03	1.5E-02	6.3E-04	8.0E-02	8.9E-03
Prickly lettuce	2.6E-02	5.3E-04	6.2E-03	4.4E-04	7.9E-02	2.1E-03
3luebunch Wheatgras	6.7E-02	1.3E-03	2.7E-02	1.0E-03	1.2E-01	3.3E-03
Mare's tail	1.6E-02	4.5E-04	7.1E-03	4.8E-04	2.8E-02	1.0E-03
Sagebrush	8.9E-03	3.1E-04	6.9E-03	3.7E-04	1.1E-02	4.6E-04
Snow buckwheat	4.4E-02	1.6E-03	4.4E-02	1.6E-03	4.4E-02	1.6E-03
Russian thistle (Kali)	7.7E-03	6.6E-04	7.7E-03	6.6E-04	7.7E-03	6.6E-04
Cheat grass	2.3E-01	4.4E-03	6.7E-02	2.4E-03	4.6E-01	1.4E-02
Vernita Shoreline						
Rush	4.5E-02	8.4E-04	7.5E-03	1.7E-03	1.4E-01	3.2E-03
)lumbia river gumwe	8.7E-02	9.8E-04	2.7E-02	7.4E-04	2.3E-01	5.1E-03
Velvet Lupine	3.3E-02	4.9E-04	8.7E-03	6.6E-04	5.0E-02	1.1E-03
Curly Dock	3.4E-02	4.6E-04	9.6E-03	5.0E-04	5.0E-02	1.1E-03
Riparian Wheat Grass	2.7E-02	6.9E-04	4.4E-03	1.3E-04	7.1E-02	2.3E-03
St Johns wort	4.7E-02	4.7E-04	2.3E-03	9.2E-05	7.2E-02	1.6E-03
Reed Canarygrass	6.0E-02	1.0E-03	1.9E-02	1.8E-03	1.1E-01	2.6E-03
Siberian elm	8.7E-03	1.5E-04	7.2E-03	1.8E-04	1.1E-02	2.8E-04
Columbia tickseed	3.0E-02	3.2E-04	7.1E-03	1.5E-04	6.6E-02	1.4E-03
identified Aquatic Pl	3.4E-01	8.8E-03	3.4E-01	8.8E-03	3.4E-01	8.8E-03
Eurasin milfoil	5.8E-01	1.2E-02	5.8E-01	1.2E-02	5.8E-01	1.2E-02
Green Algae	5.9E-01	1.3E-02	5.9E-01	1.3E-02	5.9E-01	1.3E-02

Table A-7 Average, Min, and Max Concentration Ratios by plant species for Cobalt

Cobalt						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	2.7E-02	3.5E-04	1.7E-02	3.6E-04	4.5E-02	1.4E-03
Rush	1.4E-01	2.9E-04	2.0E-02	3.3E-04	3.8E-01	6.7E-03
White Mulbery	2.1E-02	1.7E-04	5.6E-03	9.8E-05	4.3E-02	8.1E-04
Curly Dock	1.9E-01	1.5E-03	4.2E-02	7.4E-04	4.5E-01	7.8E-03
Grass	1.7E-01	1.1E-03	5.2E-02	1.2E-03	3.2E-01	5.3E-03
Scouring Rush	2.5E-01	2.6E-03	1.1E-01	2.9E-03	4.6E-01	8.1E-03
Coyote willow	7.5E-02	1.3E-03	7.5E-02	1.3E-03	7.5E-02	1.3E-03
Lupine	5.8E-02	9.8E-04	5.8E-02	9.8E-04	5.8E-02	9.8E-04
Purple Loosestrife	2.8E-02	2.9E-04	1.7E-02	5.4E-04	4.9E-02	1.2E-03
Field Bindweed	5.0E-02	1.4E-03	5.0E-02	1.4E-03	5.0E-02	1.4E-03
Bladderwort	1.1E-01	1.1E-03	2.5E-02	1.2E-03	2.4E-01	4.0E-03
Mullein	1.9E-01	1.8E-03	4.6E-02	1.7E-03	3.8E-01	6.7E-03
Reed canarygrass	6.5E-02	4.6E-04	3.9E-02	6.9E-04	1.2E-01	1.9E-03
Virginia Creeper	3.1E-02	5.3E-04	3.1E-02	5.3E-04	3.1E-02	5.3E-04
Wood's Rose	2.0E-02	1.7E-04	4.4E-03	1.1E-04	6.1E-02	1.0E-03
Green Algae	1.2E+00	1.9E-02	1.2E+00	1.9E-02	1.2E+00	1.9E-02
Russian knapweed	9.2E-03	9.6E-05	4.0E-03	9.1E-05	1.5E-02	3.7E-04
Siberian elm	2.0E-02	4.0E-04	2.0E-02	4.0E-04	2.0E-02	4.0E-04
Curled Pondweed	7.9E-02	1.5E-03	7.9E-02	2.3E-03	7.9E-02	1.9E-03
Mimosa	4.5E-02	4.4E-03	4.5E-02	4.4E-03	4.5E-02	4.4E-03
Acorns (oak)	4.5E-03	1.4E-04	4.5E-03	1.4E-04	4.5E-03	1.4E-04
Horn Rapids						
Sand dropseed	2.0E-02	1.9E-04	6.7E-03	1.7E-04	4.6E-02	7.6E-04
Russian thistle	1.4E-02	1.5E-04	8.5E-03	1.9E-04	2.5E-02	8.9E-04
Rush skeletonweed	1.6E-02	1.7E-04	7.8E-03	1.6E-04	2.6E-02	1.5E-03
Prickly lettuce	1.0E-02	1.0E-04	6.3E-03	1.5E-04	1.6E-02	3.5E-04
3luebunch Wheatgras	2.2E-02	1.9E-04	5.4E-03	2.0E-04	6.2E-02	1.0E-03
Mare's tail	4.3E-03	6.3E-05	2.5E-03	7.4E-05	5.7E-03	1.2E-04
Sagebrush	9.4E-03	1.1E-04	6.0E-03	1.1E-04	1.3E-02	2.2E-04
Snow buckwheat	6.8E-02	1.1E-03	6.8E-02	1.1E-03	6.8E-02	1.1E-03
Russian thistle (Kali)	1.2E-02	2.5E-04	1.2E-02	2.5E-04	1.2E-02	2.5E-04
Cheat grass	1.8E-01	1.4E-03	5.0E-02	8.7E-04	3.3E-01	5.3E-03
Vernita Shoreline						
Rush	1.3E-01	1.4E-03	4.5E-02	1.8E-03	2.8E-01	4.8E-03
olumbia river gumwe	1.6E-01	1.5E-03	8.1E-02	1.4E-03	4.1E-01	6.7E-03
Velvet Lupine	7.5E-02	8.1E-04	5.4E-02	1.2E-03	1.0E-01	1.7E-03
Curly Dock	1.2E-01	1.2E-03	9.9E-02	1.6E-03	1.5E-01	2.6E-03
Riparian Wheat Grass	5.2E-02	9.1E-04	3.8E-03	1.1E-04	1.4E-01	3.1E-03
St Johns wort	7.8E-02	6.4E-04	1.5E-02	2.6E-04	1.1E-01	1.7E-03
Reed Canarygrass	2.2E-01	2.4E-03	1.9E-01	4.1E-03	2.9E-01	5.4E-03
Siberian elm	1.8E-02	1.9E-04	6.9E-03	1.4E-04	2.7E-02	4.8E-04
Columbia tickseed	5.5E-02	4.4E-04	8.2E-03	1.3E-04	8.7E-02	1.4E-03
identified Aquatic Pl	5.8E-01	1.1E-02	5.8E-01	1.1E-02	5.8E-01	1.1E-02
Eurasin milfoil	7.6E-01	1.3E-02	7.6E-01	1.3E-02	7.6E-01	1.3E-02
Green Algae	9.1E-01	1.5E-02	9.1E-01	1.5E-02	9.1E-01	1.5E-02

Table A-8 Average, Min, and Max Concentration Ratios by plant species for Europium

Europium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.7E-02	4.5E-04	8.9E-03	4.7E-04	3.0E-02	2.2E-03
Rush	1.3E-01	3.2E-04	1.6E-02	3.5E-04	4.1E-01	1.0E-02
White Mulbery	4.9E-03	7.0E-05	1.0E-03	7.8E-05	1.0E-02	5.2E-04
Curly Dock	9.9E-02	1.3E-03	1.2E-02	4.6E-04	2.5E-01	7.2E-03
Grass	1.4E-01	1.4E-03	2.8E-02	1.7E-03	2.7E-01	6.2E-03
Scouring Rush	2.5E-01	4.2E-03	1.2E-01	5.5E-03	4.8E-01	1.2E-02
Coyote willow	4.5E-02	1.4E-03	4.5E-02	1.4E-03	4.5E-02	1.4E-03
Lupine	3.2E-02	8.4E-04	3.2E-02	8.4E-04	3.2E-02	8.4E-04
Purple Loosestrife	1.6E-02	3.4E-04	7.6E-03	6.7E-04	3.6E-02	1.9E-03
Field Bindweed	3.9E-02	2.3E-03	3.9E-02	2.3E-03	3.9E-02	2.3E-03
Bladderwort	1.1E-01	1.6E-03	1.1E-02	1.8E-03	2.7E-01	6.0E-03
Mullein	1.9E-01	2.9E-03	2.7E-02	2.4E-03	4.1E-01	1.0E-02
Reed canarygrass	2.8E-02	3.6E-04	1.3E-02	4.7E-04	5.1E-02	1.3E-03
Virginia Creeper	1.7E-02	4.8E-04	1.7E-02	4.8E-04	1.7E-02	4.8E-04
Wood's Rose	4.2E-03	7.1E-05	9.4E-04	6.4E-05	1.0E-02	4.0E-04
Green Algae	7.2E-01	1.7E-02	7.2E-01	1.7E-02	7.2E-01	1.7E-02
Russian knapweed	3.6E-03	9.4E-05	2.4E-03	1.3E-04	5.5E-03	4.5E-04
Siberian elm	9.6E-03	4.3E-04	9.6E-03	4.3E-04	9.6E-03	4.3E-04
Curled Pondweed	2.2E-02	1.5E-03	1.8E-02	2.3E-03	2.6E-02	1.9E-03
Mimosa	2.0E-02	6.1E-04	2.0E-02	6.1E-04	2.0E-02	6.1E-04
Acorns (oak)	2.1E-04	6.3E-06	2.1E-04	6.3E-06	2.1E-04	6.3E-06
Horn Rapids						
Sand dropseed	1.2E-02	2.1E-04	1.8E-03	2.4E-04	2.7E-02	7.3E-04
Russian thistle	3.8E-03	6.3E-05	1.7E-03	5.1E-05	1.0E-02	1.6E-03
Rush skeletonweed	9.5E-03	1.7E-04	4.9E-03	2.3E-04	1.7E-02	5.2E-04
Prickly lettuce	5.6E-03	1.2E-04	2.9E-03	2.3E-04	1.2E-02	5.5E-04
luebunch Wheatgras	1.6E-02	2.6E-04	3.0E-03	4.0E-04	4.6E-02	1.1E-03
Mare's tail	2.7E-03	1.0E-04	1.8E-03	1.4E-04	3.8E-03	1.8E-04
Sagebrush	7.5E-03	1.7E-04	4.9E-03	1.8E-04	1.0E-02	2.8E-04
Snow buckwheat	4.2E-02	1.0E-03	4.2E-02	1.0E-03	4.2E-02	1.0E-03
Russian thistle (Kali)	3.6E-03	2.3E-04	3.6E-03	2.3E-04	3.6E-03	2.3E-04
Cheat grass	1.7E-01	2.3E-03	4.4E-02	1.3E-03	3.2E-01	7.5E-03
Vernita Shoreline						
Rush	4.8E-02	1.1E-03	2.0E-02	2.8E-03	1.2E-01	3.8E-03
lumbia river gumwe	9.7E-02	1.3E-03	4.2E-02	1.3E-03	2.5E-01	6.3E-03
Velvet Lupine	3.2E-02	5.9E-04	1.1E-02	9.5E-04	4.8E-02	1.3E-03
Curly Dock	2.2E-02	3.7E-04	1.4E-02	5.4E-04	4.4E-02	1.5E-03
Riparian Wheat Grass	2.7E-02	2.4E-04	1.4E-03	1.6E-03	4.0E-02	8.3E-04
St Johns wort	5.4E-02	6.6E-04	7.9E-03	2.2E-04	7.2E-02	1.7E-03
Reed Canarygrass	8.5E-02	1.6E-03	3.8E-02	3.3E-03	1.4E-01	5.4E-03
Siberian elm	9.8E-03	1.6E-04	2.2E-03	1.2E-04	1.4E-02	4.4E-04
Columbia tickseed	1.8E-02	2.2E-04	2.6E-03	7.1E-05	2.9E-02	8.8E-04
identified Aquatic Pl	4.2E-01	1.3E-02	4.2E-01	1.3E-02	4.2E-01	1.3E-02
Eurasin milfoil	5.8E-01	1.4E-02	5.8E-01	1.4E-02	5.8E-01	1.4E-02
Green Algae	7.3E-01	1.7E-02	7.3E-01	1.7E-02	7.3E-01	1.7E-02

Table A-9 Average, Min, and Max Concentration Ratios by plant species for Hafnium

Hafnium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.9E-02	5.5E-04	1.2E-02	5.7E-04	2.6E-02	1.5E-03
Rush	1.3E-01	3.9E-04	1.3E-02	4.4E-04	3.8E-01	1.3E-02
White Mulbery	3.6E-03	6.2E-05	4.4E-04	3.8E-05	1.1E-02	4.9E-04
Curly Dock	4.7E-02	7.8E-04	5.1E-03	4.1E-04	1.2E-01	5.5E-03
Grass	1.2E-01	1.4E-03	1.3E-02	1.6E-03	2.2E-01	7.5E-03
Scouring Rush	3.1E-01	6.2E-03	1.4E-01	7.6E-03	4.8E-01	1.6E-02
Coyote willow	4.2E-02	1.7E-03	4.2E-02	1.7E-03	4.2E-02	1.7E-03
Lupine	2.7E-02	1.0E-03	2.7E-02	1.0E-03	2.7E-02	1.0E-03
Purple Loosestrife	1.1E-02	3.1E-04	2.8E-03	6.7E-04	4.6E-02	2.3E-03
Field Bindweed	2.8E-02	2.5E-03	2.8E-02	2.5E-03	2.8E-02	2.5E-03
Bladderwort	1.2E-01	2.1E-03	8.5E-03	1.5E-03	2.5E-01	7.9E-03
Mullein	2.1E-01	3.8E-03	2.6E-02	2.8E-03	3.8E-01	1.3E-02
Reed canarygrass	1.7E-02	3.1E-04	6.1E-03	4.0E-04	3.4E-02	1.3E-03
Virginia Creeper	8.5E-03	3.9E-04	8.5E-03	3.9E-04	8.5E-03	3.9E-04
Wood's Rose	2.5E-03	6.1E-05	3.5E-04	6.0E-05	5.3E-03	3.2E-04
Green Algae	4.2E-01	1.5E-02	4.2E-01	1.5E-02	4.2E-01	1.5E-02
Russian knapweed	2.7E-03	9.0E-05	1.4E-03	1.1E-04	5.0E-03	4.1E-04
Siberian elm	9.7E-03	4.9E-04	9.7E-03	4.9E-04	9.7E-03	4.9E-04
Curled Pondweed	1.1E-02	1.3E-03	9.5E-03	2.0E-03	1.2E-02	1.6E-03
Mimosa	1.0E-02	5.1E-04	1.0E-02	5.1E-04	1.0E-02	5.1E-04
Acorns (oak)	1.6E-04	8.1E-06	1.6E-04	8.1E-06	1.6E-04	8.1E-06
Horn Rapids						
Sand dropseed	1.2E-02	3.3E-04	2.0E-03	3.7E-04	2.7E-02	1.1E-03
Russian thistle	4.2E-03	1.1E-04	1.6E-03	8.3E-05	1.0E-02	2.4E-03
Rush skeletonweed	8.6E-03	2.5E-04	5.2E-03	3.5E-04	1.6E-02	8.1E-04
Prickly lettuce	5.5E-03	1.8E-04	2.6E-03	3.0E-04	1.3E-02	8.6E-04
luebunch Wheatgras	1.7E-02	4.2E-04	3.1E-03	4.7E-04	5.2E-02	1.9E-03
Mare's tail	2.9E-03	1.9E-04	2.0E-03	2.6E-04	3.4E-03	3.2E-04
Sagebrush	8.9E-03	2.7E-04	4.8E-03	2.6E-04	1.3E-02	5.1E-04
Snow buckwheat	4.6E-02	1.7E-03	4.6E-02	1.7E-03	4.6E-02	1.7E-03
Russian thistle (Kali)	4.6E-03	4.8E-04	4.6E-03	4.8E-04	4.6E-03	4.8E-04
Cheat grass	1.7E-01	3.4E-03	4.6E-02	2.0E-03	3.2E-01	1.2E-02
Vernita Shoreline						
Rush	4.3E-02	5.7E-04	2.0E-03	1.0E-04	1.6E-01	5.0E-03
lumbia river gumwe	7.1E-02	1.1E-03	2.4E-02	9.2E-04	1.8E-01	6.0E-03
Velvet Lupine	2.5E-02	5.4E-04	3.0E-03	7.2E-04	4.4E-02	1.4E-03
Curly Dock	1.1E-02	2.6E-04	4.3E-03	4.6E-04	2.6E-02	1.2E-03
Riparian Wheat Grass	6.6E-03	9.7E-05	3.6E-04	8.2E-05	1.2E-02	1.1E-03
St Johns wort	4.3E-02	5.8E-04	2.8E-03	1.2E-04	8.1E-02	2.4E-03
Reed Canarygrass	4.1E-02	1.0E-03	2.2E-02	2.3E-03	8.1E-02	2.8E-03
Siberian elm	5.4E-03	1.1E-04	7.5E-04	9.3E-05	9.8E-03	3.5E-04
Columbia tickseed	7.3E-03	1.1E-04	9.4E-04	4.4E-05	1.3E-02	5.7E-04
identified Aquatic Pl	3.3E-01	1.2E-02	3.3E-01	1.2E-02	3.3E-01	1.2E-02
Eurasin milfoil	7.8E-01	2.2E-02	7.8E-01	2.2E-02	7.8E-01	2.2E-02
Green Algae	6.6E-01	2.0E-02	6.6E-01	2.0E-02	6.6E-01	2.0E-02

