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Adrienne Martinez

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Adrienne Martinez

Candidate

Civil Engineering

Department

This thesis is approved, and it is acceptable in quality and form for publication:

Approved by the Thesis Committee:

Dr. Bruce Thomson, Chairperson

Dr. Abdul-Mehdi Ali

Jerry Lovato, PE

Karen Sterns, PE

CHARACTERIZATION OF URBAN STORM RUNOFF BY MONITORING SEDIMENTS AND RIPARIAN VEGETATION

By

ADRIENNE MARTINEZ

BACHELOR OF SCIENCE
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF NEW MEXICO, 2011

THESIS

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I have so many people I need to thank, you all have supported and nurtured my growth as a whole person during this process. I hope I have made you feel as important as you have made me feel, I hope you know who you are.

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CHARACTERIZATION OF URBAN STORM RUNOFF BY MONITORING SEDIMENTS AND RIPARIAN VEGETATION

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B.S., Civil Engineering, University of New Mexico, 2011

M.S., Civil Engineering, University of New Mexico, 2015

Abstract

Difficulties associated with monitoring urban stormwater quality present considerable challenges to stormwater managers in the arid southwest. Complexities arise from the infrequent occurrence of storm events, their highly localized extent, and the short duration of storm hydrographs. The presence of sediment in high amount can make both sample collection challenging and the interpretation of the resulting data difficult. This study explored an alternative strategy in which sediments and plant matter from within the channels in an urban watershed in the Northeast Heights of Albuquerque, New Mexico, were collected for analysis of metals from possible sources within the watershed. The upper reaches of the watershed are undeveloped and thus has no anthropogenic contaminant sources and sediment was used for comparison with down gradient impacted streams. This study focused on four metals Cu, Cr, Sb, and Zn with average sediment contamination from the top of the watershed to the bottom ranging from 2.48 to 15.6, 1.56 to 6.08, 3.12 to 5.20, and 17.9 to 83.2 mg kg^{-1}, respectively. The concentration of these constituents in plant tissue varied by plant roots, leaves, and stems. The increase in metal accumulation in both storm water sediments and plants followed the same trend as the sediments suggesting that plants may serve as indicators of the threats to receiving water in the environment as a result of urbanization of the watershed.

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Introduction

Characterizing urban watershed pollutants in arid regions is a difficult task for stormwater managers in arid climates. According to the National Research Council, “one of the challenges of managing stormwater from urban watersheds thus involves anticipating and channeling future urban growth (National Research Council, 2009).” Recognizing that stormwater characteristics are affected by the topography and climate (see Appendix A), it is reasonable to state that stormwater in the arid southwest is different from the rest of the country. Traditional methods developed for urban stormwater sample collection used for stormwater quality monitoring and watershed characterization are difficult to implement in arid environments.

The challenges associated with stormwater collection in arid regions include extended periods of drought, long time periods between storm events, and high intensity, short duration rain events. Over half of the annual precipitation in Albuquerque is the result of summer monsoonal thunder storms that usually occur between July 1 and October 15. Summer storms are typically localized but intense and have a very short duration, decreasing

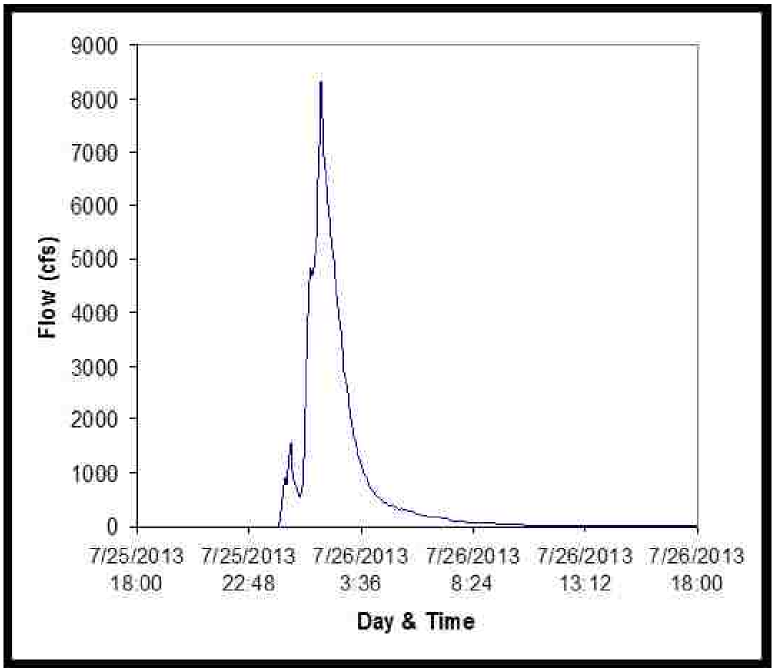

Figure 1: Typical Hydrograph of monsoonal storm in Albuquerque's North Diversion Channel

the chance of a sampling technician reaching a flowing site quickly enough to collect a representative sample of water. Note that the storm in the hydrograph in Figure 1 peaks very quickly and drops off sharply in a short amount of time. In arid regions, stormwater quality depends greatly on two important factors; antecedent conditions and that the highest concentrations occur early in the hydrograph. As dramatic changes in stormwater quality happen throughout the duration of the storm, both of the previously mentioned factors complicate the sample collection process and the interpretation of the data.

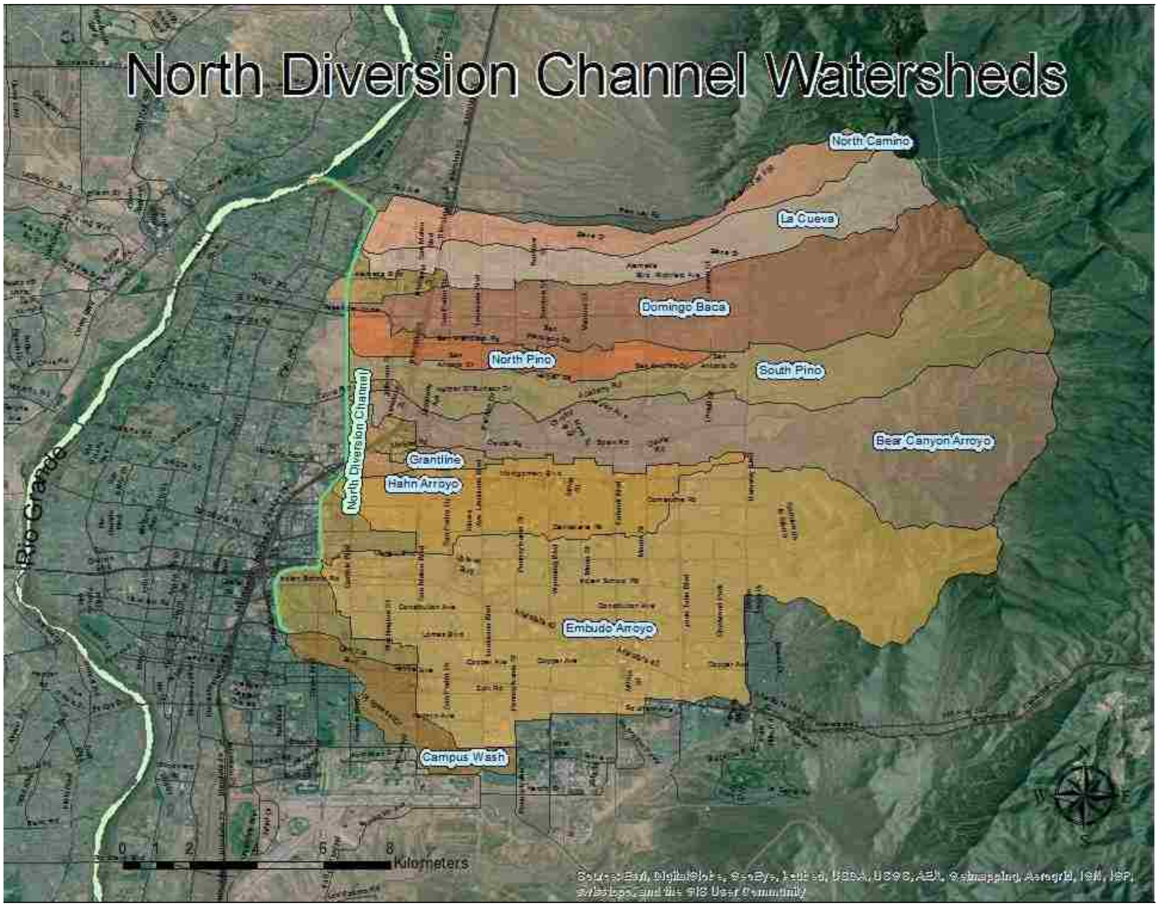

Figure 2: Watershed in the Northeast Heights of Albuquerque contributing to the North Diversion Channel

This study focused on urban watersheds located in and near Albuquerque, New Mexico, consisting of an estimated area of 188 square miles. Albuquerque is the largest city in the state averaging 8.42 inches of annual precipitation, according to the National Oceanic and Atmospheric Administration (NOAA). The topography exacerbates stormwater monitoring because the channels are steep and many are paved. This creates a very short storm hydrograph in which flows quickly increase then decrease in response to summer precipitation events.

The northeast heights of the city consists of a complex drainage network of ten watershed arroyos that drain into the North Diversion Channel (NDC), see Figure 2. The NDC ushers stormwater relayed from these watershed arroyos out to the Rio Grande which runs through the middle of the city. These arroyos begin in the Sandia Mountain foothills that line the city to the east. The typical Albuquerque watershed arroyo is naturally lined upstream and is concrete channelized in the urban setting. The average slope a given channel in this area of town is roughly six percent. High water velocities mean these arroyos have the ability carry high sediment loads which further complicates stormwater quality monitoring programs.

The National Pollutant Discharge Elimination System (NPDES) system oversees the guidance and permitting for municipal separate storm sewer systems (MS4s) governed by the Environmental Protection Agency (EPA). The current system of permitting has too many individual permittees for the EPA to oversee responsibly. With a review of current and proposed approaches to reduce pollutants from entering protected bodies of water by NPDES, the National Research Council (NRC) recommended a watershed based approach to monitor stormwater dischargers to help alleviate the problems associated with the current program (National Research Council, 2009). The watershed approach implies that the watershed that discharges to a water source needs to be characterized. This new program will offer the opportunity for struggling stormwater managers to work with other permittees to develop innovative methods for sampling and monitoring their watersheds.

The objective of this study was to investigate an alternative procedure in which stormwater sediments and material from plants growing in channels and sedimentation basins can be used to determine the impacts of urban development on receiving water quality.

This objective was studied by asking the following three questions:

1. What are the activities having the greatest impact on sediment and storm water quality?
2. Do pollutant concentrations increase moving downstream in the watershed, what are the correlations between land uses and environmental impact?
3. What management strategies can we implement to reduce these impacts?

Overall, the verification of these conditions will assist in determining if sediment and/or vegetation can be used to characterize an urban arid watershed.

Current State of Knowledge

Nonpoint contaminants from urban stormwater is recognized as a major source pollution that affects the quality of the rivers, lakes, and streams (Gallagher et al., 2011). Urbanization has changed the characteristics of stormwater in urban and suburban communities by increasing impervious areas and the pollutant loads from anthropogenic sources (National Research Council, 2009). In principle a stormwater quality monitoring program enables stormwater managers to identify the pollutants and their sources which can then lead to methods of limiting them. Knowing the sources of contamination encourages the development of better treatment methods for contaminant removal (“Watershed-based National Pollutant Discharge Elimination System (NPDES) Permitting Technical Guidance,” 2007).

Current methods for stormwater sample collection include both manual and automatic grab and flow-weighted sampling (USGS, 2003). In Albuquerque, a manual sample most nearly always means having a person enter an arroyo or channel to collect the sample. This introduces risk to the sampler because storm in Albuquerque flows are supercritical and the channels have steep side slopes that are often lined with concrete and slippery when wet. In the case of auto-sampling devices, the water depth must be enough for the sampler to register a flow. To address the difficulty of collecting stormwater samples in arid regions, the National Pollutant Discharge Elimination System (NPDES) Guidance Manual lists a set of methods for drought, extreme weather, and non-qualifying events (US EPA, 1992). The nature of storms, hydraulics, and hydrology of Albuquerque create situations that often prevent representative sample collection. These methods include:

- Arid Climate—Long periods without rain which may prevent sampling during a specified period
- Adverse Weather Conditions—Unsafe conditions, flooding, lightning storms, high winds
- False Start Rains—Unpredictable weather causing misleading volume expectations, with rain halting as soon as it starts
- Stop/Start Rains—intermittent rainfall

The solutions to these challenges suggested by EPA (USEPA, 1992) are to either document and report why a sample collection could not be achieved, wait for another representative storm event to occur, or to keep collecting samples until the mandatory minimum volume is collected as in the stop/start rain scenario.

The city of Albuquerque experiences long periods of drought with violent rain events during the summer monsoon season. Based on the unpredictable weather, it is often not possible for a simple stormwater monitoring program to reliably characterize contaminants from urban watersheds. Figure 3 is a good example of the tail end of a monsoonal storm in an arid Albuquerque watershed where the stormwater is moving at high velocities due to steep grade and can cause dangerous situations for both vehicles and pedestrians who attempt to enter or cross the flow of water. The water is heavy with sediment and may not be representative of the concentration of contaminants since the highest amounts occur in the earlier portion of the hydrograph.

Figure 3: Supercritical flow within the North Camino Arroyo Watershed near the foothills of the Sandia Mountains; a distant localized storm on the west side of the city; sediment heavy stormwater, July 2013. Photo taken by Adrienne Martinez

Contaminants Associated with Stormwater

Nonpoint source pollution carried by stormwater is considered to be the greatest contributor of contamination to natural freshwater systems such as rivers, lakes, and streams (Davis, Shokouhian, & Ni, 2001). However, the non-point sources of pollution are not well characterized in the Albuquerque watershed. Davis states that the major contribution of metals found in stormwater where no industrialization is present comes from automobiles, homes, and other buildings.

The inorganic constituents found in stormwater from brake pads, tires, and road runoff are Fe, Cu, Ba, Sb, Zn, Pb, and Cr (McKenzie, Money, Green, & Young, 2009); while urban structures contain Pb, Cu, Cd, Zn (Davis et al., 2001). Root (2000) led a study aimed at the accumulation and contribution of leaded wheel weights to road pollution, he estimated that nearly 1.5 million kg/year of Pb is left behind on urban roadways throughout the United States (Root, 2000). According to Root, in addition to lead, tire weights also contain 5% antimony, an alloying agent added to increase hardness. Trace metals have an affinity for particulate sized sediments in stormwater and receiving waters (Charlesworth & Lees, 1999).

Tiefenthaler found that trace metal loading in stormwater was greatly affected by accumulation on ground surfaces during the extended dry periods in the arid setting (Tiefenthaler, Stein, & Schiff, 2008). With this knowledge it was concluded that concentrations in stormwater were expected to be higher with trace metals in the first storm flows of the rainy period. The combination of impervious catchments and the spatial and temporal variability of storms in arid regions increases the complication of using stormwater samples collected during storm events as a means to characterize urban impacts on a watershed.

In a study comparing the concentration of metals in the water and sediment phase of stormwater discharged from an eductor truck used to clean catch basins, it was found that the concentrations in stormwater had a larger range of variation in stormwater than sediment. The sediment showed a stronger relationship for concentration difference comparisons between sites, while no significant changes in concentration were noticed in the water phase between sites (Karlsson & Viklander, 2009). In the Albuquerque watersheds many storm water quality facilities slow down and spread out flowing stormwater allowing sediments to settle and light materials to float. It is proposed here that in an arid environment, measuring contaminants associated with sediments and aquatic vegetation may be a more reliable method for characterizing the impacts of urbanization on a watershed.

Characterization of Stormwater Ponds

Many of the storm events that occur are not large enough to carry flows out to the Rio Grande. It is estimated by the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) that a minimum total runoff volume of 13 acre-feet is needed overtopping the low berm at the end of the North Diversion Channel before it can enter the Rio Grande (Correspondence with AMAFCA, 2014). This would suggest that adsorbed metals from smaller storm events would settle with ponding and infiltrating water throughout the watershed system.

Stormwater detention ponds and bio swales are two types of BMPs that are widely used in stormwater quality management. Sediments in stormwater settles in the pond and pollutant particles which removes contaminants that may adsorb or precipitate. Investigations of metals contained in the stormwater sediment and have found higher concentrations in metals than in sediments from unpolluted watersheds (Gallagher et al., 2011; Stephansen et al., 2013). This phenomenon principally applies to non-degradable contaminants that adsorb to sediments or have limited solubility. Stephansen et al. found that no correlation could be drawn from the study between the sediments and flora relating to metal concentrations and that metal concentrations are well confined within the ponds with almost no threat of contamination to the external environment.

Phytoaccumulation

As of yet, no middle Rio Grande watershed has been characterized by any methods other than stormwater quality monitoring. While testing is easy for the content of contaminants in sediments, they experience differing amounts of transport depending on flow conditions. An alternative strategy also considered in this study is to measure contaminants that may accumulate in within unlined channels and stormwater detention pond sediment Numerous plant species are known t to accumulate, or phytoextract inorganic pollutants from contaminated sediments (Lasat, 2002; Zhuang, Yang, Wang, & Shu, 2007). Many plants can accumulate high levels of pollutants without exhibiting signs of toxicity (Rascio & Navari-Izzo, 2011; Zhuang et al., 2007). Rascio and Navari-Izzo describe hyperaccumulators that translocate heavy metals from the roots to the shoots and are then trapped in the leaves. Hyperaccumulators have been considered for phytoremediation in which the plants grown in contaminated environment concentrate the pollutants in the plant tissue which is subsequently harvested and disposed in a safe method.

Rumex crispus is considered to be a weed in many countries throughout the world. It is a perennial plant that can grow up to 0.91 meters (three feet) tall with large, fleshy leaves, and a deep, dense, and multi-branched tap root. The primary reason for choosing R. crispus in this study is because it was present in abundance at all but one of the project sites. R. crispus is a known phytoextractor of polychlorinated biphenyls (Ficko, Rutter, & Zeeb, 2010, 2011) and heavy metals (Zhuang et al., 2007) with emphasis on the plant’s large biomass being the main reason for large amounts of accumulation. In Zhuang's study R. crispus and sediment samples were collected at a site contaminated with Pb, Zn, and Cd. It was found that R. crispus does not accumulate Pb in the root zone but had high phytoextraction for Zn and Cd. To achieve quicker phytoremediation, EDTA was added to the plant and sediment to increase metal transport throughout the plant. Sediment properties for Zn, Pb, and Cd in mg kg^{-1} were (mean±SD) 1,050±89, 960±54, and 7.2±0.92, respectively. R. crispus shoot and root concentration values in mg kg^{-1} for Zn, Pb, and Cd were reported as 1340±105 and 1007±326, 52±4.4 and 71±20, 8.1±1.0 and 9.7±2.1, respectively.

