CANYON CITY MILL PA/SI FINAL REPORT

CENE 486

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List of Abbreviations

ADEQ	Arizona Department of Environmental Quality
AT	Averaging Time
AZSRS	Arizona Soil Remediation Standards
BLM	Bureau of Land Management
COC	Contaminants of Concern
CR	Contact Rate
DU1	Decision Unit 1
DU2	Decision Unit 2
DU3	Decision Unit 3
ECO-SSL	Ecological Soil Screening Levels
ED	Exposure Duration
EF	Exposure Frequency
EH&S	Environmental Health and Safety
EPA	Environmental Protection Agency
EPC	Exposure Point Concentration
HI	Hazard Index
ISM	Incremental Sampling Method
IRIS	Integrated Risk Information System Database
LOD	Limit of Detection
PA/SI	Preliminary Assessment and Site Investigation
PLS	Pregnant Leach Solution
PPM	Parts per million
RfD	Reference Dose
RSD	Relative Standard Deviation
SF	Slope Factor
SLRs	Soil Remediation Levels
SAP	Sampling and Analysis Plan
QA/QC	Quality Assurance/Quality Control
XRF	X-Ray Fluorescence

Acknowledgements

Many thanks to Dr. Bridget Bero for guiding our team and generously providing her knowledge.

The team would also like to thank their mothers.

1.0 Introduction

1.1 Project Purpose

The purpose of this project is the completion of a Preliminary Assessment and Site Investigation (PA/SI) report for the Bureau of Land Management (BLM) for the Canyon City Mill site. The site was utilized for milling activities, including a cyanide heap leaching process, that led to the release of hazardous substances. The hazards substances included lead and arsenic as contaminants of concern (COC). Understanding the extent of the contamination and determining the risk to human and environmental health is imperative in determining if further remedial action is required at the site.

1.2 Project Location

The abandoned Canyon City Mill is located 1.5 miles south of the town of Oatman, Arizona, in the eastern portion of the state within Mohave County. The geographical coordinates are as follows:

- Latitude: 35°0'14.04"N

- Longitude: 114°23'3.57"W

Figure 1.1 below shows the location of the abandoned mine site within the state of Arizona and within Mohave County.

Figure 1.1: Geographical Location of Site [1]

The site can be accessed from Flagstaff by traveling on I-40 westbound and exiting on State Route 10 (Oatman Highway). The Oatman Highway is followed for approximately 1.5 miles past the town of Oatman until Stoll Road is reached. Figure 1.2 below shows an aerial image of the site in relation to Oatman.

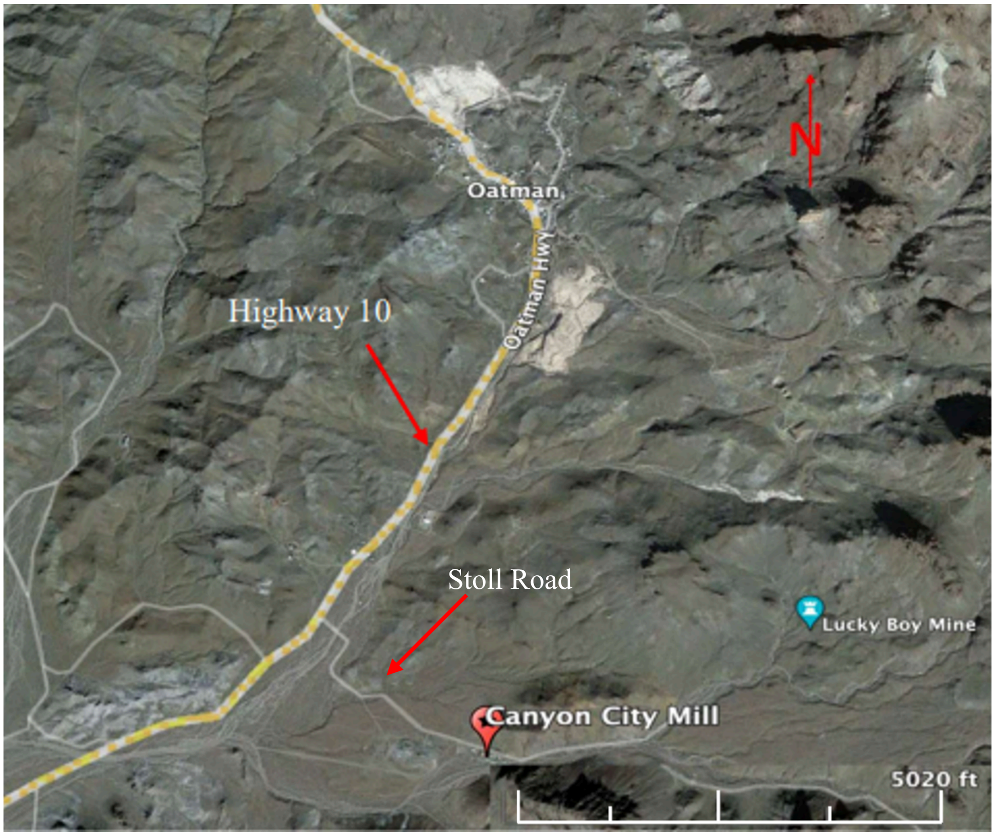


Figure 1.2: Site Location in Relation to Oatman

There are washes south of the site, which flow from northeast to west/southwest towards the Colorado River. The Colorado River is located approximately 14.5 miles downstream of the site [1]. Highway 10 is indicated by the yellow path in the top left corner of the image above. Stoll road can also be seen in the image above.

1.3 Project History

The Canyon City Mill began operation in 1986. The owner of the site, at the time of operation, was Charlie Stoll. Robert Graham, the owner of Canyon City Mill, was subleasing the site from Stoll. The site was used for a cyanide leaching process to extract gold from mined/spent ore from underground gold mines near Oatman, Arizona. One known source of the ore was the nearby Minneapolis Mine. No mining was done at the site.

The cyanide leaching operation used three 30,000-gallon tanks to store sodium cyanide solution. The cyanide solution was sprayed or dripped onto piles of crushed ore in the leach field (shown as the leach slab in Figure 1.4). As the cyanide passed through the ore, the gold was leached from the rock, creating what is known as the pregnant leach solution (PLS). The leach solution flowed into the pregnant solution pond. Cinders, which are small pieces of burnt wood or charcoal, were used as a carbon source in the pregnant solution pond to absorb the gold from the cyanide-gold complexes. The gold was recovered by carbon adsorption, and the cyanide was recycled back to the cyanide solution tanks. The spent ore was left at the site in piles south of the leach field [2]. The supernatant from the leach field, the PLS, was stored in a pregnant solution pond. The solution then went through the carbon absorption process where the cyanide was separated from the gold, which was recovered. Figure 1.3 below shows a block diagram of the general cyanide leaching process.

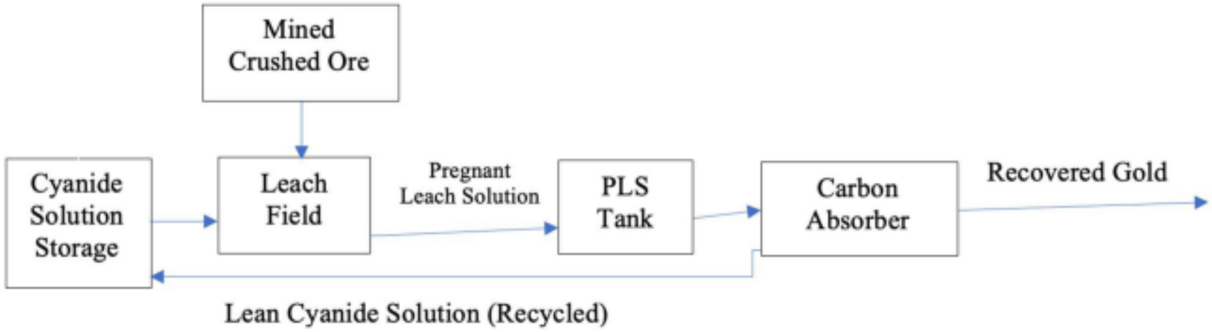


Figure 1.3: Cyanide Leaching Process Block Diagram

In 1991, the three 30,000-gallon tanks holding the cyanide solution were dumped on the site. The Bureau of Land Management and the Arizona Department of Environmental Quality (ADEQ) Emergency Response Unit were contacted and informed of the spill. This prompted a site investigation in 1991, completed by ADEQ's Office of Waste and Water Quality Management [2]. The mill site has been abandoned since 1991 when extraction operations stopped after the cyanide solution spill. The operational equipment was subsequently removed from the site after operations ceased, leaving behind a concrete holding pond, multiple concrete slabs used for holding cyanide solutions and cyanide leaching, a building foundation, and debris. Figure 1.4 below shows the current site conditions as found from Google Earth aerial imagery. The access road runs to the north of the site, and a wash is present to the south of the site that runs in the southwest direction towards Oatman Highway.

Figure 1.4: Current Site Condition [1]

According to a soil sampling effort conducted for a 2016 PA/SI by ECM Consultants [2], the presence of cyanide was not detected above background levels in the soil and sediment samples collected. However, lead and arsenic concentrations were detected above ADEQ Soil Remediation Levels (SLRs) [2]. The non-resident, ADEQ soil remediation level for arsenic is 10 mg/kg, and arsenic levels on the site ranged from 2.06 mg/kg to 214 mg/kg [2]. The non-resident, ADEQ soil remediation level for lead is 800 mg/kg, and lead levels on the site ranged from 13.7 mg/kg to 1480 mg/kg [2].

The current extent of the lead and arsenic soil contamination at the site and surrounding area is currently unknown. Representative background levels for COCs in the soil in the surrounding area are also unknown. Conducting a PA/SI of the site is necessary to determine the current status of contamination at the site. The project was confined to only soil samples; no surface water, groundwater or air samples were collected. The completion of the PA/SI report is the primary deliverable of this project.

2.0 Work Plan

Flag Environmental Solutions created a Work Plan containing the project's Sampling and Analysis Plan (SAP) and Health and Safety Plan (HASP). The Work Plan can be found in Appendix A.

3.0 Site Investigation

Field sampling was performed during the January 20-21, 2023 site investigation. The weather conditions on January 20th were clear skies and averaged temperatures of 45 degrees Fahrenheit and maximum windspeeds of 20 miles per hour. The weather conditions on January 21st were also clear with average temperatures of 47 degrees Fahrenheit and a maximum windspeed of 21 miles per hour. Flag Environmental Solutions personnel documented site conditions through photographs and field notes. Discrete sample locations and Decision Unit (DU) grid corners were identified using a handheld GPS unit and recorded in the field notes. Photographs of site features are shown in Appendix B and a copy of the field notes containing observations taken while sampling are presented in Appendix C.

3.1. Sampling Methodology and Deviation from the Work Plan

Flag Environmental Solutions created the SAP prior to the site visit detailing the sampling method that would be followed, which can be seen in the Work Plan attached in Appendix A. The original SAP approximated 110 samples to be collected at the site, of which approximately 62 collected using grid sampling methods, 30 transect samples taken in the wash, three background samples, up to ten hot-spot samples where concentrations were found to be elevated, and up to two core samples taken in the wash. Samples were to be have been collected at the surface, 0-3 inches below ground surface, using a stainless-steel trowel. Approximately ½- ¾ of a gallon were to be collected for each sample. Core samples would have been taken using a hand auger with plastic sleeve inserts.

The original SAP assumed that Flag Environmental Solutions would have vehicle access directly to the Canyon City Mill site. A few days before the site investigation, it was determined that direct access to the site could be impossible. Immediately after the turnoff from Oatman Highway, onto Stoll Road, there was a steep wash crossing exit that possibly could not be navigated with a vehicle. In order to reach the Canyon City Mill site from the wash, an additional three-quarter mile walk was estimated. Upon client recommendation from Eric Zielske, the sampling method was altered to accommodate a potential additional three-quarter mile walk with equipment and many heavy soil samples. EPA's "Incremental Sampling Method" (ISM) was determined to be a preferred alternative that would allow personnel to take fewer samples while still gathering representative samples. This plan also addressed NAU Environmental Health and Safety (EH&S) concerns, as the disposal budget for the collected potentially hazardous soil material was limited. The NAU Hazardous Waste Supervisor, Mick Kelly, at NAU recommended that the number of soil samples be decreased. Altering the SAP to include ISM decreased the estimated total hazardous waste from 30 to 9 gallons, thus decreasing the estimated disposal cost to an acceptable limit.

ISM requires identifying decision units (DUs) that are likely to yield similar soil contamination conditions, based on the site history and site-specific features. Flag Environmental Solutions identified three decision units: the industrial area, the wash, and the vegetated land west of the industrial area.

The border of DU1 was defined as the location where industrial activity occurred. DU1 includes all areas where cyanide leaching processes occurred, such as the concrete holding pond, concrete slabs where equipment was held, and the leach field. DU1 is a highly disturbed area with remaining PVC pipes, metal pipes, concrete, and trash from the original operation. Soil types in DU1 ranged drastically every few feet from red clay, gravel, black sand, and sandy clay. From the previous days of heavy rain, standing water was observed in the concrete basins at the site, and at the base of the spent ore piles as well. The standing water can be observed in Figures 3.1 and 3.2 below.

Figure 3.1: Abandoned Sedimentation Pond (photo credit: Frankie Martinez)

Figure 3.2: Water Accumulation at Base of Spent Ore Piles

The steep nature of the spent ore piles can be observed in Figures 3.3 below. Steep slopes from waste piles border the south edge of DU1.