Table A-10 Average, Min, and Max Concentration Ratios by plant species for Iron

Iron						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.8E-02	1.7E-04	1.1E-02	1.7E-04	2.8E-02	5.6E-04
Rush	1.3E-01	1.9E-04	1.7E-02	2.2E-04	4.0E-01	5.5E-03
White Mulbery	4.5E-03	2.9E-05	1.1E-03	2.1E-05	6.8E-03	1.3E-04
Curly Dock	8.9E-02	5.3E-04	1.0E-02	1.6E-04	2.2E-01	3.1E-03
Grass	1.4E-01	5.3E-04	3.4E-02	5.6E-04	2.6E-01	3.6E-03
Scouring Rush	2.4E-01	1.8E-03	9.4E-02	1.6E-03	4.5E-01	6.1E-03
Coyote willow	4.7E-02	6.6E-04	4.7E-02	6.6E-04	4.7E-02	6.6E-04
Lupine	4.1E-02	5.6E-04	4.1E-02	5.6E-04	4.1E-02	5.6E-04
Purple Loosestrife	1.4E-02	1.0E-04	7.5E-03	1.9E-04	3.3E-02	5.5E-04
Field Bindweed	3.8E-02	6.7E-04	3.8E-02	6.7E-04	3.8E-02	6.7E-04
Bladderwort	1.0E-01	6.3E-04	1.0E-02	3.3E-04	2.4E-01	3.2E-03
Mullein	1.9E-01	1.2E-03	2.8E-02	6.3E-04	4.0E-01	5.5E-03
Reed canarygrass	3.4E-02	1.7E-04	1.4E-02	3.4E-04	6.9E-02	9.4E-04
Virginia Creeper	2.7E-02	3.7E-04	2.7E-02	3.7E-04	2.7E-02	3.7E-04
Wood's Rose	5.8E-03	3.8E-05	1.4E-03	2.5E-05	1.7E-02	2.5E-04
Green Algae	8.5E-01	1.1E-02	8.5E-01	1.1E-02	8.5E-01	1.1E-02
Russian knapweed	4.0E-03	3.3E-05	2.1E-03	3.5E-05	6.8E-03	1.3E-04
Siberian elm	8.6E-03	1.4E-04	8.6E-03	1.4E-04	8.6E-03	1.4E-04
Curled Pondweed	1.7E-02	3.1E-04	1.6E-02	3.8E-04	1.8E-02	4.9E-04
Mimosa	8.9E-03	1.2E-03	8.9E-03	1.2E-03	8.9E-03	1.2E-03
Acorns (oak)	5.5E-04	2.4E-05	5.5E-04	2.4E-05	5.5E-04	2.4E-05
Horn Rapids						
Sand dropseed	1.2E-02	7.8E-05	2.2E-03	5.0E-05	2.8E-02	3.8E-04
Russian thistle	3.3E-03	3.3E-05	1.7E-03	1.1E-04	7.1E-03	2.4E-04
Rush skeletonweed	1.1E-02	8.5E-05	5.0E-03	7.7E-05	1.6E-02	5.5E-04
Prickly lettuce	5.3E-03	4.0E-05	2.6E-03	5.1E-05	1.1E-02	1.8E-04
3luebunch Wheatgras	1.6E-02	1.0E-04	3.2E-03	7.5E-05	4.7E-02	6.4E-04
Mare's tail	3.3E-03	3.2E-05	1.8E-03	3.5E-05	4.5E-03	7.0E-05
Sagebrush	7.1E-03	6.7E-05	4.6E-03	6.6E-05	9.6E-03	1.3E-04
Snow buckwheat	3.8E-02	5.1E-04	3.8E-02	5.1E-04	3.8E-02	5.1E-04
Russian thistle (Kali)	3.4E-03	6.4E-05	3.4E-03	6.4E-05	3.4E-03	6.4E-05
Cheat grass	1.6E-01	1.0E-03	4.3E-02	6.0E-04	3.1E-01	4.1E-03
Vernita Shoreline						
Rush	9.4E-02	6.2E-04	2.0E-02	5.5E-04	2.4E-01	3.2E-03
›lumbia river gumwe‹	1.3E-01	8.4E-04	6.0E-02	8.1E-04	3.3E-01	4.4E-03
Velvet Lupine	4.0E-02	3.1E-04	1.9E-02	3.2E-04	5.3E-02	7.1E-04
Curly Dock	4.8E-02	3.1E-04	1.5E-02	2.2E-04	1.2E-01	1.6E-03
Riparian Wheat Grass	3.4E-02	2.0E-04	1.6E-03	3.2E-05	9.2E-02	1.4E-03
St Johns wort	5.1E-02	3.1E-04	8.9E-03	1.2E-04	7.2E-02	9.6E-04
Reed Canarygrass	1.3E-01	9.9E-04	8.1E-02	1.7E-03	1.8E-01	2.5E-03
Siberian elm	1.1E-02	6.9E-05	2.1E-03	3.8E-05	1.7E-02	2.3E-04
Columbia tickseed	3.5E-02	2.0E-04	4.1E-03	5.5E-05	6.5E-02	8.8E-04
identified Aquatic Pl:	5.2E-01	7.1E-03	5.2E-01	7.1E-03	5.2E-01	7.1E-03
Eurasin milfoil	7.2E-01	9.6E-03	7.2E-01	9.6E-03	7.2E-01	9.6E-03
Green Algae	7.4E-01	9.8E-03	7.4E-01	9.8E-03	7.4E-01	9.8E-03

Table A-11 Average, Min, and Max Concentration Ratios by plant species for Lanthanum

Lanthanum						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.5E-02	1.0E-04	9.5E-03	1.2E-04	1.8E-02	3.2E-04
Rush	1.4E-01	1.1E-04	1.6E-02	1.3E-04	4.3E-01	3.4E-03
White Mulbery	3.9E-03	1.7E-05	8.0E-04	1.6E-05	7.1E-03	1.0E-04
Curly Dock	9.2E-02	3.2E-04	9.7E-03	1.1E-04	2.4E-01	2.4E-03
Grass	1.4E-01	2.6E-04	1.9E-02	2.7E-04	2.7E-01	2.1E-03
Scouring Rush	2.7E-01	1.2E-03	1.5E-01	1.5E-03	4.1E-01	3.4E-03
Coyote willow	3.4E-02	3.2E-04	3.4E-02	3.2E-04	3.4E-02	3.2E-04
Lupine	3.2E-02	3.0E-04	3.2E-02	3.0E-04	3.2E-02	3.0E-04
Purple Loosestrife	1.4E-02	8.1E-05	6.0E-03	1.7E-04	3.1E-02	4.1E-04
Field Bindweed	5.4E-02	6.0E-04	5.4E-02	6.0E-04	5.4E-02	6.0E-04
Bladderwort	1.3E-01	4.7E-04	7.0E-03	2.7E-04	3.0E-01	2.4E-03
Mullein	2.2E-01	8.3E-04	3.2E-02	4.9E-04	4.3E-01	3.4E-03
Reed canarygrass	2.1E-02	9.2E-05	9.3E-03	1.5E-04	3.7E-02	3.7E-04
Virginia Creeper	1.8E-02	1.5E-04	1.8E-02	1.5E-04	1.8E-02	1.5E-04
Wood's Rose	4.2E-03	1.7E-05	8.2E-04	1.4E-05	9.6E-03	1.0E-04
Green Algae	6.0E-01	5.1E-03	6.0E-01	5.1E-03	6.0E-01	5.1E-03
Russian knapweed	2.9E-03	2.9E-05	1.6E-03	8.2E-05	4.4E-03	1.1E-04
Siberian elm	9.0E-03	1.1E-04	9.0E-03	1.1E-04	9.0E-03	1.1E-04
Curled Pondweed	2.0E-02	3.6E-04	1.6E-02	5.1E-04	2.4E-02	5.1E-04
Mimosa	1.9E-02	9.0E-04	1.9E-02	9.0E-04	1.9E-02	9.0E-04
Acorns (oak)	1.3E-04	1.2E-05	1.3E-04	1.2E-05	1.3E-04	1.2E-05
Horn Rapids						
Sand dropseed	1.1E-02	6.7E-05	1.8E-03	7.9E-05	2.2E-02	2.4E-04
Russian thistle	4.1E-03	4.3E-05	2.6E-03	6.6E-05	9.0E-03	3.1E-04
Rush skeletonweed	9.8E-03	6.3E-05	5.0E-03	6.4E-05	1.4E-02	1.8E-04
Prickly lettuce	5.7E-03	3.7E-05	3.4E-03	5.6E-05	1.0E-02	2.0E-04
3luebunch Wheatgras	1.6E-02	8.2E-05	2.8E-03	7.4E-05	4.8E-02	4.3E-04
Mare's tail	3.2E-03	4.5E-05	2.6E-03	6.3E-05	4.0E-03	8.0E-05
Sagebrush	8.1E-03	7.3E-05	5.6E-03	8.5E-05	1.1E-02	1.2E-04
Snow buckwheat	5.0E-02	4.3E-04	5.0E-02	4.3E-04	5.0E-02	4.3E-04
Russian thistle (Kali)	4.0E-03	7.3E-05	4.0E-03	7.3E-05	4.0E-03	7.3E-05
Cheat grass	2.0E-01	8.6E-04	4.2E-02	4.2E-04	3.6E-01	3.0E-03
Vernita Shoreline						
Rush	3.7E-02	2.3E-04	1.0E-02	4.2E-04	1.0E-01	9.3E-04
olumbia river gumwe	8.5E-02	3.4E-04	3.7E-02	3.1E-04	2.2E-01	1.8E-03
Velvet Lupine	3.5E-02	1.7E-04	1.2E-02	1.7E-04	5.4E-02	4.2E-04
Curly Dock	1.5E-02	8.1E-05	9.2E-03	1.5E-04	2.5E-02	2.6E-04
Riparian Wheat Grass	9.8E-03	3.7E-05	7.5E-04	1.6E-05	1.8E-02	3.2E-04
St Johns wort	5.0E-02	1.8E-04	4.1E-03	3.6E-05	7.2E-02	5.6E-04
Reed Canarygrass	5.7E-02	3.0E-04	2.0E-02	4.7E-04	1.1E-01	1.1E-03
Siberian elm	7.1E-03	3.2E-05	1.4E-03	2.2E-05	1.1E-02	8.9E-05
Columbia tickseed	1.1E-02	4.2E-05	1.6E-03	1.4E-05	1.8E-02	1.8E-04
identified Aquatic Pl	2.9E-01	2.6E-03	2.9E-01	2.6E-03	2.9E-01	2.6E-03
Eurasin milfoil	6.7E-01	5.1E-03	6.7E-01	5.1E-03	6.7E-01	5.1E-03
Green Algae	5.8E-01	4.4E-03	5.8E-01	4.4E-03	5.8E-01	4.4E-03

Table A-12 Average, Min, and Max Concentration Ratios by plant species for Lutetium

Lutetium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.4E-02	9.3E-04	7.3E-03	1.0E-03	3.0E-02	4.6E-03
Rush	1.3E-01	4.3E-04	1.5E-02	4.6E-04	4.8E-01	1.6E-02
White Mulbery	6.1E-03	1.5E-04	1.2E-03	9.7E-05	1.1E-02	9.3E-04
Curly Dock	9.4E-02	2.2E-03	1.5E-02	1.5E-03	2.3E-01	1.4E-02
Grass	1.4E-01	2.8E-03	2.5E-02	3.8E-03	2.6E-01	9.8E-03
Scouring Rush	3.2E-01	7.5E-03	1.0E-01	7.7E-03	5.1E-01	1.5E-02
Coyote willow	4.6E-02	2.1E-03	4.6E-02	2.1E-03	4.6E-02	2.1E-03
Lupine	3.0E-02	1.3E-03	3.0E-02	1.3E-03	3.0E-02	1.3E-03
Purple Loosestrife	1.2E-02	2.5E-04	2.8E-03	8.9E-05	4.0E-02	4.0E-03
Field Bindweed	3.3E-02	4.0E-03	3.3E-02	4.0E-03	3.3E-02	4.0E-03
Bladderwort	1.1E-01	2.2E-03	4.6E-03	1.4E-04	3.0E-01	8.4E-03
Mullein	2.0E-01	4.8E-03	2.4E-02	4.8E-03	4.8E-01	1.6E-02
Reed canarygrass	2.9E-02	6.9E-04	9.9E-03	9.6E-04	4.4E-02	1.9E-03
Virginia Creeper	1.6E-02	7.1E-04	1.6E-02	7.1E-04	1.6E-02	7.1E-04
Wood's Rose	3.6E-03	7.3E-05	4.0E-04	1.3E-05	8.2E-03	6.1E-04
Green Algae	7.9E-01	2.5E-02	7.9E-01	2.5E-02	7.9E-01	2.5E-02
Russian knapweed	2.4E-03	5.1E-05	8.6E-04	2.8E-05	5.9E-03	1.2E-03
Siberian elm	5.9E-03	8.7E-04	5.9E-03	8.7E-04	5.9E-03	8.7E-04
Curled Pondweed	2.2E-02	2.7E-03	2.1E-02	5.3E-03	2.2E-02	3.2E-03
Mimosa	1.7E-02	5.3E-04	1.7E-02	5.3E-04	1.7E-02	5.3E-04
Acorns (oak)	5.6E-04	1.8E-05	5.6E-04	1.8E-05	5.6E-04	1.8E-05
Horn Rapids						
Sand dropseed	1.2E-02	2.3E-04	1.4E-03	4.4E-05	2.9E-02	1.3E-03
Russian thistle	3.1E-03	6.6E-05	1.7E-03	5.6E-05	5.5E-03	1.7E-04
Rush skeletonweed	1.1E-02	3.4E-04	4.7E-03	6.4E-04	1.6E-02	1.2E-03
Prickly lettuce	5.9E-03	3.1E-04	2.7E-03	7.0E-04	1.4E-02	1.5E-03
luebunch Wheatgras	1.5E-02	2.9E-04	1.9E-03	6.2E-05	4.4E-02	1.7E-03
Mare's tail	2.4E-03	5.4E-05	9.7E-04	3.2E-05	3.6E-03	7.4E-04
Sagebrush	8.1E-03	4.0E-04	5.1E-03	5.5E-04	1.1E-02	5.4E-04
Snow buckwheat	4.5E-02	1.7E-03	4.5E-02	1.7E-03	4.5E-02	1.7E-03
Russian thistle (Kali)	1.7E-03	5.6E-05	1.7E-03	5.6E-05	1.7E-03	5.6E-05
Cheat grass	1.8E-01	3.9E-03	4.9E-02	2.3E-03	3.4E-01	1.0E-02
Vernita Shoreline						
Rush	4.1E-02	7.8E-04	8.8E-03	2.8E-04	1.6E-01	6.3E-03
lumbia river gumwe	9.8E-02	2.1E-03	3.9E-02	1.9E-03	2.4E-01	1.1E-02
Velvet Lupine	3.4E-02	1.1E-03	1.5E-02	3.1E-03	4.9E-02	2.1E-03
Curly Dock	1.9E-02	7.2E-04	1.0E-02	1.6E-03	3.7E-02	2.8E-03
Riparian Wheat Grass	3.5E-02	6.6E-04	4.1E-04	1.3E-05	1.7E-01	8.1E-03
St Johns wort	5.1E-02	9.7E-04	6.4E-03	2.6E-04	7.5E-02	2.2E-03
Reed Canarygrass	7.8E-02	2.3E-03	3.4E-02	1.3E-02	1.4E-01	6.2E-03
Siberian elm	1.1E-02	3.2E-04	2.3E-03	3.2E-04	1.6E-02	5.8E-04
Columbia tickseed	1.7E-02	3.4E-04	2.1E-03	1.1E-04	3.4E-02	2.1E-03
identified Aquatic Pl	6.2E-01	2.5E-02	6.2E-01	2.5E-02	6.2E-01	2.5E-02
Eurasin milfoil	6.2E-01	1.8E-02	6.2E-01	1.8E-02	6.2E-01	1.8E-02
Green Algae	7.7E-01	2.4E-02	7.7E-01	2.4E-02	7.7E-01	2.4E-02

