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Orphan Boy and Orphan Girl: Historical information on groundwater and flooded workings

Emelina Doucette

Orphan Boy and Orphan Girl: Historical information on groundwater and flooded workings

by

Emelina H. Doucette

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Abstract

Groundwater has historically, and still is, a concern within the mining industry due to the relationships between potential environmental and safety impacts. Montana Technological University uses a once operating silver mine, the Orphan Boy, to provide students with hands-on experience and is known as the Underground Mine Education Center (UMEC). The UMEC, and neighboring Orphan Girl mine located at the World Museum of Mining, have experienced increasing water levels the past few years. A compilation of known information pertaining to the Orphan Girl and Orphan Boy groundwater connections is presented using historical groundwater and mine data, stope books, hydrographs, and previous research on the local groundwater systems.

Keywords: Groundwater, Orphan Boy, Orphan Girl, Underground Education Center (UMEC), World Museum of Mining

Dedication

To my mom and dad for their constant encouragement to follow my dreams, support for all my schooling, and excitement for all my successes. Thank you for teaching me that no dream is a bad dream and hard work will always pay off.

Uncle Dan, thank you for always entertaining my millions of questions and lifting me up for greatness. A day does not go by I do not think of you.

Grandpa Sherman the little things you did for me have pushed me to go farther than I could have imagined. Thank you for teaching me to be proud of the work I do but stay humble, to speak my mind and stand up for what is right, and that there is always an answer you just have to find it.

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Glossary of Terms

Term	Definition
Closed-Loop water system	Effectively sealed circuits where the fixed volume of water within the system is recirculated and not exposed to the atmosphere
Cu-Mo	Copper Molybdenum
Cu	Copper
H_2S	Produced from sulfur-reducing bacteria, commonly heterotrophic and obtaining organic matter from external sources, reducing SO_4^{2-}
Ma	Million Years
Supergene	Deposition or enrichment of mineral deposits by solutions moving downward through the rocks
Protore	Rock containing sub-economic material where there is the potential for economic mineral deposits to form through super gene enrichment

1. Introduction

Groundwater is often an area of concern within the mining industry due to the potential environment and safety impacts in surface and underground mining operations. This also effects the educational portions of the mining industry where students, professors, and researchers are working to educate and learn about the industry so that students are better prepared to join the workforce. Engineering schools focus on creating hands-on and real-life experiences to expose their students to situations they will experience within the industry and their careers. These experiences better prepare students for the work force and help make students more employable and desirable for companies.

Montana Technological University (Montana Tech) is known for its engineering programs, opening the campus in 1900 with degrees in mining engineering and electrical engineering. Montana Tech still specializes in science, technology, math, and engineering programs today and continues to offer its original programs, with many focused on Mining, Geological, Environmental and Metallurgical engineering.

The Mining Engineering program has continued to remain strong and since 2010 when Montana Tech was gifted a retired silver mine, the Orphan Boy Mine, directly west of campus the program has continued to strengthen. Substantial industry gifts allowed Montana Tech to initiate the development of an Underground Mine Education Center (UMEC) on campus where students from mining engineering, geological engineering, environmental engineering, metallurgical engineering, and occupational safety and health programs obtain hands-on experience. The facility also serves as a research base for underground mining methods, ventilation, fragmentation, rock mechanics, and health and safety. Currently, over 3,000 feet of workings make up the UMEC including existing underground workings of the Orphan Boy and

Orphan Girl Mines as well as new workings developed specifically for training purposes (Rosenthal & Knudsen, 2018).The Orphan Girl, also a retired silver mine and home to the World Museum of Mining, has been dedicated to preserving the history of mining since 1965 (The Montana National Register Sign Program, n.d.). Within the past five years the UMEC has been experiencing issues with rising water levels in both the Orphan Boy and the Orphan Girl shafts. Multiple papers have been published regarding the mines in Butte and the surrounding Silver-Bow County and their hydrogeological properties and relationships to one another.

This paper attempts to compile all known information into one data source beneficial to the Mining Engineering Department and form a knowledge base to build on for those who wish to further understand the hydrogeological connections and the extents of the Orphan Boy and Orphan Girl historical workings. The focus is centered on historical workings using stope books to map connecting mines and eliminate and/or consider the possibly sources of increased inflows into the Orphan Boy and Orphan Girl shafts. To further investigate these sources, hydrogeologic and geological data will be used to determine which possibilities are more likely or unlikely.

2. Site Description

2.1. Geology and Mineralization

Butte, Montana has a complex history of multiple mineralizing events that are still under investigation. Most of the Butte area host rock is the Butte Quartz Monzonite which has been dated at approximately 76 Ma. The Butte Quartz Monzonite is the largest pluton in the late Cretaceous Boulder batholith with a borderline granite-to-quartz monzonite composition. This structure, the Butte Quartz Monzonite, within Butte is cut by several pegmatite and aplite dikes that are transformations of the parent Butte Quartz Monzonite magma (Gammons C. H., 2016). The Cu-Mo system, the current focus of the Continental open pit copper mining within the Butte mining district, contains a younger set of subvertical, Cordilleran-style Main Stage that has unusually thick Hydrothermal alteration in the Main stage area is zoned with phyllic and argillic alteration in the Central zone grading outward into weaker phyllic, argillic, and propylitic alteration towards the Peripheral Zone (Figure 1). The geologic process that put Butte on the map was the Main Stage hydrothermal event that remobilized metals from the low-grade porphyry protore into the large and unusually Supergene high-grade Main Stage veins. Supergene enrichment also occurred resulting in the leaching of Cu as chalcocite below the water table. Dikes and ignimbrite made up of rhyolite in the Eocene Lowland Creek Volcanics group out crop on the west of the main zone of mineralization on Butte Hill. A large dike of Lowland Creek Volcanics makes up Big Butte (Figure 1), further separating the Peripheral zone. The Butte district is divided into East, West, and Outer Camp (Figure 5). Outer Camp is separated from East and West Camps by the Lowland Creek Volcanics intrusion and Big Butte completely isolating Outer Camp geologically. The Orphan Boy and Orphan Girl mines are in the Outer Camp of the Butte Mi ning District within the peripheral zone, known as the lead-zinc halo of the porphyry copper deposit. West Camp is within the Peripheral Zone of gold, lead, zinc and manganese of the mining district and contains the Travona Mine which was mined for silver in the late 1800s and early 1900s (Montana Department of Environmental Quality n.d.). The East Camp was, and is, the primary copper producing camp including the Central Copper Zone and portions of the Intermediate Zone. The Orphan Girl and Orphan Boy mines are in the Peripheral Zone, also known as the Outer Camp area (Figure 5).

