IDENTIFICATION AND CHARACTERIZATION OF RARE EARTH ELEMENTS IN LARGE-SCALE MINE WASTES—TASK 4

DATA SUMMARY REPORT
YEAR 2 (2023–2024)

Terence E. Duaime, Jackson T. Quarles, and Matthew J. Vitale

prepared for Army Research Laboratory,
Cooperative Agreement (CA): W911NF-22-2-0015

MBMG
Montana Bureau of Mines and Geology

Front photo: Montana Tunnels, 2024.

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TABLE OF CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The United States is reliant on foreign countries (e.g., China) for much of its rare earth element (REE) supply. The reliance on foreign countries for REEs is a major concern for the U.S. in both domestic use and military security. This task aims to identify REE occurrences in large-scale waste sources associated with past underground and open-pit mining and ore processing facilities throughout Montana. Mine types include metallic, non-metallic, and coal. Programs to identify REE deposits throughout the U.S. are underway; however, exploration and mine development can take decades before resulting in an increase in U.S. resources and production. Recovery of REEs from abandoned/inactive sites would have fewer permitting requirements, thus potentially shortening the time necessary to produce REEs. Recovery of REEs from mine waste has the secondary benefit of aiding environmental cleanup by reducing waste sources and possibly providing an unforeseen revenue source.

This data summary report presents the results of aqueous and solid sample collection and analysis performed as part of a Cooperative Agreement titled "Materials Technology for Rare Earth Elements Processing (MT-REEP)." MT-REEP consists of several tasks focused on sharing expertise with Montana Technological University, including the Montana Bureau of Mines and Geology (MBMG). The multiple research projects aim to demonstrate that REEs exist and can be produced economically—even from mining wastes—without environmental damage, thus reducing the Nation's dependence on foreign-based supply chains. Task 4 focuses on collecting samples from large-scale mining and ore processing sites throughout Montana. A preliminary list of sites was compiled and added to throughout the year as contact was made with various State and Federal agencies and private companies. The list currently consists of 23 sites; figure 1-1 shows the counties in which the sites are located, with hatched areas indicating counties where samples have been collected for analysis.

Year 2 work focused on the following activities:

1. Continue a literature search of existing information for each site and compile REE data.

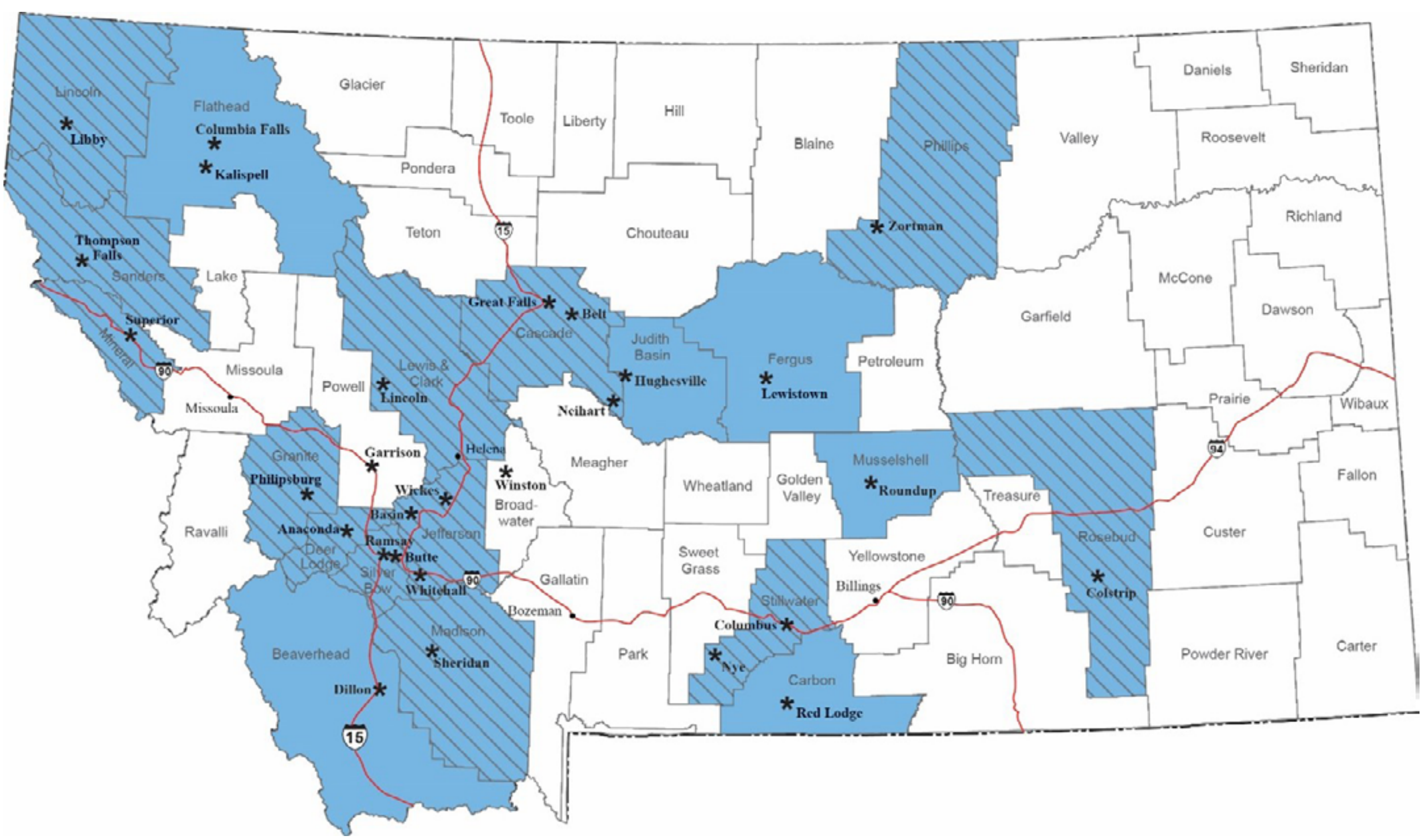

Figure 1-1. Sample site location map showing where study/sampling areas are located throughout Montana. Blue shading shows counties sampled in the second year, and hatched counties show where samples were collected during years 1 and 2. The stars represent cities as a geographic reference.

2. Update field and laboratory quality assurance project plans (QAPP) and sampling and analysis plans to ensure high-quality data are collected and analytical data meet the Army Research Laboratory (ARL) program goals.

3. Continue to contact property owners and regulatory agencies (i.e., USFS, EPA, and DEQ) for site access;

4. Continue reconnaissance/limited sampling program to collect opportunistic aqueous and solid samples for REE at sites located throughout Montana; and

5. Review REE analytical data to select sites for more detailed sampling.

This data summary report describes the sampling conducted for item 4 above. Sampling procedures followed those described in the project-specific QAPP developed under item 2 above. Many of the sites are part of ongoing U.S. Environmental Protection Agency Superfund activities or other regulatory action; therefore, sampling and analysis procedures, along with safety procedures, were designed to be compatible with those governing Superfund sites.

Solid samples were submitted to ALS Laboratories and West Virginia University (WVU) for rare earth element analysis, while aqueous samples were submitted to the WVU lab for REE analysis and the MBMG Analytical Laboratory for analysis of the dissolved and total recoverable fractions. The MBMG water-quality data are available online from the Groundwater Information Center: https://mbmggwic.mtech.edu/data/dataProject.asp?project=ENV_REE&datatype=well&2.0

2.0 YEAR 2 SAMPLING OBJECTIVES

For Year 2, sampling was continued at sites where access was easily obtained and previous data suggested the presence of REEs in the waste material. Initial reconnaissance sampling entailed collecting an adequate number of solid and/or aqueous samples at specific sites to determine if REE concentrations merited more detailed sampling. Sample sites included acid mine drainage discharge, sludge from water treatment facilities, waste dumps, smelter wastes, coal residue, and process water, as well as mill tailings.

The reconnaissance sampling results are being used to develop more detailed sampling plans at sites with elevated REE concentrations. Sites with total REE concentrations above 412 mg/kg in solids/sludge (concentration approximately two times that found in earth's crust; Balaram, 2019) and total REE concentrations above 499 µg/L in aqueous samples (value identified as having secondary recovery potential) are considered as sites with elevated concentrations. Sites were also evaluated on the ratio of the amount of critical REEs (i.e., neodymium, europium, terbium, dysprosium, erbium, and yttrium) in the REE sum to the amount of more abundant REEs, also known as the outlook coefficient (Coutl; Seredin and Dai, 2012). The higher the coefficient, the more promising the material is as a secondary source; sites with a coefficient of 0.7 or above are considered elevated for critical REEs.

3.0 BACKGROUND AND SAMPLE SITE DESCRIPTION

A total of 104 aqueous and 111 solid samples were collected from 11 sites during Year 2 activities. A description of each sample site and a summary of aqueous, sludge, and solid sample results showing average, minimum, and maximum concentrations, and number of samples collected, are presented below.

3.1 Butte Mining District

Butte, Montana, has a long mining history that dates back to the 1860s with the discovery of placer gold deposits. Soon after, silver, copper, and zinc were found in quantity and began to be mined. Duaime and McGrath (2019) noted the existence of 517 underground mines on the Butte Hill, with depths reaching up to 1 mi; ore production from these mines was prodigious, with more than 23 billion pounds of copper and 4.9 billion pounds of zinc produced from 1880 through 2017. Over 10,000 miles of underground workings (Duaime and others, 2002) were exhumed in search of these metals, and several open pit mines (e.g., the Berkeley Pit and the Continental Pit) were operated as part of mining operations. In 1982 the mines closed and the dewatering pumps were turned off. Open pit mining ended in the Berkeley Pit in 1983, but resumed in the adjacent Continental Pit in 1986. The cessation of underground mine dewatering allowed heavy-metal-laden water to flood the abandoned workings and the Berkeley Pit.

Second-year sampling activities focused on various sources from the Montana Resources Mine, including the Berkeley Pit, the Continental Pit, and associated tailings and waste (fig. 3-1). With the assistance from Montana Resources a trench was dug in one of the leach pads to allow for sampling (fig. 3-2). Solid and water samples were collected from the Continental Pit, along with solid samples from the secondary crusher. Various seeps from the Horseshoe Bend (HsB) tailings dam area were sampled as well as water from the precipitation plant, where water from the Berkeley Pit and HsB are exposed to scrape metal for copper recovery. The Berkeley Pit was sampled again and samples were submitted for REE (figure 3-3). Other opportunistic samples (both solid and aqueous) were collected in the Butte area. In total, 48 samples were collected and analyzed for REE; the results are presented in tables 3-1 through 3-12. The distribution of REEs for these samples can be found in figures 3-4 through 3-9.

3.2 Basin Mining District

The Basin mining district is located in Jefferson County, Montana and encompasses a 77-mi2 area around the town of Basin. Copper and gold mining started in the 1870s and continued through the 1960s (EPA, 2017a). Contamination of the watershed by mine wastes resulted in a Superfund listing in 1999 and can still be seen today (fig. 3-10). With mines such as the Crystal and the Bullion (fig. 3-11) within the district already being monitored by the MBMG, the area was an easy addition to the ARL project. Six water samples and three solid samples were collected from the area; assay results are presented in tables 3-13 through 3-16. REE distribution of the site can be seen in figures 3-12 and 3-13.

3.3 Montana Tunnels (Colorado Mining District)

The Montana Tunnels mine is a gold/silver operation located in Jefferson City, MT (fig 3-14). The mine first opened in 1986 and was last operational in 2008 when Pegasus Gold went bankrupt and abandoned the property (DEQ, 2025). In the 22 years of operation, over $4.85 billion worth of gold, silver, and zinc was extracted. Since 2008, the Eastern Resources Inc. (ERI) has been trying to reopen the mine but after failing to post an adequate bond in 2018, their permit was revoked by DEQ. With reserves estimated to be valued at $1.4 billion, ERI is still attempting to reopen the mine (ERI, 2025). Samples were collected via an unmanned aerial vehicle (UAV) from water within the pit and manually from the various onsite waste sources on June 6, 2024 (fig. 3-15). Results from the sampling event can be found in tables 3-17 through 3-20. REE distributions of the site can be seen in figures 3-16 and 3-17.

3.4 Neihart Mining District

The Neihart mining district, located in the Little Belt Mountains, encompasses 9,000 acres around Neihart, MT (fig. 3-18). Mining initially began in the 1890s with the discovery of silver and lead-rich ores. Over $17 million of silver and other minerals was extracted from 96 known mines until the end of mining in the area in 1945 (Western Mining History, 2024). Acid drainage from the mines polluted nearby creeks and groundwater. This site was added to the Superfund list in September 2001. The excessive amount of mine waste made it a target for the ARL project; EPA and U.S. Forest Service helped with site access. On September 25, 2023, 24 solid samples and 7 aqueous samples were collected from the district. Sampling took place in the Bakers/Hughesville area. Acid mine drainage from the Tiger/Pioneer Mines is presented in figure 3-19. The samples were sent to WVU and ALS for assay. The assay results can be found in tables 3-21 through 3-24. Distribution of REEs in the samples can be found in figures 3-20 and 3-21.