Figure 3.3: Site Terrain (photo credit: Claire Griffiths)

DU2 started at the access road and stretches down to the berm, built-up approximately 5' high adjacent to the wash in a likely attempt to prevent material from entering the wash. The area to the west of DU1 appeared to possibly have been bulldozed flat in the past. This area had a great number of shrubs and vegetation, and included steep slopes immediately south of DU1. Additionally, a minor wash has developed through the south edge of DU2, joining the main wash further downstream. Soils appeared to both sand and clay. Clay was found closer to the access road and sand was more towards the berm. The steep slopes made gridding the subsample areas difficult, which is why imperfections in the grids can be seen in Figures 3.5 below. The steep slopes are exemplified in Figure 3.3 above.

DU3, the wash, started at the southeast point of DU1 at the bank of the wash and went approximately 500 feet downstream. Although the original sampling plan included traversing the wash from the site to substantially farther downstream, this DU was based upon the belief that a representative sample of the wash should be taken adjacent to the site and not further downstream, as no information was known regarding contamination of the wash. The wash is bordered by a mountain to the south and the berm to the north. The wash broke into smaller sections that rejoined downstream, typical of a western dry wash. The wash had some vegetation, particularly on the banks, but not a great amount. This area mainly consists of gravel and sand soil types, which is consistent with washes in this area. Figure 3.4 below exemplifies the soil type in the wash.

Figure 3.4: Soil Type in the Wash

Each unit is displayed in Figure 3.5 below. Each decision unit was divided into subsample sections of approximately even area. The industrial unit was divided into 33 sections of 50 by 25 feet each. The pink shaded area, shown in Figure 3.5, displays DU1. Both the wash and vegetated unit were divided into 30 sections each. The vegetated area sections were approximately 50 by 25 feet, as shown in the orange shaded region in Figure 2.2, labeled DU2. The wash was sectioned by a width of 15 feet and extended all the way to the other side, as seen as the blue shaded area in Figure 2.2 labeled as DU3. For each decision unit, four surface soil samples were taken within each divided section. The four samples were labeled as A, B, C, and D and were randomized within the bounds of each subsample section. Each sample was ½ cup that was collected in a Ziplock bag designated for either samples A, B, C, or D, and the ½ cup samples collected in each subsample square were placed in the same Ziplock bag to be representative of one sample from the DU. This resulted in 12 samples from the three decision units and four composite samples from each unit.

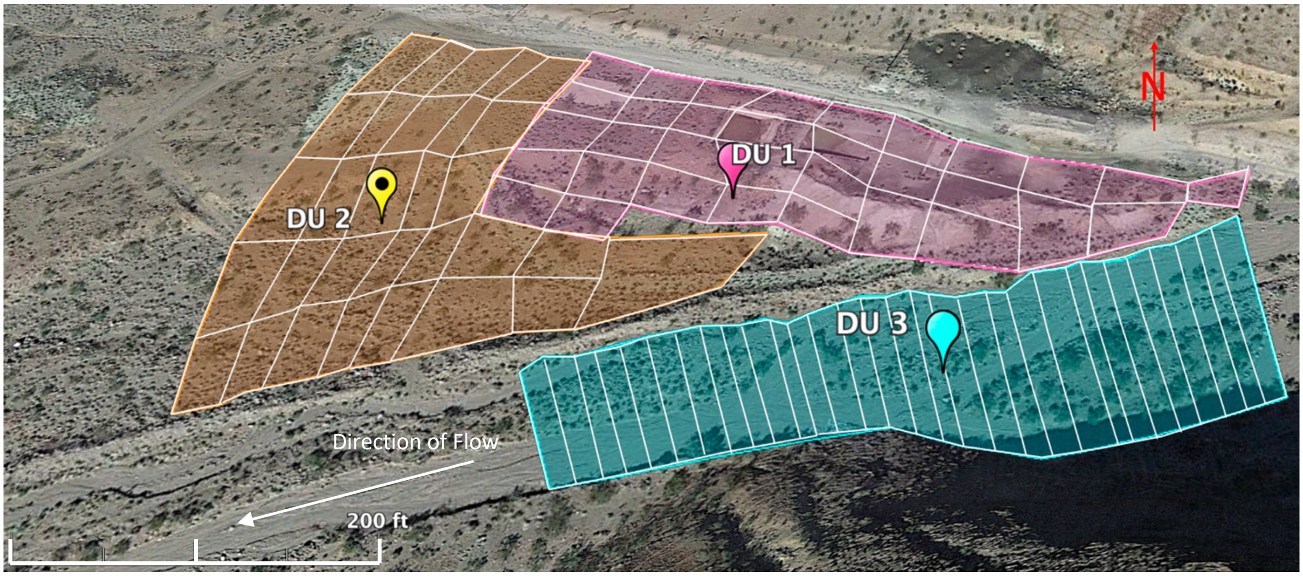


Figure 3.5: Decision Units on Site

Background samples were taken near the main entrance of the site where the land was deemed undisturbed. Two additional discrete samples were taken on the access road bordering the north of the site at two locations. These samples were taken to determine potential migration pathways of contaminants by vehicles. A total of 17 gallon-sized samples were taken from the site. Figure 2.3 below displays all sampled areas.

Figure 3.6: Location of Road Samples and Background Samples

3.2. Flora and Fauna Survey

During the site investigation, vegetation was observed lining the wash, roads, and all throughout DU2. The following vegetation was observed throughout the site: brittlebush, cholla cactus, barrel cactus, creosote bush, among other common desert vegetation not identified. An image of a decaying Cholla Cactus observed in DU2 is shown in Figure 3.6 below.

Figure 3.6: Cholla Cactus at Site (photo credit: Claire Griffiths)

Minimal vegetation was observed within the industrial area in DU1. Donkey scat was observed in every region of the site, indicating a large population of donkey endemic to the area. Figure 3.7 below shows an image of a donkey observed in DU2.

Figure 3.7: Donkey Observed at Site (photo credit: Claire Griffiths)

Jack rabbits, lizards, sparrows, crows, and other common birds were also observed during the site investigation. A Mojave tarantula molt was observed in DU2. It was apparent that DU2 experienced heightened biological activity due to the undisturbed and vegetated nature of the area when compared to DU1. An image of the tarantula molt is shown in Figure 3.8 below.

Figure 3.8: Mojave Tarantula Molt Observed at Site (photo credit: Claire Griffiths)

3.3. Sample Storage and Handling

During the site investigation, team members collected samples with clean gloves and decontaminated trowels and measuring cups between each decision unit's incremental sample. New Zip-lock freezer bags were used for each sample, and the samples were double-bagged if punctures or risk of puncture was evident. After each sample was collected, the Quality Assurance/Quality Control (QA/QC) officer documented the samples on the chain of custody forms and the samples were stored in plastic bins sealed with the appropriate chain of custody seals. A detailed description of the QA/QC procedures conducted in the field are discussed in the SAP within the Work Plan in Appendix A.

4.0 Analysis of Samples

4.1. Sample Preparation

Each soil sample was dried according to ASTM Method D2216 for approximately 17 hours at 110 degrees Celsius. Samples were poured from the Ziplock bags into clean metal drying containers that were labeled to reflect the location of the samples. For example, the drying container containing sample A from DU1 was labeled DU1-A. All 17 samples were able to be dried in one batch overnight on February 2nd, 2023. After the samples were removed the next morning, they were inspected to ensure thorough dryness. An image of the samples in the drying oven is shown in Figure 4.1 below.

Figure 4.1: Samples Drying in the Oven

After drying, the samples were broken up using rubber mallets to provide better homogeneity within the sample. Clay and silt-like materials in the samples were in large, hard clumps after drying, which were necessary to break down so that they would pass through the sieves as intended.

Samples were sieved using the 60-mesh sieve for 6 minutes each on the sieve shaker. #8-mesh and #30-mesh sieves were used on top of the 60-mesh sieve to aid in the sieving process. Due to the samples' size, it was necessary to sieve one half of each sample on the sieve shaker at a time, to ensure that all fine materials were reaching the bottom pan of the sieve. After the samples were sieved, the fines were added to labeled Zip-lock freezer bags and stored in a bin. An image of the fine material collected from a sample is shown in Figure 4.2 below. The sieves and any other tools used (scoops, mallets, etc.) were cleaned between samples with compressed air.

Figure 4.2: Dried and Sieved Fine Sample Material (photo credit Evan Downs)

Photographs from laboratory work can be found in appendix D.

4.2. X-Ray Fluorescence (XRF) Analysis

After prepping the samples, the team performed an XRF analysis. A Niton XL3t XRF was used. Each sample was subsampled nine times; subsamples were placed into the XRF testing cups. Cups were capped using a thin plastic film and the lid of the test cup. Since 9 subsamples were created from each sample, this resulted in a total of 153 subsamples. The subsamples are shown in Figure 4.3 below.

Figure 4.3: Subsample Cups (photo credit Frankie Martinez)

Each subsample was placed into the XRF test stand and were analyzed for 90 seconds. Figure 4.4 shows the XRF positioned in the test stand for analysis.

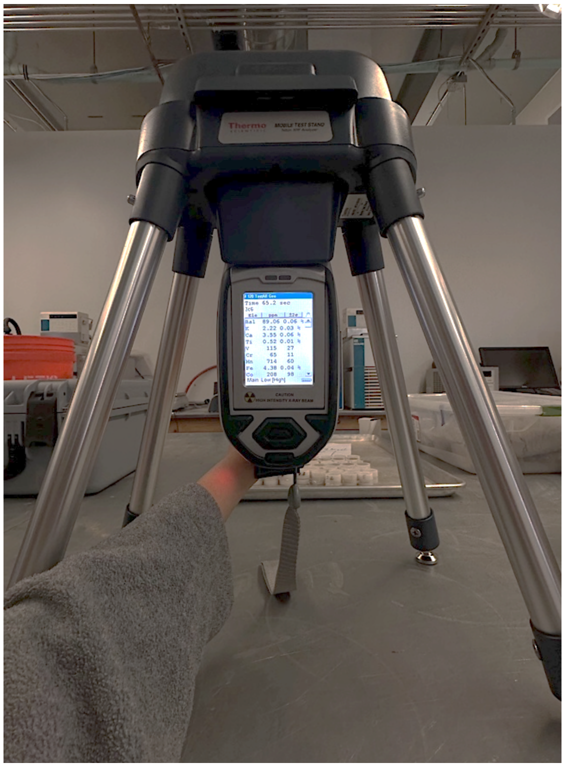


Figure 4.4: XRF Analysis (photo credit Frankie Martinez)

Raw XRF data are available in Appendix E. The maximum lead level detected was 376 ppm and the minimum lead level detected was 22 ppm. In the presence of high lead levels, XRF readings of arsenic can be inaccurate due to overlap in XRF frequency detection. EPA Method 6200 specifies that confirmatory analysis of arsenic levels is needed if the lead to arsenic ratio is greater than 10:1 [33]. The highest lead to arsenic ratio present at the site is 4.7:1. It was determined that the arsenic levels were accurate and confirmatory analysis was not needed.

5.0. Contaminants of Concern and Spatial Distribution of Contaminants

The results from the XRF were compared to the non-residential Arizona Soil Remediation Standards (AZSRS) and the EPA Ecological Soil Screening Levels (ECOSSL) in order to identify the human health and ecological COCs [3] [4]. XFR data was downloaded into an excel spreadsheet. For each sample, the highest and lowest results for each element were removed and the remaining data were averaged to provide the soil concentration. ECOSSL's are broken down into four categories: mammal, avian, soil invertebrates, and plants. Sections 5.1 through 5.5 below discuss results for each of the categories.

5.1 Human Health COCs

Only arsenic was identified as a COC for human health risk based on the XRF analysis results. The AZSRS level is 10 ppm for arsenic. Elevated arsenic levels were present in all samples A-D in DU1 with a minimum of 51.4 ppm in sample DU1-D, and a maximum level of 100.5 ppm in sample DU1-C. All samples A-D in DU2 contained slightly elevated arsenic levels, with a minimum of 14.4 ppm in sample DU2-A and a maximum of 24.1 ppm in sample DU2-B. Background samples 1 and 2 and road samples 1 and 2 also had slightly elevated arsenic levels, with averages of 11.0 ppm and 15.1 ppm respectively. The wash (DU3) contained no elevated arsenic levels. The elevated arsenic levels from 10-25 ppm are highlighted in yellow in Table 5.1 below. The elevated arsenic levels above 50 ppm are highlighted in red in Table 5.1 below.

Table 5.1: Human Health COC

Sample ID	As Concentration, ppm	Average As Concentration, ppm
AZ SRS (ppm)	10	10
B1	11.7	
B2	10.4	
B3	9.8	
R1	14.0	
R2	16.1	
DU1-A	72.0	76.1 +/- 20.357
DU1-B	80.6	
DU1-C	100.5	
DU1-D	51.4	
DU2-A	14.4	16.7 +/- 5.027
DU2-B	24.1	
DU2-C	12.8	
DU2-D	15.6	
DU3-A	8.1	8 +/- 0.557
DU3-B	7.7	
DU3-C	8.8	
DU3-D	7.5	

Elevated chromium levels were observed in the samples with a maximum level of 138.1 ppm in DU1-A and a minimum level of 66.0 ppm in background sample 3. The XRF device does not distinguish between chromium III and chromium VI (hexavalent chromium), which have different standards for human health. The non-residential standards for chromium III and hexavalent chromium are 1,000,000 parts per million (ppm) and 65 ppm respectively [5]. Trivalent chromium is naturally present in the environment and is also an essential human nutrient. Hexavalent chromium also occurs naturally, but is less common, and can be released into the environment from poor industrial waste disposal practices [6]. Trivalent chromium can become hexavalent through hot industrial work such as welding or melting chromium metal, and this type of work did not occur at the Canyon City Mill site [7]. It was therefore assumed that because trivalent chromium is more naturally occurring in the environment than hexavalent chromium, the levels provided by the XRF are reporting chromium III, and not the more toxic chromium VI. Therefore, chromium was not identified as a COC for human health.

Maps were created to spatially represent the distribution of contamination at the site. Data from Table 4.1 were used to map the COCs determined as human health risks. Data for the Decision Units are based upon the average of samples A-D. Figure 5.1 below shows the spatial distribution for arsenic.