In a similar study, R. crispus and sediment samples were collected in a field heavily contaminated with metals (Zhang et al., 2014). Sediment concentrations for Zn, Pb, Cu, Cd were reported to vary from 423-1992, 165-390, 76-147, and 14-31 mg kg^{-1}, respectively. The average concentration of metals found in R. crispus shoot and root concentration for Zn, Pb, Cu, and Cd were reported as 250 and 22, 15 and 12; 200, 13, 13, and 7 mg kg^{-1}, respectively. No studies were found in which sediment or plant materials were used to characterize contaminant concentrations associated with stormwater runoff.

Methods

Site Selection and Description

Albuquerque is made up of five major areas that divide the city. The west side which consists of the entire area west of the Rio Grande, and the northeast heights, southeast heights, and the north and south valleys which all lie east of the river. The Bear Canyon Arroyo Watershed (Bear Arroyo), which was chosen for this study, is found in the northeast heights section of the city, sites and location of the watershed are shown in figure 4.

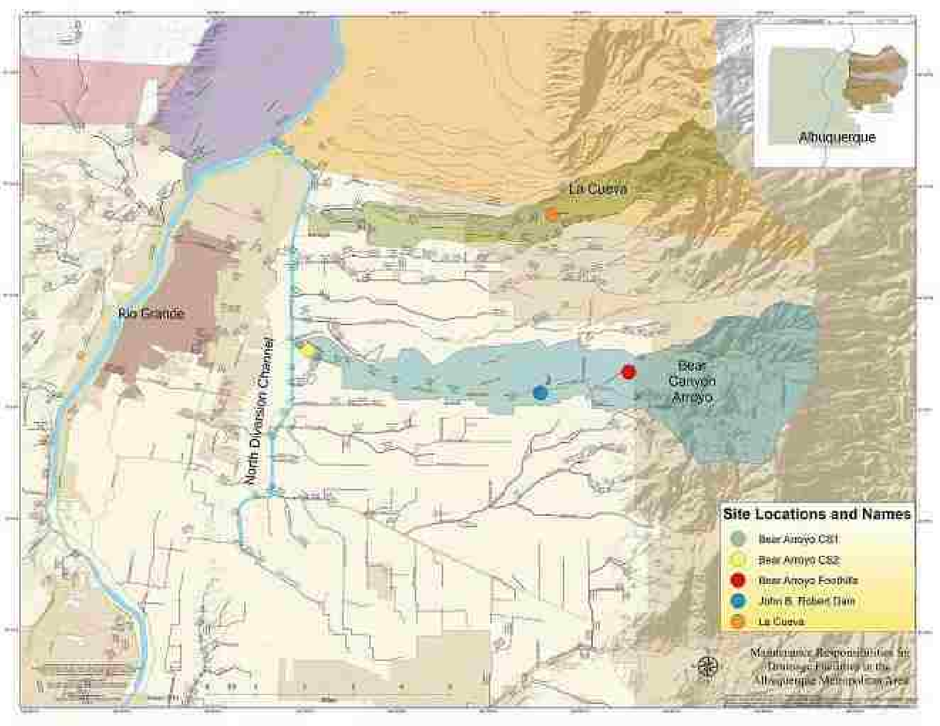

Figure 4: Site Locations, Bear and La Cueva Watersheds. Map Courtesy of AMAFCA

The Bear Arroyo is a mostly earthen lined along its entirety, vegetation within the urban portions of the arroyo was abundant, and accessibility to the sites was reasonable. This arroyo drains into the North Diversion Channel (NDC), a collector channel for the ten major arroyos (see figure 1) of the Northeast Heights and empties into the Rio Grande near the border between Bernalillo and Sandoval counties.

There are no industrial businesses in the northeast heights where this study takes place. Land uses for areas contributing to the Bear Arroyo watershed are mostly residential with no industrial inputs on the system and there is much more open space compared to residential uses in the La Cueva watershed (Figure 5). The total population of residents contributing to the Bear Arroyo watershed from the U.S. Census Bureau, 2010 Census, is 35,452 with approximately 9,991 of those people residing upstream of the John B. Robert Dam.

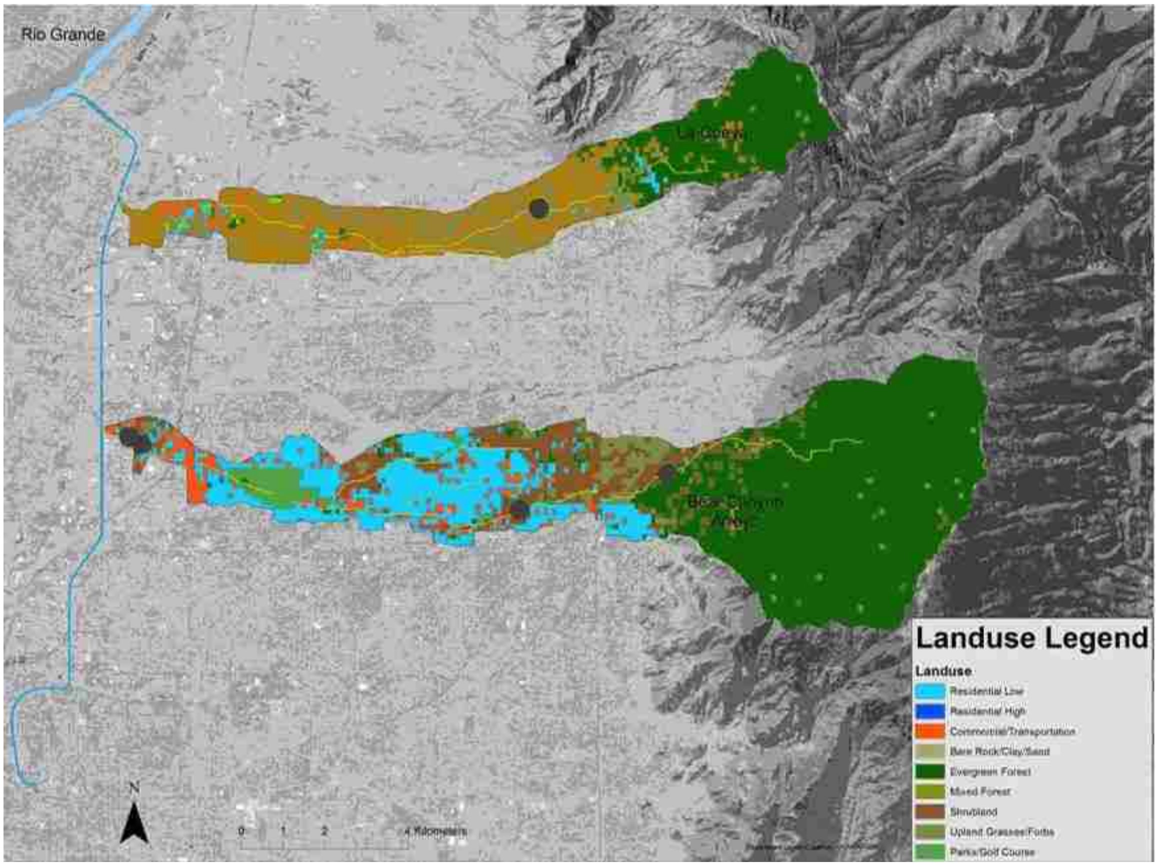

Figure 5: Land-uses for the La Cueva and Bear Arroyo Watersheds

Sites throughout the watershed were selected based on sediment accumulation and vegetation growth in the channel. The Bear Arroyo begins in the foothills of the Sandia Mountains east of the city and ends at its confluence with the North Diversion Channel. The channel is steep with an elevation drop from 1880 meters (6,168 ft.) to 1556.9 meters (5,108 ft.), over a distance of approximately roughly 8.75 miles, resulting in high velocity supercritical flows during storm events. The most upstream site of the Bear Arroyo is located in the foothills and was picked because of its lack of urban development. Chemical constituents measured in water, sediment, and vegetation samples can therefore be representative of background conditions. Unfortunately, the plant chosen for this study could not be found at the Bear Foothills site, so an alternate site was picked just north of this location in the La Cueva arroyo, where the plant was found, to compare downstream pollutant values.

Figure 6: Location of all study sites relative to the North Diversion Channel. Aerial Photo courtesy of Eagle Eye Photography

Figure 7: Sampling location in the fore bay of the John B. Robert Dam, Aerial Photo Courtesy of Eagle Eye Photography

John B. Robert Dam (Figure 7) is located 3.22 km (2 mi.) downstream of the foothills sampling site. There are some anthropogenic inputs above this site from residential sources and one major road which is Tramway Boulevard. A variety of plant species were found to be thriving on the sediment deposited during the summer 2013 monsoon season. Plants and sediment were taken within the fore bay upstream from the outlet structure where water ponds and drops sediment (see inset in Figure 8).

The Bear 1 and 2 sites were chosen due to the vegetation abundance within the Bear Arroyo and their proximity to nearby BMPs (Figure 8). This portion of the arroyo lies roughly 11.27 km (7 miles) downstream of the John B. Robert Dam and below Interstate 25, one of two heavily traveled interstates that run through the middle of the city. The portion of the Bear Arroyo below the interstate consists of three sediment basins which are each separated by baffle chutes that begin just west of I-25. The baffle chutes were constructed to decelerate the supercritical water as it enters the widened earthen channel

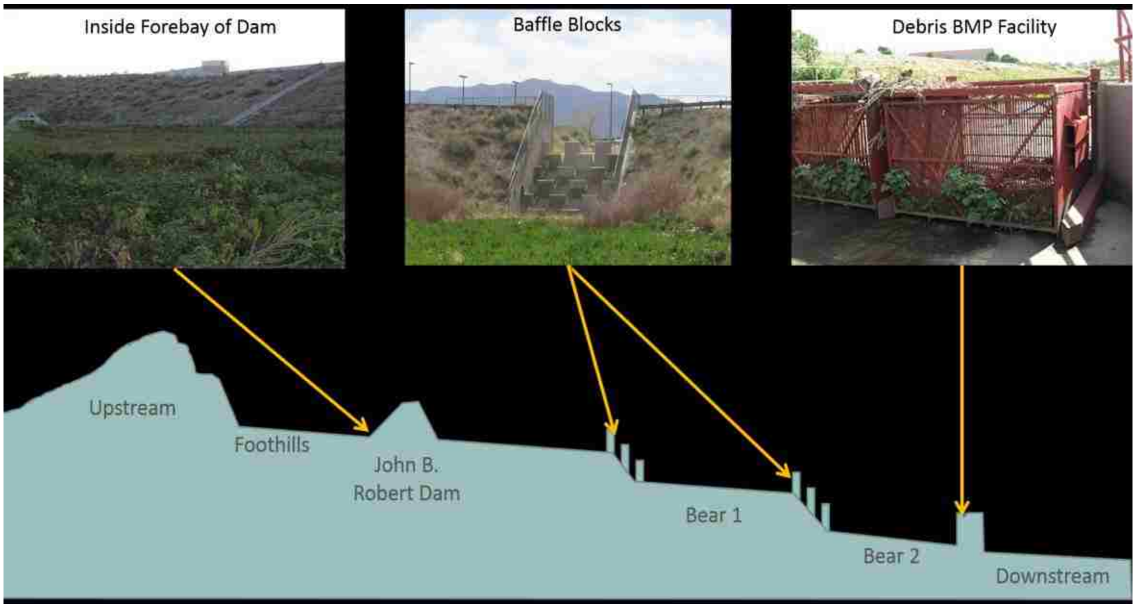

Figure 8: Schematic of sites within the Bear Arroyo watershed and water quality structure locations

sections that were designed for the water to spread out allowing sediment and trash to settle to the bottom of the arroyo. These two sites lie within the lowest two sediment basins before the arroyo empties into the NDC, respectively. Just downstream of Bear 2, in the lowest sediment basin, is a water quality structure (BMP) that captures trash and floatables. The curly dock plant (Rumex crispus) was found to be thriving in the damp and often muddy bottom of the arroyo.

Sample Collection

Samples collected from the John B. Robert Dam, Bear 1 and 2 sites were taken facing upstream and at three locations across the channel, left, center, and right (Figure 7). Three Rumex crispus plants were collected using a shovel and hand trowel at each location of the cross-section and placed in marked paper bags. Plants of similar average size were collected with an average root depth of the selected plants of 12 in. and plants that had established growth but were no larger than 2 feet in diameter, were collected.

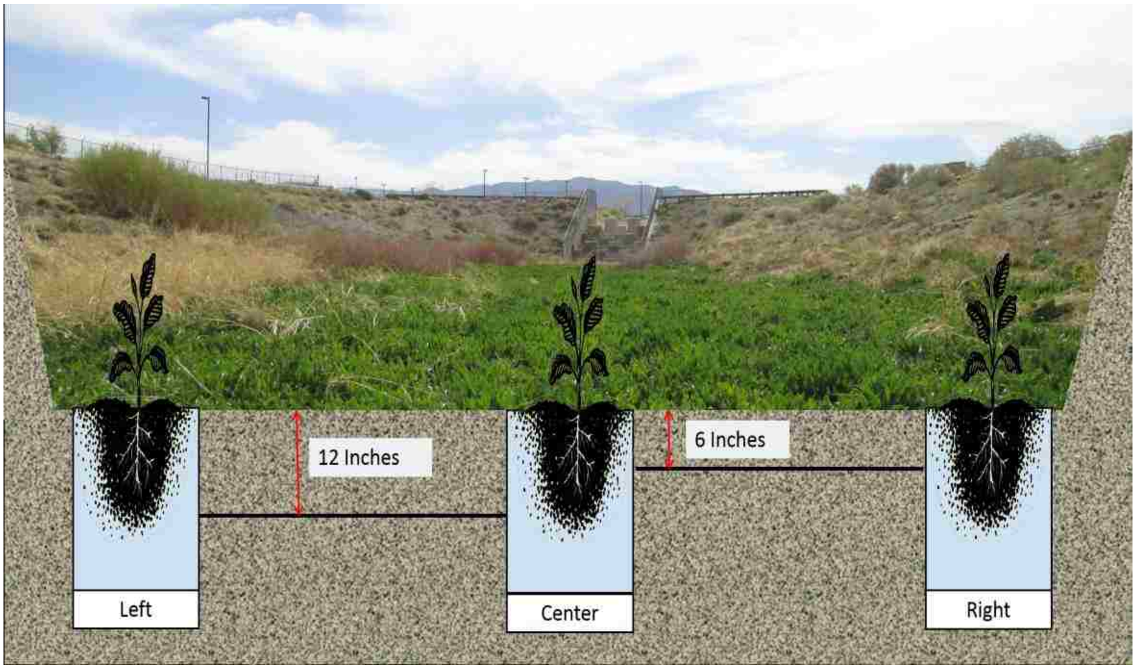

Figure 9: Cross-sectional example of plant collection within a channel

Figure 10: Typical excavated sample site, depth of hole is 12 inches

Sediment samples were taken from the holes left from the extracted plants at 6 and 12 inches of depth. This was achieved by digging horizontally into the side of the hole using a hand trowel. To avoid cross contamination the hand trowel was cleaned between sample digs. Samples were labeled with location and depth and placed in plastic bags. Curly dock was collected at each site except Bear Canyon foothills locations where it could not be found, only sediment was collected at this site. Table 1 lists the number and type of samples collected at each site.

Table 1: Materials collected at sites

SITE NAME	**Vegetation Samples**	**Sediment Samples**
Bear CS1	R. crispus	6
Bear CS2	R. crispus	6
JB Robert Dam	R. crispus	6
Bear Arroyo Foothills	N.A.	1
La Cueva	R. crispus	2

Sample Processing

Samples were prepared for processing in the geotechnical laboratory in the CE Dept. at UNM. The soils were dried in an oven at 110°C for twenty-four hours. Plant samples were thoroughly washed with DI water to remove the soil and sediment. Then each plant was separated into its three parts; roots, stems, and leaves. Each of the plant parts were placed in separate 2.5 gallon buckets filled with DI water and left to soak for ten minutes. This process repeated twice. Following the washing process, the plants were placed in the oven at 60°C for twenty-four hours. Figure 9 shows a typical dried sample for both the plant and sediment.

Figure 11: Dried samples of sediment and plant matter

Dried soil samples were pulverized using a SPEX 8510 Shatterbox (Figure 9). The sample included not only the finer soils but also the smaller sized pebbles found in the sample. The reason for including the pebbles was to achieve a representative sample of the soil content. About one gram sample was weighed and placed in a (40 ml) Teflon tube. Five ml nitric acid, 2 ml of hydrochloric acid, and 5 ml of 18 MΩ water were added to each Teflon tube containing the soil samples. Samples were digested using heat block at 95-100°C. The samples were fluxed for one hour, cooled for thirty minutes, filtered into 50 ml volumetric flasks, and brought to volume with 18 MΩ water. The filtered samples were transferred into two 20 ml scintillation vials and stored for analysis. Plant samples were dried, ground, and prepared for digestion.

Figure 12: SPEX 8510 Shatterbox, soil container with weighted ring and puck assembly with soil, final soil sample after being crushed.

Plant samples were then weighed, about 1 gram, and digested using 5 ml nitric acid in Teflon tubes. The tubes were then placed on a heat block and allowed to digest for 3 hours at 95-100°C. Eighteen Mega Ohm water was added to each sample to prevent frothing. Once digestion completed, samples were cooled, filtered into 50 ml volumetric flasks, and brought to volume with18 Mega Ohm water.

Figure 13: Digesting samples on heat block, cooling samples, filtered and filtering digested samples in 50 mL volumetric flasks

Notably, there was precipitate found in some of the scintillation vials containing plant samples. Therefore samples were filtered "0.45 micron filter" before analyzing them using the Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES).

Samples Analysis

Twenty-five metals were analyzed in each of the soil and plant matter samples using Inductively Coupled Plasma-Optical Emissions Spectrometry (ICP-OES) (Table 2).

Table 2: Analyzed Metals with Detection Limits

Metal	Location Mass Spec	Method Detection Limit (ppm)
Al	Al 396.153	0.28
As	As 188.979	0.25
B	B 249.772	0.048
Ba	Ba 455.403	0.013
Be	Be 313.107	0.007
Ca	Ca 317.933	0.1
Cd	Cd 228.802	0.027
Co	Co 228.616	0.07
Cr	Cr 267.716	0.071
Cu	Cu 324.752	0.054
Fe	Fe 259.939	0.062
K	K 766.490	0.5
Li	Li 610.362	0.5
Mg	Mg 280.271	0.003
Mn	Mn 257.610	0.014
Mo	Mo 202.031	0.079
Na	Na 589.592	0.69
Ni	Ni 231.604	0.15
Pb	Pb 220.353	0.42
Sb	Sb 206.836	0.32
Se	Se 196.026	0.75
Si	Si 251.611	0.12
Sn	Sn 189.927	1
Sr	Sr 421.552	0.008
V	V 310.230	0.064
Zn	Zn 213.857	0.018

The ICP-OES was calibrated using a blanks and three calibration standards at increasing concentrations sequentially. Initial Calibration Blank Verification (ICBV) and Initial Calibration Verification (ICV) quality control samples were analyzed after instrument calibration was established. Samples were analyzed in batches (20 samples per batch) in which a Continuing Calibration Verification (CCV) was analyzed in every twenty samples to ensure the instrument stability. Standards, QC samples, and samples were analyzed in three replicates. Mean and percent relative standard deviation were reported for each analyzed sample. Data were verified, validated (QC recoveries), and reported in mg kg-1 for each of the analyzed elements.