Table A-13 Average, Min, and Max Concentration Ratios by plant species for Neodymium

Neodymium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	2.6E-02	2.0E-03	9.4E-03	1.3E-03	3.8E-02	5.1E-03
Rush	1.2E-01	1.1E-03	1.1E-02	1.3E-03	3.7E-01	5.9E-02
White Mulbery	3.9E-03	2.6E-04	5.7E-04	8.0E-05	1.1E-02	3.2E-03
Curly Dock	1.0E-01	7.6E-03	1.6E-02	5.1E-03	2.5E-01	4.8E-02
Grass	1.3E-01	2.1E-03	1.8E-02	2.2E-03	2.6E-01	3.4E-02
Scouring Rush	2.8E-01	2.9E-02	1.0E-01	3.7E-02	5.1E-01	7.4E-02
Coyote willow	3.6E-02	8.5E-03	3.6E-02	8.5E-03	3.6E-02	8.5E-03
Lupine	2.8E-02	4.7E-03	2.8E-02	4.7E-03	2.8E-02	4.7E-03
Purple Loosestrife	2.2E-02	1.5E-03	1.1E-02	1.3E-03	3.4E-02	4.6E-03
Field Bindweed	6.4E-02	1.9E-02	6.4E-02	1.9E-02	6.4E-02	1.9E-02
Bladderwort	1.1E-01	7.6E-03	2.7E-02	3.3E-03	2.6E-01	3.2E-02
Mullein	1.9E-01	1.4E-02	5.6E-02	7.5E-03	3.7E-01	5.9E-02
Reed canarygrass	2.1E-02	6.1E-04	5.7E-03	8.0E-04	3.4E-02	7.2E-03
Virginia Creeper	1.3E-02	2.9E-03	1.3E-02	2.9E-03	1.3E-02	2.9E-03
Wood's Rose	3.7E-03	2.6E-04	1.2E-03	1.5E-04	8.7E-03	2.4E-03
Green Algae	7.8E-01	9.2E-02	7.8E-01	9.2E-02	7.8E-01	9.2E-02
Russian knapweed	5.9E-03	4.2E-04	1.6E-03	2.2E-04	9.1E-03	1.1E-03
Siberian elm	1.4E-02	3.5E-03	1.4E-02	3.5E-03	1.4E-02	3.5E-03
Curled Pondweed	7.0E-02	5.4E-03	6.2E-02	5.5E-03	7.8E-02	6.9E-03
Mimosa	1.8E-01	2.5E-02	1.8E-01	2.5E-02	1.8E-01	2.5E-02
Acorns (oak)	3.7E-03	4.7E-04	3.7E-03	4.7E-04	3.7E-03	4.7E-04
Horn Rapids						
Sand dropseed	1.5E-02	1.3E-03	7.2E-03	9.6E-04	2.9E-02	6.6E-03
Russian thistle	2.3E-02	2.0E-03	1.1E-02	1.4E-03	4.3E-02	6.2E-03
Rush skeletonweed	2.6E-02	2.1E-03	5.7E-03	7.6E-04	7.9E-02	1.1E-02
Prickly lettuce	7.9E-03	6.8E-04	5.0E-03	6.6E-04	1.2E-02	1.5E-03
3luebunch Wheatgras	1.5E-02	1.3E-03	9.1E-03	1.2E-03	4.1E-02	7.4E-03
Mare's tail	8.1E-03	7.9E-04	7.1E-03	9.1E-04	8.6E-03	1.1E-03
Sagebrush	7.3E-03	6.9E-04	3.9E-03	5.0E-04	1.1E-02	2.5E-03
Snow buckwheat	4.2E-02	6.7E-03	4.2E-02	6.7E-03	4.2E-02	6.7E-03
Russian thistle (Kali)	9.4E-03	1.2E-03	9.4E-03	1.2E-03	9.4E-03	1.2E-03
Cheat grass	1.5E-01	1.3E-02	4.5E-02	8.2E-03	2.8E-01	3.9E-02
Vernita Shoreline						
Rush	5.7E-02	4.1E-03	3.4E-02	4.4E-03	1.3E-01	1.9E-02
olumbia river gumwe	8.6E-02	6.1E-03	3.1E-02	5.6E-03	2.3E-01	3.5E-02
Velvet Lupine	2.8E-02	2.3E-03	1.4E-02	1.8E-03	4.3E-02	6.5E-03
Curly Dock	1.5E-02	1.0E-03	8.0E-03	1.1E-03	3.6E-02	1.1E-02
Riparian Wheat Grass	1.7E-02	1.0E-03	1.5E-03	2.0E-04	2.4E-02	3.1E-03
St Johns wort	5.8E-02	3.7E-03	5.7E-03	1.0E-03	7.8E-02	1.1E-02
Reed Canarygrass	7.6E-02	5.8E-03	4.0E-02	5.2E-03	1.1E-01	1.9E-02
Siberian elm	6.2E-03	4.4E-04	2.0E-03	2.6E-04	1.2E-02	2.3E-03
Columbia tickseed	1.2E-02	8.3E-04	1.8E-03	4.7E-04	2.4E-02	4.6E-03
identified Aquatic Pl	4.6E-01	6.8E-02	4.6E-01	6.8E-02	4.6E-01	6.8E-02
Eurasin milfoil	6.1E-01	7.1E-02	6.1E-01	7.1E-02	6.1E-01	7.1E-02
Green Algae	5.1E-01	6.3E-02	5.1E-01	6.3E-02	5.1E-01	6.3E-02

Table A-14 Average, Min, and Max Concentration Ratios by plant species for Nickel

Nickel						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	7.5E-02	1.7E-02	2.6E-02	1.8E-02	1.2E-01	4.6E-02
Rush	1.6E-01	7.7E-03	2.5E-02	1.0E-02	3.4E-01	1.3E-01
White Mulbery	1.4E-02	2.8E-03	2.5E-03	1.7E-03	2.5E-02	1.8E-02
Curly Dock	1.1E-01	2.2E-02	2.1E-02	1.5E-02	2.5E-01	1.8E-01
Grass	1.1E-01	2.5E-02	8.2E-02	5.8E-02	1.7E-01	6.1E-02
Scouring Rush	3.2E-01	7.0E-02	2.4E-01	9.0E-02	4.0E-01	1.5E-01
Coyote willow	5.0E-02	1.8E-02	5.0E-02	1.8E-02	5.0E-02	1.8E-02
Lupine	1.4E-01	5.7E-02	1.4E-01	5.7E-02	1.4E-01	5.7E-02
Purple Loosestrife	5.7E-02	1.0E-02	3.3E-02	1.2E-02	9.2E-02	3.5E-02
Field Bindweed	1.2E-01	4.6E-02	1.2E-01	4.6E-02	1.2E-01	4.6E-02
Bladderwort	1.3E-01	2.6E-02	7.5E-02	2.7E-02	2.6E-01	1.0E-01
Mullein	2.4E-01	4.8E-02	1.2E-01	4.2E-02	3.4E-01	1.3E-01
Reed canarygrass	6.6E-02	1.3E-02	3.7E-02	2.2E-02	1.1E-01	4.7E-02
Virginia Creeper	1.8E-02	1.3E-02	1.8E-02	1.3E-02	1.8E-02	1.3E-02
Wood's Rose	1.1E-02	2.5E-03	3.7E-03	2.2E-03	2.1E-02	1.5E-02
Green Algae	1.5E+00	6.2E-01	1.5E+00	6.2E-01	1.5E+00	6.2E-01
Russian knapweed	1.6E-02	4.1E-03	6.0E-03	4.2E-03	2.6E-02	1.8E-02
Siberian elm	2.0E-02	1.2E-02	2.0E-02	1.2E-02	2.0E-02	1.2E-02
Curled Pondweed	4.1E-01	8.5E-02	3.2E-01	7.6E-02	5.0E-01	1.5E-01
Mimosa	5.4E-01	2.0E-01	5.4E-01	2.0E-01	5.4E-01	2.0E-01
Acorns (oak)	1.0E-02	6.1E-03	1.0E-02	6.1E-03	1.0E-02	6.1E-03
Horn Rapids						
Sand dropseed	2.7E-02	7.5E-03	1.6E-02	9.8E-03	4.0E-02	1.7E-02
Russian thistle	5.0E-02	9.9E-03	1.5E-02	9.0E-03	8.8E-02	3.2E-02
Rush skeletonweed	7.5E-02	1.3E-02	1.2E-02	7.4E-03	2.0E-01	7.6E-02
Prickly lettuce	3.0E-02	5.3E-03	9.3E-03	3.9E-03	1.1E-01	2.8E-02
3luebunch Wheatgras	5.3E-02	9.0E-03	1.7E-02	7.1E-03	9.8E-02	2.9E-02
Mare's tail	1.1E-02	2.8E-03	8.7E-03	3.6E-03	1.3E-02	5.3E-03
Sagebrush	2.2E-02	4.9E-03	1.0E-02	4.2E-03	3.3E-02	1.0E-02
Snow buckwheat	2.9E-02	1.2E-02	2.9E-02	1.2E-02	2.9E-02	1.2E-02
Russian thistle (Kali)	1.5E-02	6.1E-03	1.5E-02	6.1E-03	1.5E-02	6.1E-03
Cheat grass	1.1E-01	2.0E-02	4.8E-02	2.0E-02	1.8E-01	7.7E-02
Vernita Shoreline						
Rush	2.2E-01	4.5E-02	1.6E-01	6.8E-02	2.8E-01	8.5E-02
olumbia river gumwe	1.2E-01	2.2E-02	4.7E-02	1.9E-02	2.9E-01	1.3E-01
Velvet Lupine	1.4E-01	2.8E-02	6.1E-02	2.7E-02	2.4E-01	7.5E-02
Curly Dock	1.6E-01	3.0E-02	6.2E-02	2.8E-02	2.3E-01	6.8E-02
Riparian Wheat Grass	1.5E-01	2.3E-02	9.6E-03	3.7E-03	5.1E-01	1.9E-01
St Johns wort	2.0E-01	3.1E-02	2.7E-02	1.0E-02	3.2E-01	9.7E-02
Reed Canarygrass	2.6E-01	6.3E-02	6.7E-02	9.4E-02	6.6E-01	2.2E-01
Siberian elm	9.6E-02	1.9E-02	5.6E-02	1.8E-02	1.4E-01	4.3E-02
Columbia tickseed	1.3E-01	2.1E-02	3.5E-02	9.7E-03	2.9E-01	7.7E-02
identified Aquatic Pl	6.4E-01	2.4E-01	6.4E-01	2.4E-01	6.4E-01	2.4E-01
Eurasin milfoil	4.8E-01	1.8E-01	4.8E-01	1.8E-01	4.8E-01	1.8E-01
Green Algae	5.1E-01	1.9E-01	5.1E-01	1.9E-01	5.1E-01	1.9E-01

Table A-15 Average, Min, and Max Concentration Ratios by plant species for Rubidium