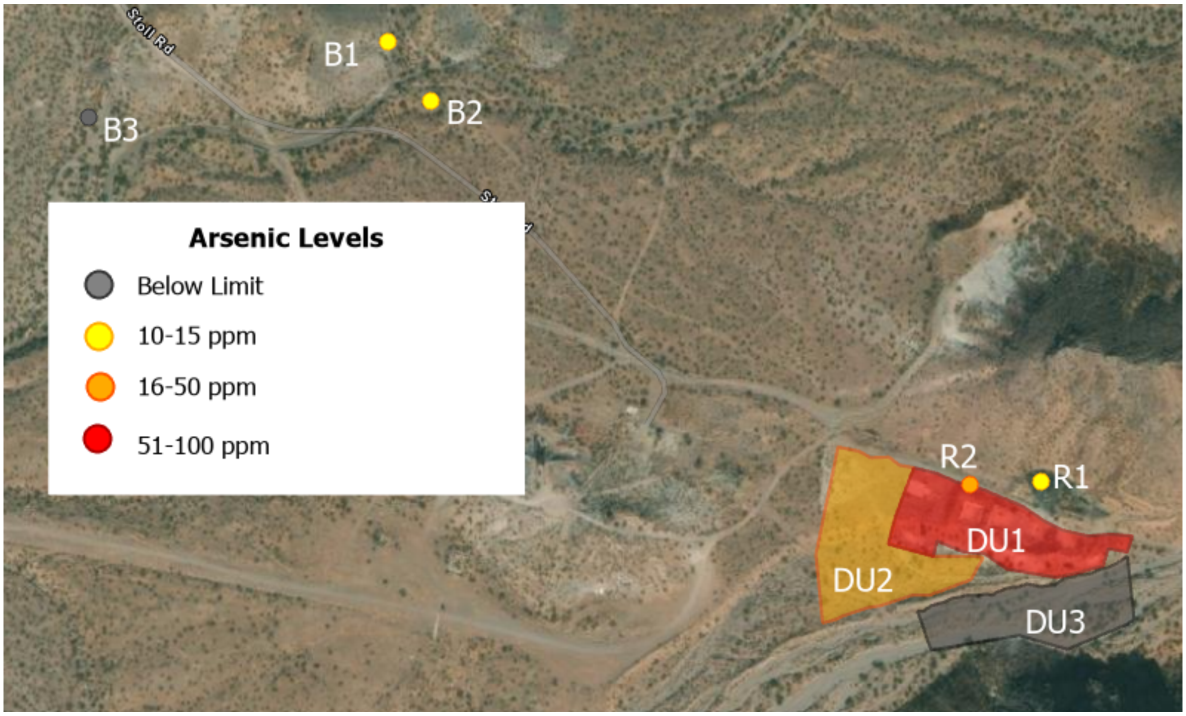


Figure 5.1: Arsenic Spatial Distribution Map for AZ SRS

5.2. Ecological COCs Mammalian

Seven COC's were identified for mammals based upon exceedance of the EPA ECOSSL. These COC's include lead, arsenic, zinc, copper, antimony, cadmium, and silver. Not all contaminants were found in each sample. In the background samples zinc, copper, antimony, and cadmium significantly exceeded ECOSSLS, which may suggest that these elements are naturally occurring in local soils. Table 5.2 shows exceedances of the ECOSSLS (red highlighted) as well as the percentage of the background level for each COC. Zinc, copper, antimony and cadmium were found in all background samples, road samples, DU1 samples, DU2 samples, and two of the DU3 samples. Elevated silver levels were found in background two, DU2-B, DU2-C, all of DU1, and all of the road samples. High lead levels were found in road two sample, DU2-A, DU2-B, DU2-D, and in all of the DU1 samples. High arsenic levels were only found in DU1.

Table 5.2: Mammalian COCs

	Element						
Sample ID	**Pb**	**As**	**Zn**	**Cu**	**Sb**	**Cd**	**Ag**
Eco-SSL (ppm)	56	46	79	49	0.27	0.36	14
B1	22	12	129	92	25	11	9
B2	28	10	121	86	28	15	16
B3	27	10	111	76	32	18	11
AVG/STDEV	25 +/- 2.7	11 +/- 0.8	120 +/- 7.5	85 +/- 6.9	28 +/- 2.7	15 +/- 2.9	12 +/- 3.0
R1	53	14	245	137	30	11	15
R2	90	16	452	134	35	11	33
AVG/STDEV	72 +/- 18.8	15 +/- 1.1	349 +/- 103.8	135 +/- 1.3	33 +/- 2.5	11 +/- 0.2	24 +/- 9.1
% of Background	3	1	3	2	1	1	2
DU1-A	327	72	2101	223	59	21	120
DU1-B	376	81	1656	168	58	19	103
DU1-C	250	101	1290	146	54	16	98
DU1-D	262	51	1934	181	52	17	115
AVG/STDEV	304 +/- 51.2	76 +/- 17.6	1745 +/- 307.2	179 +/- 28.3	56 +/- 2.8	18 +/- 1.8	109 +/- 8.7
% of Background	12	7	14	2	2	1	9
DU2-A	68	14	188	60	29	14	10
DU2-B	100	24	237	87	44	25	17
DU2-C	49	13	188	76	36	22	18
DU2-D	61	16	167	73	30	13	12
AVG/STDEV	70 +/- 19.1	17 +/- 4.4	195 +/- 25.5	74 +/- 9.6	35 +/- 5.9	18 +/- 5.2	14 +/- 3.1
% of Background	3	2	2	1	1	1	1
DU3-A	25	8	176	74	22	12	<LOD
DU3-B	26	8	80	59	27	16	<LOD
DU3-C	25	9	89	77	23	<LOD	<LOD
DU3-D	26	8	86	77	24	<LOD	<LOD
AVG/STDEV	25 +/- 0.6	8 +/- 0.5	108 +/- 39.4	72 +/- 7.6	24 +/- 2.1	14 +/- 1.9	<LOD
% of Background	1	1	1	1	1	1	<LOD

*LOD= Limit of Detection

5.3. COCs for Avian ECOSSL

Seven COC's were identified for avians. These COC's include lead, arsenic, zinc, copper, vanadium, cadmium, and silver. DU1 was contaminated with all seven COC's, while the other samples only lacked arsenic. The levels found for each sample can be found below in table 5.3.

Table 5.3: Avian COCs

	Element						
Sample ID	**Pb**	**As**	**Zn**	**Cu**	**V**	**Cd**	**Ag**
Eco-SSL (ppm)	11	43	46	28	7.8	0.77	4.2
B1	22	12	129	92	120	11	9
B2	28	10	121	86	116	15	16
B3	26	10	111	76	99	18	11
AVG/STDEV	25 +/- 2.7	11 +/- 0.8	120 +/- 7.5	85 +/- 6.9	112 +/- 9.2	15 +/- 2.9	12 +/- 3.0
R1	53	14	245	137	128	11	15
R2	90	16	453	134	95	11	33
AVG/STDEV	72 +/- 18.8	15 +/- 1.1	349 +/- 103.8	135 +/- 1.3	111 +/- 16.7	11 +/- 0.2	24 +/- 9.1
% of Background	3	1	3	2	1	1	2
DU1-A	327	72	2101	223	81	21	120
DU1-B	376	81	1656	168	86	19	103
DU1-C	250	101	1290	146	108	16	98
DU1-D	262	51	1934	181	111	17	115
AVG/STDEV	304 +/- 51.2	76 +/- 17.6	1745 +/- 307.2	179 +/- 28.3	96 +/- 13.3	18 +/- 1.8	109 +/- 8.7
% of Background	12	7	14	2	1	1	9
DU2-A	68	14	188	60	101	14	10
DU2-B	101	24	237	87	80	25	17
DU2-C	49	13	188	77	85	22	18
DU2-D	61	16	167	72	91	13	12
AVG/STDEV	70 +/- 19.1	17 +/- 4.4	195 +/- 25.5	74 +/- 9.6	85 +/- 7.7	18 +/- 5.2	14 +/- 3.1
% of Background	3	1	2	1	1	1	1
DU3-A	25	8	176	74	132	12	<LOD
DU3-B	26	8	80	59	106	16	<LOD
DU3-C	25	9	89	77	127	<LOD	<LOD
DU3-D	26	8	86	77	108	<LOD	<LOD
AVG/STDEV	25 +/- 0.6	8 +/- 0.5	108 +/- 39.4	72 +/- 7.6	118 +/- 13.2	14 +/- 1.9	<LOD

% of Background	1	1	1	1	1	1	<LOD

5.4. COCs for Soil Invertebrates ECOSSL

Three COC’s were identified for soil invertebrates. These COC’s include zinc, copper, and manganese. DU1, DU2-B, background 1, background 2, and all the road samples were contaminated with all three COC’s. Background 1, DU3-B, DU3-C, DU3-D only had high levels of manganese. While DU2-A, DU2-C, DU2-D, and DU3-A were only contaminated with zinc and manganese. The levels found for each sample can be found below in table 5.4.

Table 5.4: Soil Invertebrate COCs

	Element		
Sample ID	**Zn**	**Cu**	**Mn**
Eco-SSL (ppm)	120	80	450
B1	129	92	610
B2	121	86	642
B3	111	76	596
AVG/STDEV	120 +/- 7.5	85 +/- 6.9	616 +/- 19.6
R1	245	137	842
R2	452	134	872
AVG/STDEV	349 +/- 103.8	135 +/- 1.3	857 +/- 15.3
% of Background	3	2	1
DU1-A	2101	223	792
DU1-B	1656	168	813
DU1-C	1290	146	792
DU1-D	1934	181	806
AVG/STDEV	1745 +/- 307.2	179 +/- 28.3	801 +/- 9.1
% of Background	14	2	1
DU2-A	188	60	627
DU2-B	237	87	637
DU2-C	188	77	601
DU2-D	167	72	649
AVG/STDEV	195 +/- 25.5	74 +/- 9.6	628 +/- 17.6
% of Background	2	1	1
DU3-A	176	74	774

DU3-B	80	59	639
DU3-C	89	77	767
DU3-D	86	77	741
AVG/STDEV	108 +/- 39.4	72 +/- 7.9	730 +/- 54.1
% of Background	1	1	1

5.5. Plant ECOSSL

Six COC's were identified for plants. These COC's include lead, arsenic, zinc, copper, nickel, and manganese. DU1 is contaminated with all six COC's. The background samples, DU3-C, and DU3-D were contaminated with copper, nickel, and manganese. The road samples, DU2-C, DU2-D, and DU3-A were contaminated with zinc, copper, nickel, and manganese. DU2-A was contaminated with zinc, nickel, and manganese. Lastly DU2-B was contaminated with all of the COC's except for lead. The levels found for each sample can be found below in table 5.5.

Table 5.5: Plant COCs

	Element					
Sample ID	**Pb**	**As**	**Zn**	**Cu**	**Ni**	**Mn**
Eco-SSL (ppm)	120	18	160	70	38	220
B1	22	12	129	92	56	610
B2	28	10	121	86	52	642
B3	26	10	111	76	49	596
AVG/STDEV	25 +/- 2.7	11 +/- 0.8	120 +/- 7.5	85 +/- 6.9	52 +/- 3.1	616 +/- 19.6
R1	53	14	245	137	71	842
R2	90	16	452	134	57	872
AVG/STDEV	72 +/- 18.8	15 +/- 1.1	349 +/- 103.8	135 +/- 1.3	64 +/- 6.9	857 +/- 15.3
% of Background	3	1	3	2	1	1
DU1-A	327	72	2101	223	50	792
DU1-B	376	81	1656	168	51	813
DU1-C	250	100	1290	146	53	792
DU1-D	262	51	1934	181	59	806
AVG/STDEV	304 +/- 51.2	76 +/- 17.6	1745 +/- 307.2	179 +/- 28.3	53 +/- 3.3	801 +/- 9.1
% of Background	12	7	14	2	1	1
DU2-A	68	14	188	60	51	627
DU2-B	101	24	237	87	58	637
DU2-C	49	13	188	77	49	601

DU2-D	61	16	167	72	53	649
AVG/STDEV	70 +/- 19.1	17 +/- 4.4	195 +/- 25.5	74 +/- 9.6	53 +/- 3.2	628 +/- 17.6
% of Background	3	2	2	1	1	1
DU3-A	25	8.09	176	74	58	774
DU3-B	26	7.65	80	59	60	639
DU3-C	25	8.75	89	77	58	767
DU3-D	26	7.51	86	77	59	741
AVG/STDEV	25 +/- 0.6	8 +/- 0.5	108 +/- 39.4	72 +/- 7.6	59 +/- 0.8	730 +/- 54.1
% of Background	1	1	1	1	1	1

5.6. ECO-SSL COC Spatial Exceedances

Table 5.6 below contains the COCs that exceed ECO-SSL standards for the four categories. The COC was highlighted in light red if it exceeds the ECO-SSL and is >120% of the background levels found at the site. The COC was highlighted in dark red if it exceeds the ECO-SSL and is >1000% of the background levels. As seen by the table, DU1 contains the highest levels of contamination.