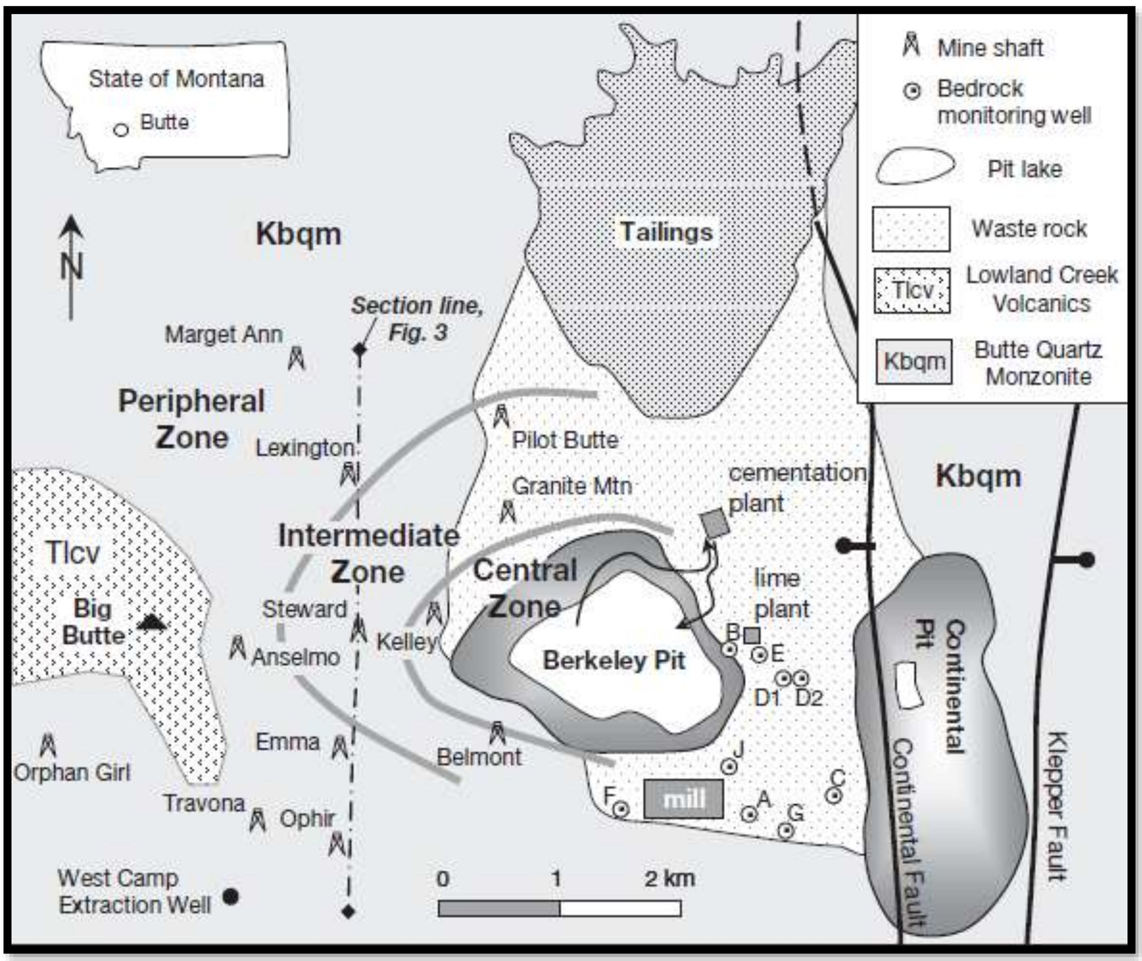

Figure 1: Map of Butte, Montana with simplified geologic and mining features. The Orphan Boy shaft is located directly north of the Orphan Girl on the map but does not have a headframe to distinguish its shaft. (Gammons & Snyder, 2009)

2.2. Historical Workings

Mining began in Butte as early as the 1860's, first as a placer mining camp when gold was discovered in Silver Bow Creek, then during the 1870's hard-rock mining of subsurface began and continued until the early 1980's with occasional interruptions in production. The Butte mining district was largely considered to be a square-set district (Dunshee, 1914) and an example of square set timbering is displayed in Figure 2. Worked out stopes were filled with waste rock from development on different levels or from the surface.

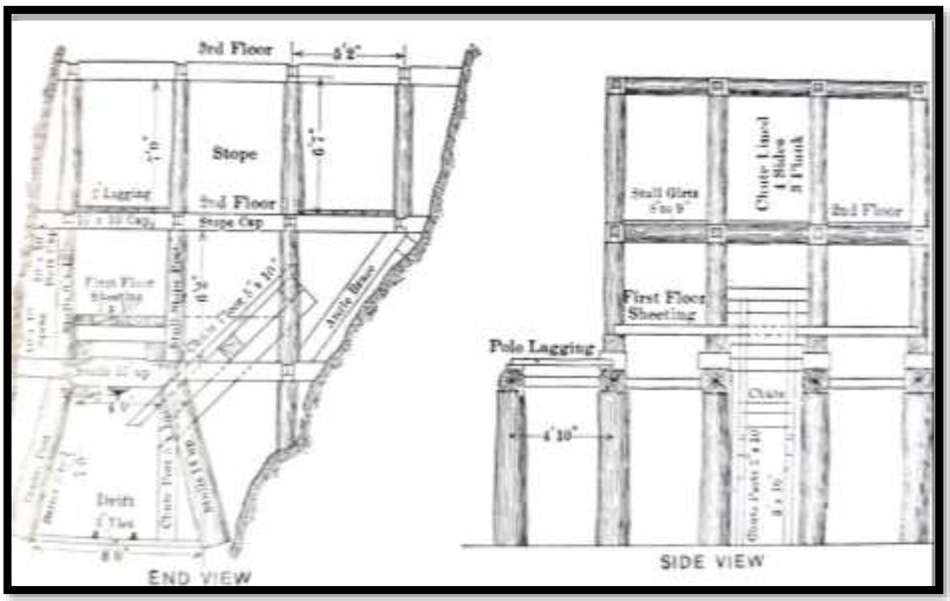

Figure 2: Example of a square set timbering method commonly used in the Butte Mining District. Image from (Dunshee, 1914)

A mining method used and locally named the "back-filling system," described a method of mining without timbers in competent, hard rock without faulting planes (Dunshee, 1914). A sill was driven first on the vein, then a raise was installed to the level above, ore on the first floor was mined, and chutes were built approximately 25 feet apart along the drift. Mining began at the raise, after the ore had been broken from the foot to hanging wall for a small distance, the miners set up a machine on the broken ore and again worked their way forward (Dunshee, 1914). This process was repeated until there the broken ore was 15-20 feet in height, the miners then move farther ahead while the shovelers began shoveling the broken ore into the raise chute until they reach the next ore chute (Figure 3). Immediately after the ore chute was passed, a temporary opening was made in the raise chute and waste was dumped into the chute from the level above and ran onto the sheeting for as long as possible. Once the limit was reached a track started approximately 6 feet from the top of the stope and the waste was taken from the chute in a car while continuing to fill the stope below. Once the shovelers were out of the way, timbermen built up ore chutes to one compartment wide and two compartments long to level the waste track. The waste men then finish filling the stope below and lay wooden planks to keep the ore clean, once the miners have mined the ore and waste from the stope, they returned and started another level on top of the waste-filled stope (Dunshee, 1914). Approximately 10,000 miles of underground workings spaced from 100-foot to 200-foot intervals, shafts reaching combined depths over 45 miles, exist under the Butte area (Watson & Burkholder, 2015).