3.5 Mike Horse Mine (Heddleston Mining District)

The Mike Horse mine is a part of the Upper Blackfoot Mining Complex (UBMC) at the headwaters of the Blackfoot River (fig. 3-22). Originally opening in 1898 to mine lead, zinc, and copper, a dam was constructed on the Upper Blackfoot to retain tailings, which held until 1975 when heavy rains caused 100,000 tons of tailings to spill (DOJ, 2024). The dam was immediately repaired, but in 2005 it was deemed unsafe and was removed. The UBMC water treatment site went online in 2009 and has been treating water from the area since (fig. 3-23). Samples were collected from the water treatment site as well as from waste piles at nearby adits. Assay results can be found in tables 3-25 through 3-28. Distribution of the REEs in these samples can be seen in figures 3-24 and 3-25.

3.6 Colstrip

Colstrip, Montana is home to two coal power plants, the Rosebud Power Plant and the Colstrip Power Plant (fig. 3-26). Both of these power plants source their coal from the local Rosebud Coal Mine, a strip-mining operation. Mining began in the 1920s by the North Pacific Railroad. Construction of the Colstrip Power Plant began in the 1960s along with a more modern coal mine. In 2015 the Rosebud Coal Mine produced and delivered 9,348,838 tons of coal to the Colstrip Power Plants (Haggerty and others, 2017). Today the Colstrip Power Plant is owned by six entities, with Talon Energy operating the facility (fig. 3-27). The Rosebud Power Plant is a municipal generation facility that is fueled by waste coal. Each facility generates coal waste in the form of fly and bottom ash. On June 6, 2024, the MBMG field crew visited the Colstrip and Rosebud Power Plants. Samples of bottom and fly ash were collected from each site, along with wastewater generated by the plants. Coal from the Rosebud Mine and a local stock pile were also collected. A total of 8 solid samples and 3 aqueous samples were collected. The results from this sampling event can be found in tables 3-29 through 3-34. Distributions of the REE concentrations can be seen in figures 3-28 and 3-29.

4.0 SUMMARY

Task 4 Year 2 field activities focused on the continued collection and analysis of solid and aqueous samples from the initial site list and sites added throughout the year. A total of 392 samples were collected at 11 sites. Several of the sampled sites are Superfund sites or have mine closure monitoring activities; however, some sampling occurred at active mine operations (e.g., Montana Resources active Butte mining operations).

Sample results showed REE present in all of the samples collected; however, concentrations vary considerably between sites and waste sources. REE concentrations were higher in surface-water and groundwater sites where pH values were less than or equal to 4.0. Sludge and solid samples with the highest REE concentrations were from sites treating acid mine water with lime, where the concentrated REEs were contained in the waste sludge. Figures 3-30 through 3-32 show total REE concentrations for all sites compared to each other.

Reconnaissance and more detailed sampling will continue during year 3 of the study, and that data combined with previous results will be used to identify sites with elevated REE concentrations for further, more detailed sampling and characterization.

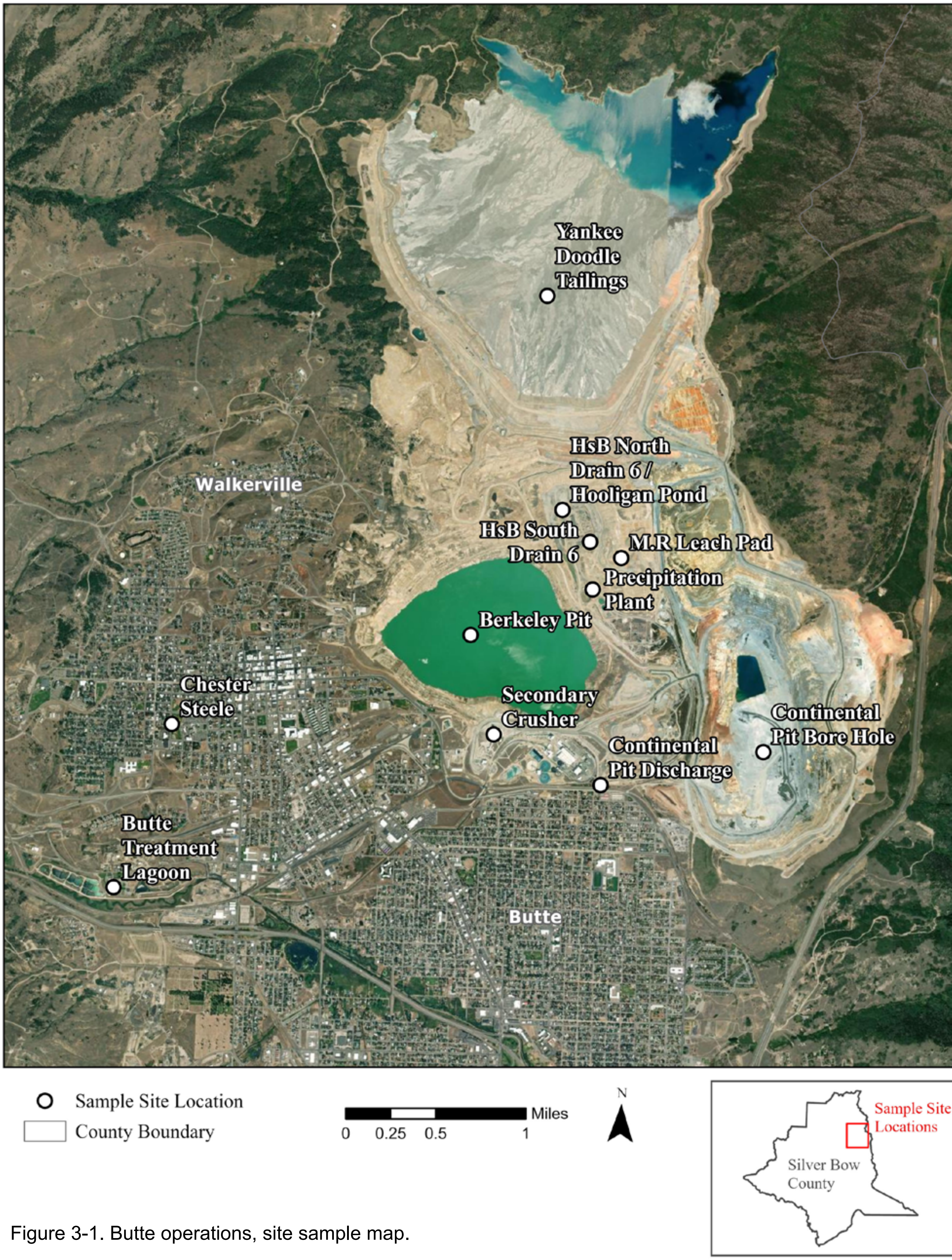

Figure 3-1. Butte operations, site sample map.

Figure 3-2. Butte operations: Montana Resources leach pads.

Figure 3-3. Butte operations: Berkeley Pit and sampling drone boat.

Table 3-1. MR Leach Pad REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
MR Leach Pad #1 Surface	1.60	1.67	0.90	0.36	0.17	0.26	0.16	9.60	1.04
MR Leach Pad #1 3'	1.50	3.44	2.09	0.74	0.32	0.56	0.32	20.20	2.22
MR Leach Pad #1 6'	1.50	4.21	2.49	0.86	0.39	0.73	0.39	24.60	2.62
MR Leach Pad #2 Surface	1.60	2.52	1.50	0.49	0.21	0.45	0.25	14.90	1.58
MR Leach Pad #2 3'	1.40	3.39	1.89	0.67	0.30	0.54	0.29	18.20	2.03
MR Leach Pad #2 6'	1.40	3.69	2.06	0.74	0.31	0.67	0.35	21.00	2.16
MR Leach Pad #3 Surface	1.70	2.50	1.50	0.48	0.27	0.40	0.23	14.30	1.64
MR Leach Pad #3 3'	1.60	3.46	2.27	0.72	0.35	0.63	0.36	20.70	2.29
MR Leach Pad #3 6'	1.50	4.24	2.69	0.91	0.48	0.73	0.43	24.70	2.86
MR Leach Pad #4 Surface	1.80	2.99	1.90	0.62	0.32	0.51	0.28	16.90	1.98
MR Leach Pad #4 3'	1.60	3.98	2.38	0.82	0.40	0.65	0.36	21.70	2.52
MR Leach Pad #4 6'	1.80	3.24	1.94	0.68	0.33	0.60	0.34	19.60	2.07
Mean	1.58	3.28	1.97	0.67	0.32	0.56	0.31	18.87	2.08
Minimum	1.40	1.67	0.90	0.36	0.17	0.26	0.16	9.60	1.04
Maximum	1.80	4.24	2.69	0.91	0.48	0.73	0.43	24.70	2.86

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
MR Leach Pad #1 Surface	43.40	0.46	1.84	22.50	16.00	4.59	2.66	8.00
MR Leach Pad #1 3'	76.20	0.89	3.61	39.00	28.60	8.00	5.26	11.00
MR Leach Pad #1 6'	86.80	1.10	4.73	44.20	34.40	9.47	5.95	12.00
MR Leach Pad #2 Surface	63.80	0.76	2.90	33.10	24.50	6.83	3.91	9.00
MR Leach Pad #2 3'	72.80	0.88	3.68	37.90	27.30	7.91	5.08	11.00
MR Leach Pad #2 6'	68.00	1.05	4.11	34.60	29.30	7.31	5.42	10.00
MR Leach Pad #3 Surface	55.70	0.69	2.86	28.10	21.40	6.11	3.99	9.00
MR Leach Pad #3 3'	80.90	1.01	4.06	41.80	30.30	8.38	5.12	11.00
MR Leach Pad #3 6'	79.20	1.13	4.75	39.30	32.40	8.93	6.03	11.00
MR Leach Pad #4 Surface	67.10	0.74	3.20	33.70	25.30	7.13	4.52	10.00
MR Leach Pad #4 3'	77.10	1.04	4.27	39.10	29.90	8.08	5.61	11.00
MR Leach Pad #4 6'	74.40	0.97	3.83	39.10	28.70	7.75	5.18	10.00
Mean	70.45	0.89	3.65	36.03	27.34	7.54	4.89	10.25
Minimum	43.40	0.46	1.84	22.50	16.00	4.59	2.66	8.00
Maximum	86.80	1.13	4.75	44.20	34.40	9.47	6.03	12.00

Table 3.1—*Continued.*

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
MR Leach Pad #5 Surface	1.40	2.11	1.25	0.42	0.25	0.35	0.20	13.10	1.38
MR Leach Pad #5 3'	1.30	3.53	1.95	0.74	0.33	0.59	0.31	19.70	2.13
MR Leach Pad #5 6'	1.40	3.42	1.92	0.74	0.40	0.60	0.34	20.50	2.2
MR Leach Pad #6 Surface	1.70	1.86	1.06	0.39	0.19	0.31	0.19	10.80	1.28
MR Leach Pad #6 3'	1.50	2.17	1.55	0.49	0.30	0.39	0.24	14.20	1.61
MR Leach Pad #6 6'	1.30	3.40	1.95	0.68	0.34	0.55	0.33	19.70	2.03
MR Leach Pad #7 Surface	1.90	2.12	1.17	0.44	0.22	0.36	0.19	11.80	1.33
MR Leach Pad #7 3'	1.70	2.71	1.51	0.52	0.28	0.47	0.29	15.90	1.7
MR Leach Pad #7 6'	1.50	2.93	1.81	0.58	0.25	0.52	0.30	18.00	1.82
MR Leach Pad #8 Surface	2.20	1.15	0.57	0.21	0.09	0.20	0.09	6.20	0.59
MR Leach Pad #8 3'	1.70	1.99	1.30	0.41	0.22	0.37	0.20	12.70	1.45
MR Leach Pad #8 6'	1.50	2.42	1.45	0.51	0.24	0.41	0.25	15.10	1.66
Mean	1.59	2.48	1.46	0.51	0.26	0.43	0.24	14.81	1.60
Minimum	1.30	1.15	0.57	0.21	0.09	0.20	0.09	6.20	0.59
Maximum	2.20	3.53	1.95	0.74	0.40	0.60	0.34	20.50	2.20

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
MR Leach Pad #5 Surface	48.30	0.63	2.45	23.80	18.40	5.23	3.41	8.00
MR Leach Pad #5 3'	70.20	0.91	3.98	35.20	27.00	7.63	4.80	10.00
MR Leach Pad #5 6'	67.10	0.99	3.75	34.70	26.50	7.26	4.84	10.00
MR Leach Pad #6 Surface	46.50	0.63	2.13	24.50	18.10	5.07	3.20	8.00
MR Leach Pad #6 3'	46.40	0.58	2.31	24.20	17.50	5.05	3.07	7.00
MR Leach Pad #6 6'	69.40	0.86	3.84	35.40	26.70	7.53	4.64	10.00
MR Leach Pad #7 Surface	44.00	0.63	2.33	22.30	17.10	4.70	3.22	8.00
MR Leach Pad #7 3'	53.70	0.81	2.95	28.10	21.30	5.67	3.63	10.00
MR Leach Pad #7 6'	60.90	0.86	3.46	32.70	22.60	6.38	4.02	10.00
MR Leach Pad #8 Surface	27.20	0.33	1.44	13.40	10.70	2.91	2.03	4.00
MR Leach Pad #8 3'	48.10	0.67	2.49	24.90	18.90	5.13	3.32	9.00
MR Leach Pad #8 6'	54.70	0.79	2.76	29.30	20.90	5.83	3.68	9.00
Mean	53.04	0.72	2.82	27.38	20.48	5.70	3.66	8.58
Minimum	27.20	0.33	1.44	13.40	10.70	2.91	2.03	4.00
Maximum	70.20	0.99	3.98	35.40	27.00	7.63	4.84	10.00

Table 3-2. MR Leach Pad total REE and Coutl.