Table 5.6: ECO-SSL Spatial Exceedances

	Road	**DU1**	**DU2**	**DU3**		**Road**	**DU1**	**DU2**	**DU3**
Plants	Pb	Pb	Pb	Pb	**Avian**	Pb	Pb	Pb	Pb
	As	As	As	As		As	As	As	As
	Zn	Zn	Zn	Zn		Zn	Zn	Zn	Zn
	Cu	Cu	Cu	Cu		Cu	Cu	Cu	Cu
	Ni	Ni	Ni	Ni		Ni	Ni	Ni	Ni
	Mn	Mn	Mn	Mn		Mn	Mn	Mn	Mn
	Sb	Sb	Sb	Sb		Sb	Sb	Sb	Sb
	Cd	Cd	Cd	Cd		Cd	Cd	Cd	Cd
	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag
Soil Invertebrates	Pb	Pb	Pb	Pb	**Mammalian**	Pb	Pb	Pb	Pb
	As	As	As	As		As	As	As	As
	Zn	Zn	Zn	Zn		Zn	Zn	Zn	Zn
	Cu	Cu	Cu	Cu		Cu	Cu	Cu	Cu
	Ni	Ni	Ni	Ni		Ni	Ni	Ni	Ni
	Mn	Mn	Mn	Mn		Mn	Mn	Mn	Mn
	Sb	Sb	Sb	Sb		Sb	Sb	Sb	Sb
	Cd	Cd	Cd	Cd		Cd	Cd	Cd	Cd
	Ag	Ag	Ag	Ag		Ag	Ag	Ag	Ag

KEY:

▨ Exceeds ECO-SSL and >120% of Background levels
🟥 Exceeds ECO-SSL and >1000% of Background levels

6.0. Migration Pathway Analysis

Figure 6.1 shows the topography surrounding Canyon City Mill. Mountainous terrain can be observed, and there are two hills to the north and south of the site at approximately 2600 feet in elevation. A wash immediately south of the site flows west to the Colorado River, as discussed in section 1.2.

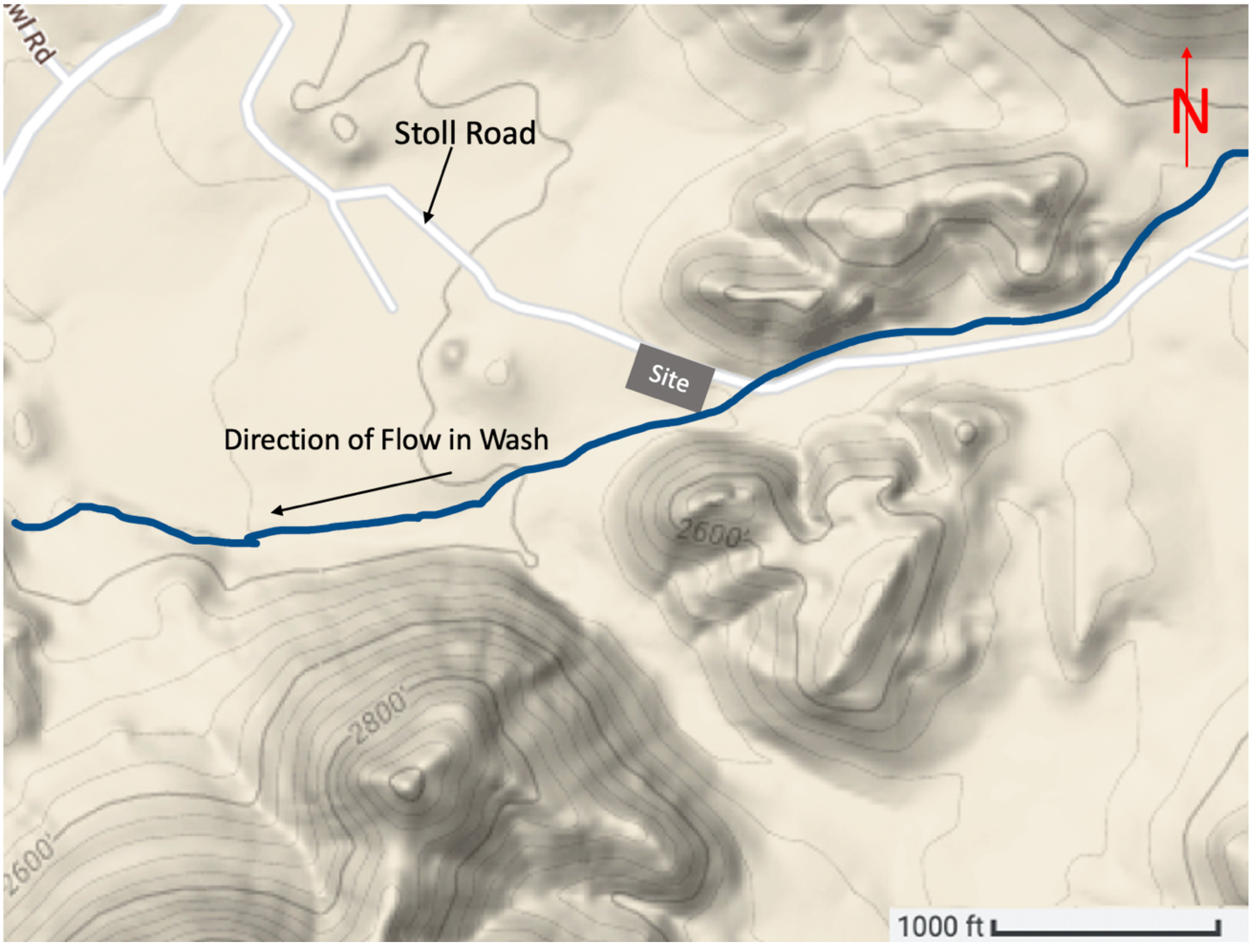


Figure 6.1: Site Topography

The topography at the site shown in Figure 6.1 indicates that incoming runoff comes from the hill north of the site. The overland flow would flow through the site, then enter the wash to the south of the site. This presents the greatest risk for contaminant migration through erosion of contaminated soils via overland flow. At this time, the data do not show that contamination from the site has migrated into the wash, as DU3 soils did not contain elevated levels of arsenic or levels above background for the ecological COCs.

The soil type varied greatly across the site, but was consistently sandy and gravely, with some clay and organic material in DU1 and DU2. Wind causing dust entrainment of contaminated soils and downwind deposition is also a possible migration pathway of contaminant migration and could occur in the event of a high winds funneling through the hillsides over the site. Figure 6.2 depicts a wind rose for the area of Oatman, Arizona over the year 2022.

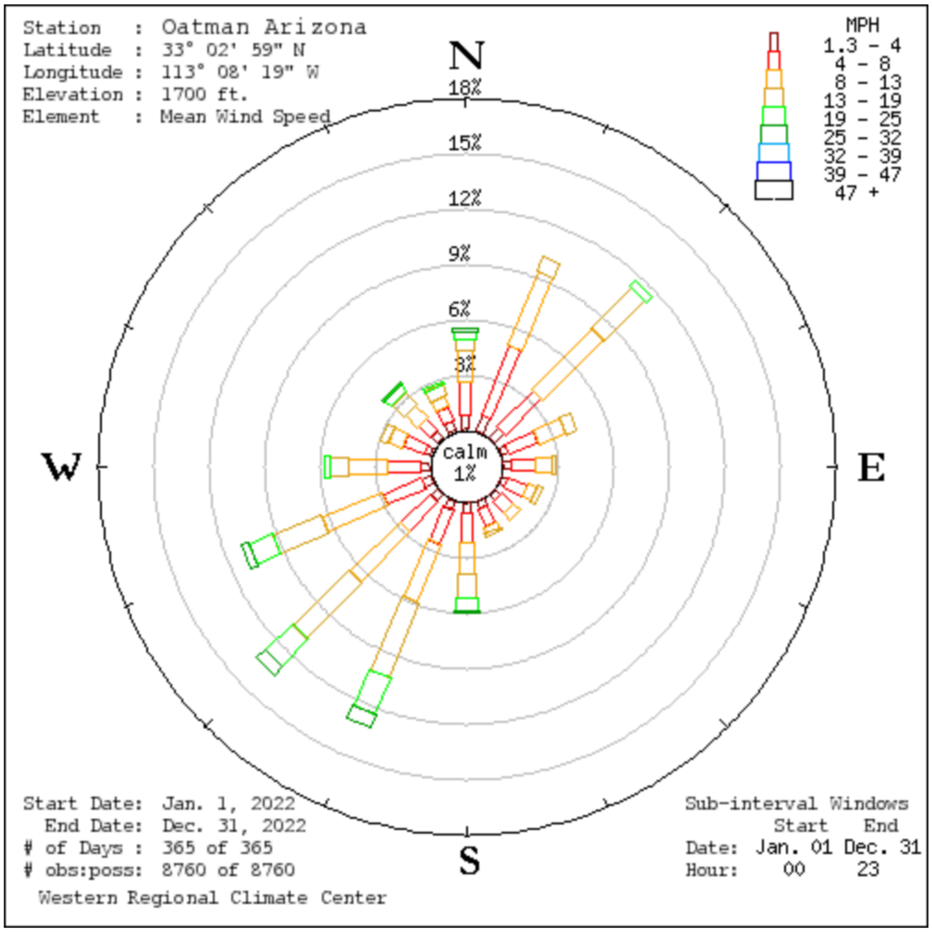


Figure 6.2: Wind Rose for Oatman Arizona [8]

The above wind rose demonstrates that the majority of the wind occurring during 2022 in the area of the site comes from the southwest and northeast directions. Wind traveling from the northeast over the site would move contaminants attached to alluvial sediment to the southwest direction, which is into the wash that is southeast of the site and downstream. Wind traveling from the southwest would carry contaminated soil to the northeast direction.

Arsenic is a toxic metalloid which can be reduced to be mobile in water. Arsenic sorbs to clay and humic material and can be inhaled when dust entrains as particulate matter into the air.

7.0. Human Health Risk Assessment

7.1. Relative Standard Deviation

The relative standard deviation (RSD) is a calculation performed to determine the precision and reliability of data collected through the ISM method. The RSD can only be used when there are three or more field replicates for each DU. An RSD value greater than 0.5 suggests that the data contains potential error and is not reliable for calculating the exposure point concentrations (EPCs). An RSD value below 0.5 is accurate and suggests that the data can reliably be used to calculate the EPCs.

Equation 7.1 demonstrates the calculation method for the relative standard deviation.

Equation 7.1: Relative Standard Deviation

$$RSD = \frac{ISM\ Replicate\ Standard\ Deviation}{ISM\ Replicate\ Mean}$$

The ISM Replicate Standard Deviation is the standard deviation of the four subsamples, or field replicates, for each DU. The ISM replicate mean is the average of the four subsamples, or field replicates for each DU.

Table 7.1 below shows the RSD values for each DU and each COC. All RSD values were below 0.5, confirming that the data are reliable for EPC calculations.

Table 7.1: RSD Values

	Element													
Sample ID	**Sr**	**Pb**	**As**	**Zn**	**Cu**	**Ni**	**Mn**	**Cr (III)**	**V**	**Ti**	**Sb**	**Sn**	**Cd**	**Ag**
DU1	0.03	0.17	0.23	0.18	0.16	0.06	0.01	0.13	0.14	0.09	0.05	0.13	0.10	0.08
DU2	0.01	0.27	0.26	0.13	0.13	0.06	0.03	0.08	0.09	0.06	0.17	0.15	0.28	0.22
DU3	0.04	0.02	0.06	0.37	0.11	0.01	0.07	0.12	0.10	0.08	0.09	0.05	0.14	0.00

7.2. Exposure Point Concentrations

Table 7.2 displays the 50% EPC for each decision unit. Because of the nature of the ISM, the arithmetic average of replicate samples provides the 50% EPCs.

Table 7.2.: 50% Exposure Point Concentrations

Arsenic 50% EPC (mg/kg)	
DU1	76
DU2	17
DU3	8

The equation used to calculate the 95% EPC for the ISM Method is shown below as Equation 7.1.

Equation 7.2: 95% EPC Calculation

$$95\%\ EPC = \bar{X} + t_{(1-\alpha)(r-1)} \times \frac{S_{\bar{X}}}{\sqrt{r}}$$

Where:

$\bar{X}$ = arithmetic mean of all ISM samples in DU

t = $(1\text{-}\alpha)^{th}$ quantile of the t-distribution with (r-1) degrees of freedom

$S_{\bar{X}}$ = standard deviation of all ISM samples in DU

r = number of ISM samples in DU

The value for “t” used to calculate the 95% EPCs is 1.645.

Table 7.3 displays the 95% EPC for each decision unit.

Table 7.3: 95% Exposure Point Concentrations

Arsenic 95% EPC (mg/kg)	
DU1	90
DU2	20
DU3	8

7.3. Exposure Assessment

This risk assessment for this site is performed for exposure to the incidental ingestion of contaminated soils from the site.

Exposure scenarios were identified to further understand possible risk to populations who may access site. The exposure assessment results in an intake dose for each exposure scenario. Both carcinogenic and non-carcinogenic intakes are computed based upon the COC. For arsenic, there are both carcinogenic and non-carcinogen effects, so both types of intakes are calculated. The intake dose is in units of milligrams of arsenic ingested per kilogram of body weight per day.

A worker exposure scenario and a recreational exposure scenario were identified. A residential scenario was not evaluated as there are no residences located near the site. The worker exposure scenario considered ingestion for adults, and the recreational exposure scenario considered exposure to both children and adults.

The worker scenario assumes that the worker is on site for cleanup purposes, and that the cleanup time is 6 months (24 weeks) total, working 8 hours per day, five days a week. The contact rate (amount of soil ingested per day) for adults is 100 mg/day [9]. The average adult body weight is 70 kilograms [10]. Averaging times for non-carcinogenic intakes equal the exposure period (6 months); averaging times for carcinogenic intakes are always 70 years. Table 7.4 shows the exposure parameters for a worker scenario.

Table 7.4: Worker Exposure Scenario

Worker Exposure Scenario - Ingestion	
Contact Rate (mg soil/day)	100
Exposure Frequency (hours/day)	8
Exposure Duration (days)	120
Average Body Weight (kg)	70
Averaging Time, Non-Carcinogen (year)	0.5
Averaging Time, Carcinogen (year)	70

The exposure assessment parameters are necessary to calculate the intake dose values which are necessary in calculating the risk of exposure for each exposure scenario. Equation 7.2 below is used to determine the daily intake of arsenic for an exposed individual.