Rubidum						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	2.3E-01	9.2E-03	1.7E-01	9.3E-03	3.4E-01	1.9E-02
Rush	2.4E-01	8.0E-04	1.3E-02	8.4E-04	6.5E-01	3.9E-02
White Mulbery	1.4E-02	5.0E-04	2.2E-03	1.9E-04	2.6E-02	2.2E-03
Curly Dock	2.7E-01	9.6E-03	7.5E-02	4.7E-03	6.7E-01	4.0E-02
Grass	4.7E-01	1.4E-02	3.8E-01	2.2E-02	6.2E-01	3.1E-02
Scouring Rush	4.3E-01	1.8E-02	2.8E-01	2.1E-02	6.1E-01	4.1E-02
Coyote willow	1.4E-01	7.8E-03	1.4E-01	7.8E-03	1.4E-01	7.8E-03
Lupine	1.6E-01	9.0E-03	1.6E-01	9.0E-03	1.6E-01	9.0E-03
Purple Loosestrife	1.3E-01	4.8E-03	9.1E-02	5.7E-03	1.7E-01	9.2E-03
Field Bindweed	1.7E-01	1.2E-02	1.7E-01	1.2E-02	1.7E-01	1.2E-02
Bladderwort	1.9E-01	7.6E-03	1.0E-01	8.0E-03	3.2E-01	1.8E-02
Mullein	4.1E-01	1.6E-02	2.9E-01	1.7E-02	6.5E-01	3.9E-02
Reed canarygrass	7.7E-02	2.0E-03	5.2E-02	3.4E-03	1.2E-01	8.7E-03
Virginia Creeper	5.2E-02	3.1E-03	5.2E-02	3.1E-03	5.2E-02	3.1E-03
Wood's Rose	1.1E-02	4.6E-04	7.1E-03	4.6E-04	1.5E-02	1.5E-03
Green Algae	6.7E-01	4.4E-02	6.7E-01	4.4E-02	6.7E-01	4.4E-02
Russian knapweed	4.7E-02	1.6E-03	6.8E-03	5.2E-04	6.7E-02	4.1E-03
Siberian elm	6.3E-02	3.5E-03	6.3E-02	3.5E-03	6.3E-02	3.5E-03
Curled Pondweed	1.8E-01	1.0E-02	1.5E-01	1.1E-02	2.0E-01	1.5E-02
Mimosa	4.5E-02	3.7E-03	4.5E-02	3.7E-03	4.5E-02	3.7E-03
Acorns (oak)	1.0E-01	5.2E-03	1.0E-01	5.2E-03	1.0E-01	5.2E-03
Horn Rapids						
Sand dropseed	2.3E-02	1.1E-03	1.6E-02	1.3E-03	3.7E-02	2.9E-03
Russian thistle	1.4E-01	5.9E-03	9.8E-02	5.4E-03	2.2E-01	1.4E-02
Rush skeletonweed	3.6E-02	1.6E-03	1.9E-02	1.4E-03	6.7E-02	1.1E-02
Prickly lettuce	3.1E-02	1.3E-03	2.4E-02	1.6E-03	3.9E-02	2.2E-03
luebunch Wheatgras	3.3E-02	1.5E-03	1.4E-02	1.5E-03	6.3E-02	4.4E-03
Mare's tail	3.4E-02	1.6E-03	2.5E-02	1.7E-03	4.1E-02	2.3E-03
Sagebrush	2.6E-02	1.3E-03	2.5E-02	1.6E-03	2.7E-02	1.6E-03
Snow buckwheat	4.6E-02	3.4E-03	4.6E-02	3.4E-03	4.6E-02	3.4E-03
Russian thistle (Kali)	2.9E-02	2.0E-03	2.9E-02	2.0E-03	2.9E-02	2.0E-03
Cheat grass	2.1E-01	8.7E-03	5.9E-02	4.8E-03	4.0E-01	2.5E-02
Vernita Shoreline						
Rush	3.1E-01	1.4E-02	1.9E-01	2.0E-02	4.0E-01	2.5E-02
lumbia river gumwe	2.5E-01	1.0E-02	1.0E-01	7.0E-03	6.7E-01	4.0E-02
Velvet Lupine	4.0E-01	1.7E-02	2.7E-01	1.5E-02	5.9E-01	3.2E-02
Curly Dock	9.9E-01	3.9E-02	3.3E-01	1.8E-02	1.7E+00	9.1E-02
Riparian Wheat Grass	2.0E-01	7.6E-03	3.0E-02	1.7E-03	2.8E-01	1.7E-02
St Johns wort	9.5E-02	3.6E-03	5.2E-03	5.9E-04	1.7E-01	1.0E-02
Reed Canarygrass	3.6E-01	1.5E-02	1.3E-01	8.6E-03	5.1E-01	3.2E-02
Siberian elm	1.5E-01	6.3E-03	9.9E-02	5.3E-03	2.4E-01	1.3E-02
Columbia tickseed	4.0E-01	1.5E-02	6.2E-02	3.3E-03	5.7E-01	2.9E-02
identified Aquatic Pl	4.3E-01	4.6E-02	4.3E-01	4.6E-02	4.3E-01	4.6E-02
Eurasin milfoil	5.3E-01	4.0E-02	5.3E-01	4.0E-02	5.3E-01	4.0E-02
Green Algae	8.8E-01	5.4E-02	8.8E-01	5.4E-02	8.8E-01	5.4E-02

Table A-16 Average, Min, and Max Concentration Ratios by plant species for Samarium

Samarium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.6E-02	2.9E-04	1.1E-02	3.6E-04	2.2E-02	1.0E-03
Rush	1.3E-01	6.6E-04	1.4E-02	1.1E-03	4.0E-01	9.0E-03
White Mulbery	4.5E-03	4.9E-05	9.7E-04	6.0E-05	7.4E-03	7.1E-04
Curly Dock	2.2E-02	2.4E-03	1.7E-03	2.9E-03	4.5E-02	6.1E-02
Grass	1.5E-01	8.1E-04	2.6E-02	8.5E-04	2.9E-01	5.3E-03
Scouring Rush	2.7E-01	2.9E-03	1.5E-01	1.0E-02	4.6E-01	1.3E-02
Coyote willow	4.6E-02	1.1E-03	4.6E-02	1.1E-03	4.6E-02	1.1E-03
Lupine	3.4E-02	1.2E-03	3.4E-02	1.2E-03	3.4E-02	1.2E-03
Purple Loosestrife	1.5E-02	2.4E-04	6.8E-03	5.3E-04	3.8E-02	1.4E-03
Field Bindweed	5.6E-02	1.2E-03	5.6E-02	1.2E-03	5.6E-02	1.2E-03
Bladderwort	1.2E-01	9.8E-04	9.1E-03	8.3E-04	2.9E-01	1.5E-02
Mullein	2.0E-01	1.6E-03	2.8E-02	1.3E-03	4.0E-01	9.0E-03
Reed canarygrass	2.3E-02	4.4E-04	9.6E-03	1.0E-03	3.8E-02	2.3E-03
Virginia Creeper	1.6E-02	1.3E-03	1.6E-02	1.3E-03	1.6E-02	1.3E-03
Wood's Rose	4.3E-03	4.9E-05	8.5E-04	6.8E-05	9.3E-03	4.9E-04
Green Algae	7.8E-01	1.6E-02	7.8E-01	1.6E-02	7.8E-01	1.6E-02
Russian knapweed	3.6E-03	8.2E-05	1.9E-03	2.3E-04	5.8E-03	3.2E-04
Siberian elm	1.0E-02	2.4E-04	1.0E-02	2.4E-04	1.0E-02	2.4E-04
Curled Pondweed	5.0E-03	2.8E-03	3.8E-03	5.4E-03	6.3E-03	3.3E-03
Mimosa	8.9E-03	1.2E-03	8.9E-03	1.2E-03	8.9E-03	1.2E-03
Acorns (oak)	1.5E-04	3.7E-05	1.5E-04	3.7E-05	1.5E-04	3.7E-05
Horn Rapids						
Sand dropseed	1.3E-02	1.4E-04	1.9E-03	2.2E-04	2.8E-02	4.9E-04
Russian thistle	3.9E-03	9.4E-05	1.4E-03	3.4E-04	9.6E-03	5.6E-04
Rush skeletonweed	1.1E-02	9.7E-05	5.7E-03	9.5E-05	1.6E-02	4.5E-04
Prickly lettuce	6.2E-03	6.3E-05	3.2E-03	8.9E-05	1.3E-02	3.3E-04
3luebunch Wheatgras	1.7E-02	1.4E-04	3.3E-03	1.4E-04	5.0E-02	6.8E-04
Mare's tail	3.6E-03	1.2E-04	2.6E-03	1.7E-04	4.4E-03	2.3E-04
Sagebrush	8.8E-03	1.3E-04	6.2E-03	1.5E-04	1.1E-02	2.2E-04
Snow buckwheat	4.7E-02	6.5E-04	4.7E-02	6.5E-04	4.7E-02	6.5E-04
Russian thistle (Kali)	4.2E-03	1.2E-04	4.2E-03	1.2E-04	4.2E-03	1.2E-04
Cheat grass	1.9E-01	1.2E-03	4.8E-02	7.2E-04	3.6E-01	4.7E-03
Vernita Shoreline						
Rush	4.0E-02	1.0E-03	1.1E-02	2.1E-03	1.1E-01	8.2E-03
›lumbia river gumwe	1.1E-01	8.1E-04	4.6E-02	8.9E-04	2.8E-01	4.4E-03
Velvet Lupine	3.4E-02	3.7E-04	1.0E-02	5.3E-04	4.6E-02	8.4E-04
Curly Dock	1.9E-02	2.7E-04	1.4E-02	6.4E-04	3.6E-02	1.1E-03
Riparian Wheat Grass	1.5E-02	1.1E-04	9.9E-04	5.9E-05	3.5E-02	1.4E-03
St Johns wort	4.2E-02	8.0E-04	3.7E-03	8.4E-04	5.9E-02	2.1E-03
Reed Canarygrass	7.2E-02	1.2E-03	2.4E-02	2.3E-03	1.3E-01	3.2E-03
Siberian elm	9.5E-03	1.1E-04	1.7E-03	9.5E-05	1.4E-02	3.1E-04
Columbia tickseed	1.6E-02	1.2E-04	2.1E-03	6.4E-05	2.6E-02	8.3E-04
identified Aquatic Pl	4.1E-01	1.0E-02	4.1E-01	1.0E-02	4.1E-01	1.0E-02
Eurasin milfoil	6.9E-01	2.3E-02	6.9E-01	2.3E-02	6.9E-01	2.3E-02
Green Algae	7.5E-01	1.1E-02	7.5E-01	1.1E-02	7.5E-01	1.1E-02

Table A-17 Average, Min, and Max Concentration Ratios by plant species for Scandium

Scandium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.7E-02	1.8E-04	1.0E-02	1.9E-04	2.9E-02	5.6E-04
Rush	1.3E-01	2.3E-04	1.6E-02	3.0E-04	3.9E-01	7.0E-03
White Mulbery	4.2E-03	3.3E-05	9.9E-04	2.0E-05	6.6E-03	1.3E-04
Curly Dock	7.7E-02	6.0E-04	1.0E-02	1.9E-04	1.9E-01	3.4E-03
Grass	1.4E-01	9.2E-03	5.3E-02	1.1E-02	2.5E-01	3.3E-02
Scouring Rush	2.4E-01	2.1E-03	8.8E-02	1.7E-03	4.7E-01	8.5E-03
Coyote willow	4.6E-02	8.4E-04	4.6E-02	8.4E-04	4.6E-02	8.4E-04
Lupine	3.3E-02	6.1E-04	3.3E-02	6.1E-04	3.3E-02	6.1E-04
Purple Loosestrife	1.3E-02	1.1E-04	6.3E-03	1.3E-04	3.6E-02	6.7E-04
Field Bindweed	3.7E-02	7.0E-04	3.7E-02	7.0E-04	3.7E-02	7.0E-04
Bladderwort	9.8E-02	7.5E-04	8.4E-03	2.0E-04	2.6E-01	4.7E-03
Mullein	1.8E-01	1.4E-03	2.8E-02	5.6E-04	3.9E-01	7.0E-03
Reed canarygrass	6.0E-02	3.2E-03	3.2E-02	5.0E-03	1.2E-01	1.9E-02
Virginia Creeper	1.1E-02	2.1E-04	1.1E-02	2.1E-04	1.1E-02	2.1E-04
Wood's Rose	3.0E-03	2.5E-05	5.9E-04	1.2E-05	5.5E-03	1.0E-04
Green Algae	8.9E-01	1.6E-02	8.9E-01	1.6E-02	8.9E-01	1.6E-02
Russian knapweed	3.7E-03	3.5E-05	1.9E-03	3.6E-05	6.2E-03	1.2E-04
Siberian elm	7.6E-03	1.4E-04	7.6E-03	1.4E-04	7.6E-03	1.4E-04
Curled Pondweed	1.5E-02	2.5E-04	1.5E-02	3.4E-04	1.5E-02	3.2E-04
Mimosa	5.6E-03	5.8E-04	5.6E-03	5.8E-04	5.6E-03	5.8E-04
Acorns (oak)	2.0E-04	9.9E-06	2.0E-04	9.9E-06	2.0E-04	9.9E-06
Horn Rapids						
Sand dropseed	1.1E-02	8.6E-05	1.6E-03	3.3E-05	2.7E-02	4.9E-04
Russian thistle	2.4E-03	2.5E-05	8.9E-04	4.9E-05	5.8E-03	1.5E-04
Rush skeletonweed	9.1E-03	9.2E-05	4.7E-03	8.7E-05	1.4E-02	2.6E-04
Prickly lettuce	4.6E-03	4.1E-05	2.0E-03	3.9E-05	1.1E-02	2.1E-04
3luebunch Wheatgras	1.6E-02	1.2E-04	2.5E-03	5.2E-05	4.7E-02	8.5E-04
Mare's tail	2.3E-03	2.6E-05	1.3E-03	2.6E-05	3.2E-03	6.0E-05
Sagebrush	6.7E-03	7.7E-05	3.8E-03	7.0E-05	9.5E-03	1.7E-04
Snow buckwheat	3.7E-02	6.7E-04	3.7E-02	6.7E-04	3.7E-02	6.7E-04
Russian thistle (Kali)	2.6E-03	5.2E-05	2.6E-03	5.2E-05	2.6E-03	5.2E-05
Cheat grass	1.7E-01	1.4E-03	4.4E-02	8.1E-04	3.2E-01	5.9E-03
Vernita Shoreline						
Rush	4.5E-02	4.1E-04	1.6E-02	4.2E-04	1.2E-01	2.2E-03
ılumbia river gumwe	1.1E-01	9.6E-04	4.3E-02	7.9E-04	2.8E-01	5.2E-03
Velvet Lupine	3.8E-02	3.3E-04	9.8E-03	2.1E-04	6.3E-02	1.1E-03
Curly Dock	2.3E-02	2.3E-04	1.5E-02	2.8E-04	4.1E-02	7.7E-04
Riparian Wheat Grass	1.6E-02	1.2E-04	1.3E-03	2.8E-05	3.5E-02	6.3E-04
St Johns wort	5.9E-02	4.7E-04	1.1E-02	2.0E-04	8.5E-02	1.5E-03
Reed Canarygrass	9.2E-02	8.3E-04	3.4E-02	7.3E-04	1.7E-01	3.1E-03
Siberian elm	1.2E-02	9.5E-05	2.0E-03	3.8E-05	1.7E-02	3.1E-04
Columbia tickseed	2.0E-02	1.5E-04	2.7E-03	5.0E-05	3.4E-02	6.3E-04
identified Aquatic Pl	4.6E-01	8.4E-03	4.6E-01	8.4E-03	4.6E-01	8.4E-03
Eurasin milfoil	6.3E-01	1.1E-02	6.3E-01	1.1E-02	6.3E-01	1.1E-02
Green Algae	8.7E-01	1.6E-02	8.7E-01	1.6E-02	8.7E-01	1.6E-02

Table A-18 Average, Min, and Max Concentration Ratios by plant species for Sodium