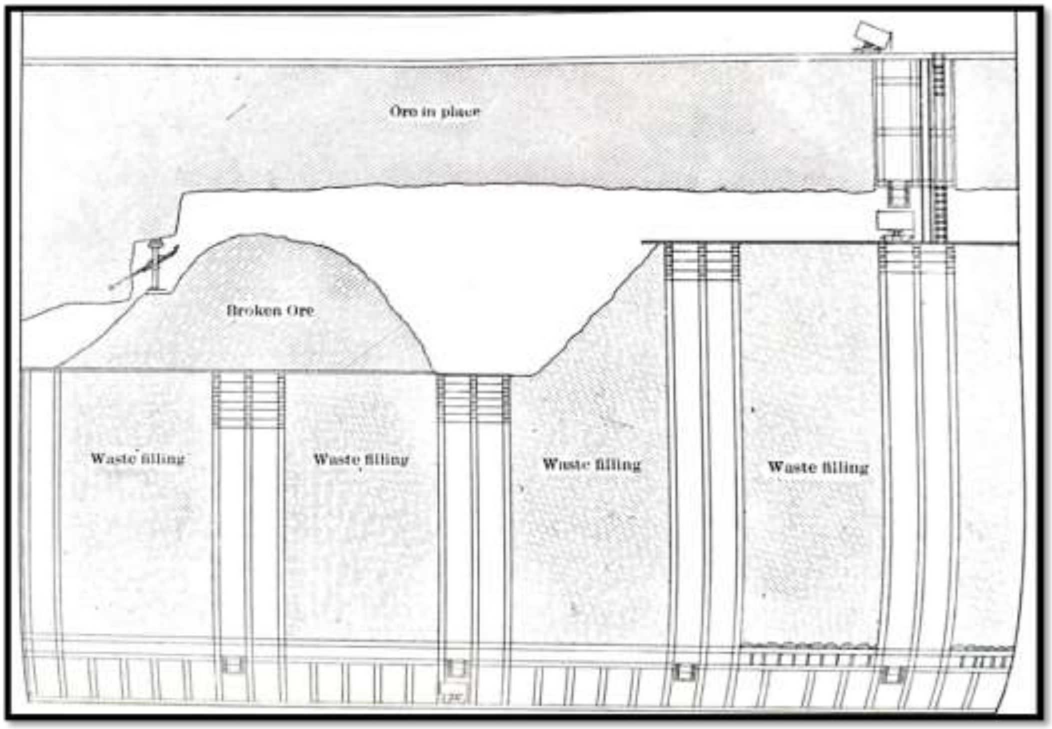

Figure 3: Sketch of the "back-filling system" used locally throughout the Butte Mining District. The waster fillings are placed within offshoots of the ore chutes once all the ore has been removed from the level (Dunshee, 1914)

Open pit mining began by the Anaconda Mining Company in the Berkeley Pit starting in 1955, ending in 1982, and the Continental Pit broke ground in 1981 (Gammons Chris H., 2009). The Continental Pit was reactivated in 1986 by Montana Minerals, now known as Montana Resources, after it had been idle since 1983.

Main pumps were installed at the 3900-foot level of the Kelley mine to keep the groundwater at bay in the Berkeley Pit and surrounding underground workings. Once West Camp mines were idled, bulkheads were constructed to limit the amount of West Camp workings that contributed to the water flowing to the Kelly Mine. Bulkheads are retaining walls installed in mine drifts and workings to contain, eliminate, or restrict water flow or oxygen to certain areas. Bulkheads were often used to create barriers around mine fires to cut off the oxygen supply and eliminate the spread of the fire, these bulkheads mined around at later dates when the fire had extinguished, sometimes years later which can be seen clearly in stope books (Roth, 2019). The Berkeley pit closed in 1982 and the pumps in the Kelly mine were turned off allowing the underground workings and the Berkeley Pit to fill with water to a protective water level at 5410 feet. The protective water level represents a level just below the lowest level of Butte's groundwater system. Below this protective water level there is a 50-foot buffer separating the contaminated water from historical workings, the water below the protective water level is in a closed-loop water system. This water cannot leave the close-loop system if it is contained below the protective water level (Pit Water, 2009), it is instead circulated through the system while preventing the contaminated water from infiltrating the treatable waters (Water Treatment Services, 2020). Once the critical/protective water level is reached, the water treatment plant at Horseshoe Bend will begin pumping to reduce the water levels in Berkeley pit until they are just below the protective water level. To keep groundwater levels below residential basements, a groundwater pump was installed in the West Camp extraction wall (WCEW) which is connected to the Travona mine workings at a depth of 525 feet below the surface (Pit Water, 2009).

When the Anaconda Company stopped pumping from the WCEW in 1965, water levels within the Travona shaft reached the elevation of 5,500 feet and began seeping into nearby basements (Pit Water, 2009). To reduce the water levels, "Relief Well No. 21" was installed in 1989 south of the Travona near Centennial Avenue. A larger pump was installed in 1998 in the same region that pumps more than 100 gallons per minute than "Relief Well No. 21", which is now used exclusively as a backup. This water was directed to a lagoon treatment system in 2002 and since pumping began in 1989 more than 1.36 billion gallons of water has been extracted from the West Camp system and been treated (Pit Water, 2009).

3. Stope Books

3.1. Stope Book Background

Stope books were used by mining companies to accurately map and update workings with day by day progress and drawn with painstaking accuracy by Anaconda Company cartographers. Each stope book page is drawn on a gridded page that covers an area that is 2,000 feet wide by 800 feet long with each page having a height of 6.4 feet, the average height of the drifts (Figure 4). The latitude and longitudinal measurements the Anaconda Company used are very accurate compared to the current USGS survey points in Butte, within 5 feet, however, the elevations within the Anaconda Company coordinate system is 54.4 feet higher than the actual elevations. Stope books are similar to puzzle pieces and once a portion of a mine is found on a specific level, that level can be traced across the district to its desired location or until the workings end or intersect with another mine and become that other mine (Roth, 2019).

The stope books are beneficial to understanding the historical workings due to the details included with each drift, shaft, and bulkhead. Each section mined is color coordinated to the year it was mined, the train elevations, survey points, shafts, and elevations are labeled within each drift. These drawings indicate the extents of the mining activity and are the best way to determine where these old workings are located at, by overlaying the drawings onto satellite images and arranging the images into the proper sector based off the book number and other surface indicators such as shaft locations. Each book is labeled by a letter and number, these labels indicate the book's location within the Butte mining district. Each physical stope book contains two "books," the left side of the book is the odd side and the right side of the book is the even numbered side, but each book is primarily named off of the left or odd side, resulting in only technically odd books being used. Each grid section also has multiple books for different depths/levels of workings, the deeper the workings go, the more books within that grid section.