Of the 26 metals tested in this method two known accumulating metals and two known non-accumulating metals were chosen as the focus of this study; copper and zinc (essential nutrients) and antimony and chromium (non-essential nutrients).

Results

Sieve Analysis

A sieve analysis was performed for three of the 5 sites involved in this study. Table 4 lists those sites and the percent finer for both the #200 and #40 sieve representing the silt/clay and fine fractions of sediment, respectively. Based on research studying total heavy metals analysis and the sediment fraction size, it was found that the <63 µm (#230 sieve, c) soil fraction contains the highest levels of concentrated contaminants (Charlesworth & Lees, 1999). Focusing strictly on the silt/clay fraction of the analysis, the average highest percentages increase from upstream to downstream for both the 6 and 12 inch depths. This is not the same case for the fine sand fraction (#40 sieve) of the analysis where the average higher percentages occur in the John B. Robert Dam (See appendix D for graphs).

Table 3: Sieve Analysis at three of the Bear Arroyo sites

Site Name	Sediment Depth	Average Percent Finer than #200 Sieve	Average Percent Finer than #40 Sieve
	in.	%	%
John B. Robert Dam	6 12	3.72 3.31	66.8 61.9
Bear Arroyo 1	6 12	7.84 5.66	44.3 34.2
Bear Arroyo 2	6 12	8.86 3.96	59.2 60.3

Sediment Sampling Results

Sediment samples were collected at the same locations as the plants at each of the sites. While the majority of the samples were taken from the outer edges and the center of the channel, the samples taken from the La Cueva and Bear Foothills locations were gathered at only the left and center, respectively, due to the scarcity of the plant. The following graphs present the metal concentration results for sediments in the off-watershed background site, La Cueva, and the 4 sites in the Bear Arroyo from the highest upstream to the lowest downstream location for convenience. Sediment concentration data is provided in Appendix C.

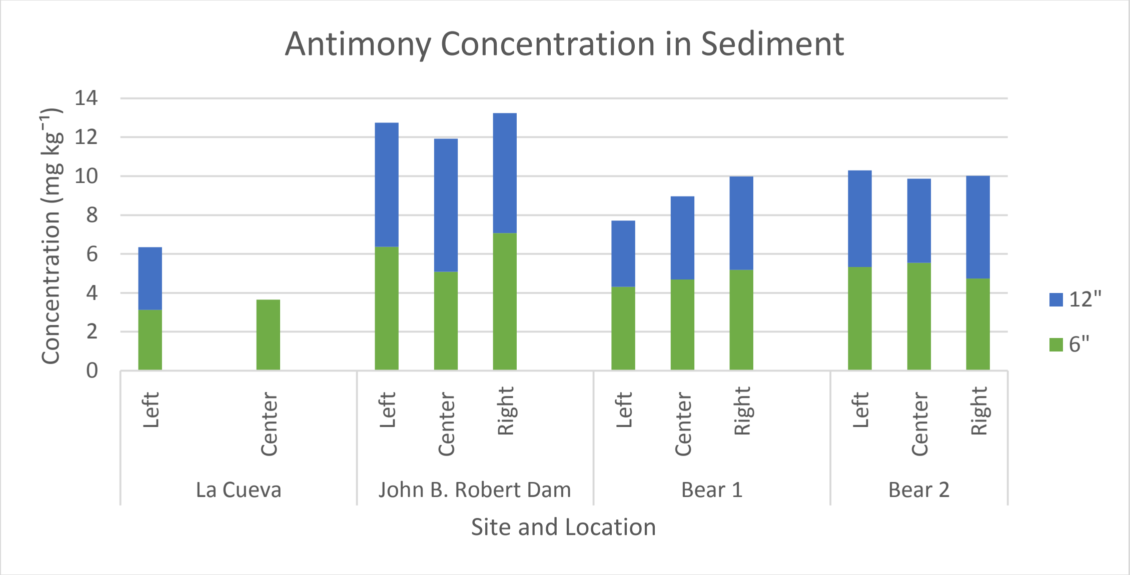

Figure 14: Antimony concentration in sediments

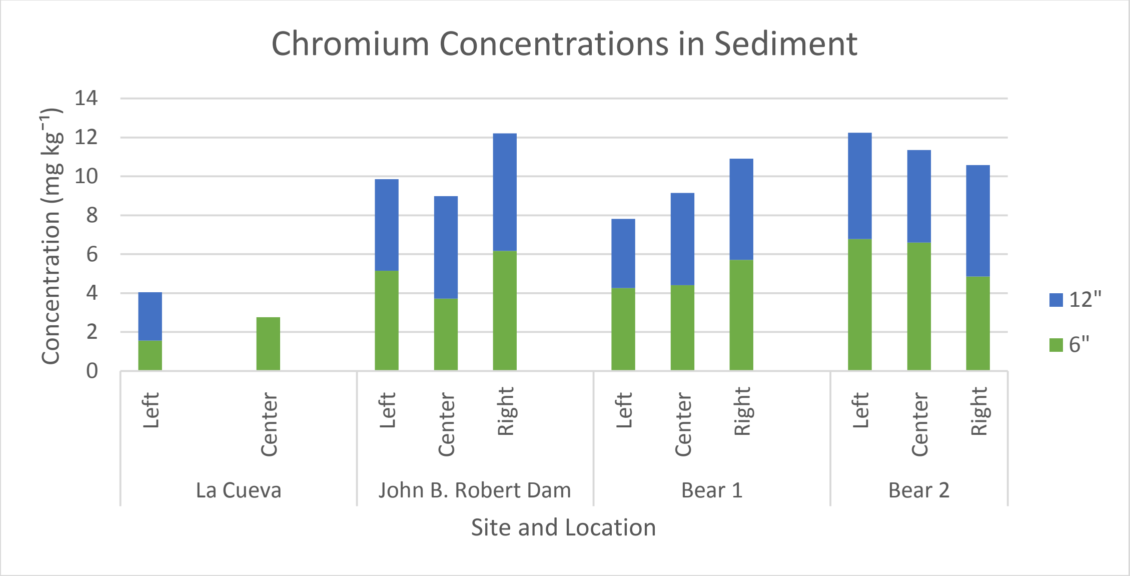

Figure 15: Chromium concentration in sediments

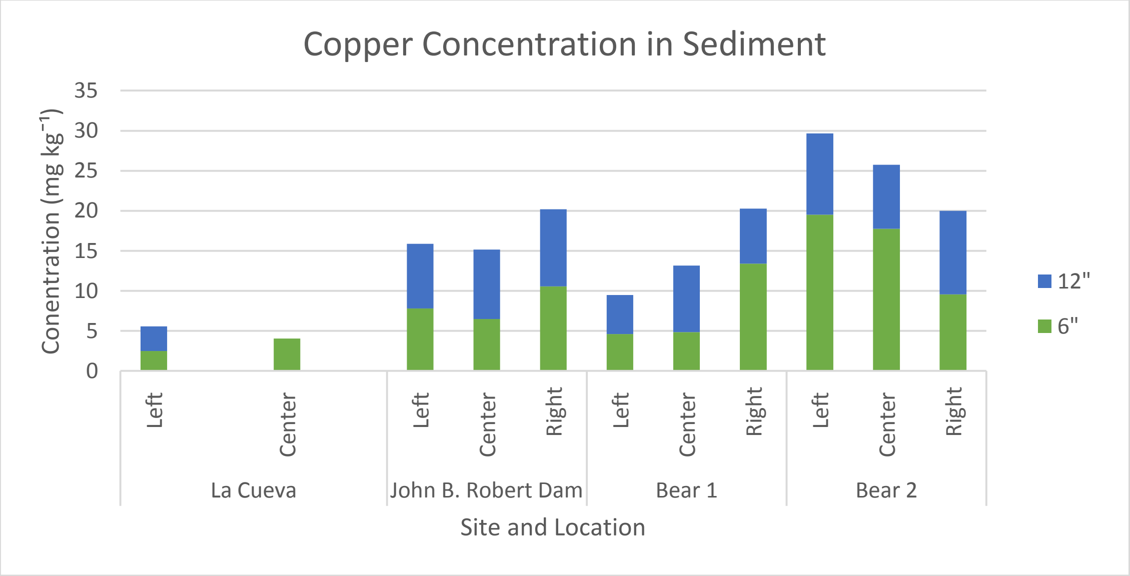

Figure 16: Copper concentration in sediments

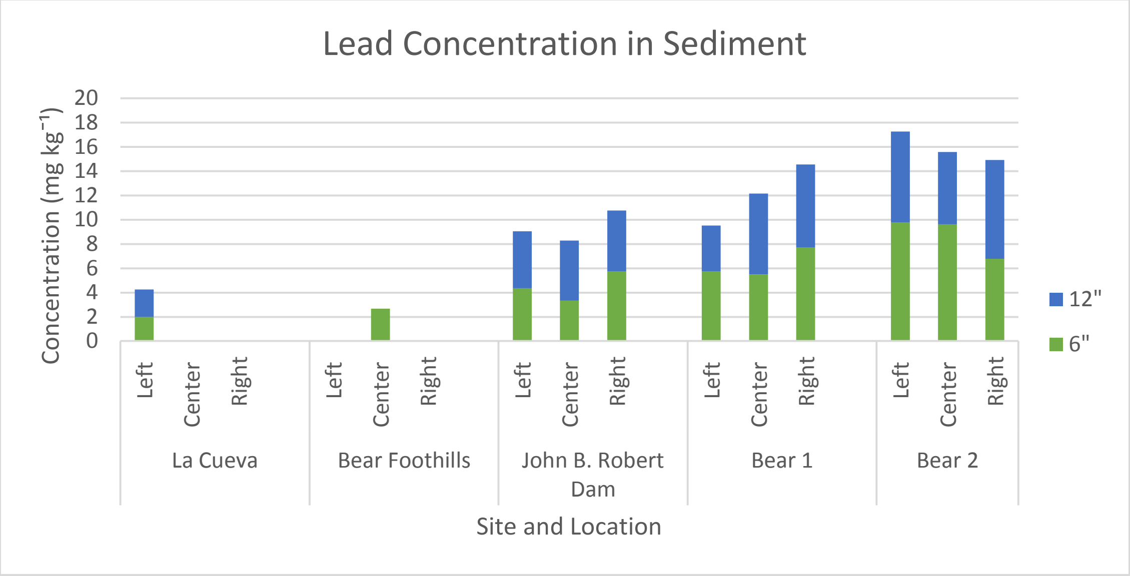

Figure 17: Lead concentration in sediments

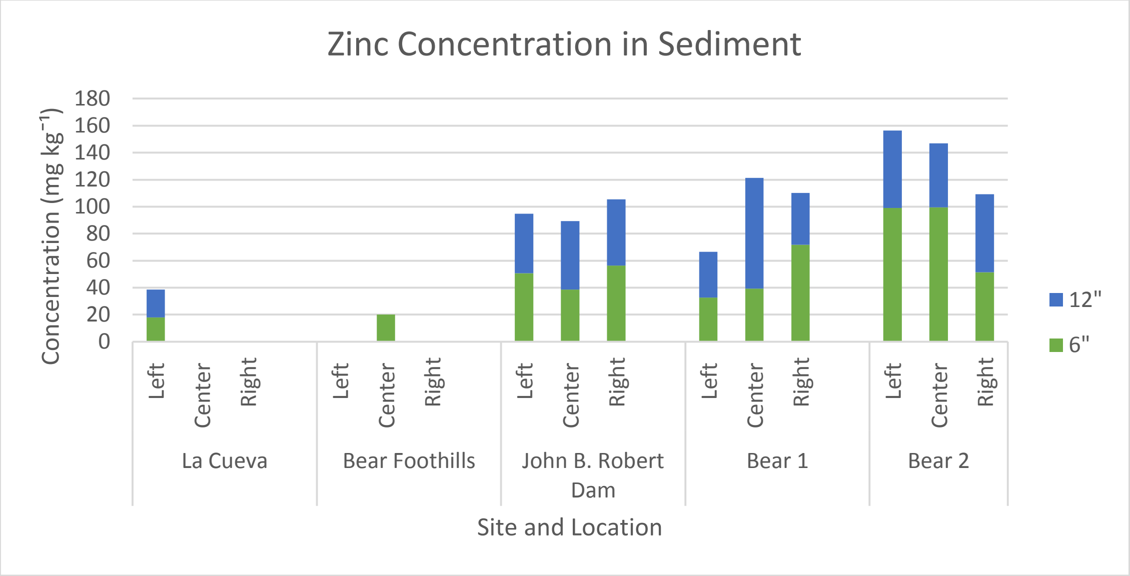

Figure 18: Zinc concentration in sediments

From the graphs shown here, the metal accumulations in the sediments taken from the La Cueva and Bear Foothills were lower than the remaining 3 downstream sites in the Bear Arroyo. All of the metal concentrations have highest concentrations at the lowest downstream site, Bear 2, except for antimony which is highest in the John B. Robert Dam.

Results of Rumex Crispus Samples

In the following graphs, no data is shown for the Bear Foothills since R. crispus was not found at that site. Metal concentration results found in R. crispus in the off-watershed background site, La Cueva, and the 4 sites in the Bear Arroyo are presented from the highest upstream to the lowest downstream location for convenience. The data used in the following figures is provided in Appendix E at the end of this report.