Sodium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	2.6E-02	4.9E-04	1.6E-02	5.1E-04	3.1E-02	1.4E-03
Rush	1.5E-01	4.7E-04	1.7E-02	6.0E-04	5.1E-01	2.3E-02
White Mulbery	5.5E-03	7.2E-05	2.0E-03	8.3E-05	1.4E-02	4.4E-04
Curly Dock	1.3E-01	1.5E-03	2.7E-02	8.5E-04	3.3E-01	1.1E-02
Grass	1.3E-01	8.2E-04	3.5E-02	8.5E-04	2.3E-01	5.5E-03
Scouring Rush	2.8E-01	4.3E-03	8.0E-02	3.7E-03	4.9E-01	2.2E-02
Coyote willow	4.6E-02	1.1E-03	4.6E-02	1.1E-03	4.6E-02	1.1E-03
Lupine	3.3E-02	1.2E-03	3.3E-02	1.2E-03	3.3E-02	1.2E-03
Purple Loosestrife	7.4E-02	8.6E-04	3.9E-02	9.4E-04	9.7E-02	4.4E-03
Field Bindweed	2.7E-02	1.3E-03	2.7E-02	1.3E-03	2.7E-02	1.3E-03
Bladderwort	1.6E-01	2.1E-03	4.7E-02	2.2E-03	3.2E-01	8.2E-03
Mullein	2.1E-01	2.6E-03	3.1E-02	1.4E-03	5.1E-01	2.3E-02
Reed canarygrass	2.9E-02	3.7E-04	1.5E-02	6.8E-04	4.7E-02	1.7E-03
Virginia Creeper	2.3E-02	7.0E-04	2.3E-02	7.0E-04	2.3E-02	7.0E-04
Wood's Rose	5.4E-03	6.3E-05	1.9E-03	4.2E-05	1.1E-02	3.4E-04
Green Algae	4.5E-01	1.7E-02	4.5E-01	1.7E-02	4.5E-01	1.7E-02
Russian knapweed	5.8E-02	8.0E-04	4.9E-02	1.1E-03	6.9E-02	1.5E-03
Siberian elm	4.1E-02	9.1E-04	4.1E-02	9.1E-04	4.1E-02	9.1E-04
Curled Pondweed	2.8E-01	8.6E-03	2.2E-01	1.0E-02	3.3E-01	1.5E-02
Mimosa	9.0E-03	5.1E-04	9.0E-03	5.1E-04	9.0E-03	5.1E-04
Acorns (oak)	4.3E-04	1.2E-05	4.3E-04	1.2E-05	4.3E-04	1.2E-05
Horn Rapids						
Sand dropseed	1.2E-02	1.5E-04	3.1E-03	1.2E-04	2.5E-02	6.1E-04
Russian thistle	6.9E-03	1.0E-04	4.4E-03	1.0E-04	1.1E-02	5.4E-04
Rush skeletonweed	1.2E-02	1.5E-04	4.9E-03	1.1E-04	1.9E-02	4.6E-04
Prickly lettuce	5.4E-03	7.0E-05	2.9E-03	6.7E-05	1.1E-02	4.1E-04
3luebunch Wheatgras	1.8E-02	2.1E-04	3.6E-03	1.1E-04	5.2E-02	1.6E-03
Mare's tail	2.8E-03	7.9E-05	2.1E-03	1.1E-04	3.8E-03	1.7E-04
Sagebrush	6.2E-03	1.6E-04	3.2E-03	1.7E-04	9.1E-03	3.1E-04
Snow buckwheat	3.8E-02	1.2E-03	3.8E-02	1.2E-03	3.8E-02	1.2E-03
Russian thistle (Kali)	5.1E-03	1.6E-04	5.1E-03	1.6E-04	5.1E-03	1.6E-04
Cheat grass	2.0E-01	2.3E-03	4.5E-02	1.4E-03	3.8E-01	1.2E-02
Vernita Shoreline						
Rush	9.0E-02	1.4E-03	7.0E-02	2.0E-03	1.1E-01	3.3E-03
olumbia river gumwe	9.2E-02	1.2E-03	4.4E-02	1.4E-03	2.4E-01	5.7E-03
Velvet Lupine	2.3E-02	3.0E-04	9.4E-03	2.4E-04	3.5E-02	8.5E-04
Curly Dock	5.8E-02	8.1E-04	4.4E-02	1.1E-03	8.8E-02	2.1E-03
Riparian Wheat Grass	1.4E-02	1.5E-04	9.5E-04	2.7E-05	2.6E-02	7.5E-04
St Johns wort	5.7E-02	6.2E-04	6.2E-03	1.5E-04	8.1E-02	2.0E-03
Reed Canarygrass	7.4E-02	1.0E-03	5.3E-02	1.3E-03	1.1E-01	3.1E-03
Siberian elm	8.3E-03	1.1E-04	3.7E-03	9.0E-05	1.1E-02	2.7E-04
Columbia tickseed	2.2E-02	2.4E-04	2.8E-03	6.9E-05	3.4E-02	1.1E-03
identified Aquatic Pl	3.0E-01	8.5E-03	3.0E-01	8.5E-03	3.0E-01	8.5E-03
Eurasin milfoil	4.4E-01	1.2E-02	4.4E-01	1.2E-02	4.4E-01	1.2E-02
Green Algae	6.4E-01	1.8E-02	6.4E-01	1.8E-02	6.4E-01	1.8E-02

Table A-19 Average, Min, and Max Concentration Ratios by plant species for Strontium

Strontium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.1E-01	1.1E-02	5.3E-02	2.0E-02	1.5E-01	2.2E-02
Rush	2.0E-01	2.0E-03	1.6E-02	2.1E-03	5.3E-01	7.5E-02
White Mulbery	4.9E-02	3.8E-03	1.2E-02	1.5E-03	8.3E-02	1.0E-02
Curly Dock	6.8E-01	5.2E-02	1.3E-01	1.5E-02	1.7E+00	2.1E-01
Grass	1.8E-01	3.2E-03	1.6E-02	3.6E-03	3.9E-01	1.9E-02
Scouring Rush	3.3E-01	3.4E-02	2.0E-01	4.8E-02	4.9E-01	7.5E-02
Coyote willow	1.0E-01	1.3E-02	1.0E-01	1.3E-02	1.0E-01	1.3E-02
Lupine	2.0E-01	2.4E-02	2.0E-01	2.4E-02	2.0E-01	2.4E-02
Purple Loosestrife	1.4E-01	1.1E-02	1.1E-01	1.3E-02	2.0E-01	2.6E-02
Field Bindweed	1.0E-01	2.1E-02	1.0E-01	2.1E-02	1.0E-01	2.1E-02
Bladderwort	2.4E-01	2.0E-02	1.5E-01	1.9E-02	3.7E-01	4.2E-02
Mullein	2.8E-01	2.5E-02	2.0E-01	4.3E-02	5.3E-01	7.5E-02
Reed canarygrass	2.5E-02	3.0E-04	4.4E-03	3.2E-04	5.3E-02	3.2E-03
Virginia Creeper	1.3E-01	1.6E-02	1.3E-01	1.6E-02	1.3E-01	1.6E-02
Wood's Rose	6.5E-02	5.1E-03	2.5E-02	2.7E-03	8.5E-02	1.0E-02
Green Algae	2.9E-01	5.3E-02	2.9E-01	5.3E-02	2.9E-01	5.3E-02
Russian knapweed	1.6E-01	1.3E-02	4.9E-02	5.9E-03	2.2E-01	2.3E-02
Siberian elm	1.7E-01	1.8E-02	1.7E-01	1.8E-02	1.7E-01	1.8E-02
Curled Pondweed	3.1E-01	3.3E-02	2.8E-01	3.9E-02	3.4E-01	4.2E-02
Mimosa	1.1E-01	1.9E-02	1.1E-01	1.9E-02	1.1E-01	1.9E-02
Acorns (oak)	2.2E-02	2.9E-03	2.2E-02	2.9E-03	2.2E-02	2.9E-03
Horn Rapids						
Sand dropseed	2.2E-02	2.5E-03	1.6E-02	2.9E-03	3.3E-02	5.1E-03
Russian thistle	1.6E-01	1.5E-02	8.1E-02	9.7E-03	2.9E-01	4.0E-02
Rush skeletonweed	1.3E-01	1.2E-02	7.2E-02	8.5E-03	2.2E-01	3.7E-02
Prickly lettuce	7.0E-02	6.5E-03	5.5E-02	7.9E-03	8.6E-02	1.0E-02
3luebunch Wheatgras	3.8E-02	3.8E-03	2.5E-02	4.7E-03	6.2E-02	9.2E-03
Mare's tail	7.2E-02	7.0E-03	5.7E-02	6.9E-03	8.6E-02	1.0E-02
Sagebrush	6.7E-02	6.8E-03	5.1E-02	6.2E-03	8.3E-02	9.7E-03
Snow buckwheat	1.8E-01	2.1E-02	1.8E-01	2.1E-02	1.8E-01	2.1E-02
Russian thistle (Kali)	9.1E-02	1.1E-02	9.1E-02	1.1E-02	9.1E-02	1.1E-02
Cheat grass	2.0E-01	1.9E-02	8.8E-02	1.3E-02	3.5E-01	5.1E-02
Vernita Shoreline						
Rush	5.2E-02	3.7E-03	2.2E-02	3.4E-03	1.1E-01	2.1E-02
olumbia river gumwe	2.5E-01	1.7E-02	1.1E-01	1.2E-02	7.7E-01	8.5E-02
Velvet Lupine	2.3E-01	1.8E-02	2.0E-01	2.1E-02	2.8E-01	3.0E-02
Curly Dock	1.4E-01	1.0E-02	9.7E-02	1.1E-02	2.7E-01	3.0E-02
Riparian Wheat Grass	1.9E-02	1.2E-03	1.0E-03	1.6E-04	5.6E-02	8.0E-03
St Johns wort	1.5E-01	9.7E-03	2.2E-02	2.5E-03	2.1E-01	2.3E-02
Reed Canarygrass	7.9E-02	5.6E-03	2.7E-02	4.2E-03	1.7E-01	2.7E-02
Siberian elm	7.3E-02	5.6E-03	5.0E-02	5.3E-03	1.1E-01	1.2E-02
Columbia tickseed	1.1E-01	6.9E-03	1.4E-02	1.5E-03	1.7E-01	1.8E-02
identified Aquatic Pl	2.9E-01	5.5E-02	2.9E-01	5.5E-02	2.9E-01	5.5E-02
Eurasin milfoil	3.3E-01	4.8E-02	3.3E-01	4.8E-02	3.3E-01	4.8E-02
Green Algae	5.0E-01	6.1E-02	5.0E-01	6.1E-02	5.0E-01	6.1E-02

Table A-20 Average, Min, and Max Concentration Ratios by plant species for Thallium

Thallium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	8.3E-03	3.3E-04	4.5E-03	3.2E-04	1.4E-02	3.8E-03
Rush	1.3E-01	5.5E-04	9.2E-03	6.6E-04	4.7E-01	2.5E-02
White Mulbery	2.7E-03	7.5E-05	2.8E-04	2.3E-05	4.6E-03	6.0E-04
Curly Dock	7.1E-02	2.1E-03	6.6E-03	9.8E-04	1.8E-01	1.4E-02
Grass	8.3E-02	2.3E-03	4.4E-03	3.2E-04	3.9E-01	1.9E-02
Scouring Rush	2.7E-01	1.0E-02	9.9E-02	1.4E-02	4.6E-01	2.6E-02
Coyote willow	5.4E-02	3.6E-03	5.4E-02	3.6E-03	5.4E-02	3.6E-03
Lupine	3.2E-02	2.0E-03	3.2E-02	2.0E-03	3.2E-02	2.0E-03
Purple Loosestrife	1.0E-02	2.9E-04	2.5E-03	1.7E-04	3.9E-02	5.0E-03
Field Bindweed	3.9E-02	5.3E-03	3.9E-02	5.3E-03	3.9E-02	5.3E-03
Bladderwort	1.2E-01	3.2E-03	7.0E-03	5.0E-04	3.1E-01	1.5E-02
Mullein	1.9E-01	5.2E-03	9.2E-03	6.6E-04	4.7E-01	2.5E-02
Reed canarygrass	2.3E-02	1.0E-03	9.2E-03	1.7E-03	4.0E-02	2.6E-03
Virginia Creeper	1.3E-02	1.0E-03	1.3E-02	1.0E-03	1.3E-02	1.0E-03
Wood's Rose	1.2E-03	3.4E-05	2.3E-04	1.6E-05	3.1E-03	3.4E-04
Green Algae	6.1E-01	3.5E-02	6.1E-01	3.5E-02	6.1E-01	3.5E-02
Russian knapweed	2.8E-03	8.2E-05	6.8E-04	4.7E-05	5.2E-03	5.3E-04
Siberian elm	4.9E-03	9.2E-04	4.9E-03	9.2E-04	4.9E-03	9.2E-04
Curled Pondweed	1.4E-02	4.9E-04	1.1E-02	4.7E-04	1.7E-02	7.4E-04
Mimosa	5.3E-02	3.8E-03	5.3E-02	3.8E-03	5.3E-02	3.8E-03
Acorns (oak)	5.6E-04	3.9E-05	5.6E-04	3.9E-05	5.6E-04	3.9E-05
Horn Rapids						
Sand dropseed	1.0E-02	3.3E-04	9.9E-04	7.0E-05	2.6E-02	2.0E-03
Russian thistle	3.0E-03	1.0E-04	9.2E-04	6.5E-05	7.0E-03	5.1E-04
Rush skeletonweed	1.0E-02	5.7E-04	3.7E-03	6.9E-04	1.6E-02	1.1E-03
Prickly lettuce	5.4E-03	1.8E-04	8.9E-04	6.3E-05	1.3E-02	1.5E-03
3luebunch Wheatgras	1.4E-02	4.5E-04	1.4E-03	9.9E-05	4.1E-02	2.8E-03
Mare's tail	2.0E-03	7.4E-05	6.0E-04	4.2E-05	2.9E-03	5.1E-04
Sagebrush	6.3E-03	4.0E-04	3.9E-03	4.5E-04	8.6E-03	6.6E-04
Snow buckwheat	3.5E-02	2.4E-03	3.5E-02	2.4E-03	3.5E-02	2.4E-03
Russian thistle (Kali)	1.1E-03	8.0E-05	1.1E-03	8.0E-05	1.1E-03	8.0E-05
Cheat grass	1.6E-01	5.7E-03	4.1E-02	3.6E-03	3.2E-01	1.9E-02
Vernita Shoreline						
Rush	2.8E-02	7.6E-04	7.3E-03	4.8E-04	9.9E-02	8.0E-03
olumbia river gumwe	1.2E-01	3.4E-03	3.0E-02	2.3E-03	3.8E-01	1.8E-02
Velvet Lupine	2.2E-02	5.9E-04	2.7E-03	1.8E-04	3.5E-02	2.2E-03
Curly Dock	1.2E-02	6.4E-04	6.4E-03	1.5E-03	2.5E-02	3.0E-03
Riparian Wheat Grass	5.7E-03	1.5E-04	3.6E-04	2.4E-05	1.4E-02	1.5E-03
St Johns wort	4.1E-02	1.1E-03	2.8E-03	2.6E-04	6.2E-02	3.4E-03
Reed Canarygrass	4.8E-02	1.3E-03	8.9E-03	5.9E-04	9.6E-02	5.9E-03
Siberian elm	6.1E-03	1.6E-04	3.2E-04	2.2E-05	9.3E-03	7.6E-04
Columbia tickseed	6.8E-03	2.0E-04	1.4E-03	1.3E-04	1.7E-02	1.4E-03
identified Aquatic Pl	4.9E-01	2.9E-02	4.9E-01	2.9E-02	4.9E-01	2.9E-02
Eurasin milfoil	6.4E-01	3.2E-02	6.4E-01	3.2E-02	6.4E-01	3.2E-02
Green Algae	5.8E-01	2.9E-02	5.8E-01	2.9E-02	5.8E-01	2.9E-02

Table A-21 Average, Min, and Max Concentration Ratios by plant species for Terbium