Sample ID	Total REE mg/kg	Coutl
MR Leach Pad #1 Surface	115.21	0.64
MR Leach Pad #1 3'	203.95	0.70
MR Leach Pad #1 6'	236.44	0.74
MR Leach Pad #2 Surface	168.30	0.67
MR Leach Pad #2 3'	195.26	0.69
MR Leach Pad #2 6'	192.17	0.81
MR Leach Pad #3 Surface	150.87	0.70
MR Leach Pad #3 3'	214.95	0.69
MR Leach Pad #3 6'	221.28	0.79
MR Leach Pad #4 Surface	178.99	0.69
MR Leach Pad #4 3'	210.51	0.73
MR Leach Pad #4 6'	200.53	0.71
Sample ID	Total REE mg/kg	Coutl
MR Leach Pad #5 Surface	130.68	0.71
MR Leach Pad #5 3'	190.30	0.73
MR Leach Pad #5 6'	186.66	0.76
MR Leach Pad #6 Surface	125.91	0.67
MR Leach Pad #6 3'	128.56	0.74
MR Leach Pad #6 6'	188.65	0.73
MR Leach Pad #7 Surface	121.81	0.72
MR Leach Pad #7 3'	151.24	0.76
MR Leach Pad #7 6'	168.63	0.73
MR Leach Pad #8 Surface	73.31	0.68
MR Leach Pad #8 3'	132.85	0.71
MR Leach Pad #8 6'	150.50	0.72

Table 3-3. Berkeley Pit aqueous data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
BP-398-Tot. Rec.	<32.00	245.20	149.33	50.03	19.68	37.58	20.00	1427.74	126.6
BP-4 ft-Tot. Rec.	<32.00	252.48	154.95	51.66	20.20	38.40	21.02	1260.04	132.7
BP-400 ft-Tot. Rec.	<32.00	268.40	165.36	54.89	21.73	41.28	22.26	1398.64	141.8
Mean	0.00	255.36	156.55	52.19	20.53	39.09	21.09	1362.14	133.7
Minimum	0.00	245.20	149.33	50.03	19.68	37.58	20.00	1260.04	126.6
Maximum	0.00	268.40	165.36	54.89	21.73	41.28	22.26	1427.74	141.8

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
BP-398-Tot. Rec.	135.96	39.22	227.72	350.15	606.63	135.96	156.92	29.93
BP-4 ft-Tot. Rec.	132.99	39.05	227.32	334.58	598.00	132.99	157.06	27.11
BP-400 ft-Tot. Rec.	131.46	39.83	232.94	346.09	600.68	131.46	154.48	25.87
Mean	132.99	39.37	229.32	343.61	601.77	133.47	156.15	27.64
Minimum	131.46	39.05	227.32	334.58	598.00	131.46	154.48	25.87
Maximum	135.96	39.83	232.94	350.15	606.63	135.96	157.06	29.93

Table 3-4. Berkeley Total REE & Coutl.

Sample ID	Total REE µg/L	Coutl
BP-398-Tot. Rec.	3758.70	1.78
BP-4 ft-Tot. Rec.	3580.55	1.86
BP-400 ft-Tot. Rec.	3777.16	1.74

Table 3-5. MR-Miscellaneous solids REE.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Yankee Doodle Tailings-1, surface	1.30	2.82	1.90	0.53	0.32	0.47	0.26	15.30	2.07
Yankee Doodle Tailings-2, 6" depth	1.30	2.93	1.84	0.59	0.27	0.47	0.23	13.60	1.88
Continental Pit Bore Hole 1	1.30	3.49	2.18	0.64	0.30	0.61	0.29	17.60	2.13
Continental Pit Bore Hole 2	1.20	3.46	2.11	0.64	0.33	0.55	0.31	18.00	2.21
Secondary Crusher 1	1.70	5.15	3.16	0.96	0.46	0.83	0.41	25.20	3.16
Secondary Crusher 2	1.60	5.10	2.89	0.90	0.45	0.83	0.40	23.90	3.14
Mean	1.40	3.83	2.35	0.71	0.36	0.63	0.32	18.93	2.43
Minimum	1.20	2.82	1.84	0.53	0.27	0.47	0.23	13.60	1.88
Maximum	1.70	5.15	3.16	0.96	0.46	0.83	0.41	25.20	3.16

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Yankee Doodle Tailings-1, surface	66.30	0.69	3.12	34.20	22.50	6.79	4.04	N/A
Yankee Doodle Tailings-2, 6" depth	54.00	0.72	3.26	26.80	20.40	5.92	4.02	N/A
Continental Pit Bore Hole 1	81.00	1.11	4.12	44.50	28.10	8.30	4.95	N/A
Continental Pit Bore Hole 2	74.50	0.90	3.77	39.10	27.50	7.57	5.04	N/A
Secondary Crusher 1	94.60	1.48	5.82	48.90	36.30	9.86	7.09	N/A
Secondary Crusher 2	91.50	1.44	5.70	47.50	35.00	9.77	6.87	N/A
Mean	76.98	1.06	4.30	40.17	28.30	8.04	5.34	N/A
Minimum	54.00	0.69	3.12	26.80	20.40	5.92	4.02	N/A
Maximum	94.60	1.48	5.82	48.90	36.30	9.86	7.09	N/A

Table 3-6. MR-Miscellaneous solids total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
Yankee Doodle Tailings-1, surface	162.61	0.63
Yankee Doodle Tailings-2, 6" depth	138.23	0.70
Continental Pit Bore Hole 1	200.62	0.63
Continental Pit Bore Hole 2	187.19	0.67
Secondary Crusher 1	245.08	0.72
Secondary Crusher 2	236.99	0.72

Table 3-7. MR-Miscellaneous aqueous REE data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
HsB South Drain 6-Tot. Rec.	<32.00	72.09	43.31	14.30	5.58	11.14	6.00	455.64	38.39
HsB North Drain 6-Tot. Rec.	<32.00	59.99	37.01	12.16	4.65	9.28	5.08	427.05	32.09
HsB Hooligan Pond-Tot. Rec.	<32.00	90.15	55.60	18.06	6.91	13.47	7.62	650.06	48.48
P.P. Influent- Diss	<32.00	233.80	142.70	47.06	19.75	35.88	19.44	1244.72	122.11
P.P. Effluent- Diss	<32.00	242.89	148.16	48.77	20.23	37.13	19.83	1291.18	125.48
P.P. Influent-Tot. Rec.	<32.00	232.47	142.74	46.87	19.44	35.86	19.08	1238.60	121.54
P.P. Effluent-Tot. Rec.	<32.00	234.62	143.93	47.55	19.53	36.19	19.31	1245.92	121.39
Continental Pit Dis - Diss	<32.00	7.41	<0.004	<0.002	<0.002	1.22	<0.002	43.73	<0.004
Continental Pit Dis- Tot. Rec.	<32.00	0.54	3.98	1.43	0.42	0.08	0.48	2.91	2.90
Mean	0.00	130.44	89.68	29.52	12.06	20.03	12.11	733.31	76.55
Minimum	0.00	0.54	3.98	1.43	0.42	0.08	0.48	2.91	2.90
Maximum	0.00	242.89	148.16	48.77	20.23	37.13	19.83	1291.18	125.48

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
HsB South Drain 6-Tot. Rec.	421.05	12.85	70.41	93.54	223.78	51.49	54.76	7.34
HsB North Drain 6-Tot. Rec.	335.52	10.19	57.36	79.30	172.24	38.23	44.41	4.09
HsB Hooligan Pond-Tot. Rec.	275.39	14.46	80.11	73.30	209.67	43.03	59.60	30.29
P.P. Influent- Diss	1246.56	37.54	221.38	332.91	576.53	126.30	144.30	24.04
P. P. Effluent- Diss	1281.18	39.10	226.38	340.52	566.53	130.15	148.15	24.78
P.P. Influent-Tot. Rec.	1226.69	37.51	220.64	334.86	586.86	126.22	143.80	24.16
P. P. Effluent-Tot. Rec.	1254.61	37.77	221.12	335.60	584.95	127.84	144.79	23.86
Continental Pit Dis - Diss	45.74	1.74	8.10	20.73	24.83	5.88	6.08	0.61
Continental Pit Dis - Tot. Rec.	4.05	0.10	0.59	1.59	2.45	0.59	0.58	0.37
Mean	4.05	0.10	0.59	1.59	2.45	0.59	0.58	0.37
Minimum	4.05	0.10	0.59	1.59	2.45	0.59	0.58	0.37
Maximum	1281.18	39.10	226.38	340.52	586.86	130.15	148.15	30.29

Table 3-8. MR-Miscellaneous aqueous total REE and Coutl.

Sample ID	Total REE µg/L	Coutl
HsB South Drain 6-Tot. Rec.	1581.67	1.83
HsB North Drain 6-Tot. Rec.	1328.64	2.00
HsB Hooligan Pond-Tot. Rec.	1676.20	3.36
P.P. Influent- Diss	4575.02	1.70
P. P. Effluent- Diss	4690.44	1.70
P.P. Influent-Tot. Rec.	4557.30	1.73
P. P. Effluent-Tot. Rec.	4598.96	1.70
Continental Pit Dis- Diss	166.07	0.00
Continental Pit Dis- Tot. Rec.	23.06	1.58

Table 3-9. Butte Treatment Lagoon solids REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
A-1 Sludge	<	0.10	0.03	0.01	<	0.36	0.00	1.19	0.01
Drying Bed Sludge	4.17	1.34	0.84	0.29	0.10	1.44	0.12	12.95	0.718
Mean	4.17	0.72	0.44	0.15	0.10	0.90	0.06	7.07	0.36
Minimum	4.17	0.10	0.03	0.01	0.10	0.36	0.00	1.19	0.01
Maximum	4.17	1.34	0.84	0.29	0.10	1.44	0.12	12.95	0.72

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
A-1 Sludge	1.22	0.07	0.36	0.56	1.43	0.30	0.36	0.28
Drying Bed Sludge	13.18	0.18	1.44	7.22	5.03	1.36	1.04	1.26
Mean	7.20	0.12	0.90	3.89	3.23	0.83	0.70	0.77
Minimum	1.22	0.07	0.36	0.56	1.43	0.30	0.36	0.28
Maximum	13.18	0.18	1.44	7.22	5.03	1.36	1.04	1.26

Table 3-10. Butte Treatment Lagoon total REE and Coutl.

Sample ID	Total REE mg/kg	Coutl
A-1 Sludge	6.27	2.28
Drying Bed Sludge	52.67	1.43

Table 3-11. Butte Flooded Mineshafts REE data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
Chester Steele-Diss.	<32.00	<0.004	<0.004	<0.002	<.002	<0.004	<.002	0.06	<0.00 4
Chester Steele-Tot. Rec.	<32.00	0.54	0.31	0.10	0.04	0.54	0.04	2.91	0.329
Mean	0.00	0.54	0.31	0.10	0.04	0.54	0.04	1.49	0.33
Minimum	0.00	0.54	0.31	0.10	0.04	0.54	0.04	0.06	0.33
Maximum	0.00	0.54	0.31	0.10	0.04	0.54	0.04	2.91	0.33

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
Chester Steele-Diss.	0.05	<0.003	<0.003	0.05	<0.004	<0.003	<0.004	0.09
Chester Steele-Tot. Rec.	4.05	0.10	0.59	4.05	0.58	0.59	0.58	0.37
Mean	2.05	0.10	0.59	2.05	0.58	0.59	0.58	0.23
Minimum	0.05	0.10	0.59	0.05	0.58	0.59	0.58	0.09
Maximum	4.05	0.54	0.59	4.05	0.58	0.59	0.58	2.91

Table 3-12. Butte Flooded Mineshafts total REE & Coutl.