Equation 7.3 Intake of Contaminant

$$I = \frac{C \cdot CR \cdot EF \cdot ED}{BW \cdot AT}$$

Where:

I = Intake (mg/(kg of body weight-day))

C = Concentration at exposure point (mg/kg)

CR = Contact Rate (kg/day)

EF = Exposure Frequency (days/year)

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (days)

Table 7.5 displays the calculated worker intake doses for each DU. This calculation was performed using Equation 7.2 and the exposure scenario assumptions found in Table 7.4.

Table 7.5 Worker Scenario Intake Dose

WORKER EXPOSURE SCENARIO				
DU #	50% EPC Intake Dose (mg/kg/day) (Carcinogenic)	50% Intake Dose (mg/kg/day) (Non-Carcinogenic)	95% Intake Dose (mg/kg/day) (Carcinogenic)	95% Intake Dose (mg/kg/day) (Non-Carcinogenic)
1	5.1E-07	7.2E-05	6.1E-07	8.6E-05
2	1.1E-07	1.6E-05	1.4E-07	1.9E-05
3	5.4E-08	7.6E-06	5.6E-08	8.0E-06

The recreational scenario considered exposure to both adults and children. Children are divided into ages 0 to 6 years and 6 to 12 years. The contact rates for children aged 0 to 6 is 200 milligrams soil ingested per day [9]. For adults and children aged 6 to 12 years, the contact rate is 100 milligrams per day [9]. An exposure frequency of 14 days was used, because that is the maximum camping limit on BLM lands. The average body weights based on age groups were determined from Chapter 8, “Body Weight Studies,” of the Exposure Factors Handbook provided by the EPA [10]. Table 7.6 shows the parameters for the recreational exposure scenario.

Table 7.6: Recreational Exposure Scenario

Recreational Exposure Scenario			
Parameter	Child Ingestion (0 to 6 years)	Child Ingestion (6 to 12 years)	Adult Ingestion
Contact Rate (mg/day)	200	100	100
Exposure Frequency (days)	14	14	14
Exposure Duration (years)	6	6	30
Average Body Weight (kg)	18	31	70
Averaging Time, Non-Carcinogen (year)	6	6	30
Averaging Time, Carcinogen (year)	70	70	70

Tables 7.7 through 7.9 display the calculated recreational intake doses for each DU. This calculation was performed using Equation 7.2 and the exposure scenario assumptions found in Table 7.6. Tables 7.7 through 7.9 differ in the ages being assessed for the recreational scenario.

Table 7.7: Recreational Scenario Intake Dose, Child 0-6

RECREATIONAL EXPOSURE SCENARIO- CHILD 0-6 YEARS				
DU #	50% EPC Intake Dose (mg/kg/day) (Carcinogenic)	50% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)
1	5.6E-06	6.5E-05	6.6E-06	7.7E-05
2	1.2E-06	1.4E-05	1.5E-06	1.7E-05
3	5.8E-07	6.8E-06	6.1E-07	7.2E-06

Table 7.8: Recreational Scenario Intake Dose, Child 6-12

RECREATIONAL EXPOSURE SCENARIO- CHILD 6-12 YEAR				
DU #	50% EPC Intake Dose (mg/kg/day) (Carcinogenic)	50% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)
1	1.6E-06	1.9E-05	1.9E-06	2.2E-05
2	3.6E-07	4.2E-06	4.3E-07	5.0E-06
3	1.7E-07	2.0E-06	1.8E-07	2.1E-06

Table 7.9: Reccreational Scenario Intake Dose, Adult

RECREATIONAL EXPOSURE SCENARIO- ADULT				
DU #	50% EPC Intake Dose (mg/kg/day) (Carcinogenic)	50% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Carcinogenic)	95% EPC Intake Dose (mg/kg/day) (Non-Carcinogenic)

1	3.6E-06	8.3E-06	4.3E-06	9.9E-06
2	8.0E-07	1.9E-06	9.5E-07	2.2E-06
3	3.8E-07	8.8E-07	3.9E-07	9.7E-07

Intake doses are higher in children than adults, because of lower body weight and that small children consume more soil due to a higher contact rate.

7.4. Toxicity Assessment

The EPA's Integrated Risk Information System (IRIS) was used to obtain toxicity data for arsenic. The slope factor (SF) is required for carcinogenic risk and the reference dose (RfD) is required for non-carcinogenic risk. The oral SF represents the risk of developing cancer per unit intake dose via ingestion. The oral RfD represents the "safe" or "threshold" intake dose via ingestion before toxic effects are seen. Carcinogenic effects may include skin, bladder, and lung cancer [11]. Non-carcinogenic effects may include vascular complications, abdominal pain, and heart attacks [11]. The slope factor and RfD values for arsenic can be found in Table 7.10 [12]:

Table 7.10: Toxicity Parameters for Arsenic

COC	**SF** $\left(\frac{mg}{kg \times day}\right)^{-1}$	**RfD** $\left(\frac{mg}{kg \times day}\right)$
Arsenic	1.5	3E-4

7.5. Risk Calculations

The data presented in the exposure and toxicity assessment, as well as the calculated intake doses, are used to compute the risk that is present to recreational users and on-site workers. Equation 7.4 displays the calculation used to determine carcinogenic risk for each exposure scenario.

Equation 7.4: Carcinogenic Risk

$$Risk = I_c \cdot SF$$

Where:
I_c = Carcinogenic Intake (mg/(kg of body weight-day))
SF = Slope Factor (mg/(kg-day))$^{-1}$

Equation 7.4 below was used to calculate non-carcinogenic risk of arsenic for each exposure scenario.

Equation 7.5: Non-carcinogenic Hazard Index

$$HI = \frac{I_N}{RfD}$$

Where:
HI = Hazard Index (unitless)
I_N = Non-Carcinogenic Intake (mg/(kg of body weight-day))
RfD = Reference Dose (mg/(kg-day))

Risk is calculated for both the 50% and 95% EPCS. Tables 7.11 and 7.12 present the carcinogenic risk for each exposure scenario in DU1 (highest As levels) for the median exposed person (50% EPC intake) and the maximally exposed person (95% EPC intake), as well as for exposure to an average for the site as a whole (DU's 1, 2, 3). For carcinogenic risk to be considered elevated, it must be greater than 1E-06 (i.e. "one in a million" chance of developing cancer). The elevated carcinogenic risk scenarios are highlighted in yellow in the tables below.

Table 7.11: 50% EPC Carcinogenic Risk

Risk	DU#1	Site Average
Worker Exposure Scenario	7.64887E-07	3.3883E-07
Recreational Exposure Scenario (Child 0-6 years)	8.32877E-06	3.6895E-06
Recreational Exposure Scenario (Child 6-12 years)	1.61202E-06	8.0247E-07
Recreational Exposure Scenario (Adult)	5.35421E-06	2.2387E-06

The carcinogenic risk from the 50% EPC intake doses are only slightly elevated.

Table 7.12: 95% EPC Carcinogenic Risk

Risk	DU#1	Site Average
Worker Exposure Scenario	9.12078E-07	4E-07
Recreational Exposure Scenario (Child 0-6 years)	9.93151E-06	4.36E-06
Recreational Exposure Scenario (Child 6-12 years)	1.92223E-06	9.45E-07
Recreational Exposure Scenario (Adult)	6.38454E-06	2.64E-06

The maximally exposed receptor has a higher carcinogenic risk than the median exposure, however the risk does not increase significantly.

Tables 7.13 and 7.14 present the 50% and 95% non-carcinogenic hazard indices for each exposure scenario in DU1, as well as an average for the site as a whole. For non-carcinogenic risk to be elevated, the hazard index must be greater than one.

Table 7.13: 50% Non-Carcinogenic Risk

Risk	DU#1	Average
Worker Exposure Scenario	0.241	0.107
Recreational Exposure Scenario (Child 0-6 years)	0.216	0.0957
Recreational Exposure Scenario (Child 6-12 years)	0.0627	0.0278
Recreational Exposure Scenario (Adult)	0.0278	0.0123

Table 7.14: 95% Non-Carcinogenic Risk

Risk	DU#1	Average
Worker Exposure Scenario	0.288	0.126
Recreational Exposure Scenario (Child 0-6 years)	0.257	0.113
Recreational Exposure Scenario (Child 6-12 years)	0.075	0.033
Recreational Exposure Scenario (Adult)	0.033	0.015

None of the hazard indices are above one, thus indicating there is no elevated non-carcinogenic risk.

8.0. Ecological Risk Assessment

The Canyon City Mill site exists in the eastern region of the Mojave Desert, which expands throughout 4 states (Nevada, Utah, Arizona, and California) and expands over 20% of California. The Mojave desert's harsh conditions still allow for biodiversity and various species to live within. However, due to increased urbanization and agricultural activity in the Mojave Desert, the destruction of habitats has led to the endangerment of several species. The federally listed species found within the Mojave Desert are listed below in Table 8.1 [13]. Endangered species are defined by the Endangered Species Act as being "in danger of extinction", threatened species are "likely to become endangered", and candidate species are "under current review to be listed" under the Act.

Table 8.1: Federally Listed Species in Mojave Desert

Common Name	Scientific Name	Federal Status
Mammals		
Amargosa southern pocket gopher	Thomomys umbrinus amargosae	Candidate
Desert bighorn sheep	Ovis canadensis nelsoni	Sensitive
Mountain lion	Felis concolor	Candidate
Townsend's big-eared bat	Plecotus townsendii	Candidate
Avian		
Bald eagle	Haliaeetus leucocephalus	Threatened
California brown pelican	Pelecanus occidentalis californicus	Endangered
Least Bell's vireo	Vireo bellii pusillus	Endangered
Mexican spotted owl	Strix occidentalis lucida	Threatened
Yuma clapper rail	Rallus longirostris yumanensis	Endangered

Reptiles		
Coachella Valley fringe-toed lizard	Uma inornata	Threatened
Desert tortoise	Gopherus agassizii	Threatened
Amphibians		
Lowland leopard frog	Rana yavapaiensis	Candidate
Fish		
Bonytail chub	Gila elegans	Endangered
Colorado squawfish	Ptychocheilus lucius	Endangered
Devil’s Hole pupfish	Cyprinodon diabolis	Endangered
Mojave tui chub	Gila bicolor mojavensis	Endangered
Humpback chub	Gila cypha	Endangered
Razorback sucker	Xyrauchen texanus	Endangered
Insects and Snails		
Badwater snail	Assiminea infima	Candidate
Devil’s Hole warm springs riffle beetle	Stenelmis calida calida	Candidate
Plants		
Bear-paw poppy	Arctomecon californica	Candidate
Foxtail cactus	Escobaria vivipara var. alversonii	Candidate
Eureka Valley Evening Primrose	Oenothera arita eurekensis	Endangered
Panamint daisy	Enceliopsis covillei	Candidate
Sticky buckwheat	Eriogonum viscidulum	Candidate

Negative ecological effects of the identified ecological COCs can also impact non-endangered species of wildlife found within the Mojave Desert. Table 8.2 contains a partial list of common plants and animals found in the Mojave Desert [13].

Table 8.2: Partial List of Common Plants and Animals Found in Mojave Desert

Common Name	Scientific Name
Mammals	
Coyote	Canis latrans
Black-tailed jackrabbit	Lepus californicus
Desert cottontail rabbit	Sylvilagus audubonii
Avian	
Common raven	Corvus corax
Gambel’s quail	Callipepla gambelii
Greater roadrunner	Geococcyx californianus
Red-tailed hawk	Buteo jamaicensis
Turkey vulture	Cathartes aura
Reptiles and Amphibians	
Desert tortoise	Gopherus agassizii
Sidewinder	Crotalus cerastes

Rosy boa	Lichanura trivirgata
Fish	
Channel catfish	Siluriformes
Largemouth bass	Micropterus salmoides
Insects	
Broad-necked darkling beetle	Coelocnemis californicus
Giant desert hairy scorpion	Hadrurus arizonensis
Plants	
Desert star	Monoptilon belliodes
Monkeyflower	Mimulus spp.
Prickly poppy	Argemone munita
Barrel Cacti	Ferocactus cylindraceus lecontei
Mojave prickly pear	Opuntia phaeacantha
Golden cholla	Opuntia echinocarpa
Teddy-bear cholla	Opuntia bigelovii
Creosote bush	Larrea tridentata
Mesquite	Prosopis glandulosa
Mojave yucca	Yucca schidigera

Many of the species identified in the table above, especially the cactus species, were observed on site during the site investigation.

The ecological COCs identified in Tables 5.2 through 5.5 present a threat to the respected ecological groups. Receptors in the region of the site are exposed to the contaminants through direct contact with soil, and through consumption of the plants or water at the site. The COCs may affect the growth of the plants on the site and be adsorbed by the plants which could then be later consumed by animal receptors. Table 8.3 below presents the identified ecological contaminants of concern, the concentration range at which they were found, and the percent of the collected samples that exceed the ECO-SSLs for the different ecological categories.

Table 8.3: Percent of Samples Containing COCs Exceeding ECO-SSLs

COC	**Range of Soil Concentrations (ppm)**	**Eco-SSLs (ppm) (Percent of Samples Exceeding Levels, %)**			
		Plants	Soil Invertebrates	Avian	Mammalian
Lead	22-376	120 (23.5%)	NA	11 (100%)	56 (47%)
Arsenic	8-100	18 (29.4%)	NA	43 (23.5%)	46 (23.5%)
Zinc	80-1934	160 (64.7%)	120 (76.5%)	46 (100%)	79 (100%)
Copper	59-223	70 (88.2%)	80 (52.9%)	28 (100%)	49 (100%)
Nickel	49-71	38 (100%)	280 NA	NA	NA
Manganese	596-872	220	450	NA	NA

		(100%)	(100%)		
Vanadium	80-132	NA	NA	7.8 (100%)	NA
Cadmium	11-25	NA	NA	0.77 (88.2%)	0.36 (88.2%)
Silver	9-120	NA	NA	4.2 (76.5%)	14 (52.9%)
Antimony	22-59	NA	NA	NA	0.27 (100%)

*NA= No samples exceeding Eco-SSL

The table indicates that avian life is particularly sensitive to lead, zinc, copper, vanadium, and silver compared to the other ecological categories.