Terbium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.3E-02	9.1E-04	1.0E-02	9.3E-04	1.7E-02	1.5E-03
Rush	1.5E-01	1.2E-03	1.8E-02	1.7E-03	5.0E-01	5.3E-02
White Mulbery	4.9E-03	2.9E-04	6.4E-04	6.8E-05	1.1E-02	2.7E-03
Curly Dock	1.1E-01	6.7E-03	1.4E-02	2.6E-03	2.7E-01	3.7E-02
Grass	1.7E-01	1.3E-03	1.4E-02	1.3E-03	3.3E-01	3.2E-02
Scouring Rush	3.5E-01	2.6E-02	1.4E-01	3.0E-02	6.1E-01	6.2E-02
Coyote willow	5.8E-02	8.0E-03	5.8E-02	8.0E-03	5.8E-02	8.0E-03
Lupine	4.1E-02	4.8E-03	4.1E-02	4.8E-03	4.1E-02	4.8E-03
Purple Loosestrife	1.2E-02	7.1E-04	5.5E-03	5.2E-04	3.6E-02	9.0E-03
Field Bindweed	5.8E-02	1.3E-02	5.8E-02	1.3E-02	5.8E-02	1.3E-02
Bladderwort	1.6E-01	9.0E-03	1.3E-02	1.2E-03	4.0E-01	3.4E-02
Mullein	2.1E-01	1.3E-02	2.1E-02	1.9E-03	5.0E-01	5.3E-02
Reed canarygrass	3.3E-02	9.9E-04	1.2E-02	1.1E-03	5.6E-02	6.2E-03
Virginia Creeper	2.2E-02	2.5E-03	2.2E-02	2.5E-03	2.2E-02	2.5E-03
Wood's Rose	4.8E-03	2.8E-04	4.8E-04	4.3E-05	8.7E-03	2.1E-03
Green Algae	1.1E+00	9.9E-02	1.1E+00	9.9E-02	1.1E+00	9.9E-02
Russian knapweed	3.7E-03	2.2E-04	1.6E-03	1.5E-04	7.4E-03	1.4E-03
Siberian elm	2.7E-03	2.4E-04	2.7E-03	2.4E-04	2.7E-03	2.4E-04
Curled Pondweed	3.9E-02	2.5E-03	3.5E-02	2.3E-03	4.4E-02	3.0E-03
Mimosa	6.2E-02	5.6E-03	6.2E-02	5.6E-03	6.2E-02	5.6E-03
Acorns (oak)	1.0E-03	9.4E-05	1.0E-03	9.4E-05	1.0E-03	9.4E-05
Horn Rapids						
Sand dropseed	1.2E-02	6.9E-04	1.5E-03	1.3E-04	2.9E-02	3.4E-03
Russian thistle	4.6E-03	2.7E-04	1.6E-03	1.4E-04	1.1E-02	9.9E-04
Rush skeletonweed	1.3E-02	1.0E-03	6.0E-03	1.1E-03	2.0E-02	1.8E-03
Prickly lettuce	6.4E-03	3.7E-04	1.4E-03	1.3E-04	1.8E-02	3.7E-03
3luebunch Wheatgras	1.5E-02	8.8E-04	2.7E-03	2.5E-04	4.1E-02	5.2E-03
Mare's tail	1.7E-03	1.2E-04	1.4E-03	1.2E-04	2.0E-03	1.8E-04
Sagebrush	9.7E-03	1.0E-03	6.8E-03	1.1E-03	1.3E-02	1.6E-03
Snow buckwheat	4.2E-02	4.4E-03	4.2E-02	4.4E-03	4.2E-02	4.4E-03
Russian thistle (Kali)	2.3E-03	2.1E-04	2.3E-03	2.1E-04	2.3E-03	2.1E-04
Cheat grass	2.1E-01	1.3E-02	6.3E-02	7.5E-03	4.2E-01	4.3E-02
Vernita Shoreline						
Rush	2.8E-02	7.6E-04	7.3E-03	4.8E-04	9.9E-02	8.0E-03
olumbia river gumwe	1.2E-01	3.4E-03	3.0E-02	2.3E-03	3.8E-01	1.8E-02
Velvet Lupine	2.2E-02	5.9E-04	2.7E-03	1.8E-04	3.5E-02	2.2E-03
Curly Dock	1.2E-02	6.4E-04	6.4E-03	1.5E-03	2.5E-02	3.0E-03
Riparian Wheat Grass	5.7E-03	1.5E-04	3.6E-04	2.4E-05	1.4E-02	1.5E-03
St Johns wort	4.1E-02	1.1E-03	2.8E-03	2.6E-04	6.2E-02	3.4E-03
Reed Canarygrass	4.8E-02	1.3E-03	8.9E-03	5.9E-04	9.6E-02	5.9E-03
Siberian elm	6.1E-03	1.6E-04	3.2E-04	2.2E-05	9.3E-03	7.6E-04
Columbia tickseed	6.8E-03	2.0E-04	1.4E-03	1.3E-04	1.7E-02	1.4E-03
identified Aquatic Pl	4.9E-01	2.9E-02	4.9E-01	2.9E-02	4.9E-01	2.9E-02
Eurasin milfoil	6.4E-01	3.2E-02	6.4E-01	3.2E-02	6.4E-01	3.2E-02
Green Algae	5.8E-01	2.9E-02	5.8E-01	2.9E-02	5.8E-01	2.9E-02

Table A-22 Average, Min, and Max Concentration Ratios by plant species for Thorium

Thorium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.5E-02	3.1E-04	8.6E-03	3.4E-04	2.1E-02	9.5E-04
Rush	1.3E-01	1.4E-04	1.1E-02	1.5E-04	4.1E-01	6.0E-03
White Mulbery	2.8E-03	3.0E-05	4.6E-04	4.9E-05	6.5E-03	2.3E-04
Curly Dock	3.9E-02	3.4E-04	5.0E-03	2.5E-04	9.5E-02	3.0E-03
Grass	1.2E-01	7.0E-04	1.6E-02	8.0E-04	2.4E-01	3.6E-03
Scouring Rush	2.4E-01	2.4E-03	1.0E-01	3.1E-03	3.6E-01	6.2E-03
Coyote willow	2.9E-02	7.3E-04	2.9E-02	7.3E-04	2.9E-02	7.3E-04
Lupine	2.9E-02	4.8E-04	2.9E-02	4.8E-04	2.9E-02	4.8E-04
Purple Loosestrife	1.1E-02	1.8E-04	2.7E-03	6.2E-04	2.3E-02	9.1E-04
Field Bindweed	7.2E-02	1.8E-03	7.2E-02	1.8E-03	7.2E-02	1.8E-03
Bladderwort	1.1E-01	9.7E-04	4.6E-03	1.1E-03	2.6E-01	3.2E-03
Mullein	1.9E-01	1.7E-03	2.2E-02	1.7E-03	4.1E-01	6.0E-03
Reed canarygrass	1.6E-02	1.8E-04	7.3E-03	2.6E-04	3.6E-02	6.0E-04
Virginia Creeper	1.3E-02	2.4E-04	1.3E-02	2.4E-04	1.3E-02	2.4E-04
Wood's Rose	2.2E-03	3.0E-05	3.2E-04	3.1E-05	4.0E-03	1.8E-04
Green Algae	5.6E-01	7.8E-03	5.6E-01	7.8E-03	5.6E-01	7.8E-03
Russian knapweed	2.4E-03	5.8E-05	1.3E-03	2.5E-04	4.3E-03	3.4E-04
Siberian elm	8.0E-03	2.4E-04	8.0E-03	2.4E-04	8.0E-03	2.4E-04
Curled Pondweed	1.6E-02	9.3E-04	9.7E-03	1.4E-03	2.2E-02	1.2E-03
Mimosa	2.6E-02	6.0E-03	2.6E-02	6.0E-03	2.6E-02	6.0E-03
Acorns (oak)	1.2E-04	2.2E-06	1.2E-04	2.2E-06	1.2E-04	2.2E-06
Horn Rapids						
Sand dropseed	1.0E-02	2.2E-04	1.4E-03	3.4E-04	2.1E-02	6.2E-04
Russian thistle	2.0E-03	2.9E-05	1.4E-03	2.9E-05	2.6E-03	3.6E-04
Rush skeletonweed	3.7E-02	3.8E-04	3.9E-03	8.0E-05	1.3E-01	1.9E-03
Prickly lettuce	5.1E-03	1.2E-04	2.6E-03	2.4E-04	9.6E-03	5.6E-04
luebunch Wheatgras	1.5E-02	2.4E-04	3.5E-03	4.7E-04	4.3E-02	9.0E-04
Mare's tail	3.1E-03	1.6E-04	2.9E-03	2.5E-04	3.4E-03	2.8E-04
Sagebrush	7.0E-03	1.5E-04	4.4E-03	1.7E-04	9.6E-03	2.3E-04
Snow buckwheat	4.8E-02	9.2E-04	4.8E-02	9.2E-04	4.8E-02	9.2E-04
Russian thistle (Kali)	3.7E-03	3.5E-04	3.7E-03	3.5E-04	3.7E-03	3.5E-04
Cheat grass	1.7E-01	1.8E-03	3.7E-02	9.8E-04	3.4E-01	6.1E-03
Vernita Shoreline						
Rush	3.4E-02	5.0E-04	7.0E-03	1.4E-03	1.2E-01	1.9E-03
lumbia river gumwe	7.2E-02	5.3E-04	2.6E-02	5.0E-04	2.1E-01	3.1E-03
Velvet Lupine	2.7E-02	2.8E-04	5.6E-03	4.7E-04	4.6E-02	6.6E-04
Curly Dock	1.1E-02	1.6E-04	6.4E-03	3.5E-04	1.7E-02	6.5E-04
Riparian Wheat Grass	7.4E-03	7.0E-05	5.5E-04	5.4E-05	1.4E-02	3.5E-04
St Johns wort	5.0E-02	3.1E-04	2.1E-03	6.6E-05	1.0E-01	1.2E-03
Reed Canarygrass	4.3E-02	5.3E-04	1.4E-02	1.3E-03	8.9E-02	2.0E-03
Siberian elm	5.9E-03	6.3E-05	8.3E-04	5.6E-05	1.0E-02	1.7E-04
Columbia tickseed	8.1E-03	5.6E-05	1.1E-03	2.6E-05	1.4E-02	3.3E-04
identified Aquatic Pl	3.2E-01	5.5E-03	3.2E-01	5.5E-03	3.2E-01	5.5E-03
Eurasin milfoil	7.7E-01	8.9E-03	7.7E-01	8.9E-03	7.7E-01	8.9E-03
Green Algae	4.9E-01	6.3E-03	4.9E-01	6.3E-03	4.9E-01	6.3E-03

Table A-23 Average, Min, and Max Concentration Ratios by plant species for Uranium

Uranium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	4.5E-02	2.8E-03	1.7E-02	3.1E-03	6.4E-02	6.8E-03
Rush	4.8E-01	3.5E-03	9.4E-02	1.3E-02	9.2E-01	4.5E-02
White Mulbery	2.7E-02	9.1E-04	4.5E-03	5.8E-04	8.4E-02	4.5E-03
Curly Dock	2.3E+00	7.7E-02	3.2E-01	1.5E-02	6.2E+00	2.7E-01
Grass	2.4E-01	6.1E-03	7.6E-02	7.1E-03	4.3E-01	2.2E-02
Scouring Rush	8.6E-01	3.1E-02	3.0E-01	2.5E-02	1.5E+00	6.5E-02
Coyote willow	1.1E-01	6.1E-03	1.1E-01	6.1E-03	1.1E-01	6.1E-03
Lupine	1.0E-01	5.6E-03	1.0E-01	5.6E-03	1.0E-01	5.6E-03
Purple Loosestrife	9.6E-02	3.7E-03	3.8E-02	5.9E-03	1.7E-01	1.2E-02
Field Bindweed	7.4E-02	9.0E-03	7.4E-02	9.0E-03	7.4E-02	9.0E-03
Bladderwort	5.2E-01	1.8E-02	6.0E-02	9.1E-03	1.4E+00	5.6E-02
Mullein	5.5E-01	2.0E-02	9.4E-02	1.3E-02	9.2E-01	4.5E-02
Reed canarygrass	1.6E-01	3.4E-03	2.4E-02	5.9E-03	2.5E-01	1.3E-02
Virginia Creeper	1.4E-01	6.5E-03	1.4E-01	6.5E-03	1.4E-01	6.5E-03
Wood's Rose	3.2E-02	1.1E-03	3.2E-03	6.1E-04	5.7E-02	2.9E-03
Green Algae	9.6E-01	6.4E-02	9.6E-01	6.4E-02	9.6E-01	6.4E-02
Russian knapweed	6.4E-03	2.3E-04	3.1E-03	1.6E-04	9.8E-03	1.6E-03
Siberian elm	1.2E-02	1.8E-03	1.2E-02	1.8E-03	1.2E-02	1.8E-03
Curled Pondweed	5.0E-01	2.1E-02	3.9E-01	2.1E-02	6.1E-01	2.8E-02
Mimosa	3.3E-02	1.8E-03	3.3E-02	1.8E-03	3.3E-02	1.8E-03
Acorns (oak)	9.8E-04	5.1E-05	9.8E-04	5.1E-05	9.8E-04	5.1E-05
Horn Rapids						
Sand dropseed	1.0E-02	5.5E-04	5.8E-03	3.7E-04	1.6E-02	4.5E-03
Russian thistle	1.2E-02	6.1E-04	5.5E-03	3.5E-04	2.0E-02	1.3E-03
Rush skeletonweed	1.9E-02	9.3E-04	2.5E-03	1.6E-04	3.5E-02	4.4E-03
Prickly lettuce	7.5E-03	3.8E-04	2.9E-03	1.8E-04	2.3E-02	5.7E-03
3luebunch Wheatgras	1.3E-02	6.8E-04	5.5E-03	3.7E-04	4.1E-02	5.0E-03
Mare's tail	7.5E-03	3.9E-04	6.3E-03	3.7E-04	8.1E-03	4.7E-04
Sagebrush	8.3E-03	4.4E-04	3.4E-03	2.3E-04	1.3E-02	2.4E-03
Snow buckwheat	4.1E-02	4.7E-03	4.1E-02	4.7E-03	4.1E-02	4.7E-03
Russian thistle (Kali)	4.7E-03	3.2E-04	4.7E-03	3.2E-04	4.7E-03	3.2E-04
Cheat grass	1.6E-01	8.8E-03	4.4E-02	6.1E-03	2.8E-01	2.8E-02
Vernita Shoreline						
Rush	3.7E-01	1.6E-02	1.3E-01	2.3E-02	1.1E+00	5.2E-02
›lumbia river gumwe‹	1.5E-01	6.4E-03	5.7E-02	4.6E-03	3.8E-01	2.6E-02
Velvet Lupine	5.8E-02	2.8E-03	3.6E-02	2.8E-03	7.6E-02	5.0E-03
Curly Dock	5.5E-02	2.8E-03	2.6E-02	3.7E-03	1.2E-01	8.7E-03
Riparian Wheat Grass	5.4E-02	2.2E-03	2.1E-03	6.8E-04	1.3E-01	1.3E-02
St Johns wort	6.4E-01	2.6E-02	1.2E-01	5.2E-03	1.1E+00	4.9E-02
Reed Canarygrass	3.0E-01	1.4E-02	1.5E-01	2.1E-02	5.4E-01	2.5E-02
Siberian elm	4.5E-02	1.9E-03	9.8E-03	7.6E-04	9.7E-02	4.5E-03
Columbia tickseed	5.4E-02	2.1E-03	6.5E-03	4.4E-04	9.1E-02	6.0E-03
identified Aquatic Pl	1.1E+00	6.0E-02	1.1E+00	6.0E-02	1.1E+00	6.0E-02
Eurasin milfoil	3.0E+00	1.4E-01	3.0E+00	1.4E-01	3.0E+00	1.4E-01
Green Algae	8.3E-01	4.7E-02	8.3E-01	4.7E-02	8.3E-01	4.7E-02

Table A-24 Average, Min, and Max Concentration Ratios by plant species for Ytterbium