Sample ID	Total REE µg/L	Coutl
Chester Steele-Dissolved	0.25	0.00
Chester Steele-Tot. Rec.	15.72	1.51

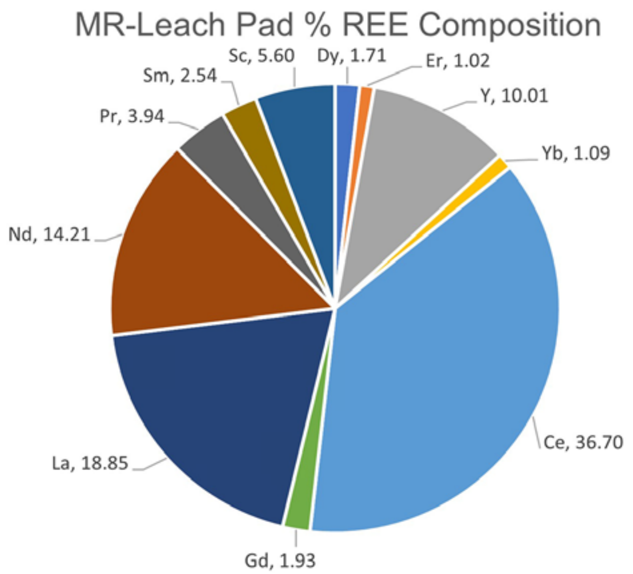

Figure 3-4. The breakdown of REE concentration percentages based on total REEs for all samples taken at the MR Leach Pad. Elements with less than 1% concentration were removed.

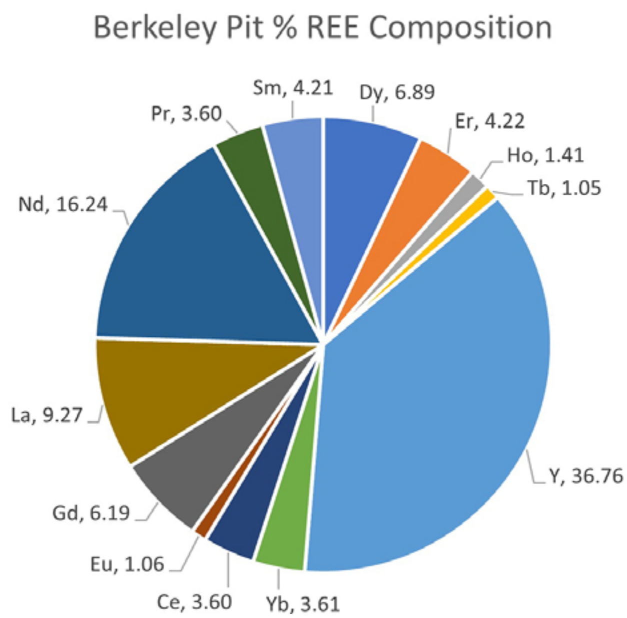

Figure 3-5. The breakdown of REE concentration percentages based on total REEs for all samples taken at the Berkeley Pit. Elements with less than 1% concentration were removed.

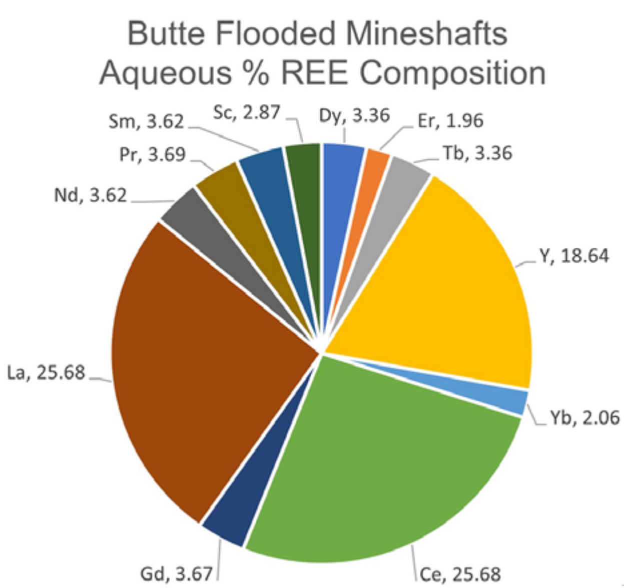

Figure 3-6. The breakdown of REE concentration percentages based on total REEs for all samples taken in the Butte Flooded Mineshafts. Elements with less than 1% concentration were removed.

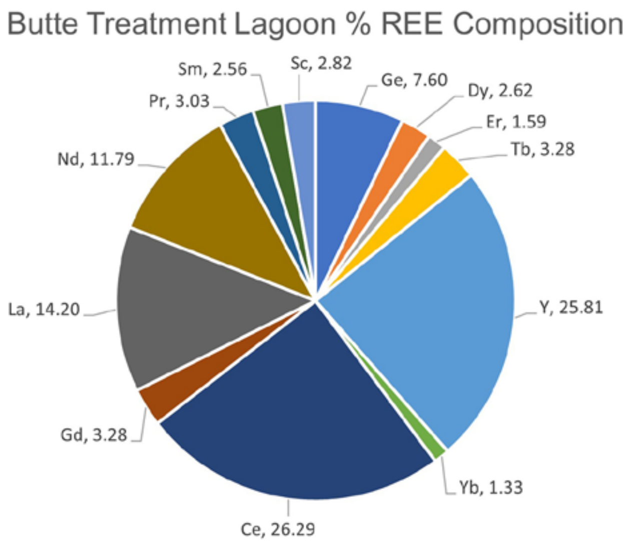

Figure 3-7. The breakdown of REE concentration percentages based on total REEs for all samples taken at the Butte Treatment Lagoon. Elements with less than 1% concentration were removed.

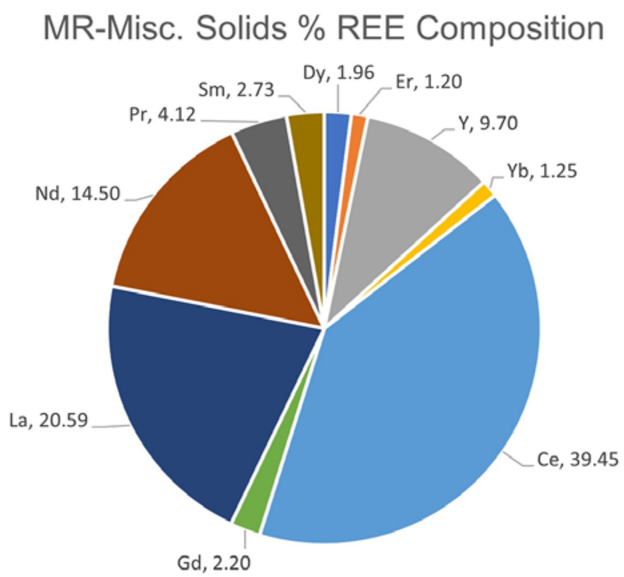

Figure 3-8. The breakdown of REE concentration percentages based on total REEs for all solid MR-Miscellaneous samples. Elements with less than 1% concentration were removed.

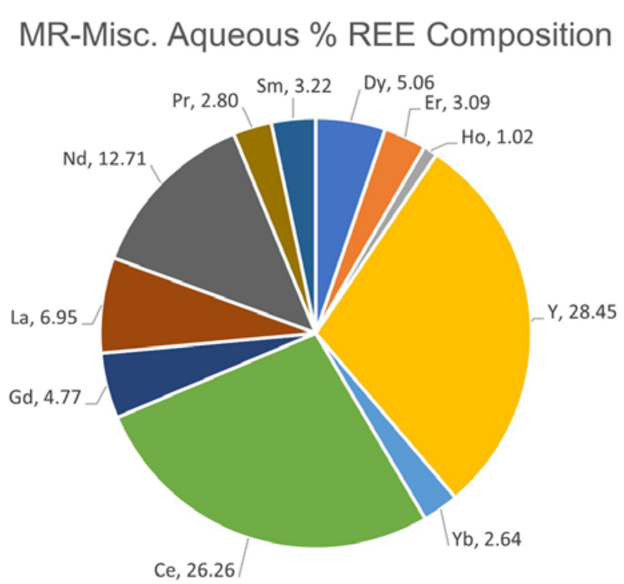

Figure 3-9. The breakdown of REE concentration percentages based on total REEs for all aqueous MR-Miscellaneous samples. Elements with less than 1% concentration were removed.

Figure 3-10. Basin/Ten Mile watershed: Lower Bullion AMD drainage.

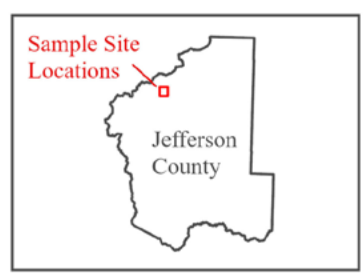

Figure 3-11. Basin/Ten Mile watershed, Crystal & Bullion site sample map.

Table 3-13. Crystal and Bullion solids REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Upper Bullion Precip.	0.90	1.37	1.02	0.33	0.18	0.26	0.14	8.60	0.94
Lower Bullion Precip.	0.90	1.60	0.97	0.34	0.15	0.30	0.19	9.30	1.1
Crystal Precip.	1.20	1.89	1.24	0.42	0.21	0.31	0.19	11.70	1.38
Mean	1.00	1.62	1.08	0.36	0.18	0.29	0.17	9.87	1.14
Minimum	0.90	1.37	0.97	0.33	0.15	0.26	0.14	8.60	0.94
Maximum	1.20	1.89	1.24	0.42	0.21	0.31	0.19	11.70	1.38

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Upper Bullion Precip.	33.50	0.37	1.72	18.60	12.80	3.71	2.13	3.00
Lower Bullion Precip.	36.80	0.45	1.76	20.00	13.20	4.20	2.25	4.00
Crystal Precip.	48.90	0.39	2.17	25.50	16.60	5.06	2.76	3.00
Mean	39.73	0.40	1.88	21.37	14.20	4.32	2.38	3.33
Minimum	33.50	0.37	1.72	18.60	12.80	3.71	2.13	3.00
Maximum	48.90	0.45	2.17	25.50	16.60	5.06	2.76	4.00

Table 3-14. Crystal and Bullion solids total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
Upper Bullion Precip.	89.57	0.70
Lower Bullion Precip.	97.51	0.67
Crystal Precip.	122.92	0.63

Table 3-15. Crystal and Bullion aqueous REE.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
Upper Bullion-Diss	<32.00	3.92	2.52	0.81	0.35	0.60	0.34	26.25	2.369
Upper Bullion-Tot. Rec.	<32.00	4.07	2.61	0.84	0.38	0.63	0.36	27.05	2.455
Lower Bullion-Diss	<32.00	4.04	2.63	0.84	0.37	0.63	0.36	27.20	2.45
Lower Bullion-Tot. Rec.	<32.00	4.17	2.70	0.87	0.38	0.65	0.37	27.63	2.53
Crystal-Diss	<32.00	1.84	1.23	0.39	0.15	0.28	0.16	14.90	1.08
Crystal-Tot. Rec.	<32.00	1.98	1.31	0.42	0.17	0.31	0.17	15.38	1.16
Mean	0.00	3.34	2.17	0.69	0.30	0.51	0.29	23.07	2.01
Minimum	0.00	1.84	1.23	0.39	0.15	0.28	0.16	14.90	1.08
Maximum	0.00	4.17	2.70	0.87	0.38	0.65	0.37	27.63	2.53

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
Upper Bullion-Diss	27.87	0.61	4.02	27.87	15.06	3.62	3.36	1.68
Upper Bullion-Tot. Rec.	28.96	0.64	4.19	28.96	15.72	3.76	3.55	1.83
Lower Bullion-Diss	29.45	0.64	4.21	29.45	16.00	3.92	3.57	1.75
Lower Bullion-Tot. Rec.	30.27	0.66	4.28	30.27	16.49	4.05	3.68	1.75
Crystal-Diss	14.26	0.18	1.78	14.26	5.90	1.60	1.31	0.18
Crystal-Tot. Rec.	15.32	0.20	1.92	15.32	6.43	1.73	1.46	0.26
Mean	24.36	0.49	3.40	24.36	12.60	3.11	2.82	1.24
Minimum	14.26	0.18	1.78	14.26	5.90	1.60	1.31	0.18
Maximum	30.27	0.66	4.28	30.27	16.49	4.05	3.68	1.83

Table 3-16. Crystal and Bullion aqueous total REE and Coutl.

Sample ID	Total REE µg/L	Coutl
Upper Bullion-Diss	121.26	1.67
Upper Bullion-Tot. Rec.	126.00	1.66
Lower Bullion-Diss	127.52	1.65
Lower Bullion-Tot. Rec.	130.76	1.64
Crystal-Diss	59.51	1.63
Crystal-Tot. Rec.	63.53	1.59

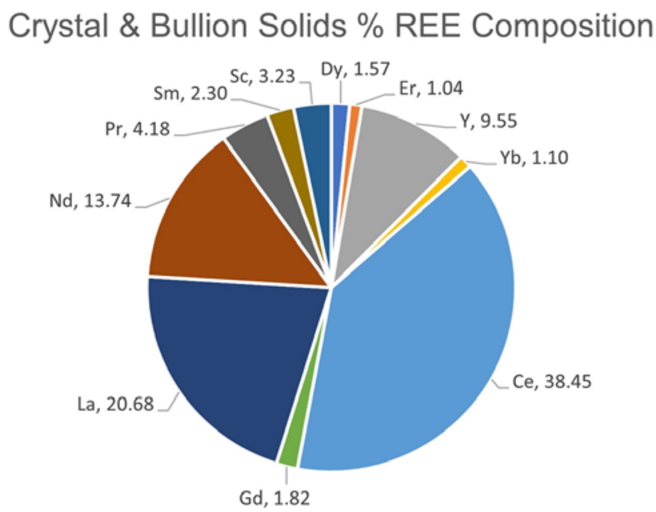

Figure 3-12. The breakdown of REE concentration percentages based on total REEs for all solid samples taken at the Crystal and Bullion Mines. Elements with less than 1% concentration were removed.