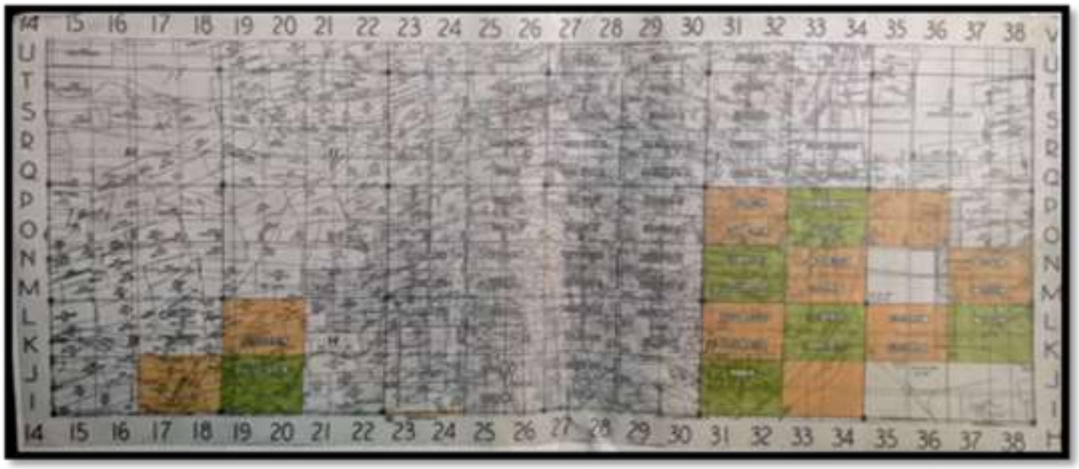

Figure 4: Grid system displaying stope book locations and mines located within certain books. This was the grid system used to connect workings for the Orphan Girl (Montana Resources , 2020).

3.2. Stope Book Reviews

By using the stope books from the Anaconda Company cartographers while the Orphan Girl and the Orphan Boy were actively being mined, it is possible to determine where bulkheads and workings exist. The main books used included L-21, K-19, K-21, J-17, J-19, J-21, I-19, I-21, H-21, and G-21. Appendix A: Stope Book Images displays an overview of the study area with all the stope book outlines and workings and specific focus areas. Figure 12 displays the study area that was created using the grid system in Figure 4. The books used were chosen due to the location of the Orphan Girl and Orphan Boy shafts and connected outward, following the Orphan Girl 1,500 Sill across books, the 1,500 Sill was chosen due to its connections across the Lowland Volcanics intrusive dike (Roth, 2019). The initial research into the stope books started on the 300 level in the Orphan Girl but extended downwards to the 1,500 Sill due to its more widespread connections.

Through the L-21 book, it was possible to determine that along the Orphan Girl 1,500 Sill and the Anselmo 1,500 Sill there is a hydrostatic concrete bulkhead located under the Mining and Geology Building on Montana Tech's campus separating Outer Camp and West Camp that was constructed in 1958. This type of bulkhead eliminates the possibility of groundwater flowing between West Camp and Outer Camp through the old mine workings as it is one of the few connections between the Camps in the Butte district (Figure 12). The thickness of this bulkhead indicates it also could be a double bulkhead seals, which is constructed from two retaining bulkheads with an impermeable seal between the two (Chekan, 1985).

Another key observation is in the J-19 stope book (Figure 13), there is a "dam" along the Orphan Girl 1500 Sill. This dam does not give an indication of why or what material it is made up of. The dam is within the Outer Camp zone, near the Orphan Girl shaft, and does not have any specific geological reason for its location. A potential theory is flooded workings beneath this level flowing down the drift and effecting workings down gradient.

4. Literature Reviews

4.1. Geochemistry of Butte Mine Water

In 2009, Dr. Gammons and Dean Snyder conducted a study on the geochemistry and stable isotopes of the flooded underground mine workings throughout the Butte district to gain a better understanding of the process that controls the chemistry of the mine waters.

Three types of water classifications were determined:

- Type I waters are highly acidic, moderately oxidized, and have very high dissolved metal concentration. Type-I waters included the Berkeley Pit lake and Kelley mine shaft. (Figure 5).
- Type II waters were classified by weakly acidic pH values, intermediate concentrations of metals, and redox conditions that were moderately reducing, most of the mine waters within East Camp were classified as Type II (Figure 5).
- Type III waters have near-neutral pH, low metal concentrations, strongly reducing characteristics, and have reduced sulfur present. West and Outer Camp shafts and wells typically display characteristics of Type III water.

There is a sharp dividing line from Type II and Type III water types that corresponds to the groundwater divide, indicated by the blue dashed line in Figure 5. The contrast between Type I and Type II water types is more gradual and is most likely gradational.

The results of this study produced data indicating measurable quantities of dissolved sulfide in the mine waters of West and Outer Camp. The Butte district also has been the only location where H_2S rich water has been observed in an abandoned metal mine to the best of the authors' knowledge. H_2S is produced from the sulfur reducing bacteria (SRB) that is present within the Butte mine shafts and workings. All the mine waters in the Outer and West Camps, specifically the Orphan Boy shaft, are high in SRB bacteria concentration growth which in turn produces large amounts of H_2S (Gammons, 2020).

The water temperature, pH, specific conductance, and Eh, mV of the Orphan Girl all remain relatively constant with depth of sampling. Near the upper portion of the Orphan Girl shaft, the pH does become slightly more basic than at depths of over 60 feet. The Outer and West Camp are undersaturated with gypsum and are close to equilibrium with calcite, amorphous barite, chalcedony, and hydroxyapatite. These waters are also supersaturated with pyrite and sphalerite, they also have aqueous metal-sulfide clusters. The Orphan Girl and Orphan Boy have lower isotopic separation values compared other mines sampled and the authors, Gammons and Snyder, believe this has some correlation to the warmer water temperatures within the shafts.

The water within the shafts has been recorded cycling upwards, this could be an indication of multiple scenarios. These scenarios include: the presence of chemical or biological reactions, different rates of vertical water movement, presence or absence of obstructions, or water entering the shaft from horizontal adjacent drifts (Gammons, 2009).