Ytterbium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.7E-02	9.3E-04	9.4E-03	2.5E-03	3.1E-02	3.5E-03
Rush	1.4E-01	4.5E-04	1.6E-02	4.8E-04	5.0E-01	1.4E-02
White Mulbery	6.0E-03	1.4E-04	1.3E-03	1.2E-04	1.1E-02	7.3E-04
Curly Dock	9.4E-02	1.9E-03	1.2E-02	1.1E-03	2.3E-01	1.3E-02
Grass	1.3E-01	2.4E-03	2.1E-02	3.1E-03	2.4E-01	7.6E-03
Scouring Rush	3.2E-01	7.2E-03	9.5E-02	9.1E-03	5.7E-01	1.6E-02
Coyote willow	4.7E-02	2.2E-03	4.7E-02	2.2E-03	4.7E-02	2.2E-03
Lupine	3.4E-02	1.5E-03	3.4E-02	1.5E-03	3.4E-02	1.5E-03
Purple Loosestrife	1.4E-02	2.6E-04	3.1E-03	9.7E-05	3.5E-02	3.7E-03
Field Bindweed	3.3E-02	3.8E-03	3.3E-02	3.8E-03	3.3E-02	3.8E-03
Bladderwort	1.3E-01	3.0E-03	1.6E-02	3.5E-03	3.5E-01	9.4E-03
Mullein	2.1E-01	4.5E-03	2.5E-02	4.2E-03	5.0E-01	1.4E-02
Reed canarygrass	3.0E-02	7.4E-04	1.1E-02	1.1E-03	4.8E-02	2.1E-03
Virginia Creeper	2.1E-02	8.3E-04	2.1E-02	8.3E-04	2.1E-02	8.3E-04
Wood's Rose	3.9E-03	1.2E-04	9.0E-04	1.4E-04	7.8E-03	6.5E-04
Green Algae	8.2E-01	2.5E-02	8.2E-01	2.5E-02	8.2E-01	2.5E-02
Russian knapweed	2.7E-03	5.0E-05	8.1E-04	2.6E-05	6.2E-03	1.2E-03
Siberian elm	9.0E-03	8.4E-04	9.0E-03	8.4E-04	9.0E-03	8.4E-04
Curled Pondweed	2.0E-02	2.9E-03	1.9E-02	3.8E-03	2.1E-02	4.6E-03
Mimosa	1.5E-02	4.6E-04	1.5E-02	4.6E-04	1.5E-02	4.6E-04
Acorns (oak)	4.1E-04	1.3E-05	4.1E-04	1.3E-05	4.1E-04	1.3E-05
Horn Rapids						
Sand dropseed	1.4E-02	2.6E-04	1.2E-03	4.0E-05	3.4E-02	1.4E-03
Russian thistle	3.1E-03	6.3E-05	1.6E-03	5.2E-05	5.5E-03	1.7E-04
Rush skeletonweed	1.0E-02	3.1E-04	4.9E-03	5.8E-04	1.6E-02	1.0E-03
Prickly lettuce	6.5E-03	3.1E-04	3.0E-03	7.6E-04	1.4E-02	1.3E-03
3luebunch Wheatgras	1.6E-02	3.0E-04	1.6E-03	5.3E-05	4.8E-02	1.9E-03
Mare's tail	2.2E-03	4.7E-05	8.1E-04	2.7E-05	4.2E-03	7.2E-04
Sagebrush	8.8E-03	4.6E-04	5.2E-03	5.8E-04	1.2E-02	7.0E-04
Snow buckwheat	4.8E-02	2.1E-03	4.8E-02	2.1E-03	4.8E-02	2.1E-03
Russian thistle (Kali)	1.6E-03	5.2E-05	1.6E-03	5.2E-05	1.6E-03	5.2E-05
Cheat grass	1.9E-01	3.9E-03	4.9E-02	2.1E-03	3.5E-01	1.3E-02
Vernita Shoreline						
Rush	4.6E-02	7.5E-04	9.0E-03	2.8E-04	1.5E-01	6.2E-03
ɔlumbia river gumwe	9.2E-02	1.7E-03	3.7E-02	1.8E-03	2.4E-01	8.9E-03
Velvet Lupine	3.0E-02	8.4E-04	9.5E-03	1.9E-03	4.8E-02	1.7E-03
Curly Dock	1.9E-02	6.4E-04	1.1E-02	1.1E-03	3.7E-02	2.9E-03
Riparian Wheat Grass	3.7E-02	5.8E-04	4.1E-04	1.3E-05	1.7E-01	6.5E-03
St Johns wort	5.5E-02	8.9E-04	6.5E-03	2.6E-04	7.8E-02	2.2E-03
Reed Canarygrass	7.7E-02	2.3E-03	2.6E-02	8.6E-03	1.3E-01	4.8E-03
Siberian elm	1.2E-02	2.7E-04	2.2E-03	2.2E-04	2.0E-02	8.0E-04
Columbia tickseed	1.7E-02	2.9E-04	2.2E-03	1.1E-04	2.9E-02	1.6E-03
identified Aquatic Pl	6.0E-01	1.9E-02	6.0E-01	1.9E-02	6.0E-01	1.9E-02
Eurasin milfoil	6.5E-01	1.8E-02	6.5E-01	1.8E-02	6.5E-01	1.8E-02
Green Algae	7.6E-01	2.0E-02	7.6E-01	2.0E-02	7.6E-01	2.0E-02

Table A-25 Average, Min, and Max Concentration Ratios by plant species for Zinc

Zinc						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.8E-01	4.1E-03	1.4E-01	5.3E-03	2.4E-01	9.0E-03
Rush	3.4E-01	1.2E-03	3.6E-02	1.3E-03	5.3E-01	1.9E-02
White Mulbery	4.9E-02	8.5E-04	8.3E-03	3.0E-04	1.3E-01	4.8E-03
Curly Dock	4.9E-01	8.7E-03	1.2E-01	4.2E-03	1.2E+00	4.3E-02
Grass	1.7E-01	7.8E-03	2.2E-02	7.9E-03	3.1E-01	7.4E-02
Scouring Rush	5.4E-01	1.1E-02	3.1E-01	1.2E-02	7.5E-01	2.7E-02
Coyote willow	1.9E-01	6.5E-03	1.9E-01	6.5E-03	1.9E-01	6.5E-03
Lupine	3.0E-01	1.1E-02	3.0E-01	1.1E-02	3.0E-01	1.1E-02
Purple Loosestrife	1.8E-01	3.3E-03	9.2E-02	3.5E-03	3.0E-01	1.1E-02
Field Bindweed	1.9E-01	7.4E-03	1.9E-01	7.4E-03	1.9E-01	7.4E-03
Bladderwort	2.4E-01	5.0E-03	1.7E-01	6.2E-03	3.0E-01	1.2E-02
Mullein	4.4E-01	9.2E-03	3.0E-01	1.1E-02	5.3E-01	1.9E-02
Reed canarygrass	3.3E-02	3.2E-03	6.9E-03	5.1E-03	6.8E-02	2.7E-02
Virginia Creeper	1.3E-01	4.5E-03	1.3E-01	4.5E-03	1.3E-01	4.5E-03
Wood's Rose	6.6E-02	1.2E-03	1.5E-02	5.2E-04	1.6E-01	5.7E-03
Green Algae	2.3E+00	8.3E-02	2.3E+00	8.3E-02	2.3E+00	8.3E-02
Russian knapweed	9.2E-02	1.7E-03	3.1E-02	1.1E-03	1.6E-01	5.4E-03
Siberian elm	9.6E-02	3.3E-03	9.6E-02	3.3E-03	9.6E-02	3.3E-03
Curled Pondweed	1.3E+00	3.5E-02	1.3E+00	4.3E-02	1.4E+00	4.6E-02
Mimosa	2.1E-01	1.8E-02	2.1E-01	1.8E-02	2.1E-01	1.8E-02
Acorns (oak)	4.5E-02	1.6E-03	4.5E-02	1.6E-03	4.5E-02	1.6E-03
Horn Rapids						
Sand dropseed	1.9E-01	4.7E-03	8.3E-02	3.2E-03	4.6E-01	1.7E-02
Russian thistle	3.5E-01	9.1E-03	2.4E-01	8.9E-03	5.4E-01	2.1E-02
Rush skeletonweed	3.2E-01	7.7E-03	8.8E-02	3.3E-03	7.5E-01	3.1E-02
Prickly lettuce	2.2E-01	5.4E-03	7.2E-02	2.7E-03	4.4E-01	1.6E-02
3luebunch Wheatgras	2.1E-01	5.0E-03	4.0E-02	1.8E-03	4.1E-01	1.5E-02
Mare's tail	1.8E-01	5.1E-03	1.6E-01	6.0E-03	2.0E-01	7.4E-03
Sagebrush	6.7E-02	2.0E-03	4.7E-02	1.8E-03	8.8E-02	3.3E-03
Snow buckwheat	8.3E-02	3.3E-03	8.3E-02	3.3E-03	8.3E-02	3.3E-03
Russian thistle (Kali)	2.0E-01	7.3E-03	2.0E-01	7.3E-03	2.0E-01	7.3E-03
Cheat grass	2.9E-01	7.1E-03	1.2E-01	4.7E-03	5.8E-01	2.2E-02
Vernita Shoreline						
Rush	5.8E-01	1.1E-02	5.3E-01	1.8E-02	6.3E-01	2.1E-02
ılumbia river gumwe	7.5E-01	1.2E-02	3.4E-01	1.1E-02	2.2E+00	7.3E-02
Velvet Lupine	2.6E-01	5.3E-03	2.1E-01	6.7E-03	3.3E-01	1.1E-02
Curly Dock	3.5E-01	7.0E-03	3.2E-01	1.0E-02	3.9E-01	1.3E-02
Riparian Wheat Grass	1.7E-01	2.6E-03	1.6E-02	5.6E-04	3.1E-01	1.1E-02
St Johns wort	2.2E-01	3.3E-03	2.1E-02	6.8E-04	4.3E-01	1.4E-02
Reed Canarygrass	7.7E-01	1.4E-02	6.5E-01	2.1E-02	1.1E+00	3.5E-02
Siberian elm	4.3E-02	8.3E-04	2.2E-02	7.3E-04	7.4E-02	2.4E-03
Columbia tickseed	1.9E-01	3.0E-03	3.0E-02	9.7E-04	3.1E-01	1.0E-02
identified Aquatic Pl	7.6E-01	2.6E-02	7.6E-01	2.6E-02	7.6E-01	2.6E-02
Eurasin milfoil	7.6E-01	2.5E-02	7.6E-01	2.5E-02	7.6E-01	2.5E-02
Green Algae	7.0E-01	2.3E-02	7.0E-01	2.3E-02	7.0E-01	2.3E-02

Table A-26Average, Min, and Max Concentration Ratios by plant species for Zirconium

Zirconium						
Richland	Average	SD	Min	SD	Max	SD
Showy Milkweed	1.6E-02	3.0E-03	7.1E-03	5.2E-03	2.5E-02	7.0E-03
Rush	1.7E-01	4.4E-03	1.8E-02	6.6E-03	4.0E-01	8.9E-02
White Mulbery	6.0E-03	8.0E-04	6.8E-04	5.0E-04	1.9E-02	8.1E-03
Curly Dock	3.3E-01	4.0E-02	3.8E-02	1.5E-02	8.7E-01	3.4E-01
Grass	8.3E-02	9.7E-03	6.9E-03	5.1E-03	3.1E-01	7.4E-02
Scouring Rush	2.9E-01	3.5E-02	5.7E-02	1.6E-02	5.6E-01	1.2E-01
Coyote willow	6.1E-02	1.6E-02	6.1E-02	1.6E-02	6.1E-02	1.6E-02
Lupine	4.8E-02	2.0E-02	4.8E-02	2.0E-02	4.8E-02	2.0E-02
Purple Loosestrife	1.5E-02	2.0E-03	8.7E-03	3.2E-03	2.2E-02	8.1E-03
Field Bindweed	2.6E-02	7.3E-03	2.6E-02	7.3E-03	2.6E-02	7.3E-03
Bladderwort	1.6E-01	1.9E-02	2.0E-02	5.6E-03	3.8E-01	8.4E-02
Mullein	2.3E-01	2.7E-02	3.1E-02	8.8E-03	4.0E-01	8.9E-02
Reed canarygrass	2.0E-01	5.6E-03	5.4E-02	7.3E-03	3.1E-01	3.1E-02
Virginia Creeper	2.9E-02	1.2E-02	2.9E-02	1.2E-02	2.9E-02	1.2E-02
Wood's Rose	4.6E-03	5.8E-04	9.7E-04	3.2E-04	1.1E-02	4.7E-03
Green Algae	6.7E-01	2.7E-01	6.7E-01	2.7E-01	6.7E-01	2.7E-01
Russian knapweed	4.4E-03	7.8E-04	1.7E-03	1.2E-03	7.3E-03	5.4E-03
Siberian elm	5.5E-03	1.8E-03	5.5E-03	1.8E-03	5.5E-03	1.8E-03
Curled Pondweed	7.3E-02	1.1E-02	6.4E-02	1.1E-02	8.3E-02	2.6E-02
Mimosa	1.1E-01	3.1E-02	1.1E-01	3.1E-02	1.1E-01	3.1E-02
Acorns (oak)	2.4E-03	7.7E-04	2.4E-03	7.7E-04	2.4E-03	7.7E-04
Horn Rapids						
Sand dropseed	1.5E-02	2.2E-03	5.2E-03	1.7E-03	3.9E-02	1.1E-02
Russian thistle	1.2E-02	1.8E-03	5.4E-03	1.8E-03	2.6E-02	7.5E-03
Rush skeletonweed	2.2E-02	3.2E-03	4.7E-03	1.6E-03	6.7E-02	2.2E-02
Prickly lettuce	5.5E-03	9.1E-04	3.2E-03	9.3E-04	9.6E-03	2.8E-03
3luebunch Wheatgras	1.5E-02	2.1E-03	6.0E-03	1.8E-03	4.2E-02	1.2E-02
Mare's tail	3.7E-03	7.3E-04	3.0E-03	8.8E-04	4.3E-03	1.3E-03
Sagebrush	3.2E-03	7.1E-04	2.7E-03	7.9E-04	3.7E-03	1.1E-03
Snow buckwheat	2.6E-02	8.4E-03	2.6E-02	8.4E-03	2.6E-02	8.4E-03
Russian thistle (Kali)	5.0E-03	1.5E-03	5.0E-03	1.5E-03	5.0E-03	1.5E-03
Cheat grass	1.6E-01	2.3E-02	4.5E-02	1.3E-02	3.5E-01	8.0E-02
Vernita Shoreline						
Rush	6.4E-02	6.8E-03	1.3E-02	3.6E-03	2.2E-01	4.2E-02
olumbia river gumwe	8.4E-02	9.9E-03	3.2E-02	8.4E-03	1.8E-01	5.9E-02
Velvet Lupine	3.1E-02	5.3E-03	1.2E-02	6.4E-03	4.9E-02	1.5E-02
Curly Dock	9.5E-03	2.0E-03	6.2E-03	3.2E-03	1.8E-02	9.6E-03
Riparian Wheat Grass	1.7E-02	1.7E-03	1.5E-03	4.9E-04	3.1E-02	9.8E-03
St Johns wort	1.0E-01	1.1E-02	1.5E-02	4.3E-03	1.8E-01	5.0E-02
Reed Canarygrass	6.9E-02	9.9E-03	4.4E-02	1.4E-02	1.0E-01	3.0E-02
Siberian elm	8.0E-03	1.1E-03	1.5E-03	8.1E-04	1.8E-02	5.8E-03
Columbia tickseed	1.0E-02	1.1E-03	1.5E-03	5.5E-04	1.9E-02	5.3E-03
identified Aquatic Pl	1.1E-01	3.6E-02	1.1E-01	3.6E-02	1.1E-01	3.6E-02
Eurasin milfoil	1.4E+00	2.6E-01	1.4E+00	2.6E-01	1.4E+00	2.6E-01
Green Algae	8.2E-01	1.6E-01	8.2E-01	1.6E-01	8.2E-01	1.6E-01