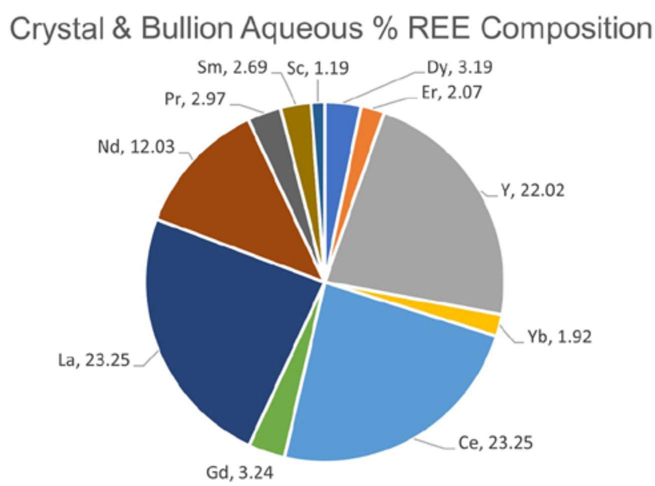

Figure 3-13. The breakdown of REE concentration percentages based on total REEs for all aqueous samples taken at the Crystal and Bullion Mines. Elements with less than 1% concentration were removed.

Figure 3-14. Montana Tunnels site sample map.

Figure 3-15. Montana Tunnels: UAV equipped with Data Sonde.

Table 3-17. Montana Tunnels solids REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
M.T. Tailings	1.20	1.37	0.81	0.26	0.13	0.24	0.14	8.00	0.83
M.T. Primary Crusher 1	1.30	1.35	0.79	0.28	0.13	0.26	0.14	8.00	0.91
M.T. Primary Crusher 2	1.40	1.00	0.59	0.21	0.12	0.19	0.11	5.50	0.71
M.T. Dump 5 #1	0.80	1.32	0.61	0.23	0.08	0.30	0.08	6.10	0.54
M.T. Dump 5 #2	0.90	1.32	0.63	0.23	0.09	0.26	0.10	6.70	0.59
M.T. Dump 5 #3	0.80	1.37	0.58	0.24	0.08	0.25	0.09	6.60	0.6
Mean	1.07	1.29	0.67	0.24	0.11	0.25	0.11	6.82	0.70
Minimum	0.80	1.00	0.58	0.21	0.08	0.19	0.08	5.50	0.54
Maximum	1.40	1.37	0.81	0.28	0.13	0.30	0.14	8.00	0.91

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
M.T. Tailings	28.50	0.55	1.53	15.30	11.80	3.21	2.18	3.00
M.T. Primary Crusher 1	36.20	0.69	2.08	19.10	15.00	4.07	2.72	4.00
M.T. Primary Crusher 2	27.20	0.37	1.31	14.80	11.10	3.17	1.98	3.00
M.T. Dump 5 #1	48.10	0.90	2.12	25.90	19.60	5.42	3.21	3.00
M.T. Dump 5 #2	44.30	0.80	2.03	23.60	17.70	4.75	2.90	3.00
M.T. Dump 5 #3	48.10	0.94	2.11	25.50	19.90	5.10	3.10	3.00
Mean	38.73	0.71	1.86	20.70	15.85	4.29	2.68	3.17
Minimum	27.20	0.37	1.31	14.80	11.10	3.17	1.98	3.00
Maximum	48.10	0.94	2.12	25.90	19.90	5.42	3.21	4.00

Table 3-18. Montana Tunnels solids total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
M.T. Tailings	79.05	0.76
M.T. Primary Crusher 1	97.02	0.69
M.T. Primary Crusher 2	72.76	0.66
M.T. Dump 5 #1	118.31	0.59
M.T. Dump 5 #2	109.90	0.60
M.T. Dump 5 #3	118.36	0.60

Table 3-19. Montana Tunnels aqueous REE data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
M.T Pit Surface -Diss	<32.00	0.02	0.00	<0.002	<0.002	<0.002	<0.002	0.21	<0.004
M.T Pit Surface-Tot. Rec.	<32.00	0.02	0.01	<0.002	<0.002	<0.002	<0.002	0.22	0.007
M.T Pit 25m-Diss	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	0.04	<0.004
M.T Pit 25m-Tot. Rec.	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	0.03	<0.004
M.T Pit 52m-Diss	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	0.02	<0.004
M.T Pit 52m-Tot. Rec.	<32.00	0.23	0.10	0.04	<0.002	0.20	0.01	1.57	0.032
M.T Tailings Barge-Diss	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	<0.004	<0.004
M.T Tailings Barge-Tot. Rec.	<32.00	0.02	<0.004	<0.002	<0.002	0.07	<0.002	0.41	<0.004
M.T South Pond-Diss	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	0.12	<0.004
M.T South Pond-Tot. Rec.	<32.00	0.14	0.08	0.02	0.01	0.48	0.01	2.48	0.041
Mean	0.00	0.09	0.05	0.03	0.01	0.25	0.01	0.57	0.03
Minimum	0.00	0.02	0.00	0.02	0.01	0.07	0.01	0.02	0.01
Maximum	0.00	0.23	0.10	0.04	0.01	0.48	0.01	2.48	0.04

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
M.T Pit Surface -Diss	0.23	<0.003	0.01	0.07	0.07	0.02	<0.004	<0.037
M.T Pit Surface-Tot. Rec.	0.31	<0.003	0.02	0.12	0.11	0.03	<0.004	<0.037
M.T Pit 25m-Diss	0.04	<0.003	<0.003	0.01	<0.008	<0.003	<0.004	0.04
M.T Pit 25m-Tot. Rec.	0.03	<0.003	<0.003	0.01	<0.008	<0.003	<0.004	<0.037
M.T Pit 52m-Diss	0.01	<0.003	<0.003	0.00	<0.008	<0.003	<0.004	0.04
M.T Pit 52m-Tot. Rec.	0.76	0.01	0.15	0.26	0.28	0.07	<0.004	<0.037
M.T Tailings Barge-Diss	<0.008	<0.003	<0.003	<0.003	<0.008	<0.003	<0.004	<0.037
M.T Tailings Barge-Tot. Rec.	0.13	<0.003	0.01	0.05	0.05	0.01	<0.004	0.07
M.T South Pond-Diss	0.10	<0.003	<0.003	0.07	0.02	0.00	<0.004	0.06
M.T South Pond-Tot. Rec.	0.69	0.01	0.13	0.22	0.44	0.05	0.02	0.07
Mean	0.25	0.01	0.06	0.09	0.16	0.03	0.02	0.06
Minimum	0.01	0.01	0.01	0.00	0.02	0.00	0.02	0.04
Maximum	0.76	0.01	0.15	0.26	0.44	0.07	0.02	0.07

Table 3-20. Montana Tunnels aqueous total REE & Coutl.

Sample ID	Total REE µg/L	Coutl
M.T Pit Surface - Diss	0.63	0.00
M.T Pit Surface- Tot. Rec.	0.84	0.00
M.T Pit 25m - Diss	0.13	0.00
M.T Pit 25m - Tot. Rec.	0.06	0.00
M.T Pit 52m - Diss	0.07	0.00
M.T Pit 52m - Tot. Rec.	3.71	0.00
M.T Tailings Barge - Diss	0.00	0.00
M.T Tailings Barge - Tot. Rec.	0.81	0.00
M.T South Pond - Diss	0.37	0.00
M.T South Pond - Tot. Rec.	4.87	5.02

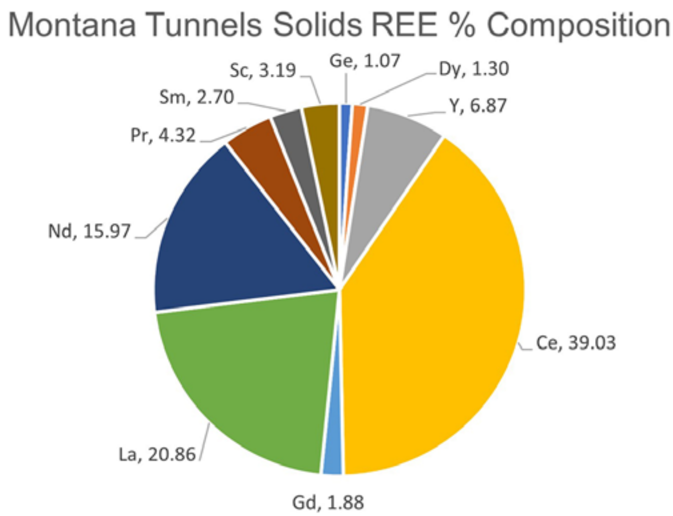

Figure 3-16. The breakdown of REE concentration percentages based on total REEs for all solid samples taken at the Montana Tunnels Mine. Elements with less than 1% concentration were removed.

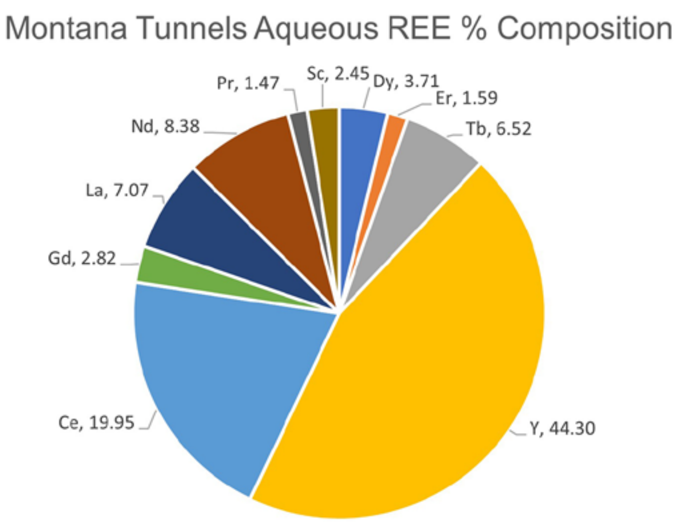

Figure 3-17. The breakdown of REE concentration percentages based on total REEs for all aqueous samples taken at the Montana Tunnels Mine. Elements with less than 1% concentration were removed.

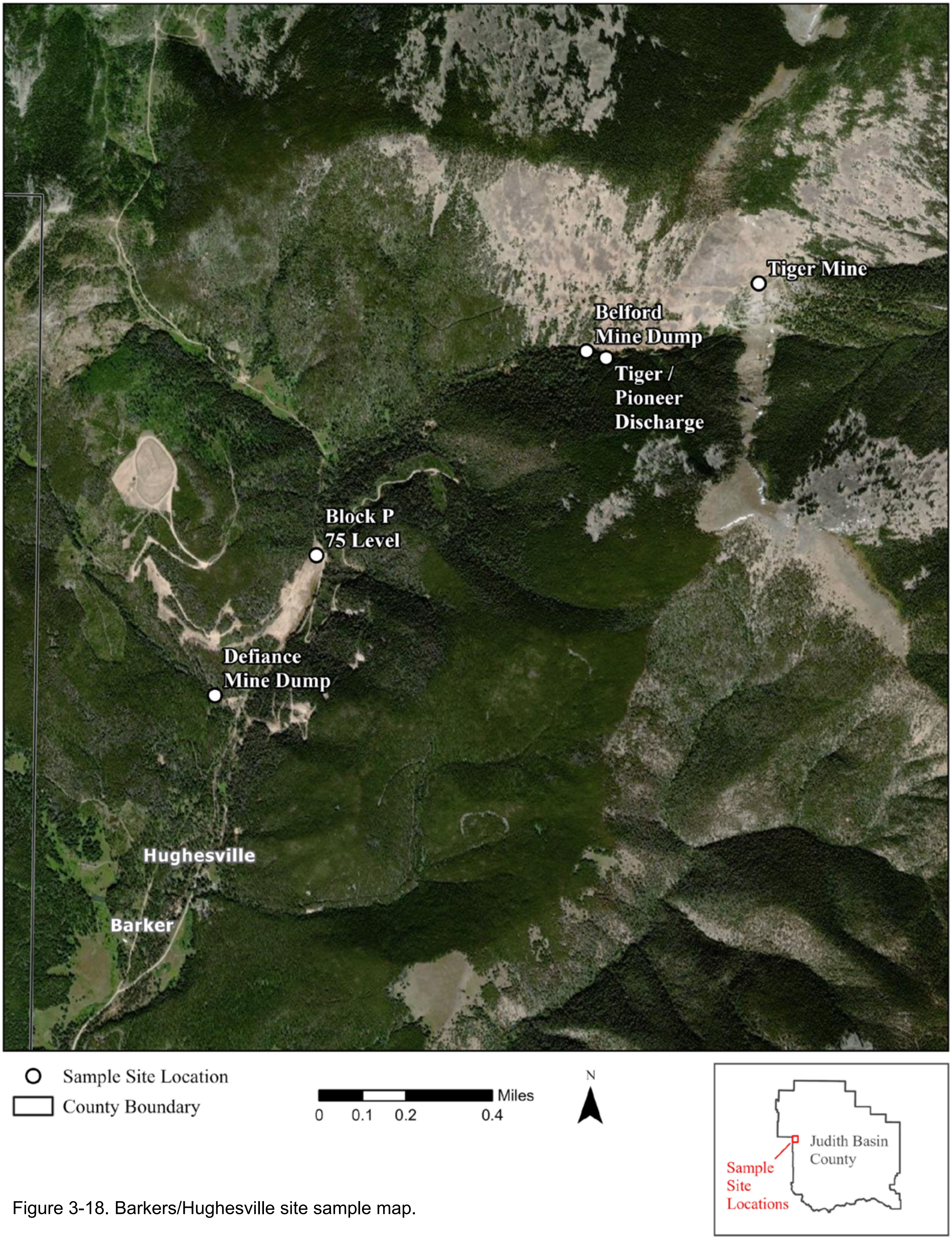

Figure 3-18. Barkers/Hughesville site sample map.