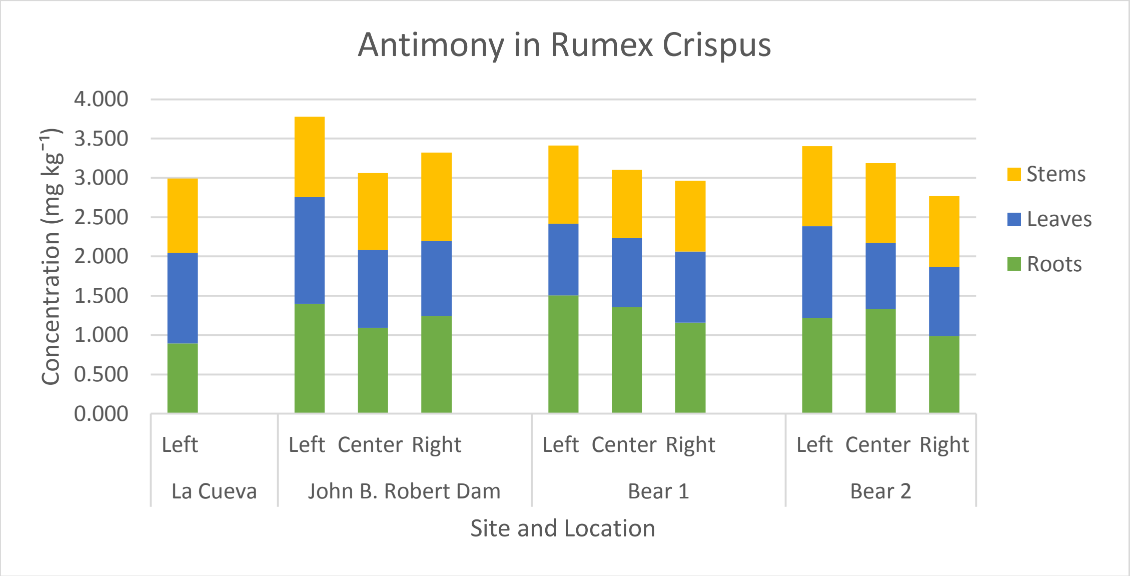

Figure 19: Antimony concentration in Curly Dock

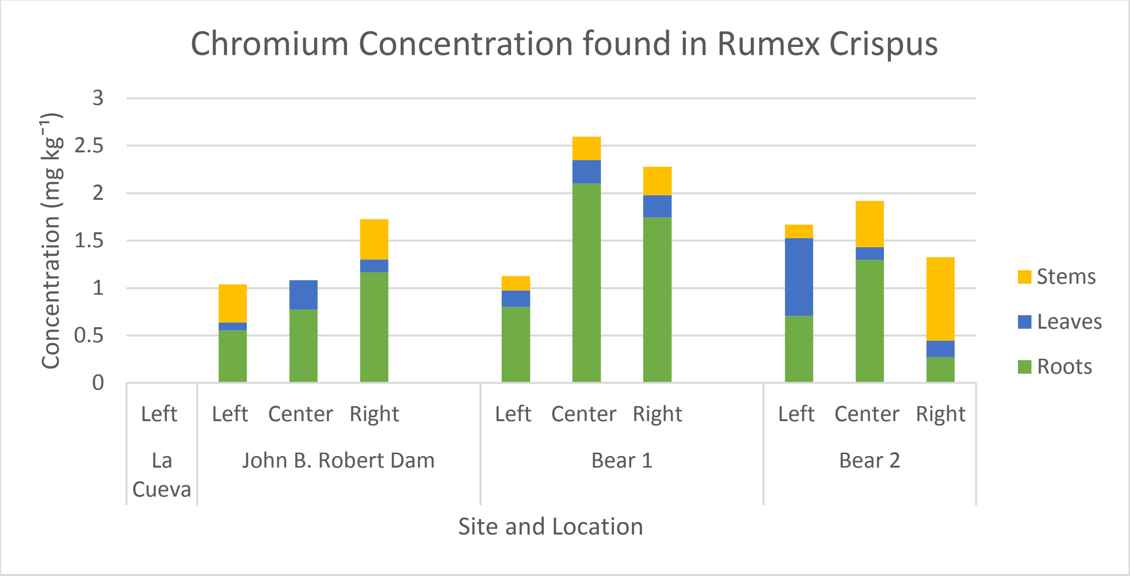

Figure 20: Chromium concentration in Curly Dock

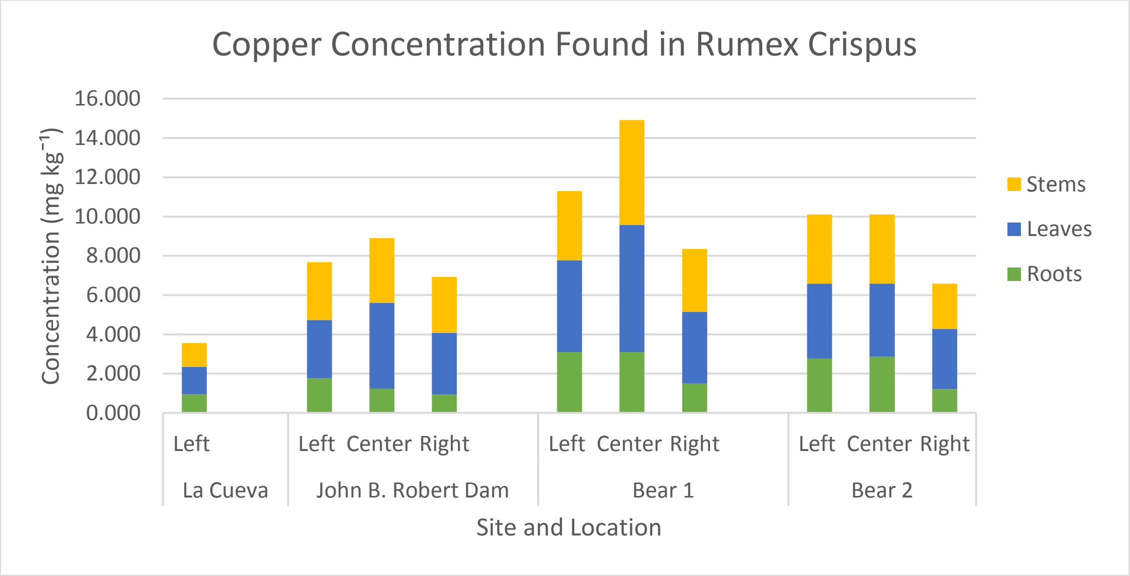

Figure 21: Copper concentration in Curly Dock

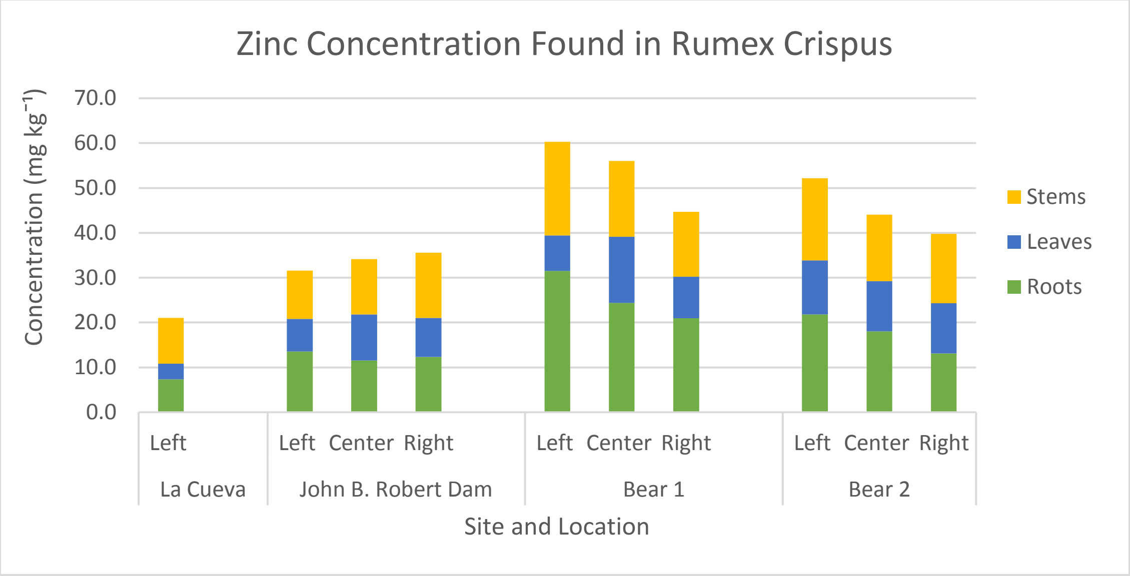

Figure 22: Zinc concentration in Curly Dock

As also observed in the sediment results, the site with the lowest concentrations of metals in the R. crispus plant were taken from the La Cueva. No detectable concentrations of lead were presented in the data for any of the plant matter.

Translocation and Biological Concentration Factors

To estimate the metal accumulation potential of R. crispus in the sampling sites, the bioconcentration (BCF), translocation (TF), and bioaccumulation factors (BAF) are presented in this section. The bioconcentration factor is the ratio of metal concentration in the roots over the metal concentration in the sediment; the translocation factor is the ratio of metal concentration in the shoots over the metal concentration in the roots; and the bioaccumulation factor is the ration of shoots to soil, the results of these findings are listed in Table 4 (Yoon, Cao, Zhou, & Ma, 2006).

In the plant preparation process of this study, the plant was separated into 3 sections; roots, leaves, and stems. To calculate the translocation factor, which helps to determine the plants capability to transfer the metals from the roots into the shoots, the results of the leaves and stems were combined additionally to obtain a value for “shoots.” To determine how well the plant bioaccumulates heavy metals, the bioaccumulation factor was calculated as the ratio of the concentration in the shoots of the plant to the concentration of heavy metals found in both the 6 and 12 inch depths of sediment.

The general rule of thumb is that if both the TF and BAF are greater than 1, then the plant may be considered for phytoextraction (Zhang et al., 2014).

The data that was used to calculate these factors are an average of the left, center, and right locations from the sites that the plants and sediment were taken from.

Table 4: BCF, TF, and BAFs for Rumex Crispus

Averaged Factor	Metal	La Cueva	John B. Robert Dam	Bear 1	Bear 2
Bioconcentration Factor, BCF (6" Sediment)	Sb	0.286	0.204	0.287	0.226
	Cr	-	0.168	0.323	0.119
	Cu	0.384	0.234	0.557	0.143
	Zn	0.409	0.261	0.627	0.219
Bioconcentration Factor, BCF (12" Sediment)	Sb	0.276	0.193	0.333	0.247
	Cr	-	0.152	0.335	0.150
	Cu	0.308	0.152	0.411	0.249
	Zn	0.354	0.262	0.590	0.328
Translocation Factor, TF	Sb	**2.35**	**1.72**	**1.37**	**1.66**
	Cr	-	0.577	0.317	**1.92**
	Cu	**2.74**	**5.35**	**3.67**	**3.21**
	Zn	**1.86**	**1.73**	**1.12**	**1.62**
Average Bioaccumulation Factor, BAC (6")	Sb	0.673	0.352	0.388	0.374
	Cr	0.002	0.087	0.094	0.151
	Cu	**1.054**	**1.106**	**1.915**	0.449
	Zn	0.763	0.451	0.674	0.363
Average Bioaccumulation Factor, BAC (12")	Sb	0.650	0.332	0.448	0.402
	Cr	0.001	0.083	0.100	0.164
	Cu	0.846	0.748	**1.371**	0.715
	Zn	0.660	0.442	0.617	0.512

Discussion

The purpose of this study was to determine if impacts of urbanization of a watershed could be measured by determining the metals concentration in stormwater sediments and the tissues plants along the flow path in an arroyo and investigating the following:

1. What are the activities having the greatest impact on sediment and storm water quality?
2. Do pollutant concentrations increase moving downstream in the watershed, what are the correlations between land uses and environmental impact?
3. What management strategies can we implement to reduce these impacts?

The Bear Arroyo Watershed consisted mostly of residential housing, with some recreational portions and almost no industrial areas within the watershed. The research provided here shows evidence that the metal concentrations in sediment and plant tissue vary throughout the watershed with an apparent increasing concentration trend as one proceeds downstream through the watershed. No correlations were studied between the soil and the Rumex crispus plant, partly since only one sample was collected at each site making statistical analysis results undependable but mostly because total metal concentrations are considered to be poor indicators of metal availability to plants (Yoon, 2006).

The major patterns that show up in the data and observations are that the concentration of metals in the sediment and plant tissues increase from the upstream sites to the downstream sites studied in this urban watershed. Appendix C illustrates the heavy metal concentrations in the collected sediments throughout the Bear Arroyo. As can be observed in the results of the data, the concentrations of all of the elements in the sediments collected were variable throughout the sites. While the fore bay of the dam is where sediment “drops” out of the stormwater it was surprising that the average percent finer passing through the #200 sieve was lower at the dam location compared to the other two collection sites downstream. While metal concentrations of the elements in sediments sometimes showed up higher in the dam than the downstream sites, it can be noted that this is reasonable and expected considering that the main sources of stormwater are from road surfaces and residential neighborhoods. New Mexico State Road 556, known as Tramway Boulevard, is a heavily trafficked four lane road that lies approximately 0.7 miles upstream of the dam. Stormwater runoff from road surfaces often contains metals like Zn found in tires; Cu, Pb, Sb, and Zn found in vehicle brakes; and Cr and Pb found in the yellow paint stripes on roadways; and residential houses contributing to the pollution of Cu, Pb, and Zn (McKenzie et al., 2009). Lead tire weights are often ground down into smaller particle sizes by vehicles running over them, and with long antecedent periods in arid regions, the build-up of this metal increases before it is washed away by stormwater (Root, 2000). Sediments from the two lowest sites on the Bear Arroyo had higher metal concentrations than the two upstream background sites. Dense residential development and road surface runoff above these sites also contribute to the pollutant load.

While sediment samples were collected 6 and 12 inches below the bottom of the channel, no sediment samples were taken at the surface. The decision to neglect the collection of surface sediments was based on the depth of the plant root and the desire to correlate heavy metal characterization in the watershed using both the plant and the sediment.

Comparing the results in this study to the values provided in Zhang's paper:

Table 5: Comparison of Zhang (2013) values of Zn and Cu in sediment and R. crispus

Zhang (2013)			Martinez (2014)		
	Zinc (mg kg^{-1})	Copper (mg kg^{-1})		Zinc (mg kg^{-1})	Copper (mg kg^{-1})
Sediment Range	423-1992	76-147	Sediment Range	17.9-99.5	2.48-19.53
Shoot Average	250	13	Root Range	7.33-31.5	0.952-3.10
Root Average	200	12	Leaf Range	3.49-11.5	1.40-6.46
			Stem Range	10.2-17.4	1.21-5.36

While Zhang's test site took place in a known heavily contaminated locations due to large industrial companies, the sites in this study have no industrialized corridors associated with them. Zhang reported results that R. crispus measured as a TF of 3.98 for Pb, >1 for Zn In this study no Pb was detected in the plants collected although Pb was found at every site, with the differences being that the contaminated sites had levels of Pb much higher (total Pb 165±14.7 to 390±24.9 mg-kg^{-1}) than in this research (average total Pb 1.98 to 9.77 mg-kg^{-1}).

To determine if the contamination of metals in the sediments exceeded any levels set by the EPA, two documents were chosen as reference. The first being the New Mexico Stream Standards which are based in part on drinking water standards. These criteria levels are measured in µg/L meaning that they are a measure of a liquid sample, these do not translate to sediment sample that are measured in mg/L. There is no way to check the results in this study using this criteria (NMAC, 2000). Instead sediment screening levels for contaminated sediments were used to compare from the New Mexico Environment Department guidance document (NMED, 2006). In it residential sediment values were given in mg kg^{-1} for Sb, Cr (III), Cr (VI), Co, and Zn as 3.13E+01, 1.00E+05, 2.34E+02, 3.13E+03, and 2.35E+04. Cr (III) and Cr (VI) were not individually tested for in this study. This research was strictly developed for scoping purposes. Using the above sediment screening levels (SSL) none of the sediments in this study exceeded the limits developed in the NMED guidance document.

Conclusion

Prepared with the knowledge that current stormwater collection methods used throughout the country are not implemented easily for most storms in the arid southwest, the confidence of finding a new medium to measure the concentration levels of heavy metals within a watershed was elevated. While the initial hope was to correlate the metals concentration in the vegetation to that in the sediment within the sites in the watershed in this study is soon became evident that this was not likely. A possible trend of increasing contamination from the upstream site to the downstream sites can be proposed from both the sediment and vegetation data. When comparing known results from others who tested R. crispus and sediment in highly contaminated areas, R. crispus followed the same trend-like patterns. In this study both the vegetation and sediment data showed a variably increasing trend in contaminant concentration from the upstream sites to the downstream sites strongly suggesting that sources of pollution come from the surrounding urban influences.

The five heavy metals focused on in this study were found in much lower concentrations than those reported by the two studies from Zhang and Zhuang (Zhang et al., 2014; Zhuang et al., 2007). The concentrations for Sb, Cr, Cu, Pb, and Zn concentrations in sediment ranged from 3.12 to 6.84, 1.56 to 6.78, 2.48 to 19.53, 1.98 to 9.77, and 17.9 to 99.5 mg kg^{-1}, respectively. R. crispus showed signs of accumulation of Sb at all sediment metal concentrations throughout the arroyo watershed, whereas, the first appearance of Cr at the La Cueva site shows up in the plant when the sediment concentration registered at 1.56 mg kg^{-1}.

In an effort to address the deficiencies and limitations of conventional stormwater quality monitoring methods in an arid urban setting, the results presented in this thesis paper strongly indicate that the procedure proposed may be an appropriate substitute. It is the nature of the arid system that creates the difficulties of implementing the developed and accepted stormwater collection methods that work for the greater part of the country. Beginning with the obvious weather and climate difference (Appendix A), the atmospheric conditions just aren't appropriate for storm cell building. The high elevation and distance from large bodies of water limit the formation of storm clouds and making the number and type of events in a monsoon season highly unpredictable. The location of the city is situated between the Sandia Mountains to the east and the mesa plateaus to the west with the Rio Grande flowing through the valley. The steep sloping terrain creates supercritical flows carrying unstable sediments, pollution, and debris into the arroyo channels. As with the northeast side of Albuquerque where ten arroyo watersheds contribute to the flow in the North Diversion Channel, the combination of unpredictable localized rainfall and the terrain can make it near impossible to reach a sub-watershed in time for a representative sample collection.

With these known limitations and difficulties, the proposed method procedures can contribute to the knowledge base of the pollutant contribution and sources throughout any watershed in an arid region. The results of this study are encouraging as it relates to multiple aspects of the arid stormwater community. Initially, this procedure was developed with only urban watershed difficulties in mind. With the EPA shifting permitting from a politically based boundary system to a watershed based approach, smaller entities will be expected to play a part in the pollutant characterization of the watersheds they may share with adjacent permittees. The approach defined in this paper to characterize an arid watershed may be the answer to substituting information in times of drought or lack of representative storm events in any arid setting, urban, rural, or otherwise.

This substitute procedure is not limited to vegetation type. The vegetation found in arid watersheds are hearty and may be assumed to have adapted to survival in the unpredictable environment. More studies and research ought to be done with different types of local vegetation based on their availability within the watershed. Collecting sediment at areas with no anthropogenic inputs can help to build a background for future studies to compare pollution to, which is something that was not available at the time of this research. Metal speciation would also greatly help in the understanding of the threat level of toxicity that may be available. At this time, it is unclear if a correlation between R. crispus and the sediment can be made for heavy metal accumulation, but further studies and multiple materials collections need to be performed.

References

Charlesworth, S. M., & Lees, J. A. (1999). The Distribution of Heavy Metals in Deposited Urban Dusts and Sediments, Coventry, England. *Environmental Geochemistry and Health*, (21), 97–115.

Davis, a P., Shokouhian, M., & Ni, S. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere*, *44*(5), 997–1009. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11513434

Ficko, S. A., Rutter, A., & Zeeb, B. A. (2010). Potential for phytoextraction of PCBs from contaminated soils using weeds. *Science of The Total Environment*, *408*(16), 3469–3476. doi:http://dx.doi.org/10.1016/j.scitotenv.2010.04.036

Ficko, S. A., Rutter, A., & Zeeb, B. A. (2011). Phytoextraction and uptake patterns of weathered polychlorinated biphenyl-contaminated soils using three perennial weed species. *Journal of Environmental Quality*, *40*(6), 1870–7. doi:10.2134/jeq2011.0144

Gallagher, M. T., Snodgrass, J. W., Ownby, D. R., Brand, A. B., Casey, R. E., & Lev, S. (2011). Watershed-scale analysis of pollutant distributions in stormwater management ponds. *Urban Ecosystems*, *14*(3), 469–484. doi:10.1007/s11252-011-0162-y

Karlsson, K., & Viklander, M. (2009). Trace Metal Composition in Water and Sediment from Catch Basins, *134*(10), 870–879.

Lasat, M. M. (2002). Phytoextraction of toxic metals: a review of biological mechanisms. *Journal of Environmental Quality*, *31*(1), 109–20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11837415

McKenzie, E. R., Money, J. E., Green, P. G., & Young, T. M. (2009). Metals associated with stormwater-relevant brake and tire samples. *The Science of the Total Environment*, *407*(22), 5855–60. doi:10.1016/j.scitotenv.2009.07.018

National Research Council. (2009). *Urban Stormwater Management in the United States*. The National Academies Press. Retrieved from http://www.nap.edu/openbook.php?record_id=12465

NMAC. Environmental Protection Water Quality Standards for Interstate and Intrastate Surface Waters, 20.6.4 NMAC (2000).

NMED. (2006). *Technical Background Document for Development of Soil Screening Levels; Volume 1 Tier 1: Soil Screening Guidance Technical Background Document* (pp. 1–86).

Rascio, N., & Navari-Izzo, F. (2011). Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? *Plant Science*, *180*(2), 169–181. Retrieved from http://www.sciencedirect.com/science/article/pii/S0168945210002402

Root, R. a. (2000). Lead loading of urban streets by motor vehicle wheel weights. *Environmental Health Perspectives*, *108*(10), 937–40. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1240125&tool=pmcentrez&rendertype=abstract

Stephansen, D. a., Nielsen, A. H., Hvitved-Jacobsen, T., Arias, C. a., Brix, H., & Vollertsen, J. (2013). Distribution of metals in fauna, flora and sediments of wet detention ponds and natural shallow lakes. *Ecological Engineering*. doi:10.1016/j.ecoleng.2013.05.007

Tiefenthaler, L. L., Stein, E. D., & Schiff, K. C. (2008). Watershed and land use-based sources of trace metals in urban storm water. *Environmental Toxicology and Chemistry / SETAC*, *27*(2), 277–87. doi:10.1897/07-126R.1

US EPA. (1992). *NPDES Storm Water Sampling Guidance Document* (p. 177).

USGS. (2003). *Municipal Stormwater Sampling Program , Metropolitan Area , Albuquerque , New Mexico--Summary of Sampling , 1992-2002* (pp. 1–4).

Watershed-based National Pollutant Discharge Elimination System (NPDES) Permitting Technical Guidance. (2007), (August).

Yoon, J., Cao, X., Zhou, Q., & Ma, L. Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *The Science of the Total Environment*, *368*(2-3), 456–64. doi:10.1016/j.scitotenv.2006.01.016

Zhang, C., Song, N., Zeng, G.-M., Jiang, M., Zhang, J.-C., Hu, X.-J., … Zhen, J.-M. (2014). Bioaccumulation of zinc, lead, copper, and cadmium from contaminated sediments by native plant species and Acrida cinerea in South China. *Environmental Monitoring and Assessment*, *186*(3), 1735–45. doi:10.1007/s10661-013-3489-4

Zhuang, P., Yang, Q. W., Wang, H. B., & Shu, W. S. (2007). Phytoextraction of Heavy Metals by Eight Plant Species in the Field. *Water, Air, and Soil Pollution*, *184*(1-4), 235–242. doi:10.1007/s11270-007-9412-2

Appendix A – Climate

The following figures show a typical monsoon season in the city of Albuquerque. Both measurable precipitation and days where rain was present but not measurable are provided to help explain that often there are not representative storms available in the arid environment. Also notice that there are a total of two rain events in June, there were no trace events reported.