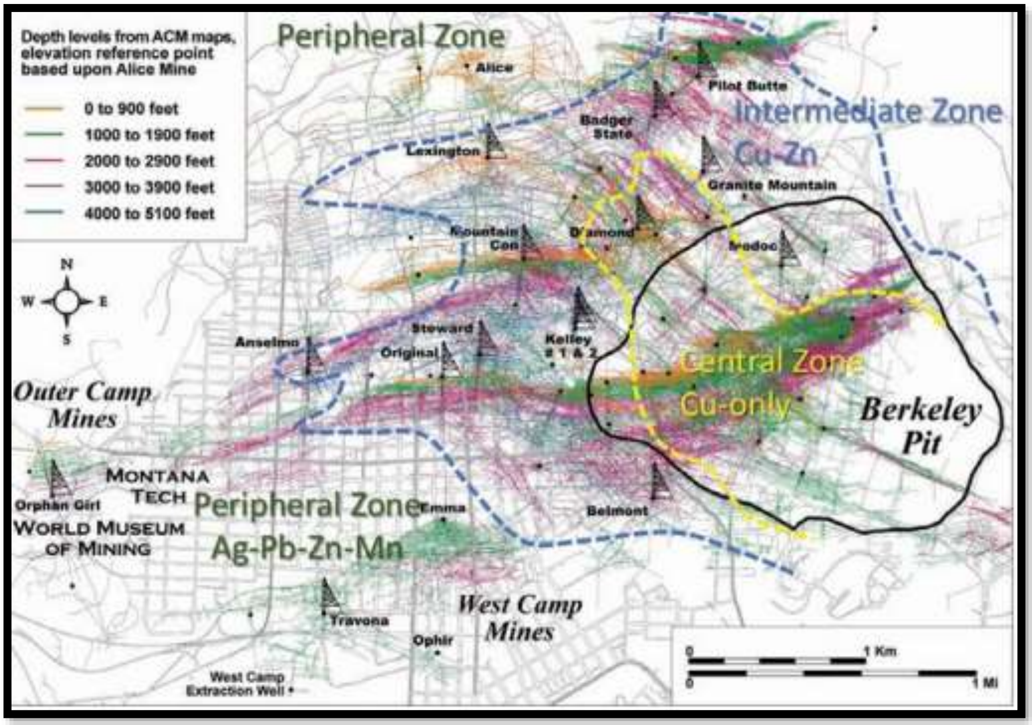

Figure 5:An incomplete map of underground mines within the Butte area with West, and Outer Camp labeled in the general area where the mines are located (Chris H. Gammons 2009). East Camp is located with the Intermediate Zone. This map also illustrates the Central Zone where most of the mining in the Butte mining district took place.

4.2. Aquifer Testing and Evaluation at the Travona Mine and Marget Ann Mine Butte, Montana

John J. Metesh (1990) conducted multiple aquifer tests on mine shafts in the Outer and West Camp of the Butte mining district to determine the hydraulic conductivity and storage factors of mine shafts in relation to the underground workings as well as the natural bedrock aquifer conditions. Metesh ran aquifer tests on the Marget Ann Mine, Travona Mine, the Marget Ann Block well, and a well at Chester Steele Park to investigate the fractured aquifer material and gain an understanding the relationship between the mines and the groundwater flow.

The Travona Mine is in West Camp in the Butte district with the only current underground connection with the Emma Mine, north and east of the Travona shaft. The Travona and Emma mines were isolated from the majority of the workings in the central mining zone of the district by bulkheads at various levels resulting in higher water levels and lower water level recovery rates compared to central and intermediate zones. The first level is at a depth of 200 feet, a total depth of 1,500 feet and horizontal workings every 100 feet.

The Marget Ann is located on the far extents of the Outer Camp portion of the Butte mining district and was first opened in 1878 until 1882 to which a depth of 190 feet was reached at the same level groundwater was encountered (Metesh, 1990). Mining was then restricted to veins above the 190-foot level and was reopened in 1950 and operated into the late 1950's. By the closure of the Marget Ann the shaft had a depth of 550 feet with approximately 20,000 tons of ore extracted. The ore included lead, zinc, silver, and minor gold production.

The Chester Steele Park well that was selected for testing is approximately 1,000 feet to the northwest of the Travona Mine shaft. This well was drilled in 1988 with the goal of providing irrigation to Chester Steele Park however the idea was later abandoned due to the low yield from the well. The total depth is approximately 700 feet, completed with 4-inch PVC and saw-slotted in the interval of 300 feet to 700 feet (Metesh, 1990). Core log data indicates unconsolidated clay and sand to 20 feet below the surface and fractured granite, a "broken" zone exists from 361-366 feet, to the depth of 700 feet. This is the only detailed indication to the fracture spacing or orientation, the other shafts and wells tested did not have well logs.

Aquifer tests were conducted with observation wells that were checked over the course of the pumping and drawdown was recorded. Aquifer tests were spaced out to ensure the recharge times were recorded properly and did not affect the next tests. Specific conductivity, pH, and alkalinity measurements were taken throughout the tests as well as water samples prior to the conclusion of the tests (Metesh, 1990). Recovery data was also collected from each of the tests to try and obtain a storage value.

Results from the four aquifer tests indicate that the Travona Mine shaft has multiple fractures with high hydraulic conductivity and is dominated by the fractures with some shaft storage effects. The Chester Steel well aquifer did not produce conclusive data for radial flow or show an indication for facture dominated flow. The Marget Ann Block Well S-4 indicated fracture dominated flow similar to that of the Marget Ann and Travona but the fractures indicated low hydraulic conductivity (Metesh, 1990). The Marget Ann showed similar results to that of the Travona, dominated fractures of high hydraulic conductivity and showed shaft storage effects.

Throughout the test Metesh was unable to precisely determine the time of transition from the aquifer-storage to the mine-storage time to determine a more accurate storage factor than what was calculated. The results from this study should be restricted to a maximum depth of 500 feet to maintain a one-half order of magnitude limitation due to the horizontal fractures associated with unloading assumed to be insignificant to the contribution of flow and the fractures being vertically oriented and of constant aperture both laterally and with depth. Both of which do not accurately describe the aquifer material the Butte district (Metesh, 1990). The results also indicate an increased hydraulic conductivity near the mine shafts which could correlate in part to blasting and exploration drill holes for increased fracturing.

5. Groundwater and Surface Water Interactions

5.1. Hydrographs and Surface Water Infiltration

Groundwater and surface water inflows to the Orphan Girl and Orphan Boy comes from a relatively small watershed shown in Figure 6. The main boundary of this watershed is on the eastern portion, bound by the Lowlands Volcanic intrusion, which separates not only the surface watersheds but also is a solid groundwater divide (Gammons, 2009).

Comparing hydrographs from the Orphan Boy shaft and the “Tech Well” (Figure 7) surface water precipitation has influence on the water levels within the shaft and well. The data in Figure 7 indicates there is a delayed response from the high influxes of precipitation with the increased water levels in the Orphan Boy shaft and the Tech Well. The delayed response is due to time it takes the surface water to infiltrate the groundwater flow paths and reach the aquifer that recharges both the shaft and well. The historical data indicates 1997 had the highest water level elevation in the Orphan Boy in the past 30 years, then in 2017 the water elevation spiked again.