Figure 3-19. Barkers/Hughesville: Tiger and Pioneer Mines AMD.

Table 3-21. Neihart Mining District solids REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Tiger 1	0.80	0.76	0.52	0.15	0.09	0.16	0.09	4.70	0.57
Tiger 2	<0.5	0.68	0.35	0.12	0.04	0.15	0.04	3.20	0.28
Tiger 3	1.10	1.52	0.90	0.29	0.12	0.29	0.14	7.60	0.78
Tiger 4	1.20	1.25	0.70	0.25	0.12	0.26	0.11	6.40	0.79
Tiger 5	<0.5	0.53	0.33	0.11	0.05	0.14	0.04	2.80	0.31
Defiance 1	2.30	1.44	0.82	0.27	0.12	0.32	0.11	7.20	0.81
Defiance 2	7.30	1.93	0.90	0.32	0.16	0.38	0.14	9.20	1.04
Belford 1	1.70	2.21	1.23	0.46	0.16	0.41	0.19	12.00	1.19
Belford 2	1.50	2.78	1.49	0.54	0.23	0.47	0.23	13.40	1.42
Block P75 Level	4.30	1.82	0.99	0.37	0.17	0.34	0.16	9.40	1.12
Mean	2.53	1.49	0.82	0.29	0.13	0.29	0.13	7.59	0.83
Minimum	0.80	0.53	0.33	0.11	0.04	0.14	0.04	2.80	0.28
Maximum	7.30	2.78	1.49	0.54	0.23	0.47	0.23	13.40	1.42

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Tiger 1	64.80	0.51	1.44	37.40	20.90	6.52	2.83	3.00
Tiger 2	33.90	0.30	0.88	20.00	11.80	3.36	1.73	1.00
Tiger 3	86.20	0.70	1.97	50.60	28.20	8.29	3.61	4.00
Tiger 4	63.90	0.69	1.78	34.00	22.60	6.32	3.31	3.00
Tiger 5	36.60	0.35	1.23	20.30	13.20	3.93	2.09	1.00
Defiance 1	101.50	1.09	2.29	60.00	32.00	9.67	4.24	3.00
Defiance 2	140.00	1.79	2.97	82.20	44.00	13.50	5.86	3.00
Belford 1	48.60	0.68	2.38	25.50	19.20	5.24	3.62	7.00
Belford 2	50.60	0.73	3.19	24.80	21.20	5.61	4.41	11.00
Block P75 Level	117.50	1.56	2.85	70.20	34.50	10.75	5.20	5.00
Mean	74.36	0.84	2.10	42.50	24.76	7.32	3.69	4.10
Minimum	33.90	0.30	0.88	20.00	11.80	3.36	1.73	1.00
Maximum	140.00	1.79	3.19	82.20	44.00	13.50	5.86	11.00

Table 3-22. Neihart Mining District solids total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
Tiger 1	145.24	0.42
Tiger 2	77.83	0.48
Tiger 3	196.31	0.45
Tiger 4	146.68	0.49
Tiger 5	83.01	0.47
Defiance 1	227.18	0.42
Defiance 2	314.69	0.41
Belford 1	131.77	0.71
Belford 2	143.60	0.76
Block P75 Level	266.23	0.41

Table 3-23. Neihart Mining District aqueous REE data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
Tiger Discharge-Diss	<32.00	0.25	0.10	0.04	0.00	0.04	0.00	1.35	0.082
Pioneer Discharge-Diss	<32.00	1.01	0.45	0.17	0.04	0.19	0.04	5.15	0.316
Block P Discharge-Diss	<32.00	3.87	1.54	0.70	0.23	0.72	0.25	22.41	1.55
Tiger Discharge-Tot. Rec.	<32.00	0.26	0.10	0.03	<0.002	0.03	<0.002	1.40	0.078
Pioneer Discharge-Tot. Rec.	<32.00	1.02	0.44	0.16	0.03	0.19	0.03	5.34	0.317
Block P Discharge-Tot. Rec.	<32.00	3.89	1.53	0.70	0.23	0.72	0.24	22.20	1.55
Mean	0.00	1.72	0.69	0.30	0.11	0.32	0.11	9.64	0.65
Minimum	0.00	0.25	0.10	0.03	0.00	0.03	0.00	1.35	0.08
Maximum	0.00	3.89	1.54	0.70	0.23	0.72	0.25	22.41	1.55

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
Tiger Discharge-Diss	5.43	0.10	0.39	3.19	2.34	0.64	0.40	0.17
Pioneer Discharge-Diss	27.94	0.45	1.62	16.66	11.26	3.21	1.94	0.53
Block P Discharge-Diss	100.59	1.54	5.97	44.35	43.80	12.00	6.51	0.85
Tiger Discharge-Tot. Rec.	5.64	0.10	0.39	3.29	2.44	0.65	0.43	0.21
Pioneer Discharge-Tot. Rec.	28.60	0.44	1.66	17.11	11.53	3.31	1.95	0.51
Block P Discharge-Tot. Rec.	103.36	1.53	6.08	45.45	45.32	12.39	6.65	0.94
Mean	45.26	0.69	2.69	21.67	19.45	5.37	2.98	0.53
Minimum	5.43	0.10	0.39	3.19	2.34	0.64	0.40	0.17
Maximum	103.36	1.54	6.08	45.45	45.32	12.39	6.65	0.94

Table 3-24. Neihart Mining District aqueous Total REE & Coutl.

Sample ID	Total REE µg/L	Coutl
Tiger Discharge-Diss	14.52	0.77
Pioneer Discharge-Diss	70.97	0.66
Block P Discharge-Diss	246.89	0.73
Tiger Discharge-Tot. Rec.	15.05	0.00
Pioneer Discharge-Tot. Rec.	72.63	0.66
Block P Discharge-Tot. Rec.	252.756	0.724148

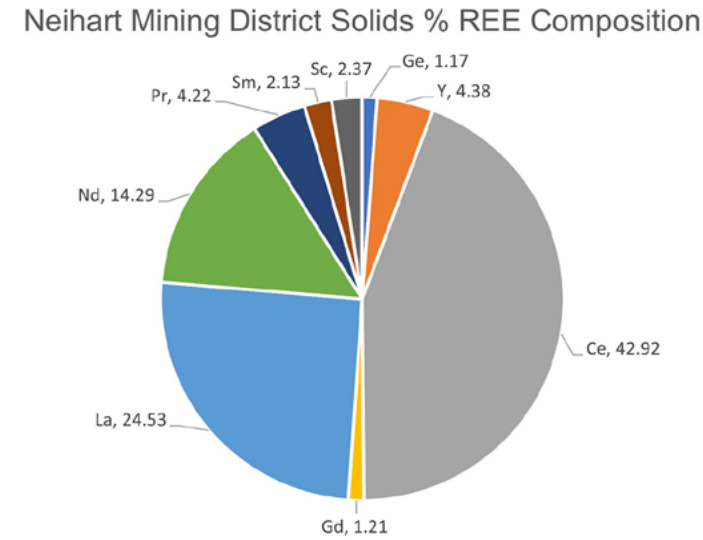

Figure 3-20. The breakdown of REE concentration percentages based on total REEs for all solid samples taken in the Neihart Mining District. Elements with less than 1% concentration were removed.

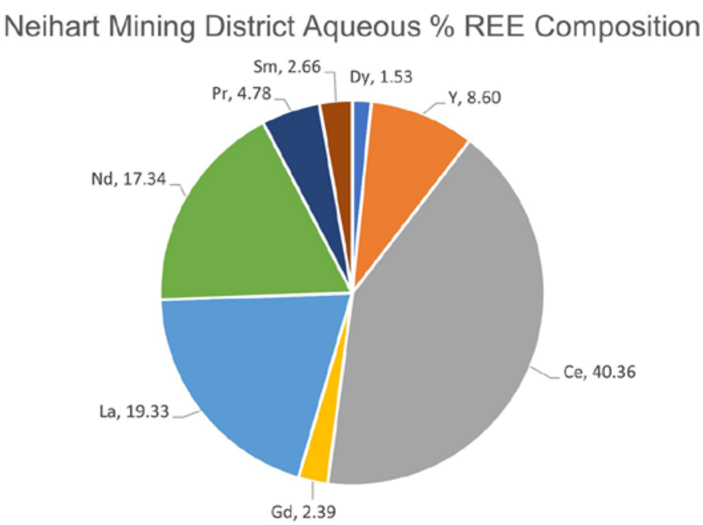

Figure 3-21. The breakdown of REE concentration percentages based on total REEs for all aqueous samples taken in the Neihart Mining District. Elements with less than 1% concentration were removed.

Figure 3-22. Mike Horse Mine site sample map.

Figure 3-23. Mike Horse Mine: clarifier inside the Mike Horse Mine water treatment plant.

Table 3-25. Mike Horse solids REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Mike Horse 200 Level	1.60	5.98	3.61	1.24	0.57	0.95	0.54	33.60	3.69
Mike Horse 300 Level	1.90	8.99	5.25	1.86	0.70	1.50	0.73	47.40	4.82
Mike Horse Bin 1	<0.5	2.23	1.13	0.44	0.13	0.38	0.17	17.70	0.84
Mike Horse Bin 2	<0.5	1.82	0.82	0.37	0.09	0.27	0.09	16.80	0.64
Mike Horse Bin 3	<0.5	2.94	1.54	0.56	0.13	0.48	0.19	26.50	1.04
Mike Horse Bin 4	<0.5	2.30	1.30	0.45	0.12	0.37	0.15	20.00	0.79
Mike Horse WTP- Sludge	<0.032	0.61	1.81	0.66	0.18	0.61	0.22	29.30	1.304
Mike Horse WTP- Sludge	<	1.20	3.43	1.29	0.32	1.20	0.39	52.31	2.212
Mean	1.75	3.26	2.36	0.86	0.28	0.72	0.31	30.45	1.92
Minimum	1.60	0.61	0.82	0.37	0.09	0.27	0.09	16.80	0.64
Maximum	1.90	8.99	5.25	1.86	0.70	1.50	0.73	52.31	4.82

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Mike Horse 200 Level	83.50	1.15	6.08	38.60	13.00	9.93	6.96	N/A
Mike Horse 300 Level	110.50	1.98	9.50	48.20	12.45	12.30	8.77	N/A
Mike Horse Bin 1	16.40	0.60	2.54	9.00	0.15	2.03	2.10	1.00
Mike Horse Bin 2	13.80	0.47	2.07	8.60	0.07	1.63	1.58	<1
Mike Horse Bin 3	19.80	0.67	3.44	11.40	<0.05	2.27	2.24	<1
Mike Horse Bin 4	16.20	0.56	2.71	9.30	0.06	1.93	1.68	<1
Mike Horse WTP- Sludge	24.19	0.94	4.40	13.55	14.17	3.16	3.27	2.86
Mike Horse WTP- Sludge	50.42	2.72	11.53	20.06	44.50	8.75	12.42	1.51
Mean	41.85	1.14	5.28	19.84	12.06	5.25	4.88	1.79
Minimum	13.80	0.47	2.07	8.60	0.06	1.63	1.58	1.00
Maximum	110.50	2.72	11.53	48.20	44.50	12.30	12.42	2.86

Table 3-26. Mike Horse solids total REE and Coutl.