The EPA provides an Interim Ecological Soil Screening Level Document for all identified contaminants. The document outlines common health effects that the COC causes towards each ecological group. Tables 8.3-8.5 list the health effects of the identified COCs for each ECO-SSL group. Effects on soil invertebrates were not included due to limited data.

Table 8.4: Effects of ECO-SSL COCs on Plants

Plants	
COC	**Health Effect**
Lead	Inhibits growth, reduces photosynthesis, interferes with cell division and respiration, reduces water absorption and transpiration, and reduces chlorophyll and ATP synthesis [14]
Arsenic	Decreases the ability of cells to produce ATP and carry out normal metabolism [16].
Zinc	Excess levels lead to iron chlorosis [18].
Copper	Effects nitrogen fixation, valence changes, and cell wall metabolism [19].
Nickel	Growth depression, impaired reproduction, and other biochemical changes [26].
Manganese	Iron chlorosis, leaf puckering, necrotic brown spots, and an uneven distribution of chlorophyll in older leaves [25].

Table 8.5: Effects of ECO-SSL COCs on Avian Wildlife

Avian Wildlife	
COC	**Health Effect**

Lead	Behavioral signs such as anxiety, locomotor disturbances, rapid labored breathing, anorexia, weight loss, dehydration, emaciation, fetal death, mortality and impaired postnatal growth, reduced pregnancy rate, and interference with resistance to infectious disease [14].
Arsenic	Muscular incoordination, debility, slowness, jerkiness, falling, hyperactivity, fluffed feathers, drooped eyelids, huddled position, unkempt appearance, loss of righting reflex, immobility, seizures [15].
Zinc	Decreased body weight, gizzard and pancreatic lesions, and biochemical changes [18].
Copper	Gastrointestinal, pancreatic and kidney problems, seizures, weight loss, and dysphagia [20].
Vanadium	No sufficient data on effects.
Cadmium	Impaired development and decreased bone mineral content [22].
Silver	Reduced growth and reproduction and increased mortality [24].

Table 8.6: Effects of ECO-SSL COCs on Mammalian Wildlife

Mammalian	
COC	**Health Effect**
Lead	Behavioral signs such as anxiety, locomotor disturbances, rapid labored breathing, anorexia, weight loss, decreased milk production, dehydration, emaciation, fetal death, mortality and impaired postnatal growth, reduced pregnancy rate, and interference with resistance to infectious disease [14].
Arsenic	Intense abdominal pain; diarrhea, or bloody or mucoid diarrhea; a staggering gait; an irregular or thready, weak pulse; and dehydration [17].
Zinc	Vomiting, depressed growth rate, purgation, and ataxia [18].
Copper	Acute copper toxicity in mammals include sporadic fever, tachycardia, hypotension, oliguria, uremia, coma, cardiovascular collapse, and death. Chronic copper poisoning in mammals may induce nausea, vomiting, epigastric pain, dizziness, jaundice, and general debility [19].
Antimony	Cardiovascular changes such as degeneration of the myocardium, arterial hypotension, heart dysfunction, arrhythmia, and altered electrocardiogram patterns [23].

Cadmium	Nephrotoxicity and also possible effects on the liver, reproductive organs, and the hematopoietic, immune, skeletal, and cardiovascular systems [21].
Silver	Reduced growth and reproduction and increased mortality [24].

Understanding the adverse health effects caused by the COCs helps to qualitatively assess the impact of the site's contamination on the surrounding ecology.

9.0. Remediation Alternative Analysis

After analyzing the risk on site, potential remediation technologies to apply to DU1 were explored. Comparing the COC levels in the 2016 ECM PA/SI to Flag Environmental Solutions data, a No Action alternative is plausible. Additional actions that can be taken are institutional controls such as fencing and signage indicating the site is contaminated. This would prevent the public and larger mammals from entering contaminated areas. Excavation is another remediation alternative that would remove the contaminated soil and transfer it to a waste facility. Bioremediation, specifically phytoremediation, is also considered. A cost-benefit analysis of the proposed remediation alternatives is presented in the following sections.

9.1. Remediation Alternatives

9.1.1. Alternative 1: No Action

A no action alternative would be feasible for the Canyon City Mill site due to the low risk associated with the contamination. While there is elevated carcinogenic risk for adolescent recreational receptors, the risk remains low as it is unknown how frequently the site is actually used for recreational purposes. There is no cost associated with this alternative.

9.1.2. Alternative 2: Phytoremediation

Phytoremediation is a bioremediation process that uses plants to extract the pollutants on site and restore the native vegetation. Additionally, plants would decrease erosion and contaminant migration from wind and water. This would benefit the surrounding ecology and has potential to restore the site to background levels. To analyze the cost of phytoremediation, the site was classified as a small moderate site. The moderate rating refers to the ability to navigate the site's terrain. To remediate a small moderate site with phytoremediation, it would cost approximately $5.00 per square foot of land [27]. DU1 has a land area of 52,000 square feet (not including concrete foundations), which would cost the BLM approximately $260,000 to remediate with native plants.

9.1.3. Alternative 3: Institutional Controls

Institutional controls would consist of fencing and signage around DU1 where site contamination is predominately located. Access to site structures located on DU1 (concrete holding pond and concrete slabs) would be restricted. Direct exposure to humans and large mammals would be prevented through institutional controls. The approximate cost for fencing materials is $13.00 per linear foot, and the approximate cost for labor is $30.00 per hour [28]. The estimated completion time for this project is 130 hours. This alternative is estimated to cost $21,000.

9.1.4. Alternative 4: Excavation

Excavation of the site would consist of removing the top layer of soil then treating or disposing of the soil ex-situ. This would effectively remove the contamination from the site, making this option highly effective in reducing human and ecological risk. Considering the difficult access to the site and the uneven terrain of DU1, this option would likely be a challenge to implement. Another challenge concerning excavation is the high cost. Assuming that the cost of soil removal and disposal is $2,500 per ton, and the size of DU1 is 52,000 square feet (not including concrete foundations) and the depth of soil to be removed is half a foot, the total estimation of excavation cost would be approximately $2,900,000 [29].

9.1.5. Alternative 5: Phytoremediation and Institutional Controls

Alternative five combines both phytoremediation and institutional controls. The phytoremediation process will use plants to remove pollutants at the site. These plants will be native to Arizona to ensure no habitat destruction. Again, the site will be classified as a small moderate site. The expected cost will be approximately $260,000 to remediate with native plants. Institutional controls will require fencing and signage where the site is contaminated the most. This will restrict recreational use to the public and limit access to the local fauna in the area. The institutional controls are expected to cost $21,000. Both the phytoremediation and institutional controls will be in DU1. The fencing will surround the area while the flora will be planted inside the fence, covering all of DU1. Overall alternative 5 is estimated to cost $281,000.

9.2. Decision Matrix Criteria

For the decision matrix, four different criteria were selected. They are described below.

9.2.1. Ecological Effectiveness

Ecological effectiveness exams how the alternatives benefit the ecology within the area. A rating system between 1-3 was used; 3 being the best option and 1 being the worst option. This criterion has a 25% weight due to the high ecological risk the site poses. Alternative 1 was given a score of 1 due to no improvement or benefit to the ecosystem. No Action leaves contaminants in place allowing the land to remediate itself, leaving the ecosystem in the area at risk. Alternative 2 was scored a 3 because phytoremediation is shown to effectively uptake heavy metals and improve natural habits. Alternative 3 was scored a 1 because the fencing and signage would not prevent birds and soil invertebrates from entering the area. Therefore, it has the same affect for ecology as alternative 1. Alternative 4 was rated a 3 because it would completely remove the contamination at the site. This would completely prevent all exposure to the local ecology. Alternative 5 was rated a 3 because phytoremediation would remove the contaminants while restoring the natural habitat.

9.2.2. Human Health Effectiveness

Human health effectiveness examines how the alternatives benefit humans within the area. The same 1-3 rating system was used. 3 being the best option and 1 being the worst option. It was weighed 15% because humans are not greatly affected from the contamination on site but are still at risk. Alternative 1 scored a 1 because it did not help improve the site's health for humans at all. Instead, it left the site contaminated. This would still pose a threat to humans. Alternative 2 was scored a 2 because phytoremediation is shown to effectively remove heavy metals, but it would still leave humans at risk. Alternative 3 was scored a 3 because the fencing and signage would prevent recreational users from entering the area. Alternative 4 was rated a 3 because it would completely remove the contamination at the site. This would completely prevent all exposure to the local ecology. Alternative 5 was rated a 3 because the institutional controls will prevent the public from entering.

9.2.3. Cost

Cost was selected as one of the criteria for the design. It was weighted at 35% because the lack of significant risk from the site does not warrant an expensive clean up. The 1-3 rating system was used:

- Score of 3: $50,000 or less.
- Score of 2: $50,000-$500,000
- Score of 1: Greater than $500,000

No Action was rated a 3 because it does not cost anything. Alternative 2 was rated a 2 because the cost was between $50,000 and $500,000. Alternative 3 was rated a 3 because the estimated cost was below $50,000. Alternative 4 was scored a 1 because excavation exceeds $500,000. Alternative 5 was scored a 2 because the estimated cost was between $50,000 and $500,000. Table 9.1 gives the estimated cost of each of the remediation alternatives.

Table 9.1: Cost of Alternatives

Alternatives	Cost
1. No Action	$0
2. Phytoremediation	$260,000
3. Institutional Controls	$21,000
4. Excavation	$2,900,000
5. Phytoremediation and Institutional Controls	$281,000

9.2.4. Implementability

Implementability is the measure of the alternatives' ability to be implemented in an effective manner. Implementability was weighted 25% because it was deemed to be a relatively important criteria, but not as important as cost. Alternative 1: No Action, scored a 3 for implementability because it requires no installation and is essentially already implemented. Alternative 2: phytoremediation, scored a 2 considering the possible challenge of getting the required flora to grow in the soil at the site, as well as the possible challenge of getting the required resources into the site. Alternative 3: institutional controls, scored a 2 because the challenging topography could lead to a challenge in installing the fencing, as well as the possible challenge of getting the required resources into the site. Alternative 4: excavation, scored a 1 because the challenge of getting heavy machinery into the site was deemed difficult given the conditions of the site. The soil from excavation would also need to be moved off site making the implementability even more challenging. Alternative 5: phytoremediation and intuitional controls, scored a 2 because of the challenges as described in alternative 2 and 3 can be completed the alterative will be successful.

9.3. Recommended Remediation Strategy

Table 9.2 displays the decision matrix used to select the recommended remediation strategy.

Table 9.2: Decision Matrix

Remediation Alternatives						
Criteria	**Weight**	**No Action**	**Phytoremediation**	**Institutional Controls**	**Excavation**	**Phytoremediation and Institutional Controls**
Ecological Effectiveness	0.25	1	3	1	3	3
Human Health Effectiveness	0.15	1	2	3	3	3
Cost	0.35	3	2	3	1	2
Implementability	0.25	3	2	2	1	2
Total	**1**	**2.2**	**2.25**	**2.25**	**1.8**	**2.4**

Alternative 5, a combination of phytoremediation and institutional controls, scored the highest per the matrix. For phytoremediation, short grass species and sunflowers are recommended for the vegetation to be plated. According to the EPA, small plants like ferns and grasses are used in areas where soil contamination is shallow [30]. Since contamination is predominantly at the surface, grass would be recommended. Deer grass is highly recommended for use because it requires low to moderate water, can endure large exposure to the sun, can live above 2,000 ft in elevation, and is native to Arizona. Yellow Pygmy Sunflowers are suggested due to their ability to withstand high amounts of arsenic [31]. Josue A. Juarez, an alumnus of NAU conducted a research study that showed that not only were Yellow Pygmy Sunflowers able to absorb arsenic from the soil, but they were also found to be taller and healthier than sunflowers not exposed to arsenic [32]. Sunflowers are also native to Arizona, can withstand high exposure to sunlight, need low to moderate water, and can survive in elevations above 2,000 ft. Fencing and signage will also be put around DU1. Signage will warn recreational visitors and inform the public of potential hazards on the site. Signage will also include information regarding the process of phytoremediation and the plants being used. Fencing will cover the perimeter of DU1 to prevent human and animal access.

10.0. Project Impact Analysis

The triple bottom line is a tool used to assess the environmental, economic, and societal impacts of a project. The Canyon City Mill project was evaluated for its impacts in the following three categories.

10.1. Environmental Impact

The environmental impacts of the Canyon City Mill project depend on whether or not remedial action is pursued. Pursuing a No Action alternative would leave the eleven COCs exceeding Eco-

SSLs to impact existing plants and animals such as the grazing donkey herd. The soil contamination would also have the potential to migrate through surface run off and wind transport, thus spreading to nearby ecosystems. Leaving the contamination untouched would expose endangered or threatened species in the area to the pollutants. Pursuing phytoremediation combined with institutional controls as a remediation strategy would allow the site to return close to background conditions. Phytoremediation would benefit the surrounding environment and the Canyon City Mill by increasing vegetation and prevent erosion of contaminated soil. The institutional controls which include fencing would decrease the donkey population's ability to access the more heavily contaminated area of DU1, thus preventing their exposure.

10.2. Economic Impact

Economic impacts of the projects also depend on whether or no remediation is pursued. Remediating the site would have an associated expense as discussed in Section 9.2.3 but would benefit the local economy of Oatman. Remediating the site to background conditions and creating an accessible recreational area could bring hikers or mountain bikers to the area, which would encourage them to travel through Oatman and spend money in the town.