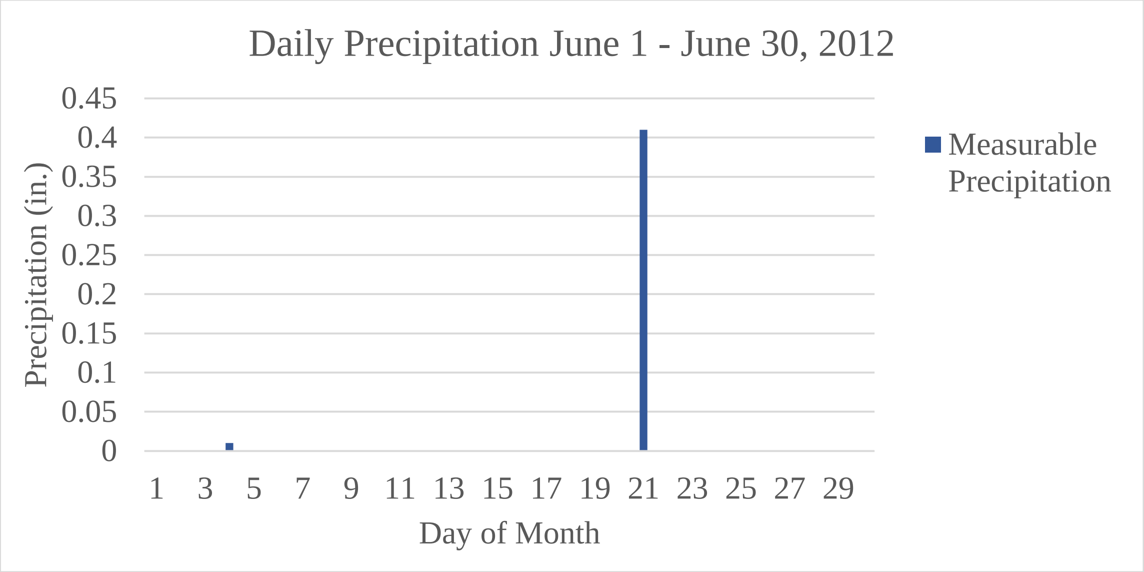

Figure 23: June 2012 Monsoon Storms

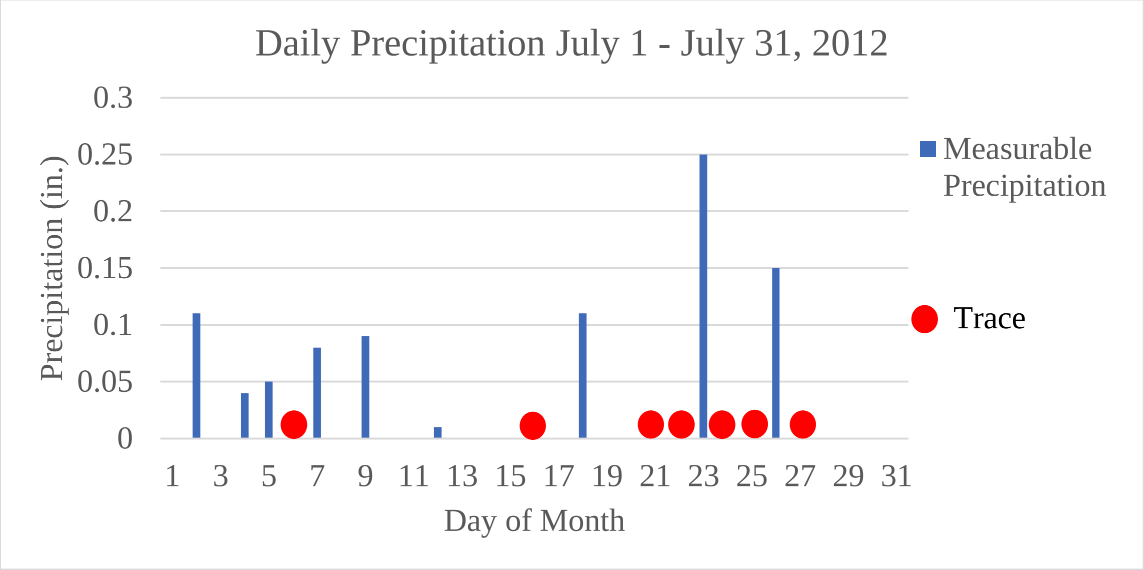

Figure 24: July 2012 Monsoon Storms

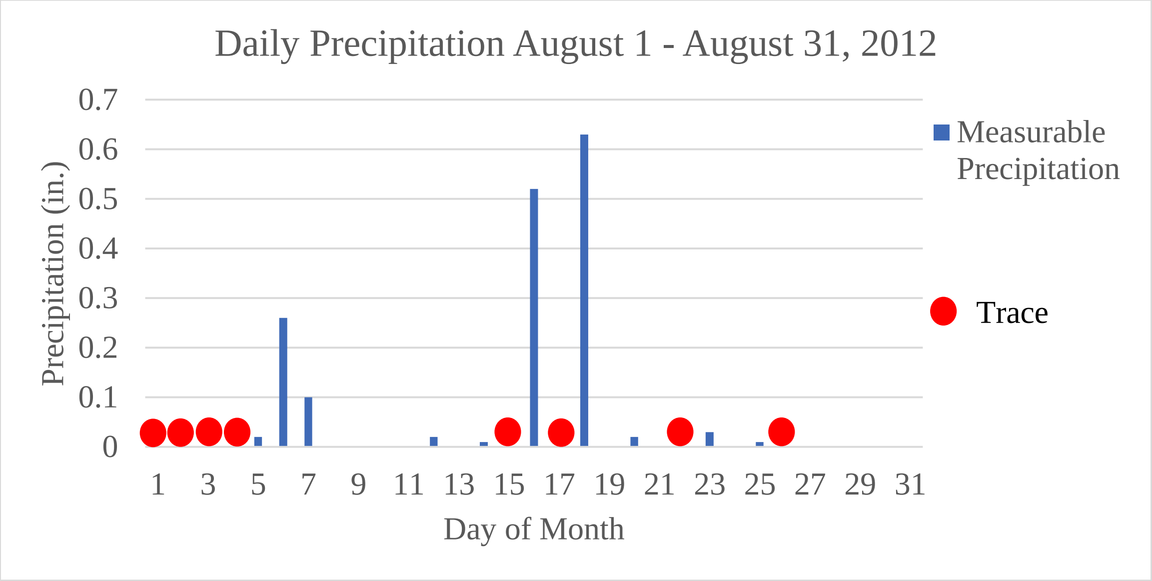

Figure 25: August 2012 Monsoon Storms

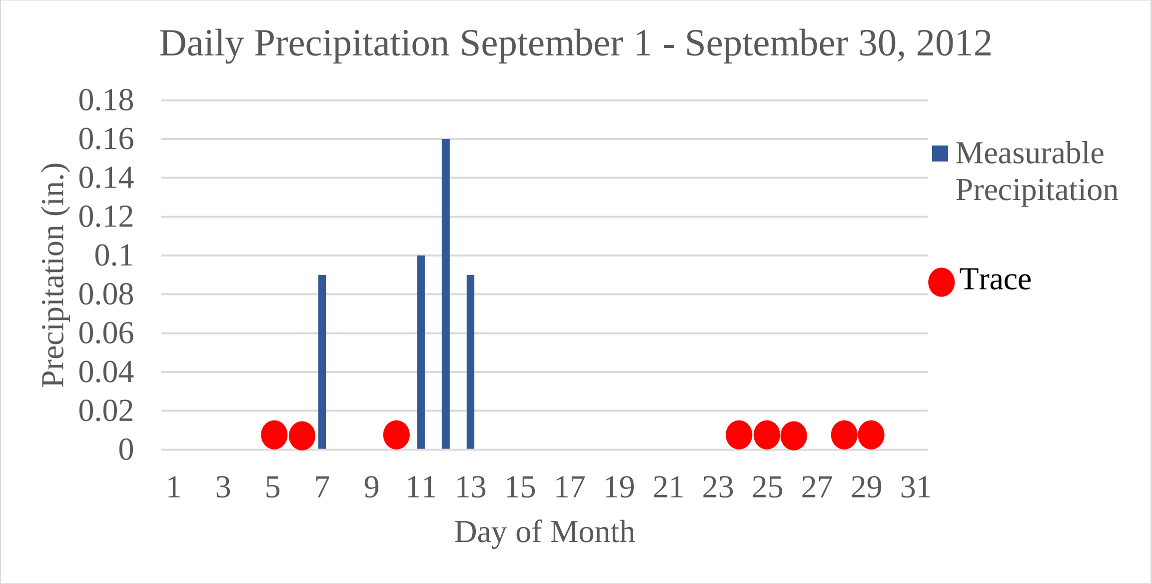

Figure 26: September 2012 Monsoon Storms

Figure 27: Typical Arid Monsoon Storm in Albuquerque with Multiple Localized Storms

Appendix B –Maps and Site Locations

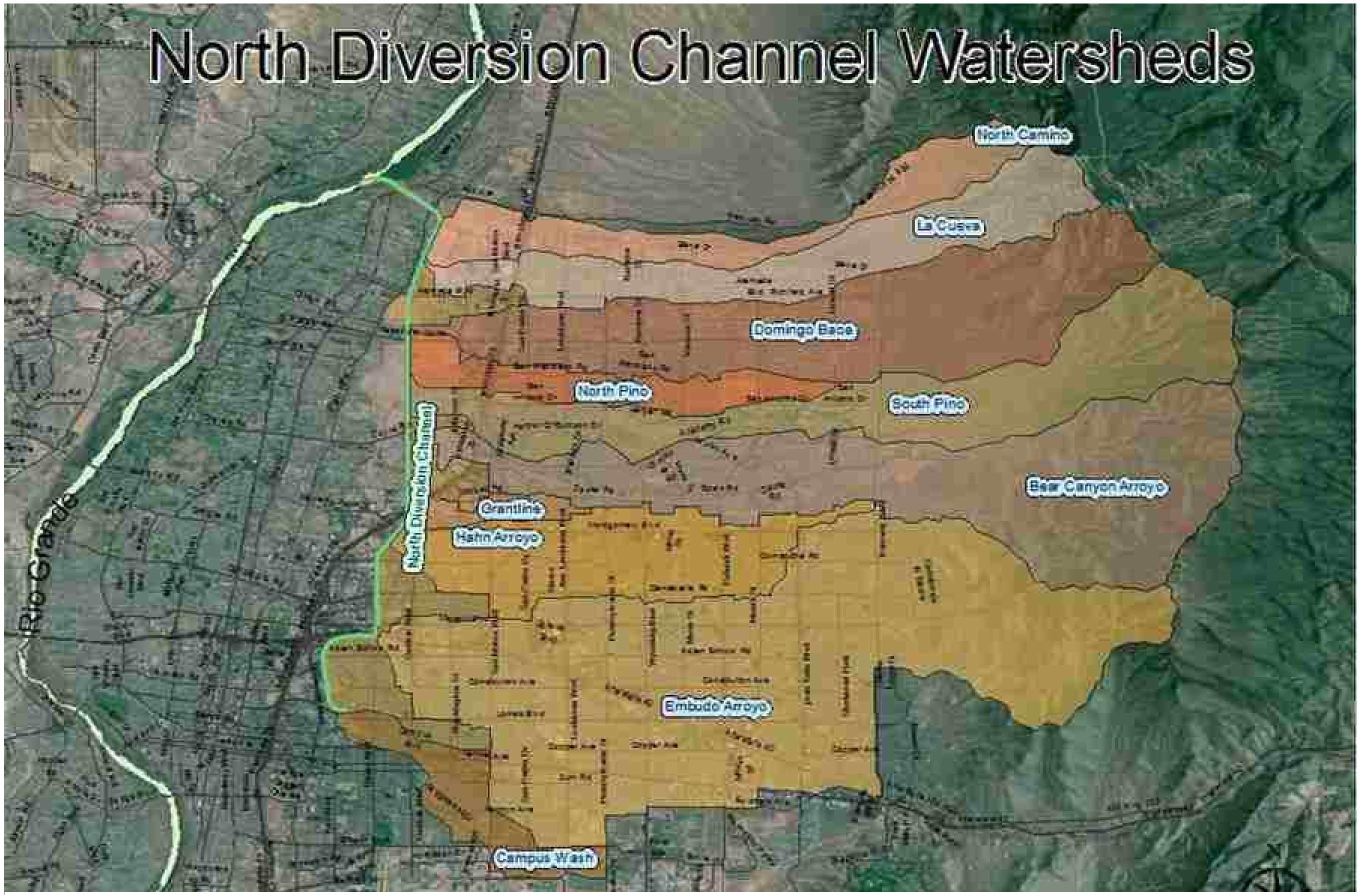

Figure 28: North Diversion Channel Watersheds, Northeast Heights, Albuquerque, NM

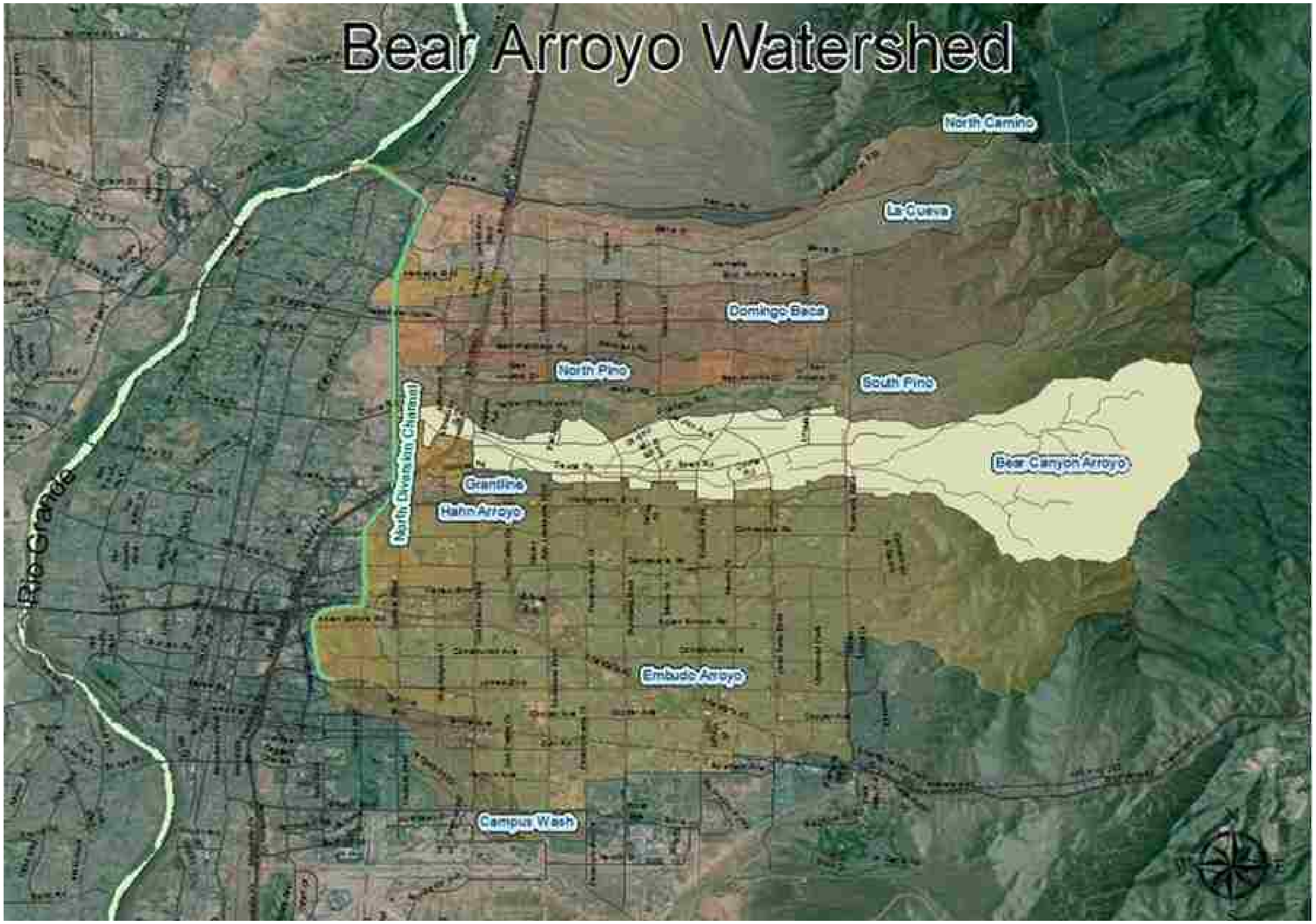

Figure 29: Location of the Bear Arroyo Watershed in the Northeast Heights, Albuquerque, NM