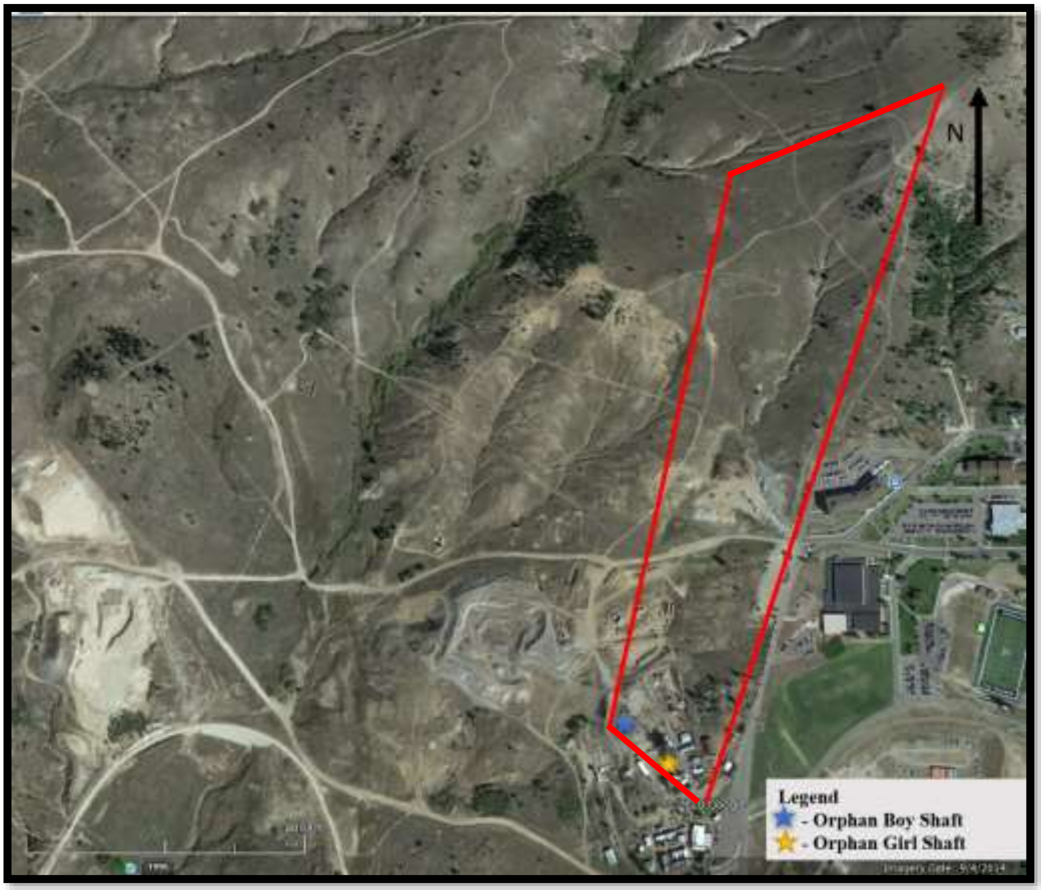

Figure 6: Displays a rough sketch of the watershed the Orphan Girl and Orphan Boy shafts collect surface water from the region outlined in red. The blue star represents the Orphan Boy shaft while the yellow star represents the Orphan Girl shaft.

Groundwater did not connect from East or West Camp to Outer Camp through historical workings due to the bulkheads spread across the connecting workings and the rhyolitic intrusion, Lowland Volcanics. Assuming the bulkheads remain structurally sound, groundwater does not have a path of least resistance across the Lowland Volcanics. There is also the possibility of a deeper bedrock aquifer, below the depth of the Orphan Girl shaft of 3,200 feet, with low hydraulic conductivity that has been feeding into the workings as the surface water does not account for the amount of flow that has been within the workings in the recent years as displayed in Figure 7.

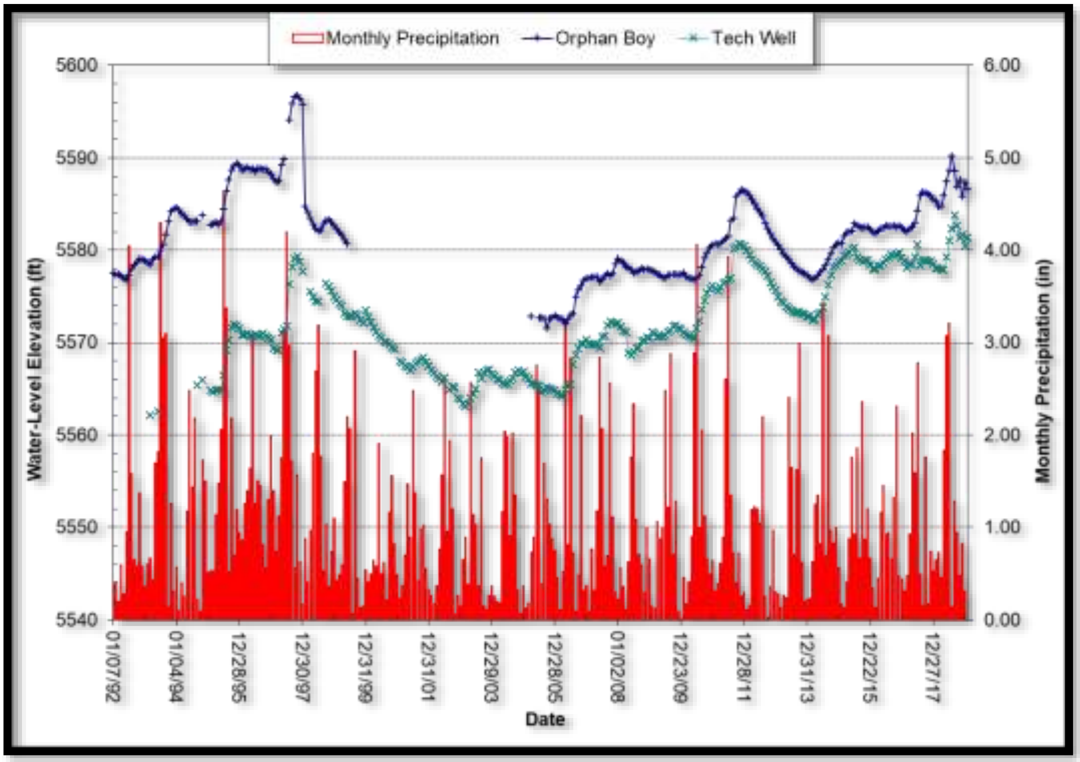

Figure 7: Hydrographs including the Tech Well and Orphan Boy shaft water levels in correlation to the monthly surface precipitation

The groundwater within the Orphan Girl and Orphan Boy shafts appears to drain in the "Green Seep" located downhill to the southwest through connections of the Orphan Girl and Minnie Jane workings (Gammons personal communication, 2020). The Minnie Jane was primarily mined for manganese and silver with gold, lead, and zinc mined as secondary minerals (USGS, n.d.) and is located southwest and down gradient of the Orphan Boy and Orphan Girl shafts. A flow meter is located at the Green Seep to record outflows of water seeping from the ground starting in 1995 and continues to collect data currently (Figure 8). The data from 2017-2019 is unreliable due to vegetation hindering the outflows and slowing down water flows resulting in the flow meter recording no flow or unrealistic spikes, Green Seep was clean and cleared in October 2019 (Duaime T. , 2020).