Appendix B Soil and Sediment Concentrations

Table B -1 Soil and Sediment Concentration

	Antimony	σ	Arsenic	σ	Barium	σ	Cerium	σ	Cesium	σ	Chromium	σ
1	5.9E-01	2.8E-02	4.3E+00	1.8E-01	7.4E+02	1.4E+01	6.6E+01	4.2E-01	2.2E+00	6.7E-02	5.9E+01	8.2E-01
2	6.4E-01	3.2E-02	4.8E+00	2.1E-01	6.9E+02	1.3E+01	7.2E+01	4.5E-01	2.4E+00	6.7E-02	5.9E+01	8.6E-01
3	1.1E+00	3.6E-02	5.8E+00	4.0E-01	6.8E+02	1.3E+01	9.2E+01	5.1E-01	1.8E+00	6.8E-02	1.4E+02	1.4E+00
4	6.8E-01	3.1E-02	6.5E+00	3.3E-01	6.8E+02	1.3E+01	9.6E+01	5.2E-01	2.6E+00	7.1E-02	1.6E+02	1.4E+00
5	3.7E-01	2.8E-02	1.8E+00	1.5E-02	6.8E+02	1.3E+01	5.5E+01	4.4E-01	2.4E+00	7.5E-02	4.6E+01	8.4E-01
	Cobalt	**σ**	**Europium**	**σ**	**Hafnium**	**σ**	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
1	9.2E+00	7.4E-02	1.2E+00	1.5E-02	7.2E+00	1.0E-01	3.3E+04	1.9E+02	3.4E+01	1.2E-01	3.2E-01	6.6E-03
2	1.1E+01	8.2E-02	1.3E+00	1.5E-02	7.2E+00	1.1E-01	3.7E+04	2.1E+02	3.7E+01	1.2E-01	3.4E-01	6.8E-03
3	1.1E+01	8.6E-02	1.3E+00	1.5E-02	9.5E+00	1.3E-01	4.5E+04	2.6E+02	4.7E+01	1.6E-01	3.6E-01	6.6E-03
4	1.2E+01	9.2E-02	1.3E+00	1.5E-02	1.3E+01	1.6E-01	4.9E+04	2.7E+02	4.9E+01	1.6E-01	3.9E-01	6.1E-03
5	1.6E+01	1.1E-01	1.4E+00	1.6E-02	4.7E+00	8.8E-02	4.8E+04	2.7E+02	2.6E+01	1.0E-01	3.3E-01	6.3E-03
	Neodymium	**σ**	**Nickel**	**σ**	**Rhubidium**	**σ**	**Scandium**	**σ**	**Samarium**	**σ**	**Strontium**	**σ**
1	2.8E+01	1.8E+00	1.9E+01	3.3E+00	6.8E+01	2.2E+00	1.1E+01	8.1E-02	5.2E+00	2.7E-02	5.5E+02	3.7E+01
2	3.2E+01	2.1E+00	2.1E+01	3.5E+00	6.7E+01	2.3E+00	1.2E+01	8.9E-02	5.4E+00	3.0E-02	4.9E+02	3.7E+01
3	3.8E+01	2.3E+00	2.0E+01	3.0E+00	6.2E+01	2.3E+00	1.0E+01	7.8E-02	6.0E+00	3.8E-02	6.0E+02	3.9E+01
4	4.3E+01	2.4E+00	2.9E+01	4.7E+00	6.8E+01	2.5E+00	1.1E+01	8.5E-02	6.2E+00	4.9E-02	4.5E+02	3.5E+01
5	2.6E+01	2.1E+00	2.3E+01	3.4E+00	6.6E+01	2.5E+00	1.6E+01	1.2E-01	5.1E+00	2.8E-02	4.3E+02	3.7E+01
	Sodium	**σ**	**Thallium**	**σ**	**Terbium**	**σ**	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
1	2.1E+04	2.1E+02	9.4E-01	2.6E-02	7.0E-01	3.7E-02	9.6E+00	7.2E-02	2.4E+00	9.0E-02	2.0E+00	3.5E-02
2	1.9E+04	2.0E+02	9.0E-01	2.4E-02	6.4E-01	3.7E-02	1.1E+01	7.6E-02	3.1E+00	1.0E-01	2.2E+00	3.9E-02
3	2.2E+04	2.4E+02	1.1E+00	2.9E-02	7.8E-01	3.9E-02	1.5E+01	9.1E-02	3.0E+00	1.2E-01	2.4E+00	3.8E-02
4	1.9E+04	2.0E+02	1.5E+00	3.2E-02	8.0E-01	4.2E-02	1.5E+01	8.7E-02	6.5E+00	1.4E-01	2.6E+00	4.1E-02
5	2.0E+04	2.0E+02	8.2E-01	2.6E-02	7.7E-01	4.4E-02	6.8E+00	7.0E-02	2.0E+00	1.0E-01	2.3E+00	4.2E-02
	Zinc	**σ**	**Zirconium**	**σ**								
1	1.0E+02	1.9E+00	2.2E+02	2.1E+01								
2	1.2E+02	2.0E+00	1.7E+02	1.9E+01								
3	2.3E+02	3.4E+00	2.3E+02	2.2E+01								
4	1.8E+02	2.9E+00	3.3E+02	2.7E+01								
5	7.1E+01	1.6E+00	1.3E+02	1.8E+01								

1. Richland Shoreline Sediment
2. Richland Shoreline Soil
3. Vernita Shoreline Soil
4. Vernita Shoreline Sediment
5. Horn Rapids Road Soil

Appendix C Elemental Concentrations in Water

Table C-1. Elemental water concentrations in ppm

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Richland	3.2E-05	4.1E-07	5.2E-04	2.0E-05	1.7E-02	1.4E-03
Vernita	3.0E-05	4.3E-07	4.4E-04	2.2E-05	1.5E-02	1.3E-03
Average	3.1E-05	3.0E-07	4.8E-04	1.5E-05	1.6E-02	9.7E-04
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Richland	2.2E-04	9.6E-07	9.2E-06	1.5E-07	4.1E-03	6.4E-05
Vernita	2.2E-04	9.0E-07	1.3E-05	1.7E-07	5.7E-04	4.3E-05
Average	2.2E-04	6.6E-07	1.1E-05	1.1E-07	2.3E-03	3.6E-05
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Richland	1.3E-04	3.3E-06	4.4E-06	4.4E-08	7.7E-06	1.7E-07
Vernita	8.2E-05	3.4E-06	3.4E-06	4.1E-08	7.8E-06	1.7E-07
Average	1.0E-04	2.4E-06	3.9E-06	3.0E-08	7.8E-06	1.2E-07
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Richland	7.0E-02	2.5E-03	4.7E-05	1.0E-07	1.8E-06	2.0E-08
Vernita	1.1E-01	2.9E-03	7.3E-05	4.4E-06	1.6E-06	1.7E-08
Average	8.9E-02	1.9E-03	6.0E-05	1.0E-07	1.7E-06	1.3E-08
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Richland	5.7E-04	2.7E-05	1.3E-02	7.4E-04	5.0E-04	1.2E-05
Vernita	5.8E-04	2.8E-05	1.6E-03	5.0E-04	5.0E-04	1.2E-05
Average	5.8E-04	1.9E-05	7.3E-03	4.2E-04	5.0E-04	8.5E-06
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Richland	2.8E-06	2.1E-08	5.2E-06	2.3E-08	1.4E+00	1.1E-02
Vernita	2.9E-06	2.2E-08	1.7E-05	3.3E-07	1.2E+00	8.5E-03
Average	2.8E-06	1.5E-08	1.1E-05	2.3E-08	1.3E+00	6.7E-03
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Richland	7.5E-02	4.0E-03	5.5E-06	1.6E-07	4.8E-06	1.4E-07
Vernita	5.8E-02	3.8E-03	5.8E-06	1.7E-07	4.2E-06	1.3E-07
Average	6.6E-02	2.8E-03	5.7E-06	1.1E-07	4.5E-06	9.2E-08
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Richland	8.7E-06	6.5E-08	7.9E-04	1.7E-05	1.1E-05	1.2E-07
Vernita	8.9E-06	6.7E-08	5.7E-04	1.4E-05	9.6E-06	1.1E-07
Average	8.8E-06	4.7E-08	6.8E-04	1.1E-05	1.0E-05	8.2E-08
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Richland	2.4E-02	1.7E-04	2.3E-03	3.1E-04		
Vernita	3.1E-03	1.1E-04	2.2E-03	3.0E-04		
Average	1.3E-02	9.2E-05	2.3E-03	2.2E-04		

Appendix D. Insect and Arachnid Concentration Ratios by Species

Table D-1. Cricket/Grasshopper aggregate sample concentration Ratio

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Horn Rapids	3.9E-02	3.3E-03	8.2E-02	2.3E-03	1.5E-02	6.7E-03
Richland	3.0E-02	1.7E-03	4.0E-02	2.9E-03	1.5E-02	7.3E-04
Vernita	5.3E-02	8.1E-03	2.0E-02	1.5E-03	1.0E-02	5.0E-04
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Horn Rapids	2.6E-02	2.6E-03	4.7E-02	6.6E-03	3.2E-02	3.7E-03
Richland	2.9E-03	2.5E-03	2.4E-02	6.5E-03	4.3E-03	1.5E-04
Vernita	6.8E-03	1.5E-03	6.0E-02	8.5E-03	6.4E-03	9.3E-04
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Horn Rapids	5.0E-02	1.2E-03	3.3E-02	2.2E-03	3.8E-02	3.6E-03
Richland	2.6E-02	1.5E-03	4.2E-03	1.3E-04	6.6E-03	2.5E-03
Vernita	3.5E-02	1.1E-03	9.0E-03	1.8E-03	8.8E-03	1.2E-03
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Horn Rapids	3.4E-02	5.9E-04	3.1E-02	6.7E-04	3.5E-02	6.8E-03
Richland	1.3E-02	4.4E-04	8.5E-03	3.8E-04	1.2E-02	3.8E-04
Vernita	1.2E-02	2.9E-04	7.1E-03	2.4E-04	7.1E-03	2.3E-04
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Horn Rapids	5.3E-02	7.4E-03	1.4E-01	5.3E-02	4.9E-02	8.3E-03
Richland	5.9E-02	7.8E-03	1.5E-01	5.8E-02	6.2E-02	9.6E-03
Vernita	3.6E-02	4.7E-03	1.2E-01	4.4E-02	1.3E-01	1.1E-02
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Horn Rapids	3.6E-02	1.0E-03	3.1E-02	5.9E-04	8.1E-02	2.3E-03
Richland	1.1E-02	1.0E-03	1.1E-02	2.8E-04	5.9E-02	1.7E-03
Vernita	1.3E-02	6.4E-04	1.3E-02	2.9E-04	7.1E-02	2.0E-03
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Horn Rapids	2.5E-02	4.1E-03	3.6E-02	5.1E-03	1.6E-02	1.4E-03
Richland	2.4E-02	3.8E-03	8.1E-03	5.4E-04	1.9E-02	1.6E-03
Vernita	5.8E-02	1.4E-02	4.6E-03	3.0E-04	1.1E-02	9.6E-04
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Horn Rapids	2.9E-02	2.2E-03	3.1E-02	2.0E-03	3.3E-02	6.9E-03
Richland	1.8E-03	3.3E-05	2.8E-02	1.5E-03	1.3E-02	4.0E-04
Vernita	6.6E-03	7.9E-04	4.0E-02	1.2E-02	6.9E-03	2.1E-04
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Horn Rapids	1.2E+00	4.7E-02	4.9E-02	1.6E-02		
Richland	9.0E-01	3.0E-02	3.7E-02	1.2E-02		
Vernita	5.3E-01	1.7E-02	2.0E-02	6.5E-03		

Table D-2. Beetle Concentration Ratios by Element

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Beetle	3.4E-02	2.9E-03	5.5E-02	1.5E-03	1.1E-02	5.6E-04
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Beetle	1.5E-02	2.9E-03	6.8E-03	3.4E-04	1.5E-02	4.1E-03
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Beetle	2.1E-02	8.3E-04	1.4E-02	2.1E-03	3.5E-02	3.2E-03
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Beetle	1.2E-02	3.3E-04	1.5E-02	4.5E-04	9.0E-03	2.9E-04
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Beetle	5.4E-02	7.5E-03	1.1E-01	4.2E-02	7.5E-03	5.9E-04
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Beetle	1.5E-02	6.9E-04	1.1E-02	2.4E-04	4.0E-02	1.1E-03
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Beetle	2.3E-02	3.9E-03	7.7E-03	5.3E-04	1.3E-02	1.1E-03
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Beetle	1.4E-02	2.1E-03	2.7E-02	1.7E-03	8.8E-03	2.9E-04
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Beetle	8.0E-01	3.1E-02	3.9E-02	1.3E-02		

Table D-3 Aggregate Spider Sample Concentration Ratio

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Richland Spider	4.2E-02	2.7E-03	1.3E-01	2.4E-02	1.4E-02	7.1E-04
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Richland Spider	3.6E-03	5.6E-05	8.1E-03	3.8E-04	4.2E-03	1.6E-04
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Richland Spider	1.0E-02	9.1E-04	3.0E-03	9.4E-05	2.2E-03	1.1E-04
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Richland Spider	7.3E-03	3.3E-04	3.2E-03	3.9E-04	9.4E-03	3.1E-04
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Richland Spider	6.8E-02	9.0E-03	1.5E-01	5.7E-02	1.3E-01	1.1E-02
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Richland Spider	1.1E-03	2.2E-05	3.5E-03	1.6E-04	2.1E-01	5.9E-03
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Richland Spider	2.4E-02	3.8E-03	7.5E-03	5.0E-04	1.7E-02	1.5E-03
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Richland Spider	1.7E-03	3.3E-05	2.2E-02	1.1E-03	8.2E-03	2.6E-04
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Richland Spider	1.2E+00	4.0E-02	3.4E-02	1.1E-02		

Appendix E Aquatic Animal Concentration Ratios (Animal vs. Water)

Table E-1. Concentration Ratios for Northern Pikeminnow.

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Northern Pikeminnow	3.7E+03	3.0E+01	8.5E+02	1.3E+01	3.1E+02	9.6E+00
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Northern Pikeminnow	4.4E+02	2.5E+00	9.9E+03	1.5E+02	3.7E+01	5.4E-01
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Northern Pikeminnow	1.6E+02	4.3E+00	9.2E+01	9.8E-01	7.9E+02	1.3E+01
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Northern Pikeminnow	3.8E+02	7.4E+00	6.4E+01	3.1E-01	9.2E+02	9.5E+00
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Northern Pikeminnow	1.4E+03	6.0E+01	8.5E+01	2.2E+01	2.8E+04	4.2E+02
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Northern Pikeminnow	4.0E+03	2.9E+01	7.2E+01	4.6E-01	1.9E+03	2.7E+01
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Northern Pikeminnow	7.6E+02	3.0E+01	1.5E+02	3.9E+00	3.3E+02	9.0E+00
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Northern Pikeminnow	7.5E+02	5.3E+00	1.0E+02	1.5E+00	8.7E+02	9.4E+00
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Northern Pikeminnow	3.0E+03	3.3E+01	3.3E+02	4.1E+01		

Table E-2. Concentration Ratios For Crayfish

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Crayfish	5.4E+02	1.3E+02	3.2E+03	7.7E+04	7.5E+03	2.4E+05
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Crayfish	1.1E+03	1.5E+02	8.8E+03	3.2E+05	7.7E+01	4.2E+00
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Crayfish	2.6E+03	4.3E+03	7.4E+02	3.0E+02	1.4E+03	2.5E+03
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Crayfish	1.8E+03	3.4E+03	2.1E+03	2.4E+04	2.1E+03	1.6E+03
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Crayfish	2.9E+03	5.8E+04	2.4E+02	3.6E+03	3.0E+04	1.1E+06
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Crayfish	1.0E+04	1.4E+06	3.3E+03	5.2E+03	4.9E+03	8.2E+03
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Crayfish	6.6E+03	1.5E+05	5.9E+02	7.2E+02	1.4E+03	4.7E+03
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Crayfish	1.6E+03	4.2E+02	1.3E+02	1.5E+01	2.5E+03	2.5E+03
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Crayfish	5.7E+03	1.5E+04	1.5E+03	1.1E+05		

Table E-3. Concentration Ratios for Asian Clams

Element	**Antimony**	**σ**	**Arsenic**	**σ**	**Barium**	**σ**
Asian Clams	1.3E+03	2.0E+02	2.1E+03	2.0E+02	4.9E+03	4.1E+02
Element	**Cerium**	**σ**	**Cesium**	**σ**	**Chromium**	**σ**
Asian Clams	1.0E+04	4.6E+02	1.2E+04	1.3E+03	1.0E+03	7.4E+01
Element	**Cobalt**	**σ**	**Europium**	**σ**	**Hafnium**	**σ**
Asian Clams	4.4E+03	1.6E+02	1.3E+04	7.0E+02	3.3E+04	1.9E+03
Element	**Iron**	**σ**	**Lanthanum**	**σ**	**Lutetium**	**σ**
Asian Clams	1.5E+04	4.0E+02	1.9E+04	3.1E+02	1.1E+04	1.2E+03
Element	**Neodymium**	**σ**	**Nickel**	**σ**	**Rubidium**	**σ**
Asian Clams	1.4E+03	1.7E+02	3.5E+02	1.2E+02	7.4E+03	1.0E+03
Element	**Samarium**	**σ**	**Scandium**	**σ**	**Sodium**	**σ**
Asian Clams	7.2E+04	2.5E+03	3.7E+04	6.6E+02	2.8E+03	7.3E+01
Element	**Strontium**	**σ**	**Thallium**	**σ**	**Terbium**	**σ**
Asian Clams	6.8E+03	5.8E+02	8.1E+03	9.2E+02	7.4E+03	1.6E+03
Element	**Thorium**	**σ**	**Uranium**	**σ**	**Ytterbium**	**σ**
Asian Clams	4.4E+04	1.5E+03	2.9E+02	3.8E+01	9.1E+03	9.6E+02
Element	**Zinc**	**σ**	**Zirconium**	**σ**		
Asian Clams	1.1E+03	4.1E+01	2.3E+03	7.3E+02		