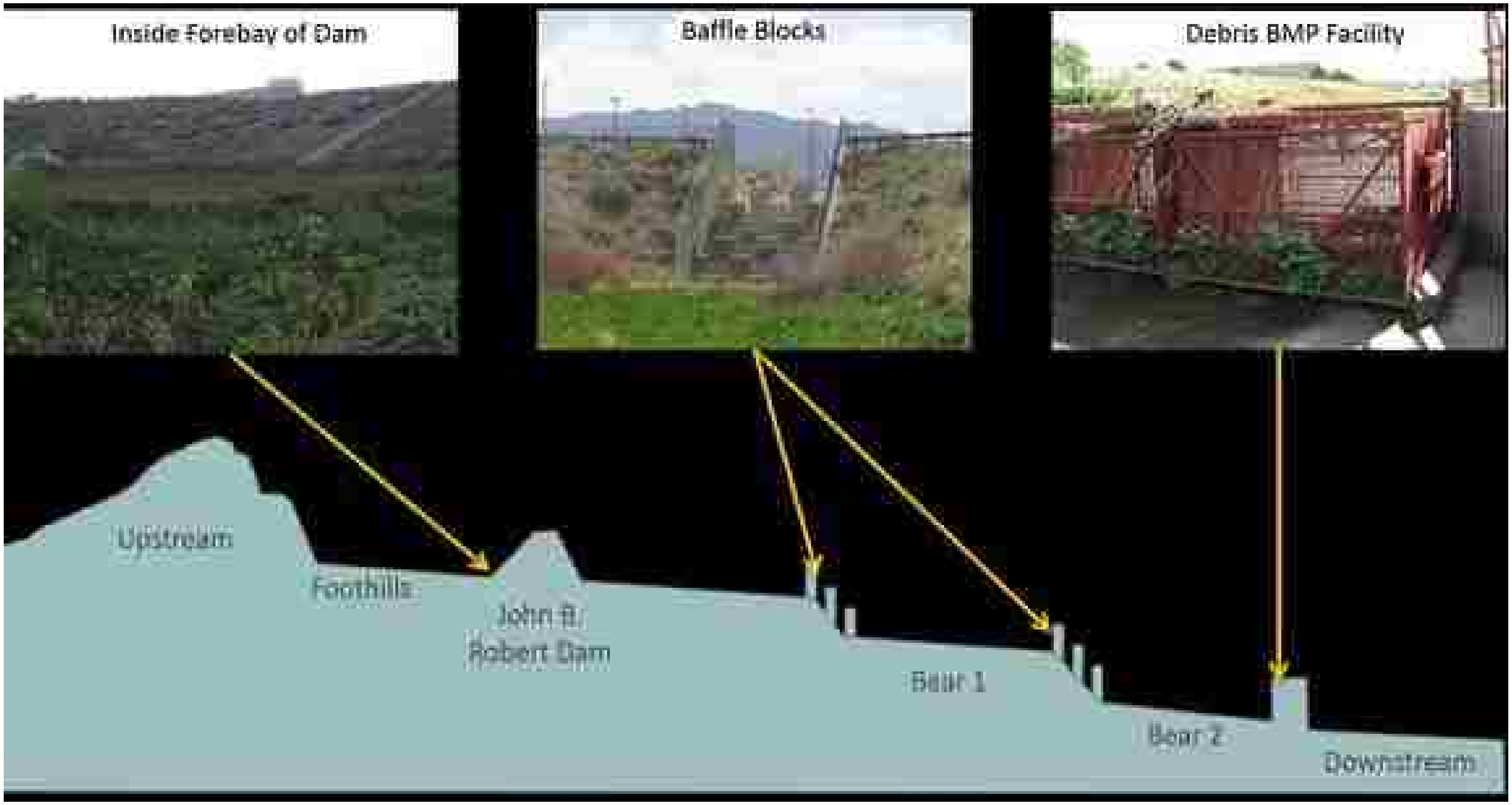

Figure 30: Schematic of Bear Arroyo beginning at the Foothills of the Sandia Mountains and ending at the last site in this study, Bear 2

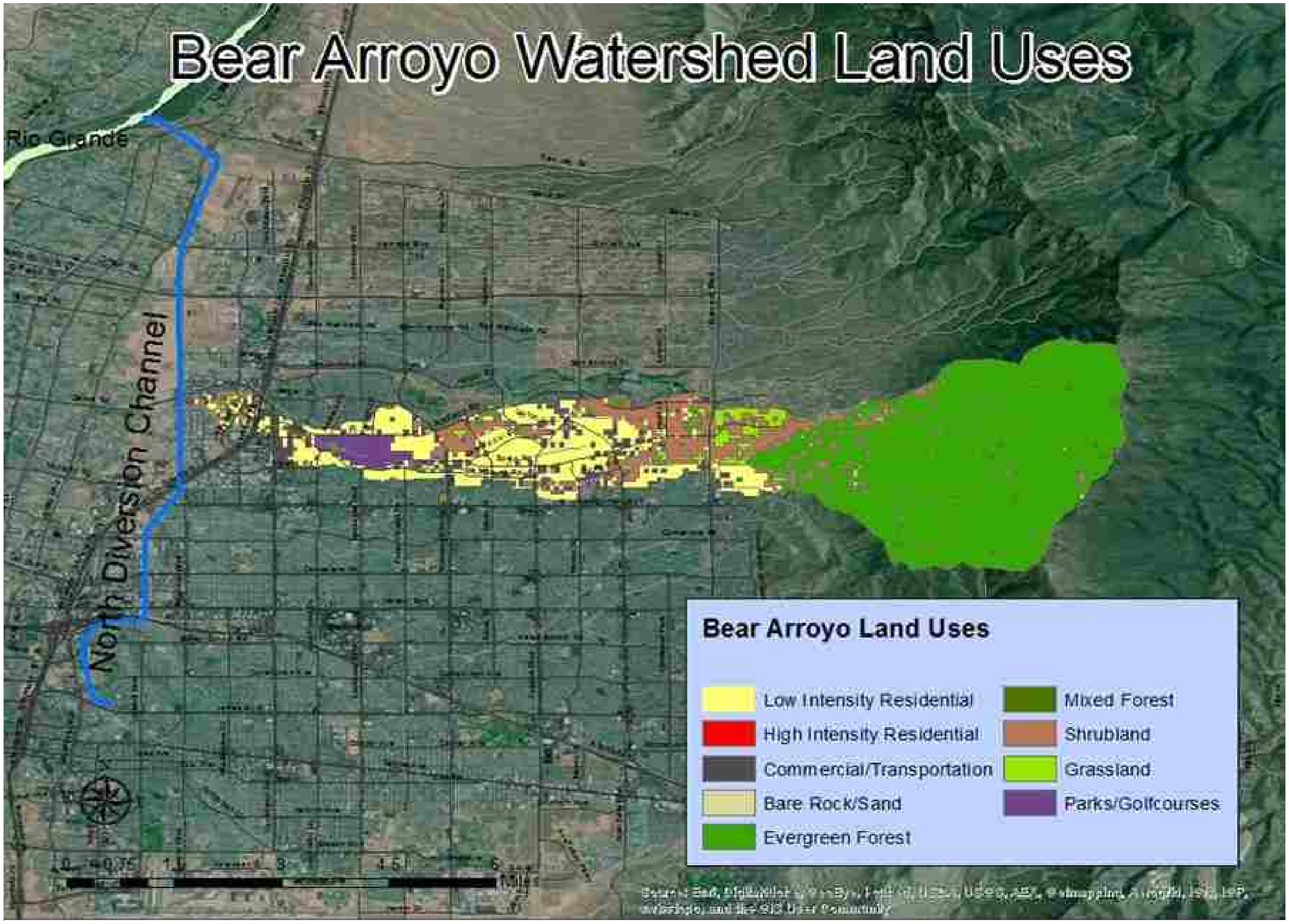

Figure 31: Land Uses within the Bear Arroyo Watershed

Figure 32: Sampling Location of Bear 1 looking downstream

Figure 33: Sampling Location of Bear 2 looking upstream

Appendix C –Heavy Metal Concentrations in Sediments

Table 6: Antimony Concentration in Sediments

Antimony Concentration in Sediments (mg-kg^{-1})			
Site	Location	6"	12"
La Cueva	Left	3.12	3.23
	Center	-	-
	Right	-	-
Bear Foothills	Left	-	-
	Center	3.65	-
	Right	-	-
John B. Robert Dam	Left	6.36	6.38
	Center	5.08	6.84
	Right	7.07	6.18
Bear 1	Left	4.31	3.40
	Center	4.68	4.29
	Right	5.18	4.80
Bear 2	Left	5.33	4.96
	Center	5.55	4.33
	Right	4.73	5.28

Table 7: Chromium Concentration in Sediments

Chromium Concentration in Sediments (mg-kg^{-1})			
Site	Location	6"	12"
La Cueva	Left	1.56	2.49
	Center		
	Right		
Bear Foothills	Left		
	Center	2.76	
	Right		
John B. Robert Dam	Left	5.15	4.71
	Center	3.71	5.27
	Right	6.18	6.04
Bear 1	Left	4.26	3.55
	Center	4.41	4.74
	Right	5.70	5.21
Bear 2	Left	6.78	5.46
	Center	6.59	4.75
	Right	4.85	5.73

Table 8: Copper Concentration in Sediments

Copper Concentration in Sediments (mg-kg^{-1})			
Site	Location	6"	12"
La Cueva	Left	2.48	3.09
	Center	-	-
	Right	-	-
Bear Foothills	Left	-	-
	Center	4.06	-
	Right	-	-
John B. Robert Dam	Left	7.80	8.08
	Center	6.49	8.65
	Right	10.6	9.61
Bear 1	Left	4.62	4.84
	Center	4.83	8.31
	Right	13.4	6.85
Bear 2	Left	19.5	10.1
	Center	17.7	8.00
	Right	9.58	10.4

Table 9: Lead Concentration in Sediments

Lead Concentration in Sediments (mg-kg^{-1})			
Site	Location	6"	12"
La Cueva	Left	1.98	2.26
	Center	-	-
	Right	-	-
Bear Foothills	Left	-	-
	Center	2.68	-
	Right	-	-
John B. Robert Dam	Left	4.35	4.70
	Center	3.32	4.97
	Right	5.73	5.04
Bear 1	Left	5.73	3.79
	Center	5.49	6.66
	Right	7.74	6.80
Bear 2	Left	9.77	7.50
	Center	9.64	5.94
	Right	6.78	8.15

Table 10: Zinc Concentration in Sediments

Zinc Concentration in Sediments (mg-kg^{-1})			
Site	Location	6"	12"
La Cueva	Left	17.9	20.7
	Center	-	-
	Right	-	-
Bear Foothills	Left	-	-
	Center	20.1	-
	Right	-	-
John B. Robert Dam	Left	50.8	44.0
	Center	38.6	50.8
	Right	56.3	49.2
Bear 1	Left	32.6	33.9
	Center	39.3	82.1
	Right	71.8	38.5
Bear 2	Left	98.9	57.6
	Center	99.5	47.5
	Right	51.4	58.0

The following figures illustrate the heavy metal concentrations found within the watershed. Note that Antimony (Sb) is the only heavy metal of the five researched in this paper, that does not follow the same increasing trend as the other elements do. The area in red in the Antimony map is the area above the John B. Robert Dam, where the main sources to this location are residential homes and side street runoff, and Tramway Boulevard.