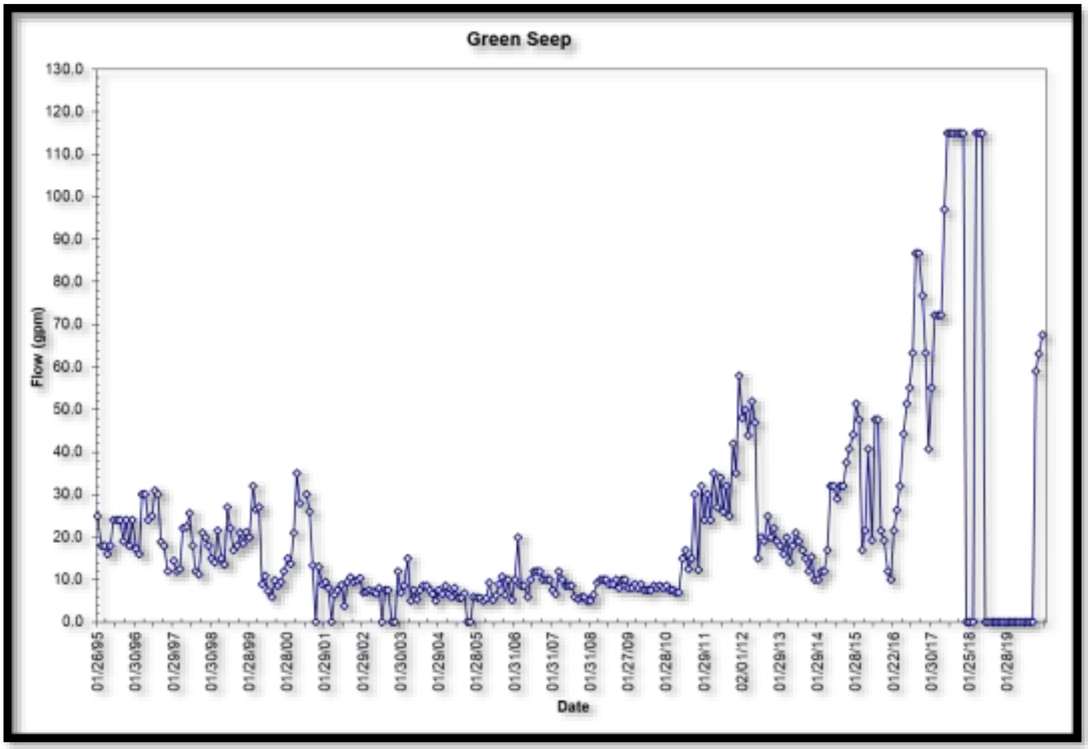

Figure 8: Green seep data dating back to 1995. Data shows spikes and flat areas due to the Green Seep becoming clogged by vegetation.

The most recent data collected is displayed in Figure 9, this data was collected after the cleaning of Green Seep to allow for to allow for more accurate readings from the flow meter. Due to the recent the rejuvenation of Green Seep, there is not enough data to pick out trends within the past year. The most basic observation is the outflows increase in the later winter months, most likely due to snow melt infiltrating into groundwater systems that eventually drain into the Green Seep or the lag time from the previous year’s precipitation infiltrating and traveling through the groundwater systems.

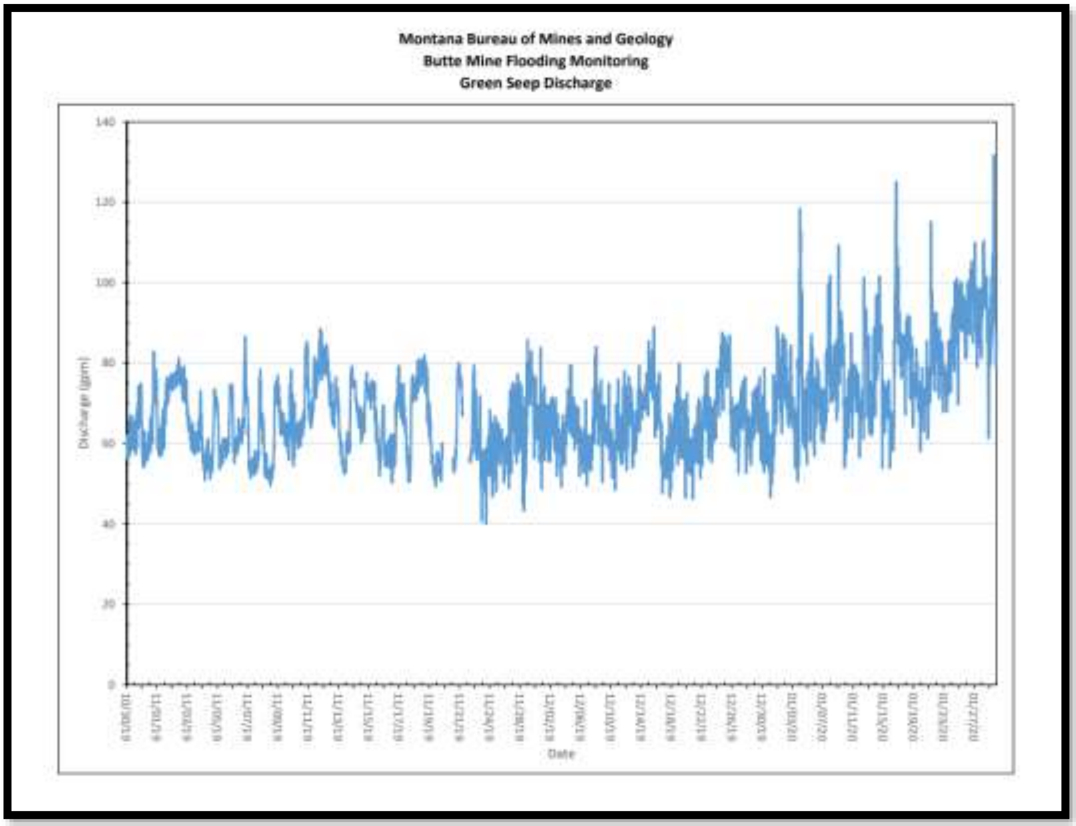

Figure 9: Data displaying an increase in flows over various months after rejuvenation of Green Seep and re-installation of flow meter.

Figure 10 displays the historical and current water levels in the Orphan Boy shaft, the highest point on the graph is approximately October 2017, which is also evident in Figure 8. Figure 10 also clearly shows the effects pumping the Orphan Boy shaft has on the shaft water levels and the quick recovery rate of the water level. There are multiple pumping events displayed in the graph, especially within the recent years in response to the rising water levels seen in both the Orphan Girl and Orphan Boy shafts. The most significant pumping event displayed is in the fall of 2018, the water level drops approximately 10 feet in elevations within the Orphan Boy shaft.