Within the specific scope of this project, the cost was decreased due to the change of sampling method. By using the Incremental Sampling Method as opposed to the original sampling strategy outlined in the Work Plan, the total volume of samples decreased, and less money was spent on materials and hazardous waste disposal.

10.3. Societal Impact

Again, the societal impacts of this project depend on if remediation is pursued. No Action would increase the risk to public health by exposing recreational users to the contaminants. Loss of public land is a negative societal impact associated with pursuing No Action. Remediating the site using phytoremediation would restore the aesthetic value of the site, and further developing the area for recreation would promote public health by encouraging exercise. Signage could be added to the site to explain what the Canyon City Mill was, the scope of contamination it created, and the remediation strategy applied. This development would have a positive societal impact by educating the public about phytoremediation, creating a sense of community pride in the town of Oatman, and would restore the land to the public for recreational uses.

11.0. Summary of Engineering Work

The initial Gantt chart, can be seen in Appendix F. This schedule changed slightly due to the change of sampling method as well as the concentration of the contaminants. The change in sampling method to the ISM allowed the team to complete the sample preparation and XRF analysis faster than initially expected. With the results of the analysis showing the concentration of lead to be lower than expected, it was determined that the arsenic concentrations could be assumed to be reliably accurate from the XRF analysis. This assumption removed Tasks 3.4 through 3.6 considering further lab analysis was deemed unnecessary. For the reasons stated above, as well effective time management, the team was able to stay on schedule and even ahead of the projected due dates as laid out in the Gantt chart.

12.0. Summary of Engineering Costs

The total number of hours worked during this project and the total end cost are significantly less than originally estimated. This can be attributed to the change of the sampling method that resulted in less samples and subsequently less time needed for lab analysis. Table 12.1 below displays the proposed staffing hours and the actual staffing hours for this project.

Table 12.1: Proposed and Actual Total Staffing Hours

Total Staffing Hours					
	SENG	**ENG**	**TECH**	**INT**	**TOTAL**
Proposed	96	173	166	165	600
Actual	60	130	107	95	392

The original estimation of staffing hours was 600 and the actual total hours worked were 392. The actual hours for the technician and intern positions were roughly half of what was originally proposed due to significantly less time spent performing lab analysis. The change in the project's sampling method resulted in less than half of the originally estimated collected samples. The original sampling plan included 110 samples, while the modified sampling plan resulted in 17 samples. This resulted in all tasks, with the exception of Task 4.1 Spatial Distribution Maps and Task 5.4 Risk Calculations, taking significantly less time than what was expected. Tasks 3.4 through 3.6 (acid digestion, FAA/ICP analysis, and correlation of data) were determined to be unnecessary for this project. This also contributed to fewer staffing hours. The proposed and the actual total number of staffing hours spent on each task by each staff member can be found in Appendix G as Table G.1 and G.2, respectively.

Tables 12.2 and 12.3 below show the total proposed cost of engineering services and the actual cost, respectively. The actual cost of the project is $48,801, $22,521 less than originally estimated. As mentioned above, the time needed for lab analysis was less than originally estimated, and the samples were not sent to a subcontracted lab for confirmatory analysis resulting in a much lower cost.

Table 12.2: Proposed Cost of Engineering Services

Personnel	**Classification**	**Hours**	**Rate ($/hour)**	**Cost ($)**
	SENG	96	205	$19,680
	ENG	173	170	$29,410
	TECH	166	60	$9,960
	INT	165	30	$4,950
	Total	600		$64,000
Travel	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	NAU Mileage	395 miles	$0.445/mile	$176
	NAU 12 Passenger Van	2 days	$68/day	$136
	Hotel, 1 night, 4 rooms per night	4 rooms	$94/room/night	$376
	Full Day Rate Meals	2 days, 5 people	$45/day/ person	$450
Supplies	Classification	Quantity	Rate	Cost ($)

	Ziplock bags	2 packs	$15/pack	$30
	Trowel	5	$6/trowel	$28
	Soil Core Sleeves	2	$5/sleeve	$10
	GPS	2 days	$75/day	$150
	Dish Soap	1	$5	$5
	Marking Flags	1 pack (100 per pack)	$2/pack	$2
	Buckets	3	$5/bucket	$15
	Large Bins	3	$16/bin	$48
	Water	25 gallons	$0.35/gallon	$9
	Water Jug	1	$10	$10
	Paper Towels	1 pack	$10/pack	$10
	Pens	1 pack	$6/pack	$6
	Field Logbooks	4	$10/book	$40
	Gloves	3 pack	$4/pack	$12
	Trash Bags	1 pack	$15/pack	$15
	Clip boards	5	$3/board	$15
	Scrub brushes	2	$5/brush	$10
Analysis	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	NAU Environmental Engineering and Soils Labs	15 days	$100/day	$1,500
	XRF Device	5 days	$654/day	$3,270
Subcontract	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	Western Tech	10 samples	$100/sample	$1,000
Total				**$71,322**

Table 12.3: Actual Cost of Engineering Services

Personnel	Classification	Hours	Rate ($/Hr)	Cost ($)
	SENG	60	205	$12,300
	ENG	130	170	$22,100
	TECH	107	60	$6,420
	INT	95	30	$2,850
	Total	392		$43,670
Travel	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	NAU Mileage	395 miles	$0.445/mile	$176
	NAU 12 Passenger Van	2 days	$68/day	$136
	Hotel, 1 night, 4 rooms per night	4 rooms	$94/room/night	$376
	Full Day Rate Meals	2 days, 5 people	$45/day/ person	$450
Supplies	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	Ziplock bags	2 packs	15	$30
	Trowel	5	6	$28
	Soil Core Sleeves	0	5	$0

	GPS (RENTAL)	2 days	75	$150
	Dish Soap	1	5	$5
	Marking Flags (100 pack)	1 pack	2	$2
	5-gallon Buckets	3	5	$15
	Large Bins	3	16	$48
	Water (gallons)	5	0.35	$2
	Water Jug	1	10	$10
	Paper Towels (pack)	1	10	$10
	Pens (pack)	1	6	$6
	Field Logbooks	2	10	$20
	Gloves (packs)	3	4	$12
	Trash bags (1 pack)	1	15	$15
	Clip boards	5	3	$15
	Scrub brushes	2	5	$10
Analysis	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	NAU Env. Eng Labs/Soils Labs (per day)	10	100	$1,000
	XRF	4	654	$2,616
Subcontract	**Classification**	**Quantity**	**Rate**	**Cost ($)**
	Western Tech (per sample)	0	100	$0
Total				$48,801

13.0. Conclusion

Flag Environmental Solutions successfully completed a Preliminary Assessment and Site Investigation Report for the Canyon City Mill. A site investigation using the Incremental Sampling Method (ISM) was conducted to collect soil samples to determine the extent of contamination. The samples underwent lab analysis to determine contaminants of concern present at the site. The results of the XRF analysis were determined to be accurate and reliable; therefore, further confirmatory analysis was not needed. Human health and ecological risk assessments were performed.

The human health risk assessment found that arsenic presents a slight carcinogenic risk to recreational users of all ages. The ecological risk assessment found elevated concentrations of lead, arsenic, zinc, copper, nickel, manganese, vanadium, cadmium, silver, and antimony that pose a risk to plants, soil invertebrates, avian and mammalian wildlife. Based on the results of the risk assessment, five alternative remediation plans were compared using a decision matrix based on specific criteria, such as cost, implementability, and effectiveness. A remediation plan was recommended for the site based on the highest decision matrix score. Phytoremediation and institutional controls were the recommended remediation methods should site remediation be desired. Yellow Pygmy Sunflowers and Deer Grass are the recommended plants to be used for phytoremediation. It is recommended that fencing and signage around DU1 are used as institutional controls since DU1 presents the greatest risk to human and ecological health.

14.0. References

[1] *Google Earth*. [Online]. Available: https://www.google.com/intl/en_in/earth/. [Accessed: 19-Sept-2022].

[2] ECM Consultants, “Preliminary Assessment and Site Inspection Report,” 2016. [Accessed 19-Sept-2022].

[3] Arizona Department of Environmental Quality , "Arizona Soil Remediation Standards," 2009.

[4] United States Environmental Protection Agency , "Interim Ecological Soil Screening Level Documents," 8 September 2021. [Online]. Available: https://www.epa.gov/chemical-research/interim-ecological-soil-screening-level-documents. [Accessed 12 March 2023].

[5] Arizona Department of Environmental Quality, “Arizona Administrative Code Title 18. Chapter 7,” *ADEQ*. [Accessed 10-Mar-2023].

[6] EPA, “Chromium in Drinking Water,” *EPA*. [Online]. Available: https://www.epa.gov/sdwa/chromium-drinking-water. [Accessed: 10-Mar-2023].

[7] A. A. D. T. V. B. P; “Extent of oxidation of cr(iii) to cr(vi) under various conditions pertaining to natural environment,” *Journal of hazardous materials*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/16297546/. [Accessed: 10-Mar-2023].

[8] WRCC, “Oatman Wind Rose,” *Oatman Arizona*. [Online]. Available: https://raws.dri.edu/cgi-bin/rawMAIN.pl?azAOAT. [Accessed: 10-Mar-2023].

[9] United States Environmental Protection Agency , "Update for Chapter 5 of the Exposure Factors Handbook," EPA, September 2017. [Online]. Available: https://www.epa.gov/sites/default/files/2018-01/documents/efh-chapter05_2017.pdf. [Accessed 17 March 2023].

[10] United States Environmental Protection Agency, "Exposure Factors Handbook," EPA, September 2011. [Online]. Available: https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=526169. [Accessed 17 March 2023].

[11] World Health Organization. (2022, December 7). *Arsenic*. World Health Organization. Retrieved March 17, 2023, from https://www.who.int/news-room/fact-sheets/detail/arsenic#:~:text=In%20addition%20to%20skin%20cancer,water%20is%20carcinogenic%20to%20humans.

[12] United States Environmental Protection Agency, “Integrated Risk Information System,” 24 March 2022. [Online]. Available: https://www.epa.gov/iris. [Accessed 17 March 2022]

[13] “Mojave Desert Discovery - Endangered Species,” *National Parks Service*. [Online]. Available: https://www.nps.gov/moja/learn/education/classrooms/mojave-desert-discovery.htm. [Accessed: 02-Apr-2023].

[14] “Ecological Soil Screening Levels for Lead.” U.S. Environmental Protection Agency, 2005.

[15] R. Eisler, “A Review of Arsenic Hazards To Plants And Animals With Emphasis On Fishery And Wildlife Resources.” *U.S. National Biological Survey*, 1994.

[16] Finnegan PM, Chen W. “Arsenic Toxicity: The Effects on Plant Metabolism.” *Front Physiol*, 2012.

[17] T. Garland, “Overview of arsenic poisoning in animals - toxicology,” *Merck Veterinary Manual*, 22-Mar-2023. [Online]. Available: https://www.merckvetmanual.com/toxicology/arsenic-poisoning/overview-of-arsenic-poisoning-in-animals. [Accessed: 05-Apr-2023].

[18] “Ecological Soil Screening Levels for Zinc.” U.S. Environmental Protection Agency, 2007.

[19] “Ecological Soil Screening Levels for Copper.” U.S. Environmental Protection Agency, 2006.

[20] “Heavy metal poisoning in birds,” *Bird & Exotics Veterinarian*, 16-Jun-2020. [Online]. Available: https://www.birdexoticsvet.com.au/factsheets/2020/6/6/heavy-metal-poisoning-in-birds. [Accessed: 05-Apr-2023].

[21] “Ecological Soil Screening Levels for Cadmium.” U.S. Environmental Protection Agency, 2005.

[22] R. Segelken and 2000 July 12, “Diet Produces Brittle Bones in Rocky Mountain Birds,” *Cornell Chronicle*, 12-Jul-2000. [Online]. Available: https://news.cornell.edu/stories/2000/07/cadmium-makes-brittle-bones-rocky-mt-birds. [Accessed: 05-Apr-2023].

[23] “Ecological Soil Screening Levels for Antimony.” U.S. Environmental Protection Agency, 2005.

[24] “Ecological Soil Screening Levels for Silver.” U.S. Environmental Protection Agency, 2006.

[25] “Ecological Soil Screening Levels for Manganese.” U.S. Environmental Protection Agency, 2007.

[26] “Ecological Soil Screening Levels for Nickel.” U.S. Environmental Protection Agency, 2007.

[27] “Phytoremediation- In Situ Soil Remediation Technology,” *4-3 phytoremediation*. [Online]. Available: https://frtr.gov/matrix2/section4/4-3.html. [Accessed: 05-Apr-2023].

[28] “Arizona Fences Costs & Prices - ProMatcher Cost Report,” *Promatcher*. [Online]. Available: https://fences.promatcher.com/cost/arizona.aspx. [Accessed: 05-Apr-2023].

[29] S. Batterman, "Contaminated Soil Cleanup Costs and Standards," Science Jrank, [Online]. Available: https://science.jrank.org/pages/1737/Contaminated-Soil-Cleanup-costs-standards.html#:~:text=Excavation%20and%20incineration%20of%20contaminated,have%20averaged%20about%20%2426%20million.). [Accessed 6 April 2023].

[30] “A citizen's guide to phytoremediation - US EPA,” Sep-2012. [Online]. Available: https://www.epa.gov/sites/default/files/2015-04/documents/a_citizens_guide_to_phytoremediation.pdf. [Accessed: 20-Apr-2023].

[31] “The Plant List helping you find the perfect native plant for your landscape.,” *The Arizona Native Plant Society | The Plant List*, 2023. [Online]. Available: https://aznps.com/the-plant-list/. [Accessed: 20-Apr-2023].

[32] J. A. Juarez, Flagstaff, Arizona , rep., 2018.

[33] “Method 6200: Field Portable X-Ray Fluorescence Spectrometry For The Determination Of Elemental Concentrations In Soil And Sediment,” *Environmental Protection Agency*. [Online]. Available: https://www.epa.gov/sites/default/files/2015-12/documents/6200.pdf. [Accessed: 02-May-2023].