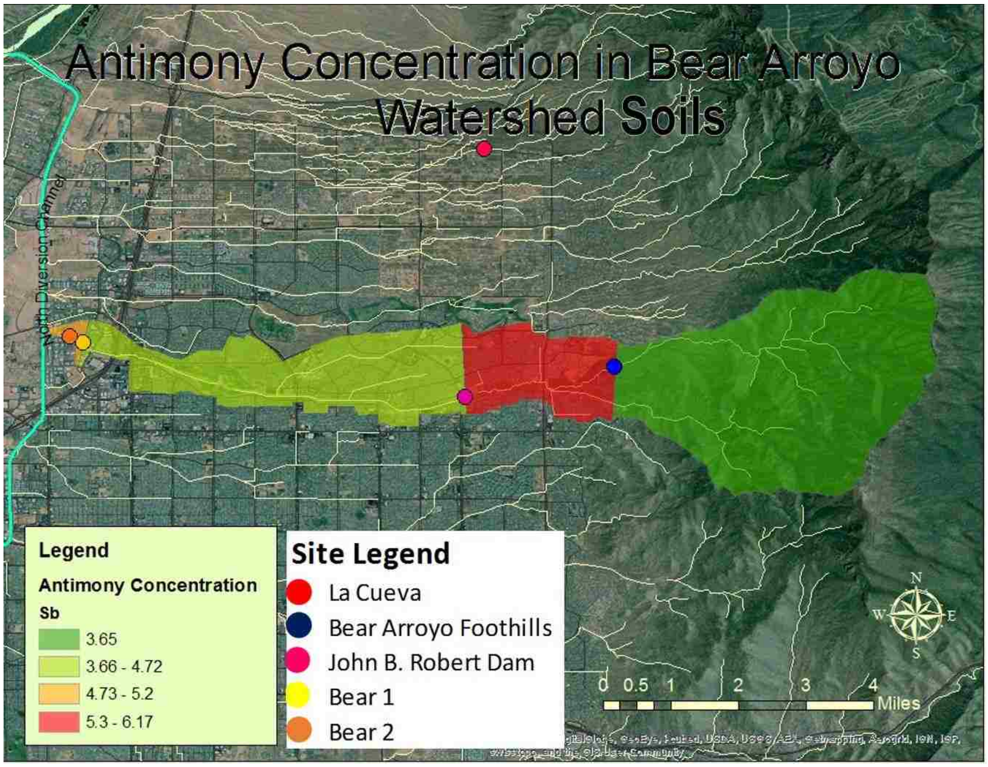

Figure 34: Antimony Concentrations found in Sediments

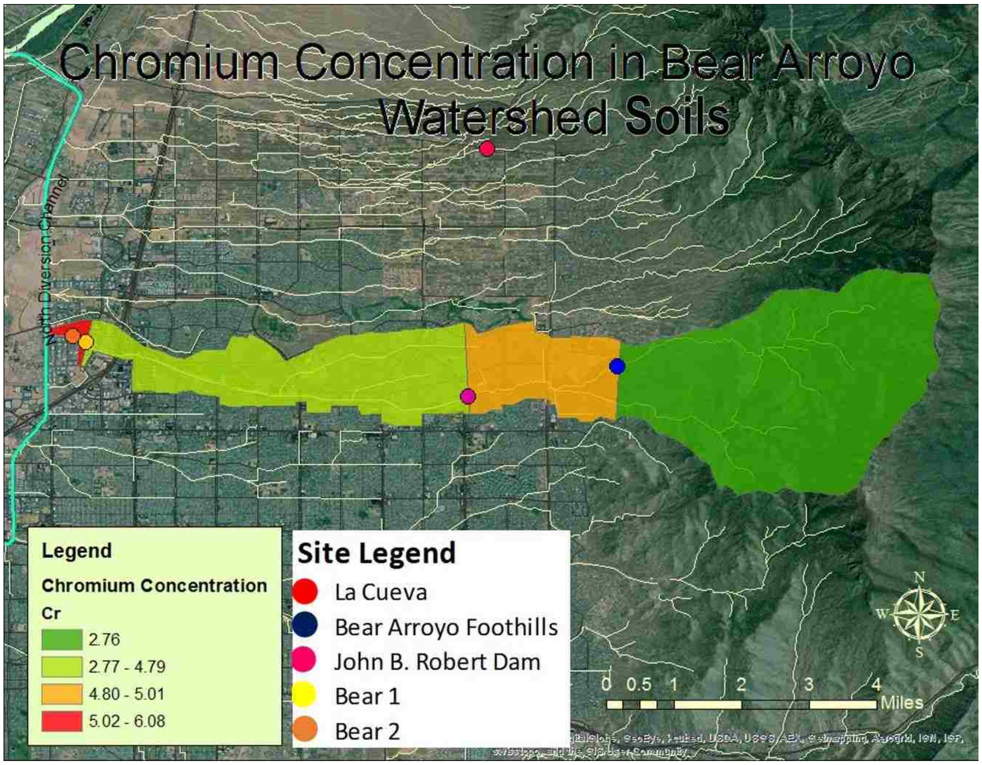

Figure 35: Chromium Concentrations found in Sediments

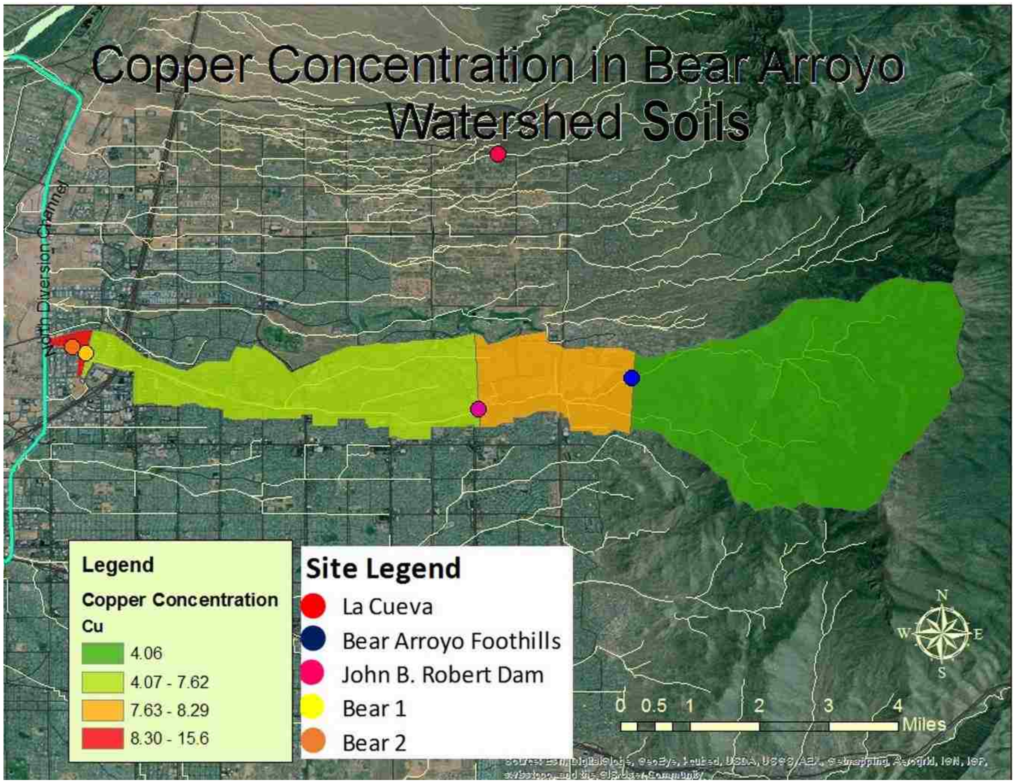

Figure 36: Copper Concentrations found in Sediments

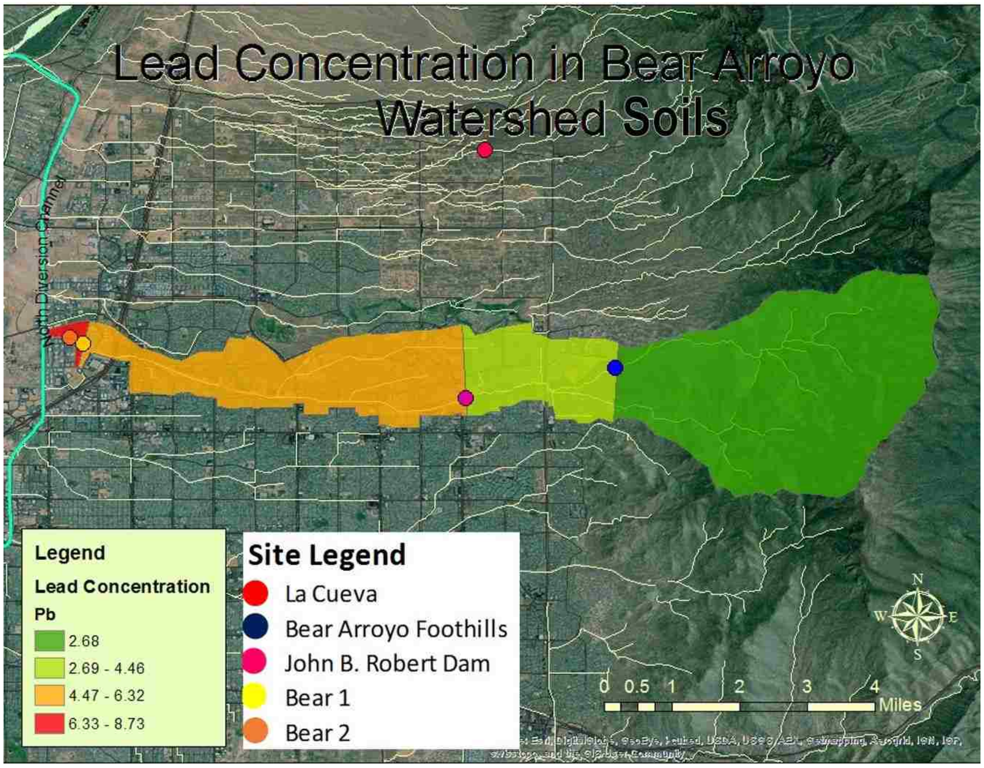

Figure 37: Lead Concentrations found in Sediments

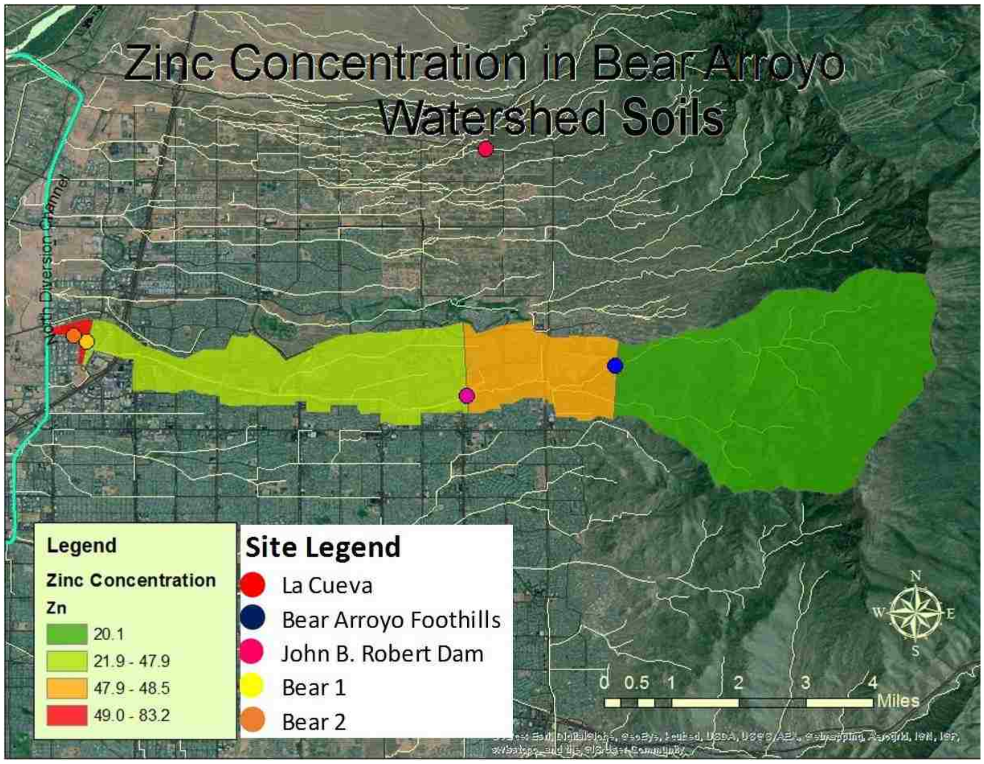

Figure 38: Zinc Concentrations found in Sediments

Appendix D—Sieve Analysis Graphs

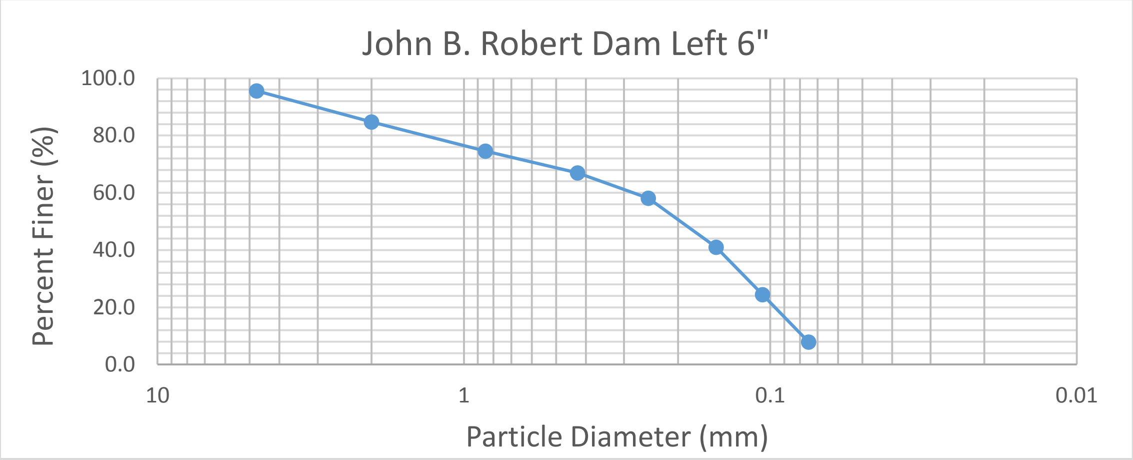

Figure 39: 6" Left Location - Sieve Analysis JBR Dam

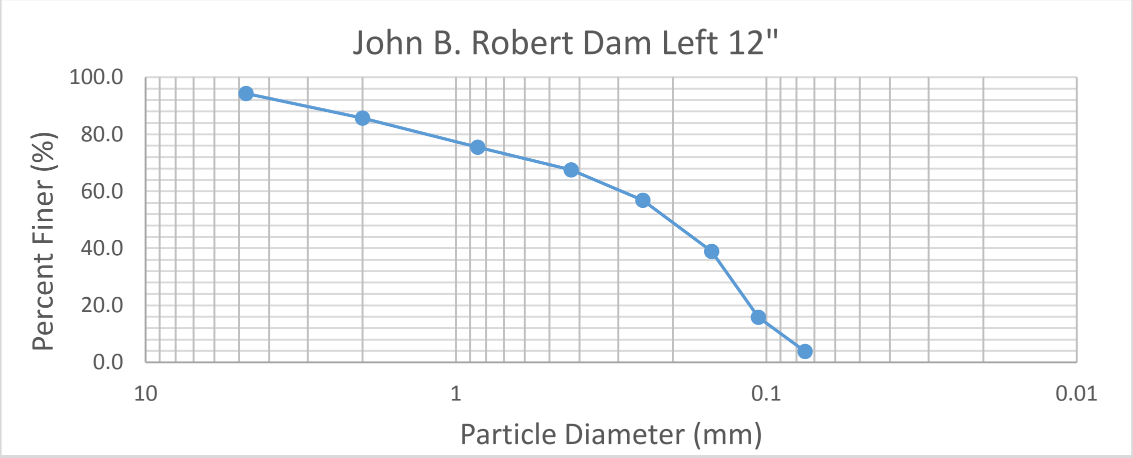

Figure 40:12" Left Location - Sieve Analysis JBR Dam

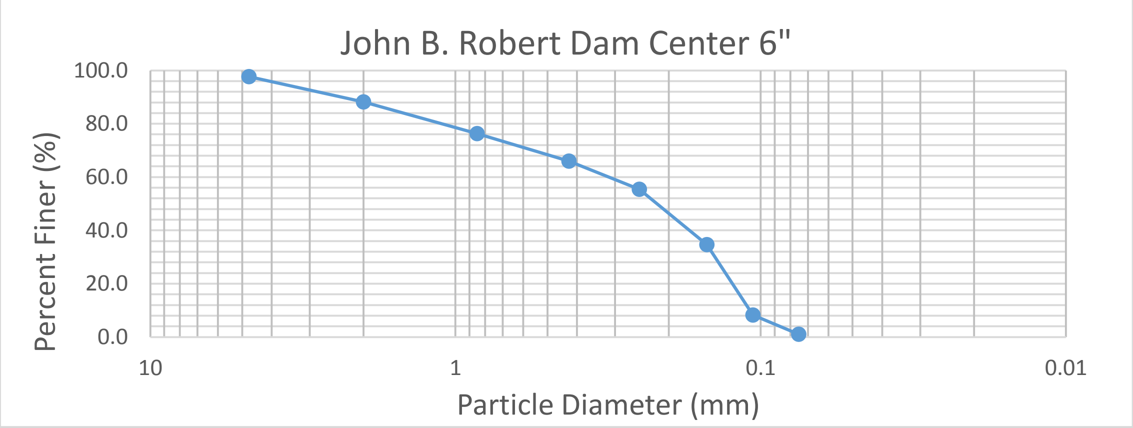

Figure 41: 6" Center Location Sieve Analysis JBR Dam

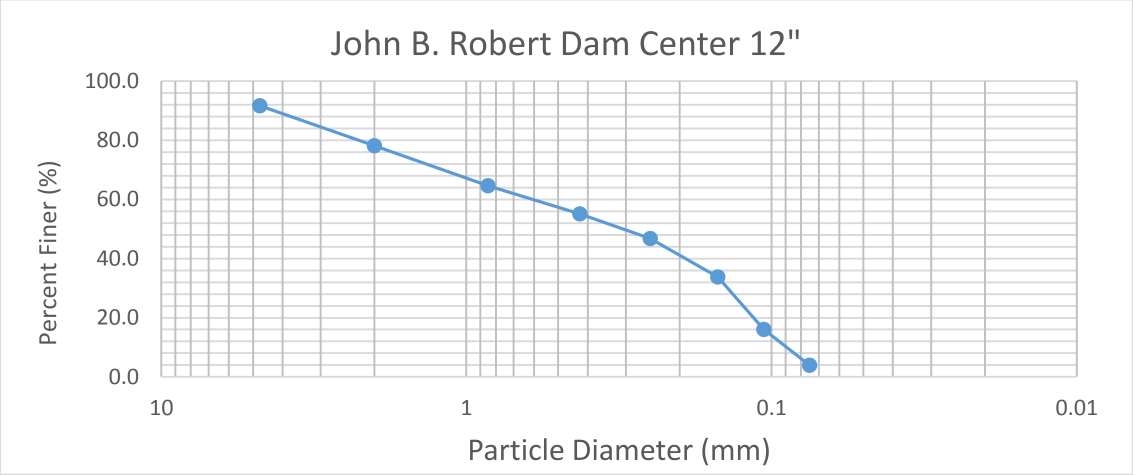

Figure 42: 12" Center Location - Sieve Analysis JBR Dam

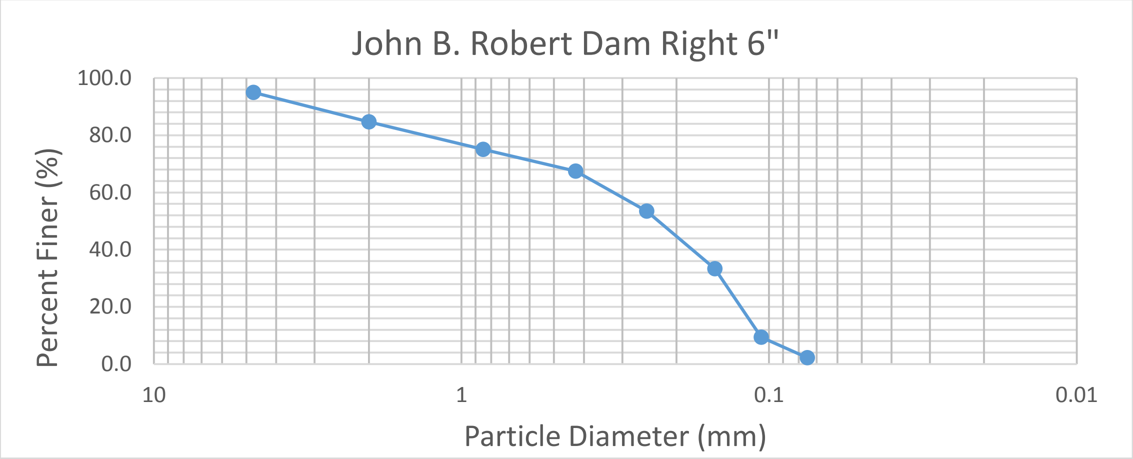

Figure 43: 6" Right Location - Sieve Analysis JBR Dam

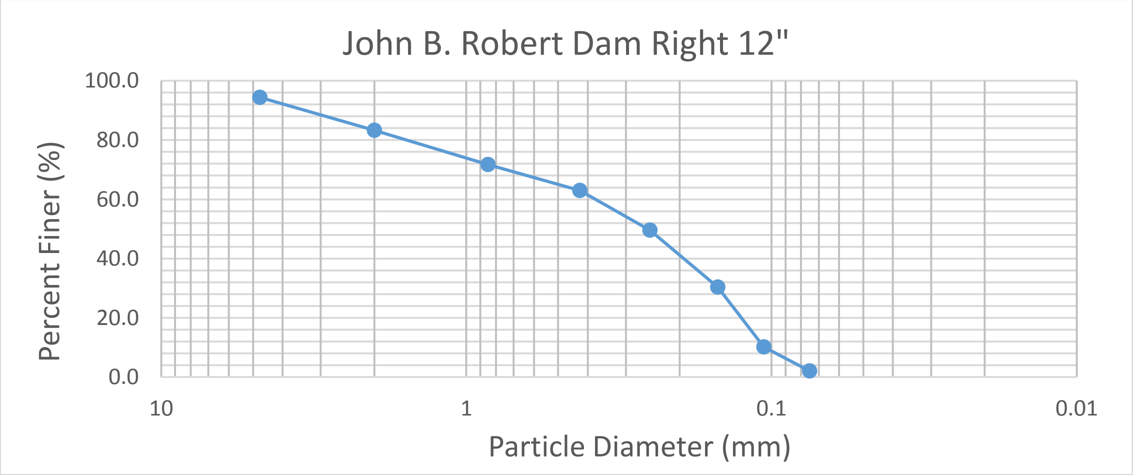

Figure 44:12" Right Location - Sieve Analysis JBR Dam

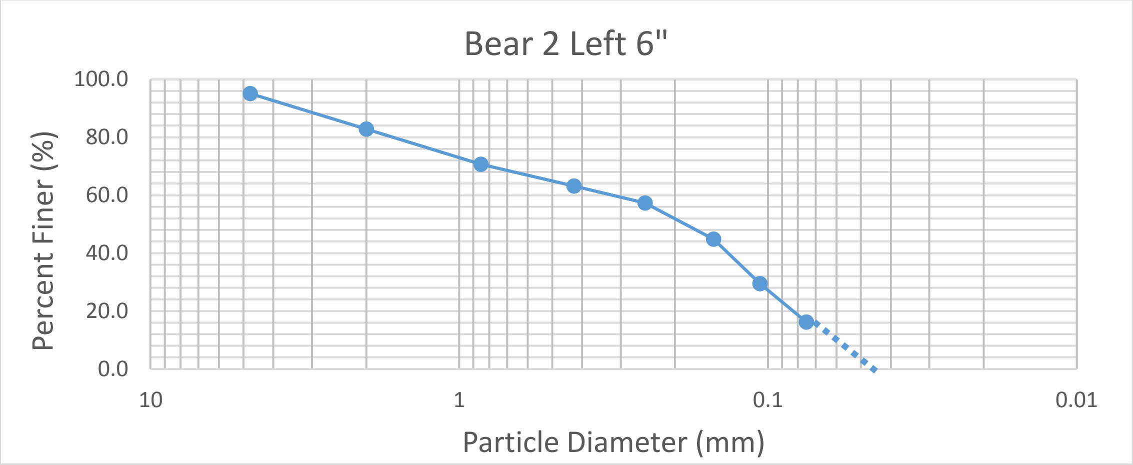

Figure 45: 6" Left Location - Sieve Analysis Bear 2

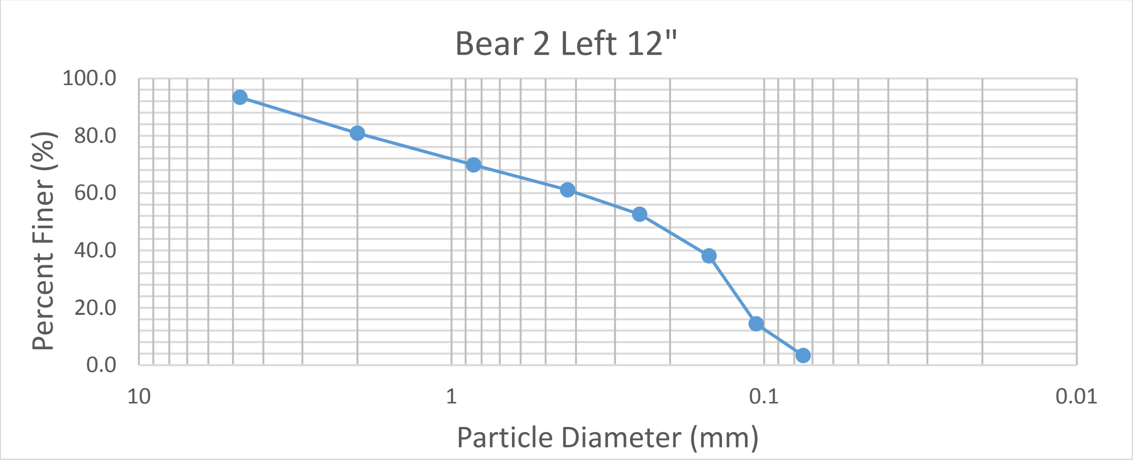

Figure 46: 12" Left Location - Sieve Analysis Bear 2

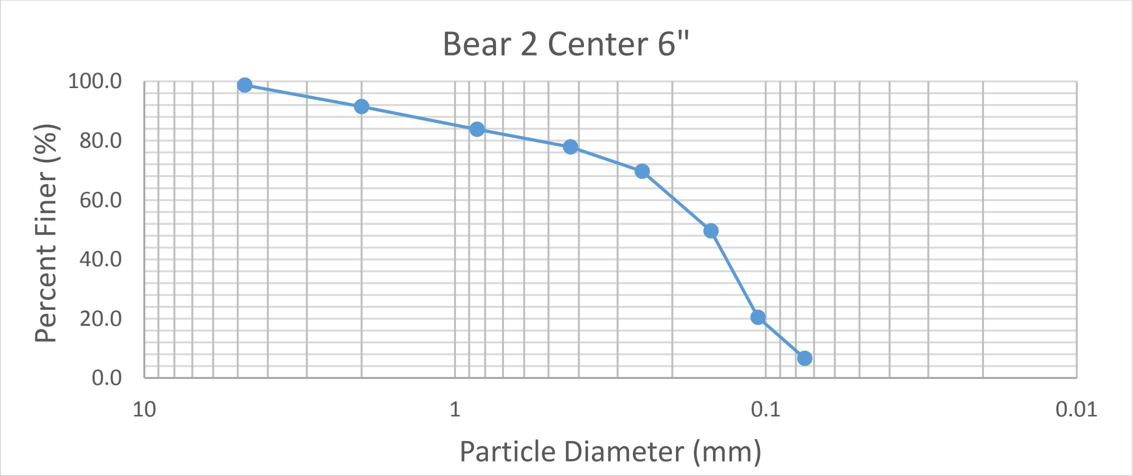

Figure 47: 6" Center Location - Sieve Analysis Bear 2

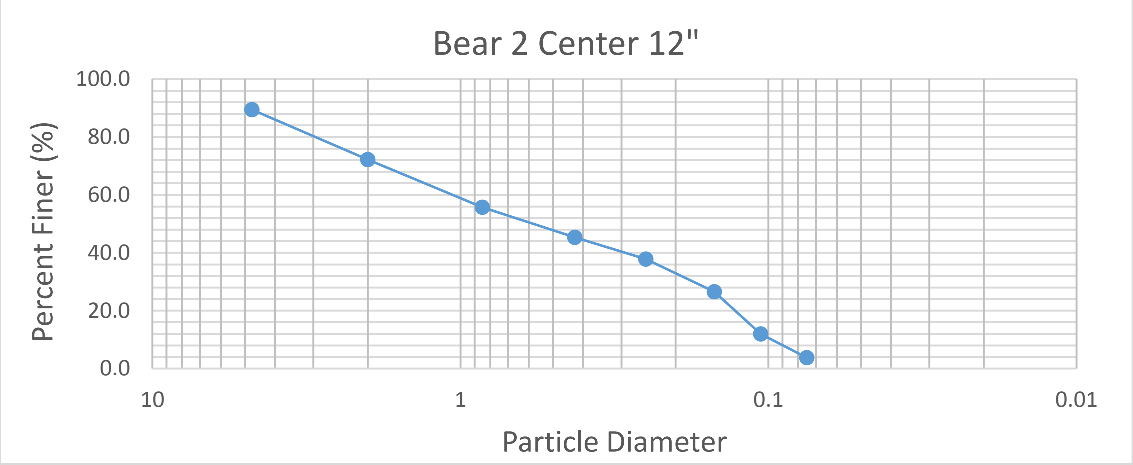

Figure 48: 12" Center Location - Sieve Analysis Bear 2

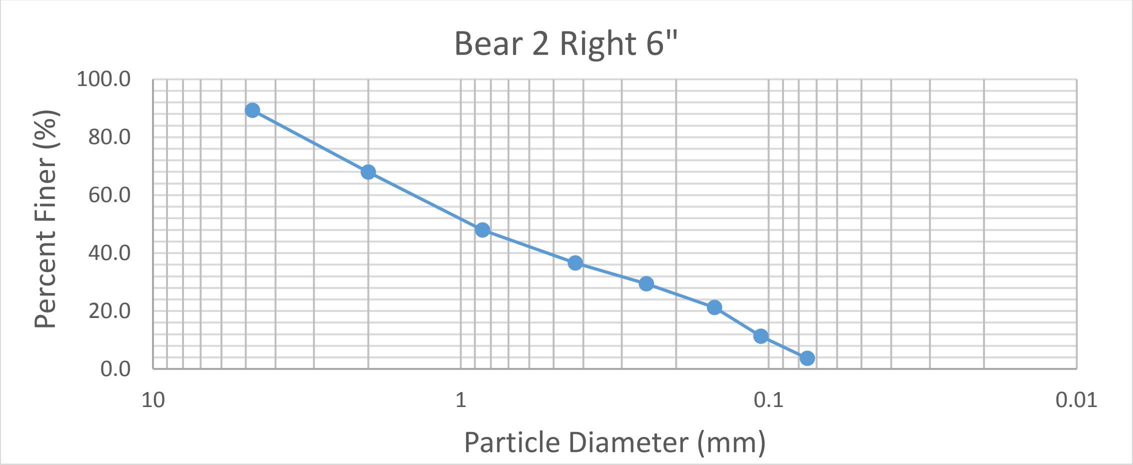

Figure 49: 6" Right Location - Sieve Analysis Bear 2

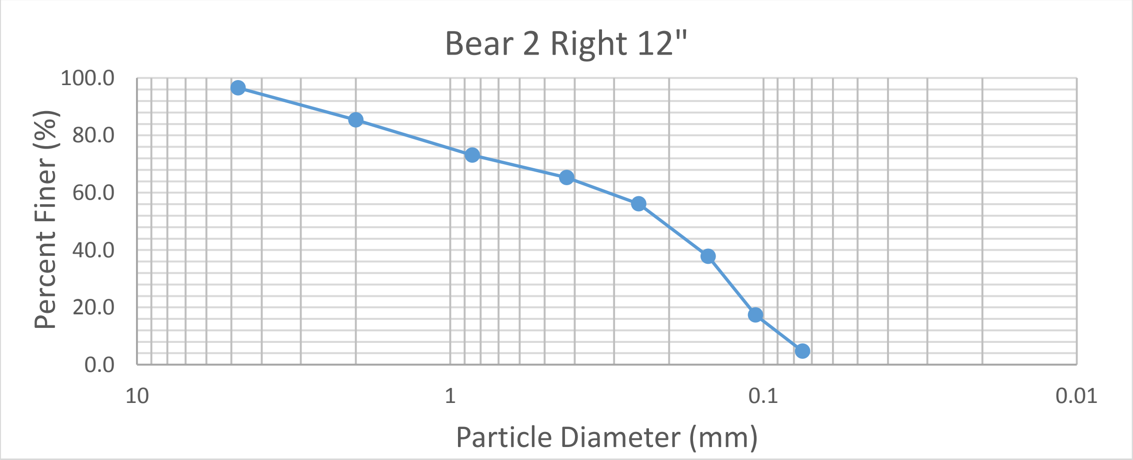

Figure 50: 12"Right Location - Sieve Analysis Bear 2

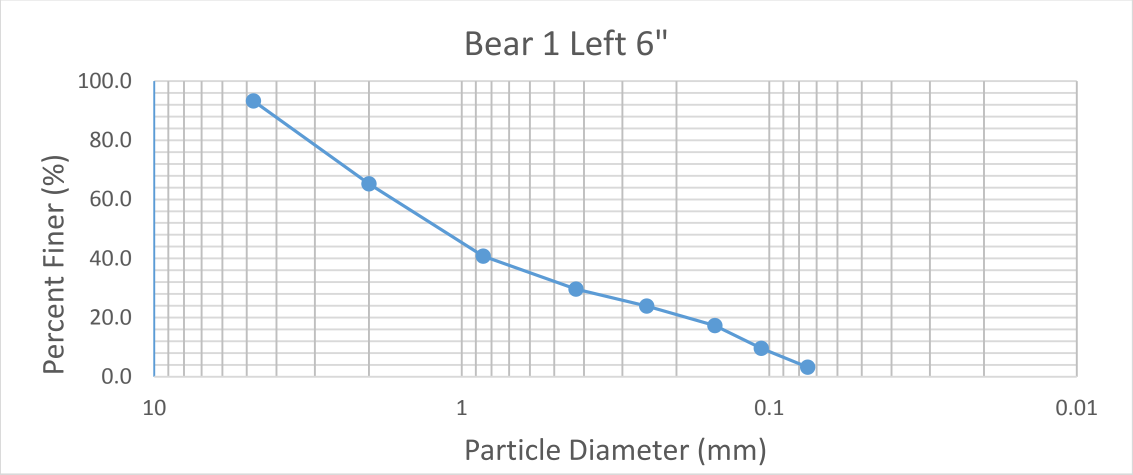

Figure 51: 6" Left Location - Sieve Analysis Bear 1

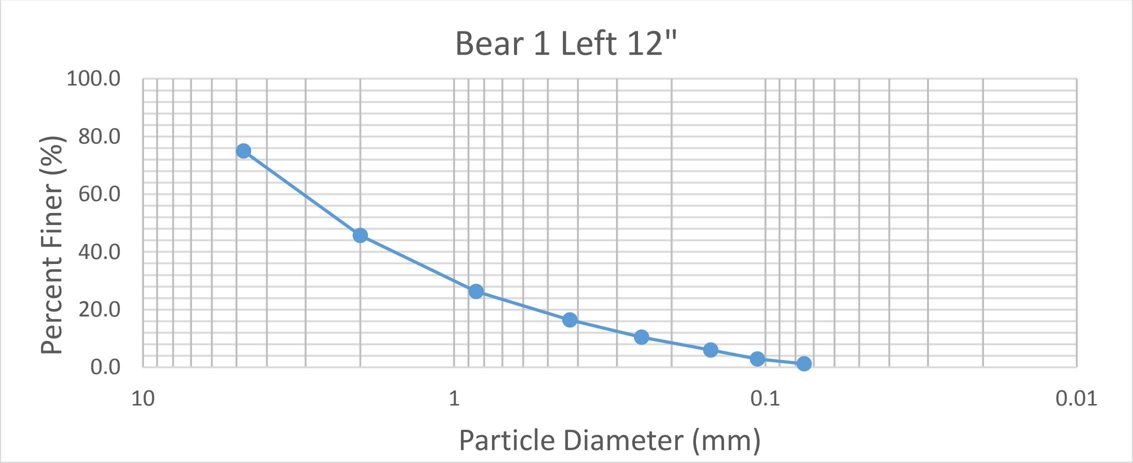

Figure 52: 12" Left Location - Sieve Analysis Bear 1

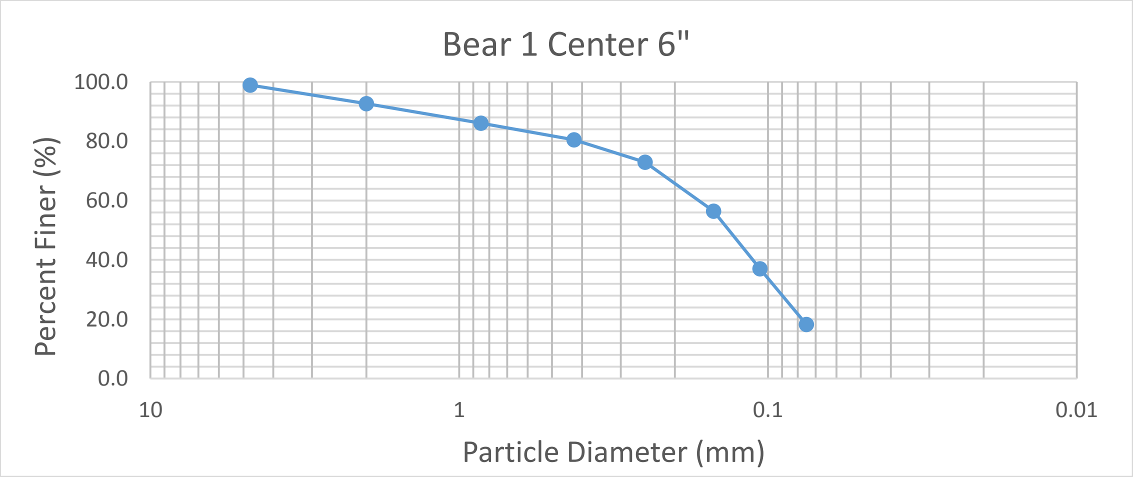

Figure 53: 6" Center Location - Sieve Analysis Bear 1

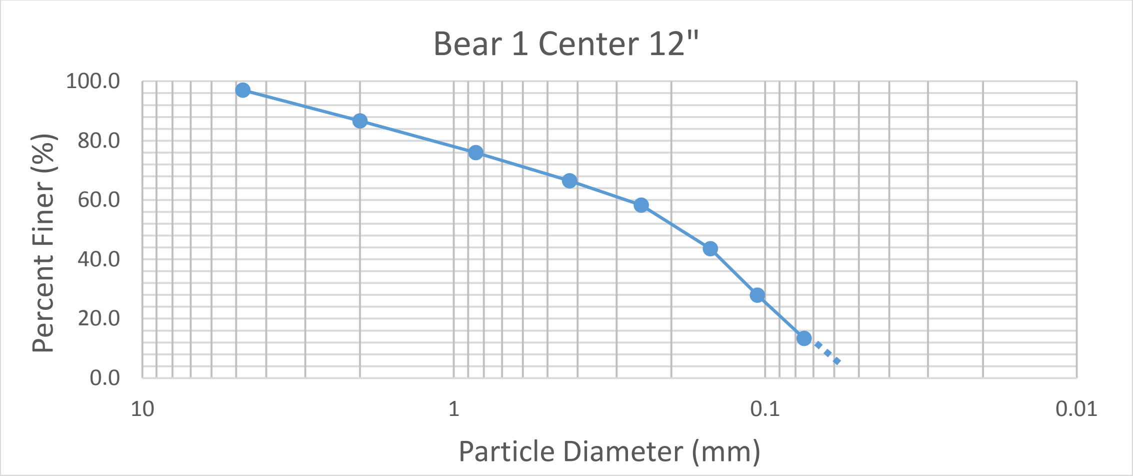

Figure 54: 12" Center Location - Sieve Analysis Bear 1