Sample ID	Total REE mg/kg	Coutl
Mike Horse 200 Level	211.00	0.92
Mike Horse 300 Level	276.85	0.95
Mike Horse Bin 1	56.84	1.70
Mike Horse Bin 2	49.12	1.77
Mike Horse Bin 3	73.20	1.93
Mike Horse Bin 4	57.92	1.83
Mike Horse WTP- Sludge	101.22	1.90
Mike Horse WTP- Sludge	214.25	2.03

Table 3-27. Mike Horse aqueous REE data.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
Mike Horse WTP Influent	<32.00	0.11	0.06	0.02	0.00	0.02	0.01	1.42	0.032
Mike Horse WTP Effluent	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	<0.004	<0.004
Mike Horse WTP Influent-Tot. Rec.	<32.00	0.15	0.09	0.03	0.01	0.02	0.01	1.82	0.049
Mike Horse WTP Effluent-Tot. Rec	<32.00	<0.004	<0.004	<0.002	<0.002	<0.002	<0.002	0.04	<0.004
Mike Horse WTP- Sludge Decant-Tot. Rec.	<32.00	0.18	0.10	0.03	0.01	0.03	0.01	1.26	0.066
Mike Horse WTP- Sludge Decant-Tot. Rec.	<32.00	0.12	0.07	0.02	0.01	0.02	0.01	1.21	0.043
Mike Horse-Level 100 Adit-Diss	<32.00	19.75	10.12	3.63	1.15	3.39	1.28	94.39	7.994
Mike Horse-Level 300 Adit-Diss	<32.00	0.73	0.39	0.14	0.03	0.11	0.04	7.42	0.229
Mike Horse-Level 100 Adit-Tot. Rec.	<32.00	21.37	11.02	3.94	1.27	3.69	1.39	98.46	8.759
Mike Horse-Level 300 Adit-Tot. Rec.	<32.00	1.07	0.56	0.21	0.05	0.18	0.07	9.14	0.362
Mean	0.00	5.44	2.80	1.00	0.31	0.93	0.35	23.91	2.19
Minimum	0.00	0.11	0.06	0.02	0.00	0.02	0.01	0.04	0.03
Maximum	0.00	21.37	11.02	3.94	1.27	3.69	1.39	98.46	8.76

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
Mike Horse WTP Influent	0.97	0.02	0.12	0.78	0.35	0.09	0.05	0.04
Mike Horse WTP Effluent	0.06	<0.003	<0.003	0.02	<0.008	<0.003	<0.004	<0.037
Mike Horse WTP Influent-Tot. Rec.	1.42	0.03	0.18	1.01	0.60	0.14	0.10	0.06
Mike Horse WTP Effluent-Tot. Rec	0.21	<0.003	0.01	0.08	0.04	0.01	<0.004	<0.037
Mike Horse WTP- Sludge Decant-Tot. Rec.	1.42	0.05	0.20	0.59	0.64	0.13	0.15	0.10
Mike Horse WTP- Sludge Decant-Tot. Rec.	0.84	0.03	0.15	0.44	0.43	0.10	0.09	0.05
Mike Horse-Level 100 Adit-Diss	153.63	5.54	23.17	50.74	82.43	17.80	20.47	5.94
Mike Horse-Level 300 Adit-Diss	5.28	0.16	0.86	3.64	2.32	0.54	0.47	0.16
Mike Horse-Level 100 Adit-Tot. Rec.	157.48	5.91	24.90	52.29	85.46	18.55	21.59	6.31
Mike Horse-Level 300 Adit-Tot. Rec.	7.39	0.27	1.29	4.46	3.61	0.86	0.83	0.26
Mean	32.87	1.50	5.65	11.40	19.54	4.25	5.47	1.61
Minimum	0.06	0.02	0.01	0.02	0.04	0.01	0.05	0.04
Maximum	157.48	5.91	24.90	52.29	85.46	18.55	21.59	6.31

Table 28. Mike Horse solids total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
Mike Horse 200 Level	211.00	0.92
Mike Horse 300 Level	276.85	0.95
Mike Horse Bin 1	56.84	1.70
Mike Horse Bin 2	49.12	1.77
Mike Horse Bin 3	73.20	1.93
Mike Horse Bin 4	57.92	1.83
Mike Horse WTP- Sludge	101.22	1.90
Mike Horse WTP- Sludge	214.25	2.03

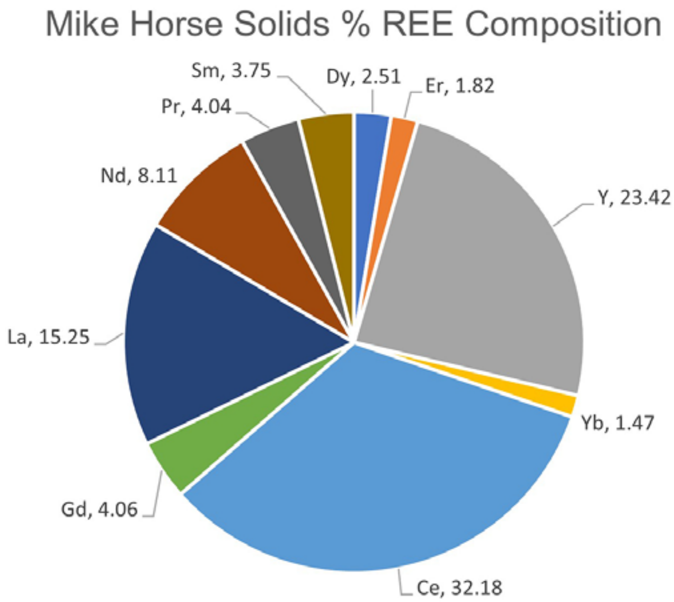

Figure 3-24. The breakdown of REE concentration percentages based on total REEs for all solid samples taken at the Mike Horse Mine. Elements with less than 1% concentration were removed.

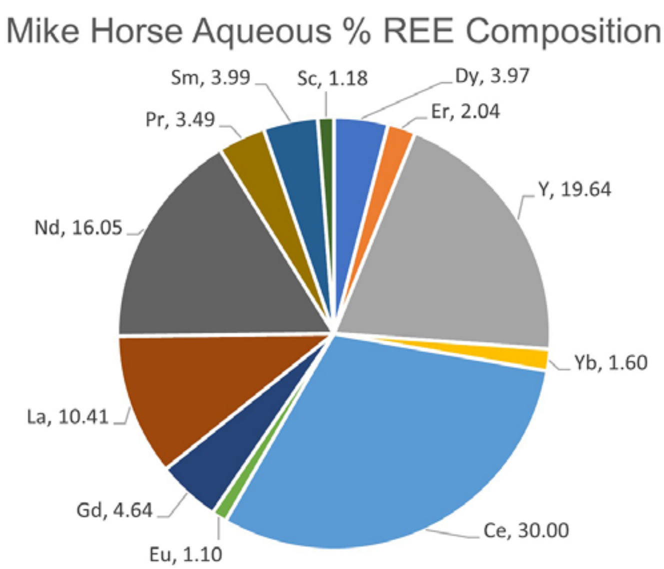

Figure 3-25. The breakdown of REE concentration percentages based on total REEs for all aqueous samples taken at the Mike Horse Mine. Elements with less than 1% concentration were removed.

Figure 3-26. Colstrip site sample map.

Figure 3-27. Colstrip: Talon Energy coal power plant.

Table 3-29. Colstrip solids ALS REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Unit 3 and 4 Fly Ash	3.00	3.75	2.27	0.82	0.32	0.65	0.32	23.10	2.07
Unit 3 and 4 Bottom Ash	1.30	4.85	2.91	0.98	0.47	0.75	0.44	28.60	2.97
Unit 1 and 2 Bottom Ash	1.50	4.41	2.71	0.94	0.46	0.75	0.38	28.20	2.63
Pond 1 and 2 Fly Ash	3.20	3.52	2.01	0.73	0.29	0.62	0.27	20.60	2.00
Rosebud Fly Ash	4.70	3.62	2.19	0.75	0.31	0.57	0.33	24.30	2.20
Rosebud Bottom Ash	5.00	1.76	1.00	0.38	0.16	0.34	0.14	11.90	0.98
Rosebud Coal	<0.5	0.64	0.39	0.12	0.05	0.12	0.05	3.40	0.36
Rosebud Reserve Coal	<0.5	1.40	0.72	0.27	0.12	0.27	0.12	7.00	0.65
Mean	3.12	2.99	1.78	0.62	0.27	0.51	0.26	18.39	1.73
Minimum	1.30	0.64	0.39	0.12	0.05	0.12	0.05	3.40	0.36
Maximum	5.00	4.85	2.91	0.98	0.47	0.75	0.44	28.60	2.97

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Unit 3 and 4 Fly Ash	57.20	0.79	3.70	32.20	23.90	6.52	4.56	9.00
Unit 3 and 4 Bottom Ash	66.80	1.11	4.58	36.50	28.00	7.53	5.87	10.00
Unit 1 and 2 Bottom Ash	66.30	1.01	4.36	36.40	27.50	7.43	5.40	9.00
Pond 1 and 2 Fly Ash	67.20	0.80	3.58	37.30	25.50	7.47	5.09	10.00
Rosebud Fly Ash	45.60	0.67	3.60	24.50	19.60	5.16	4.08	7.00
Rosebud Bottom Ash	26.00	0.44	2.06	14.00	11.80	3.00	2.25	4.00
Rosebud Coal	8.80	0.11	0.54	4.90	3.60	0.91	0.65	1.00
Rosebud Reserve Coal	22.00	0.41	1.49	11.50	9.50	2.57	2.08	2.00
Mean	44.99	0.67	2.99	24.66	18.68	5.07	3.75	6.50
Minimum	8.80	0.11	0.54	4.90	3.60	0.91	0.65	1.00
Maximum	67.20	1.11	4.58	37.30	28.00	7.53	5.87	10.00

Table 3-30. Colstrip solids ALS total REE & Coutl

Sample ID	Total REE mg/kg	Coutl
Unit 3 and 4 Fly Ash	174.17	0.90
Unit 3 and 4 Bottom Ash	203.66	0.92
Unit 1 and 2 Bottom Ash	199.38	0.91
Pond 1 and 2 Fly Ash	190.18	0.75
Rosebud Fly Ash	149.18	1.04
Rosebud Bottom Ash	85.21	0.98
Rosebud Coal	25.64	0.88
Rosebud Reserve Coal	62.10	0.83

Table 3-31. Colstrip solids WVU REE data.

Sample ID	Ge mg/kg	Dy mg/kg	Er mg/kg	Ho mg/kg	Lu mg/kg	Tb mg/kg	Tm mg/kg	Y mg/kg	Yb mg/kg
Unit 3 and 4 Fly Ash	<0.032	4.43	2.46	0.83	0.35	0.74	0.33	16.35	2.163
Unit 3 and 4 Bottom Ash	20.53	4.90	2.95	0.92	0.38	0.69	0.32	14.58	2.694
Unit 1 and 2 Bottom Ash	<0.032	4.45	2.66	0.92	0.44	0.73	0.36	19.85	2.476
Pond 1 and 2 Fly Ash	<0.032	4.87	3.01	1.00	0.47	0.77	0.45	17.67	2.907
Rosebud Fly Ash	19.41	3.62	2.27	0.67	0.33	0.57	0.31	21.77	1.989
Rosebud Bottom Ash	69.28	2.85	1.47	0.49	0.20	0.42	0.18	16.56	1.224
Rosebud Coal	<0.032	6.77	3.71	1.30	0.53	1.15	0.50	32.08	3.152
Rosebud Reserve Coal	56.04	5.41	2.79	1.05	0.36	0.94	0.35	28.03	2.293
Mean	41.31	4.66	2.66	0.90	0.38	0.75	0.35	20.86	2.36
Minimum	19.41	2.85	1.47	0.49	0.20	0.42	0.18	14.58	1.22
Maximum	69.28	6.77	3.71	1.30	0.53	1.15	0.50	32.08	3.15

Sample ID	Ce mg/kg	Eu mg/kg	Gd mg/kg	La mg/kg	Nd mg/kg	Pr mg/kg	Sm mg/kg	Sc mg/kg
Unit 3 and 4 Fly Ash	81.82	1.53	5.33	46.13	33.81	8.93	6.27	10.86
Unit 3 and 4 Bottom Ash	67.56	1.68	5.40	36.32	28.71	8.40	5.43	6.94
Unit 1 and 2 Bottom Ash	71.59	1.34	5.38	41.00	29.55	8.05	5.62	10.36
Pond 1 and 2 Fly Ash	70.94	1.67	5.47	39.94	32.69	12.32	5.65	8.61
Rosebud Fly Ash	47.95	0.95	4.25	26.53	21.40	5.77	4.11	9.63
Rosebud Bottom Ash	35.17	0.74	3.43	19.05	16.89	4.37	3.19	6.98
Rosebud Coal	95.71	1.75	7.69	50.47	43.34	11.55	8.57	20.28
Rosebud Reserve Coal	84.90	1.36	6.26	48.90	34.89	9.39	6.75	16.69
Mean	69.46	1.38	5.40	38.54	30.16	8.60	5.70	11.29
Minimum	35.17	0.74	3.43	19.05	16.89	4.37	3.19	6.94
Maximum	95.71	1.75	7.69	50.47	43.34	12.32	8.57	20.28

Table 3-32. Colstrip solids WVU total REE & Coutl.