Appendices

Appendix A: Work Plan

Appendix B: Site Investigation Photolog

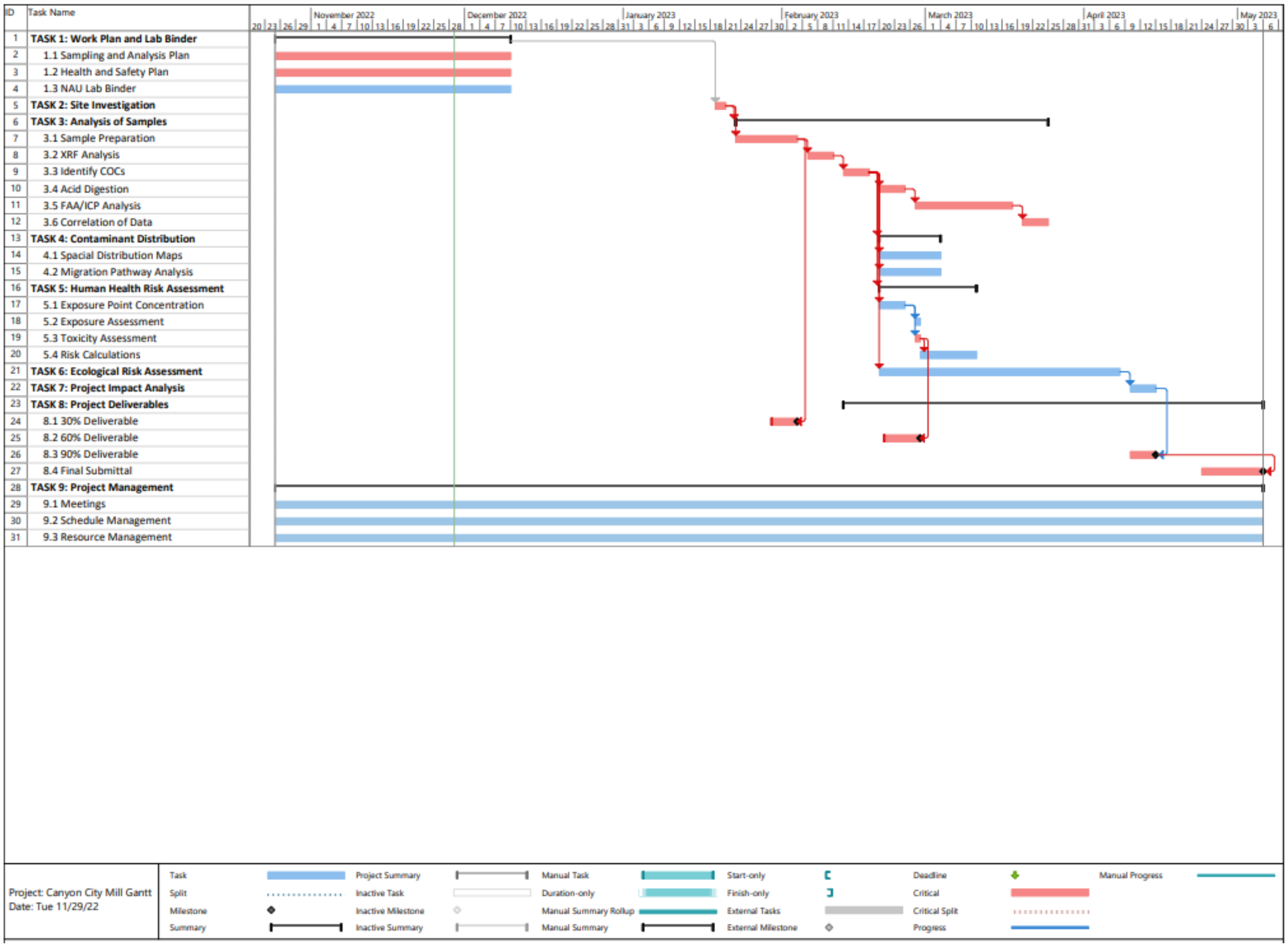
Appendix C: Site Investigation Field Notes

Appendix D: Lab Analysis Photolog

Appendix E : XRF Raw Data

Appendix F : Gantt Chart

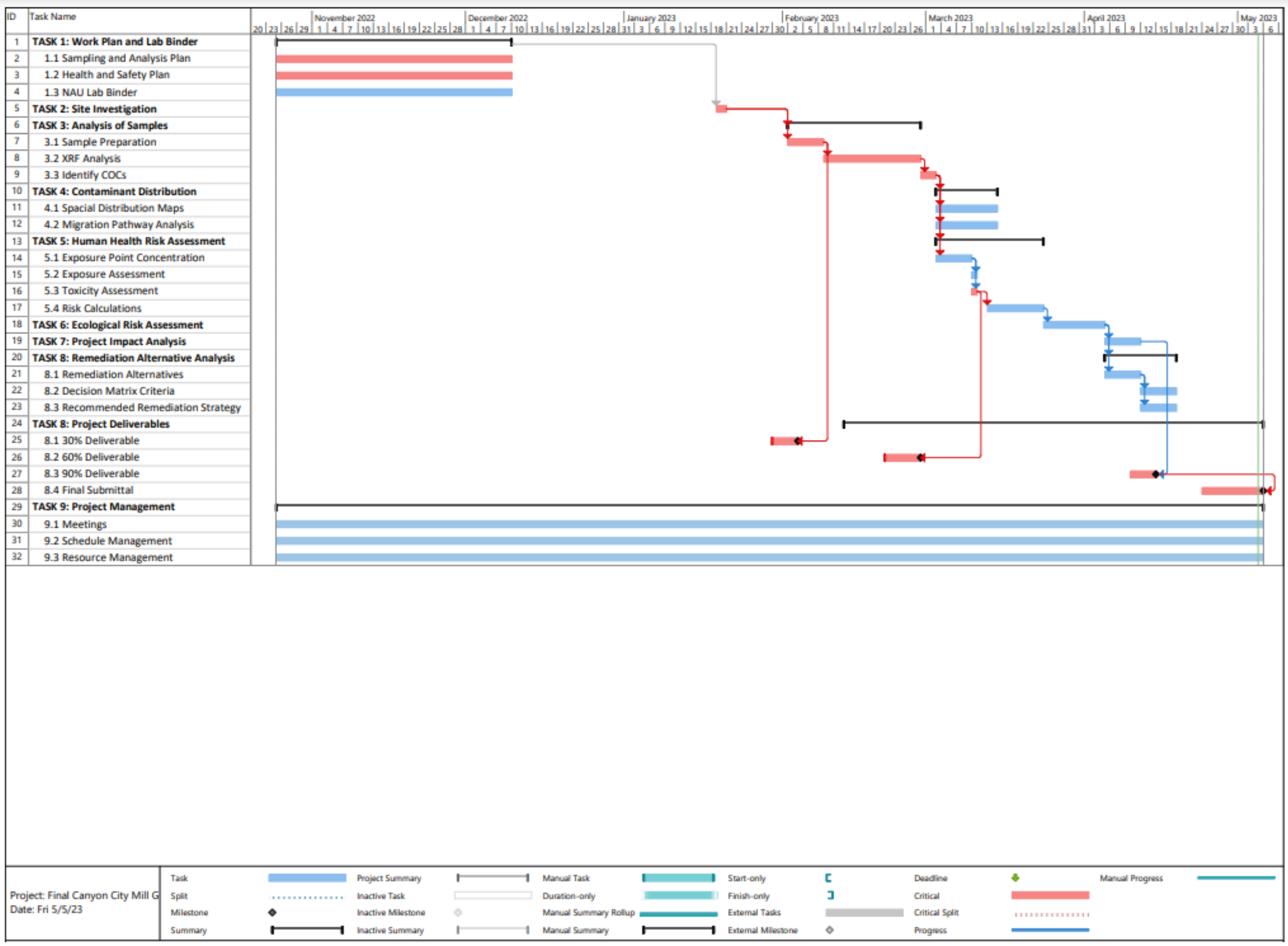
Figure F.1: Proposed Gantt Chart



ID	Task Name
1	**TASK 1: Work Plan and Lab Binder**
2	1.1 Sampling and Analysis Plan
3	1.2 Health and Safety Plan
4	1.3 NAU Lab Binder
5	**TASK 2: Site Investigation**
6	**TASK 3: Analysis of Samples**
7	3.1 Sample Preparation
8	3.2 XRF Analysis
9	3.3 Identify COCs
10	3.4 Acid Digestion
11	3.5 FAA/ICP Analysis
12	3.6 Correlation of Data
13	**TASK 4: Contaminant Distribution**
14	4.1 Spacial Distribution Maps
15	4.2 Migration Pathway Analysis
16	**TASK 5: Human Health Risk Assessment**
17	5.1 Exposure Point Concentration
18	5.2 Exposure Assessment
19	5.3 Toxicity Assessment
20	5.4 Risk Calculations
21	**TASK 6: Ecological Risk Assessment**
22	**TASK 7: Project Impact Analysis**
23	**TASK 8: Project Deliverables**
24	8.1 30% Deliverable
25	8.2 60% Deliverable
26	8.3 90% Deliverable
27	8.4 Final Submittal
28	**TASK 9: Project Management**
29	9.1 Meetings
30	9.2 Schedule Management
31	9.3 Resource Management

Project: Canyon City Mill Gantt
Date: Tue 11/29/22

Figure F.2: Modified Gantt Chart



ID	Task Name
1	**TASK 1: Work Plan and Lab Binder**
2	1.1 Sampling and Analysis Plan
3	1.2 Health and Safety Plan
4	1.3 NAU Lab Binder
5	**TASK 2: Site Investigation**
6	**TASK 3: Analysis of Samples**
7	3.1 Sample Preparation
8	3.2 XRF Analysis
9	3.3 Identify COCs
10	**TASK 4: Contaminant Distribution**
11	4.1 Spacial Distribution Maps
12	4.2 Migration Pathway Analysis
13	**TASK 5: Human Health Risk Assessment**
14	5.1 Exposure Point Concentration
15	5.2 Exposure Assessment
16	5.3 Toxicity Assessment
17	5.4 Risk Calculations
18	**TASK 6: Ecological Risk Assessment**
19	**TASK 7: Project Impact Analysis**
20	**TASK 8: Remediation Alternative Analysis**
21	8.1 Remediation Alternatives
22	8.2 Decision Matrix Criteria
23	8.3 Recommended Remediation Strategy
24	**TASK 8: Project Deliverables**
25	8.1 30% Deliverable
26	8.2 60% Deliverable
27	8.3 90% Deliverable
28	8.4 Final Submittal
29	**TASK 9: Project Management**
30	9.1 Meetings
31	9.2 Schedule Management
32	9.3 Resource Management

Project: Final Canyon City Mill G
Date: Fri 5/5/23

Appendix G : Staffing

Figure G.1: Proposed Staffing Hours

Proposed Staffing Hours				
Task	**SENG**	**ENG**	**TECH**	**INT**
1.0 Work Plan				
1.1 Sampling and Analysis Plan	12	30		
1.2 Health & Safety Plan		16		4
1.3 Lab Binder			6	10
2.0 Site investigation	20	20	20	20
3.0 Analysis of Samples				
3.1 Sample Preparation			4	4
3.1.1 Soil Drying			24	
3.1.2 Soil Sieving			32	
3.2 XRF Analysis		60	60	
3.4 Acid Digestion			8	
3.5 FAA or ICP Analysis				
3.6 Correlate Data		6		6
4.0 Contaminant Distribution				
4.1 Spatial Distribution Maps		4		6
4.2 Migration Pathway Analysis		10		14
5.0 Human Health Risk Assessment				
5.1 Exposure Point Concentrations	2	10		14
5.2 Exposure Assessment	2	10		16
5.3 Toxicity Assessment	2	12		14
5.4 Risk Calculations	2			
6.0 Ecological Risk Assessment	2	16		14
7.0 Project Impact Analysis				6
8.0 Project Deliverables				
8.1.1 30% Milestone	4	8	8	10
8.2.1 60% Milestone	2	4	4	4
8.3.1 90% Milestone	4	6	6	6
8.4 Final Submittal	6	6	6	6
9.0 Project Management				
9.1 Meetings	20	20	20	20
9.2 Schedule Management	5			
9.3 Resource Management	5			
Total	**88**	**238**	**198**	**174**

Figure G.2: Actual Staffing Hours

Actual Staffing Hours				
Task	**SENG**	**ENG**	**TECH**	**INT**
1.0 Work Plan				
1.1 Sampling and Analysis Plan	1	12		
1.2 Health & Safety Plan		5		1
1.3 Lab Binder		3	2	6
2.0 Site investigation	18	36	19	18
3.0 Analysis of Samples				
3.1 Sample Preparation			2	1
3.1.1 Soil Drying				16
3.1.2 Soil Sieving			20	
3.2 XRF Analysis			27	
3.3 Identify COCs		10		
4.0 Contaminant Distribution				
4.1 Spatial Distribution Maps		9	5	3
4.2 Migration Pathway Analysis		1		
5.0 Human Health Risk Assessment				
5.1 Exposure Point Concentrations	1	3		1
5.2 Exposure Assessment		4		
5.3 Toxicity Assessment	1			
5.4 Risk Calculations	2	6		
6.0 Ecological Risk Assessment	2	3		1
7.0 Remediation		1	2	2
8.0 Project Impact Analysis				6
9.0 Project Deliverables				
9.1.1 30% Milestone	5	4		7
9.2.1 60% Milestone	4	8	1	1
9.3.1 90% Milestone	6	8	7	7
9.4 Final Submittal	2	2	2	2
10.0 Project Management				
10.1 Meetings	10	15	20	23
10.2 Schedule Management	4			
10.3 Resource Management	4			
Total	**60**	**130**	**107**	**95**