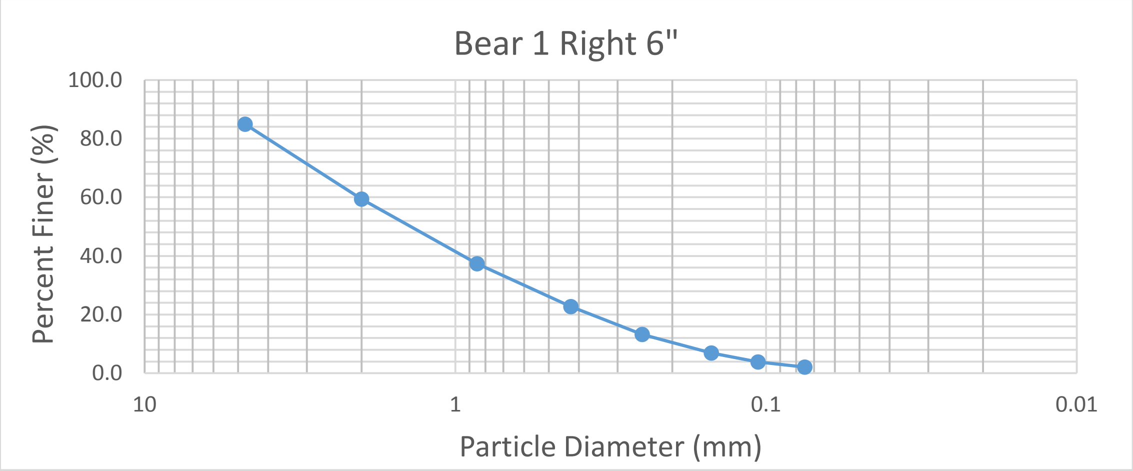

Figure 55: 6" Right Location - Sieve Analysis Bear 1

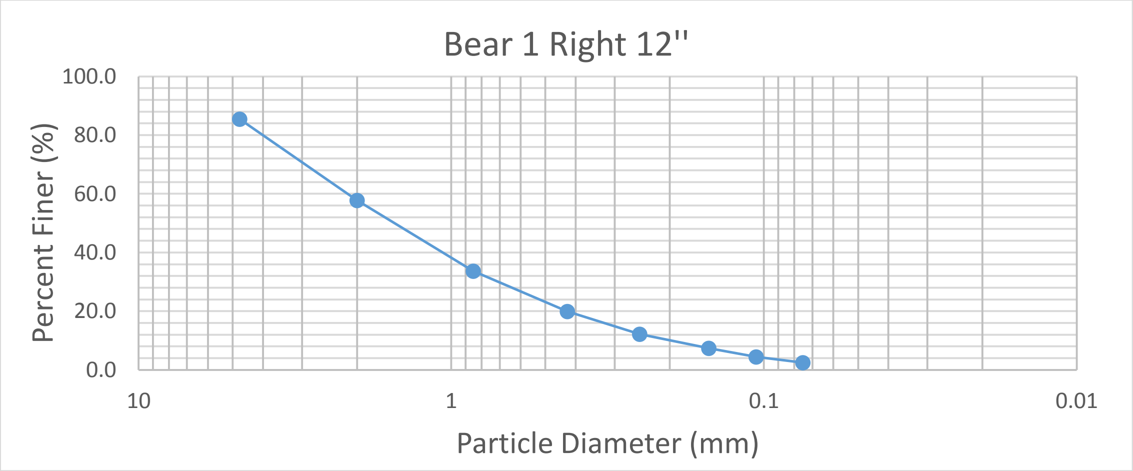

Figure 56: 12" Right Location - Sieve Analysis Bear 1

Appendix E –Heavy Metal Concentrations in Rumex Crispus

Table 11: Antimony Concentration in Rumex crispus

Antimony Concentrations in R. crispus (mg-kg^{-1})				
Site	Location	Roots	Leaves	Stems
La Cueva	Left	0.893	1.16	0.944
	Center	0	0	0
	Right	0	0	0
John B. Robert Dam	Left	1.40	1.36	1.02
	Center	1.09	0.991	0.976
	Right	1.25	0.950	1.12
Bear 1	Left	1.50	0.914	0.994
	Center	1.35	0.881	0.868
	Right	1.16	0.903	0.900
Bear 2	Left	1.22	1.17	1.02
	Center	1.33	0.841	1.02
	Right	0.988	0.879	0.900

Table 12: Chromium Concentration in Rumex crispus

Chromium Concentrations in R. crispus (mg-kg^{-1})				
Site	Location	Roots	Leaves	Stems
La Cueva	Left	-	0.00	-
	Center	-	-	-
	Right	-	-	-
John B. Robert Dam	Left	0.55	0.09	0.40
	Center	0.77	0.310	0.000
	Right	1.17	0.135	0.42
Bear 1	Left	0.80	0.175	0.152
	Center	2.10	0.250	0.244
	Right	1.74	0.235	0.301
Bear 2	Left	0.71	0.82	0.14
	Center	1.30	0.131	0.49
	Right	0.269	0.176	0.880

Table 13: Copper Concentration in Rumex crispus

Copper Concentrations in R. crispus (mg-kg^{-1})				
Site	Location	Roots	Leaves	Stems
La Cueva	Left	0.952	1.40	1.21
	Center	--	--	--
	Right	--	--	--
John B. Robert Dam	Left	1.76	2.97	2.95
	Center	1.22	4.38	3.30
	Right	0.938	3.146	2.84
Bear 1	Left	3.09	4.68	3.52
	Center	3.10	6.46	5.36
	Right	1.50	3.65	3.20
Bear 2	Left	2.77	3.82	3.52
	Center	2.86	3.722	3.53
	Right	1.21	3.06	2.32

Table 14: Zinc Concentration in Rumex crispus

Zinc Concentrations in R. crispus (mg-kg^{-1})				
Site	Location	Roots	Leaves	Stems
La Cueva	Left	7.33	3.49	10.2
	Center	--	--	--
	Right	--	--	--
John B. Robert Dam	Left	13.5	7.33	10.7
	Center	11.6	10.2	12.4
	Right	12.3	8.72	14.5
Bear 1	Left	31.5	7.92	20.9
	Center	24.4	14.7	16.9
	Right	20.9	9.26	14.5
Bear 2	Left	21.8	12.1	18.3
	Center	18.0	11.2	14.9
	Right	13.1	11.2	15.4

All photos in this report unless stated otherwise were taken by Adrienne Martinez.