Sample ID	Total REE mg/kg	Coutl
Unit 3 and 4 Fly Ash	137.87	0.69
Unit 3 and 4 Bottom Ash	160.39	0.74
Unit 1 and 2 Bottom Ash	157.40	0.77
Pond 1 and 2 Fly Ash	156.94	0.80
Rosebud Fly Ash	110.21	0.99
Rosebud Bottom Ash	63.55	1.04
Rosebud Coal	20.51	0.88
Rosebud Reserve Coal	51.55	0.83

Table 3-33. Colstrip aqueous REE.

Sample ID	Ge µg/L	Dy µg/L	Er µg/L	Ho µg/L	Lu µg/L	Tb µg/L	Tm µg/L	Y µg/L	Yb µg/L
H Cell Pond- Tot. Rec.	<32.00	2.81	1.64	0.57	0.21	0.46	0.19	25.34	0.213
A Cell Clear Well- Tot. Rec.	<32.00	1.96	1.18	0.40	0.14	0.35	0.14	17.56	0.135
Unit 1&2 Bot Ash Trench- Tot. Rec.	<32.00	0.02	0.01	0.00	<0.002	<0.002	<0.002	0.13	<0.002
Mean	0.00	1.60	0.94	0.32	0.17	0.41	0.16	14.34	0.17
Minimum	0.00	0.02	0.01	0.00	0.14	0.35	0.14	0.13	0.14
Maximum	0.00	2.81	1.64	0.57	0.21	0.46	0.19	25.34	0.21

Sample ID	Ce µg/L	Eu µg/L	Gd µg/L	La µg/L	Nd µg/L	Pr µg/L	Sm µg/L	Sc µg/L
H Cell Pond- Tot. Rec.	34.97	0.61	3.83	30.33	15.67	4.34	2.73	1.04
A Cell Clear Well- Tot. Rec.	31.50	0.47	2.82	30.64	13.46	3.86	2.13	0.64
Unit 1&2 Bot Ash Trench- Tot. Rec.	0.28	0.01	0.02	0.17	0.12	0.03	0.02	0.05
Mean	22.25	0.36	2.22	20.38	9.75	2.74	1.63	0.58
Minimum	0.28	0.01	0.02	0.17	0.12	0.03	0.02	0.05
Maximum	34.97	0.61	3.83	30.64	15.67	4.34	2.73	1.04

Table 3-34. Colstrip aqueous total REE & Coutl.

Sample ID	Total REE µg/L	Coutl
H Cell Pond- Tot. Rec.	31.44	1.29
A Cell Clear Well- Tot. Rec.	21.86	1.09
Unit 1&2 Bot Ash Trench- Tot. Rec.	0.16	0.00

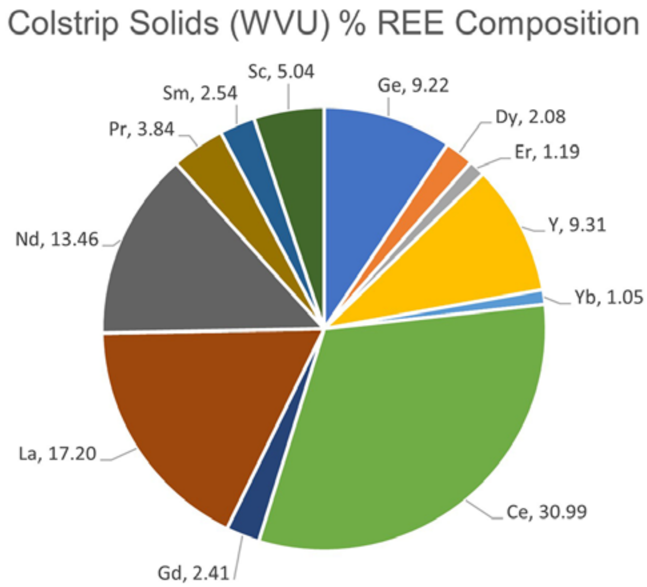

Figure 3-28. The breakdown of REE concentration percentages based on total REEs for all solid samples taken in Colstrip. Elements with less than 1% concentration were removed.

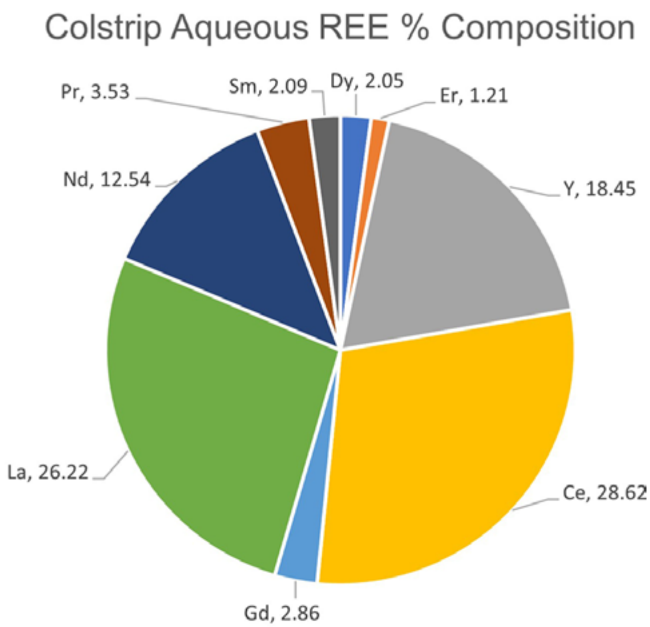

Figure 3-29. The breakdown of REE concentration percentages based on total REEs for all aqueous samples taken in Colstrip. Elements with less than 1% concentration were removed.

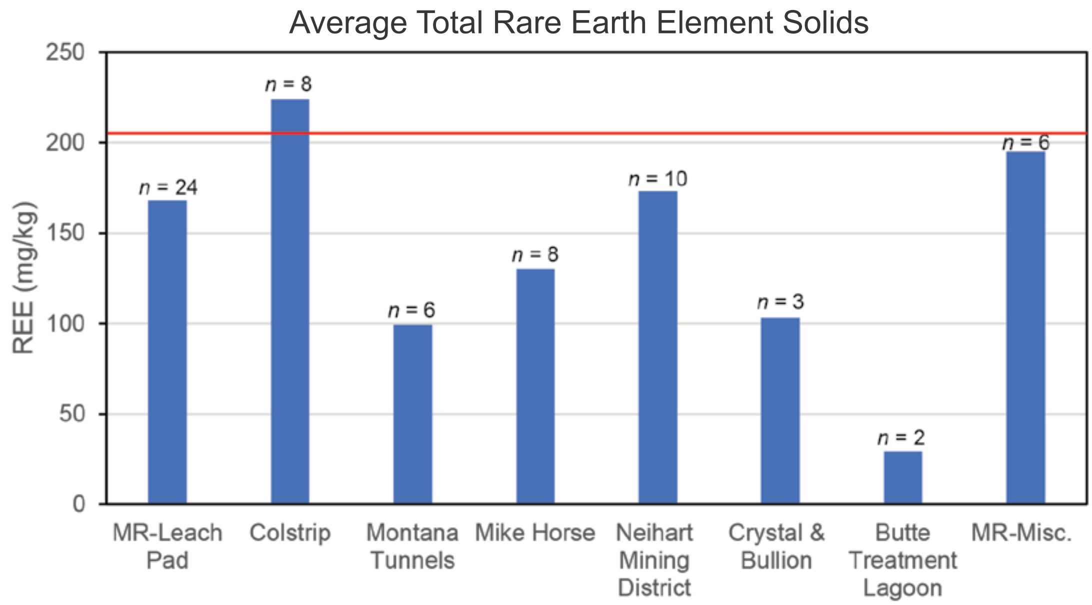

Figure 3-30. The average total REE concentrations per solid sample all sites. The red line represents the average REE concentration in the Earth's crust, which is about 206 mg/kg.

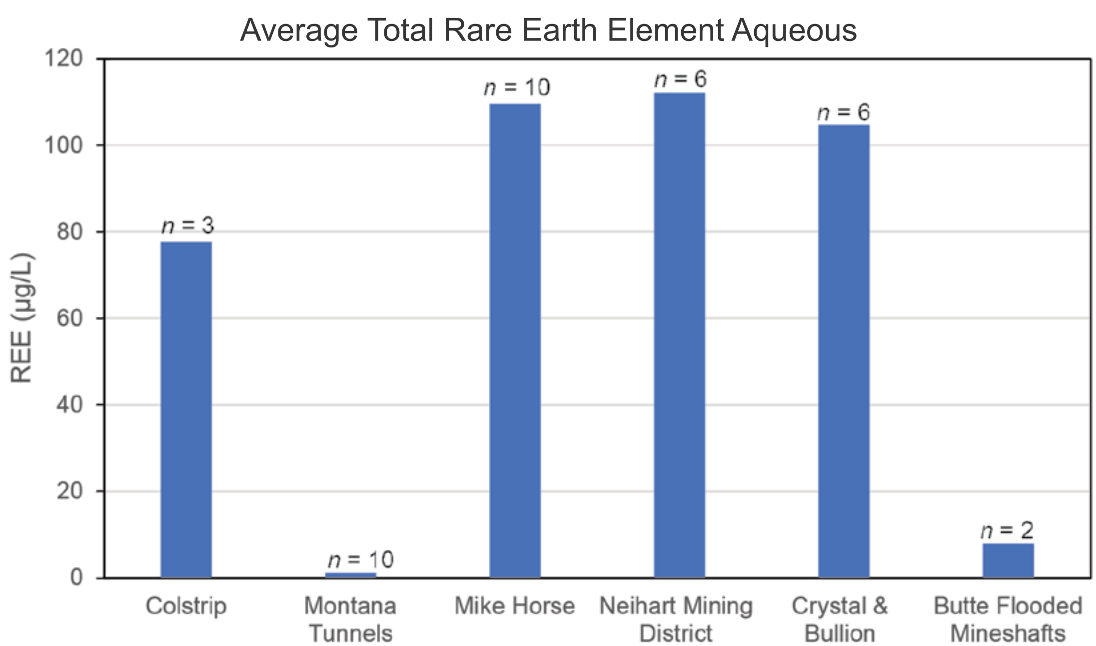

Figure 3-31. The average total REE concentrations per aqueous sample site below 115 µg/L.

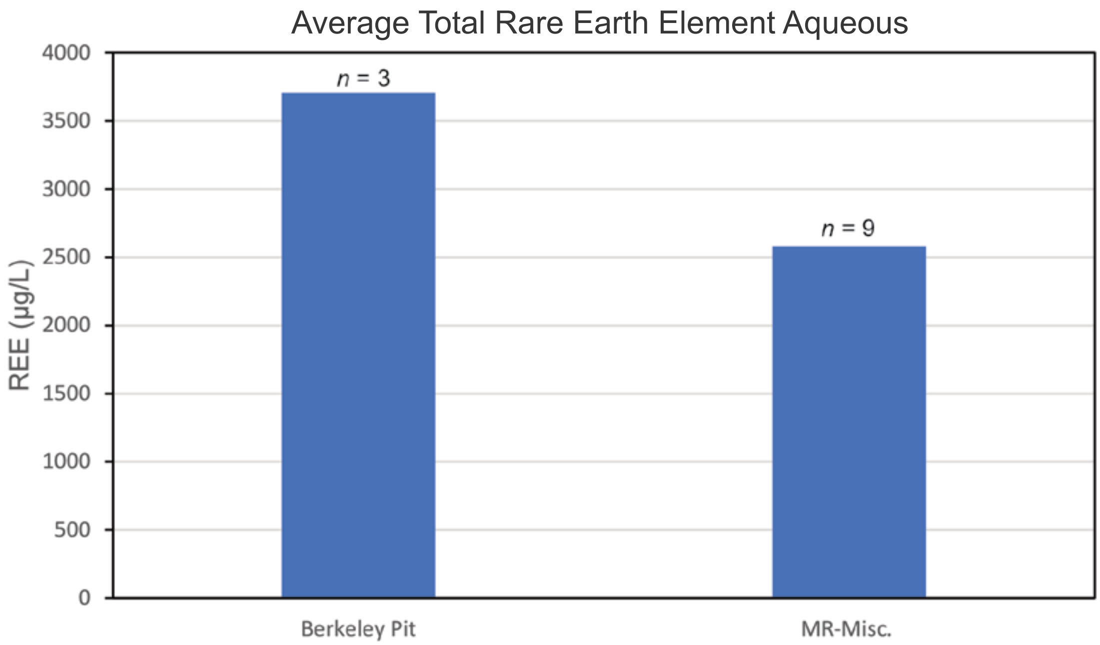

Figure 3-32. The average total REE concentrations per aqueous sample site above 115 µg/L.

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