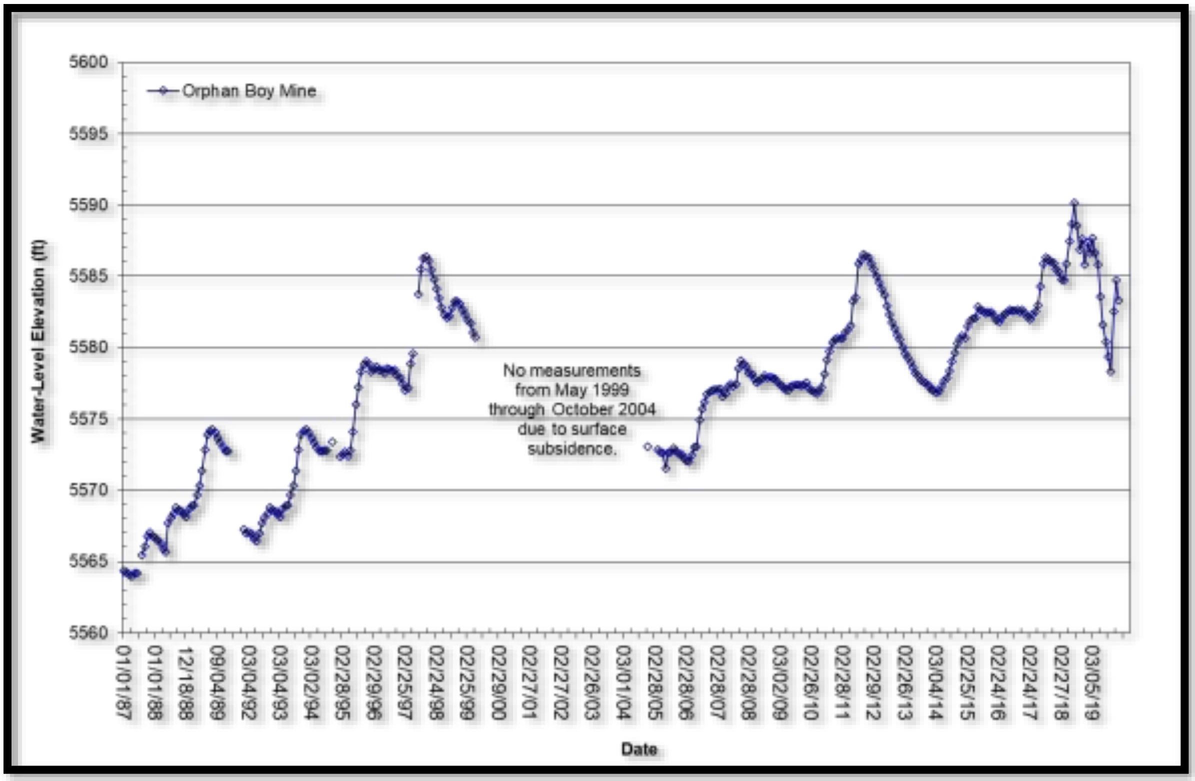

Figure 10: Historical water levels of the Orphan Boy Shaft (Montana Bureau of Mines and Geology, 2020).

The most recent data, (Figure 11), from the Orphan Boy highlights the effect pumping has on the water levels in the Orphan Boy shaft. This data, provided by the Montana Bureau of Mines and Geology (MBMG), is from the month of September 2020 showing how water levels were on the rise until pumping was used consistently towards the end of the month.

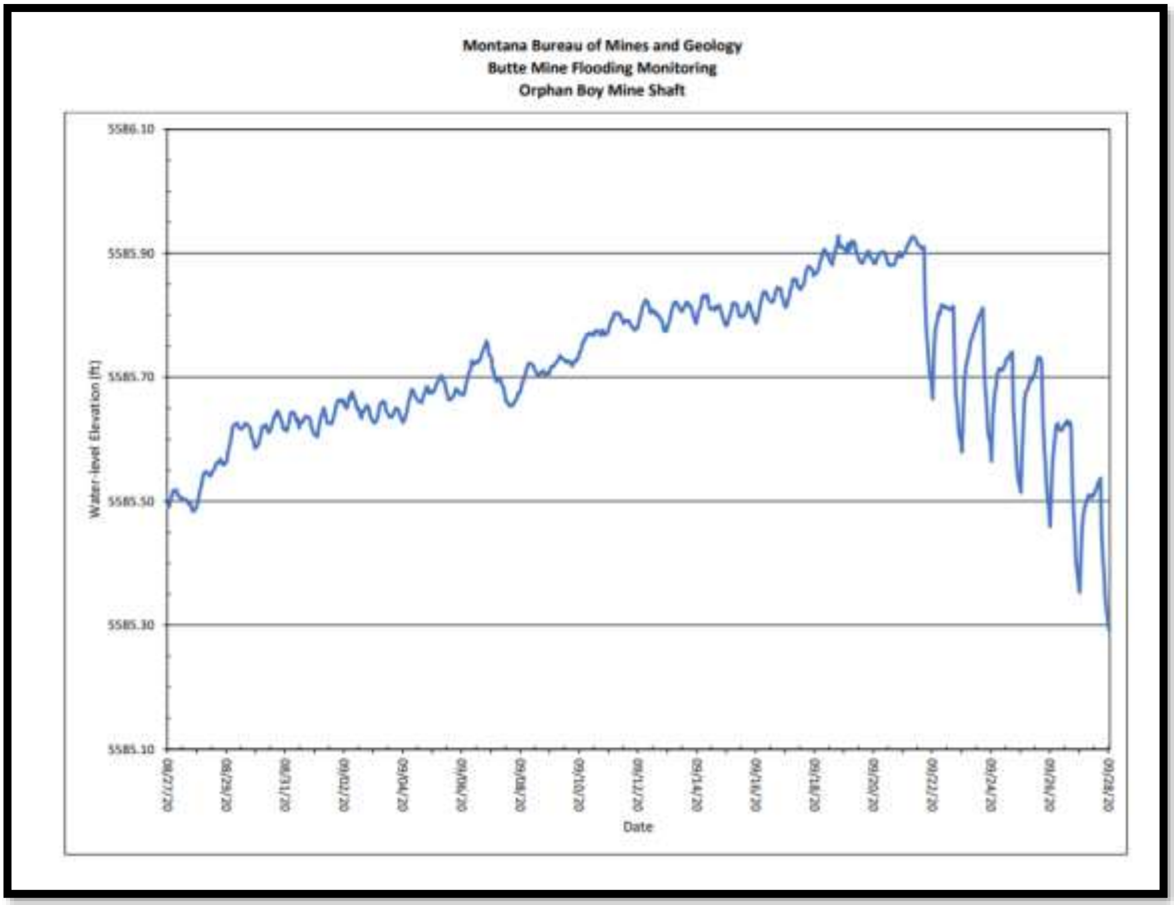

Figure 11: Most recent hydrograph from the Orphan Boy. Clearly displayed is when pumping was resumed in September 2020 (Montana Bureau of Mines and Geology, 2020).

This increase in water level could be related to the hypothesized deep bedrock aquifer (Gammons personal communication, 2020) which would be located deeper than 3,000 feet below the surface due to no records of the Orphan Girl hitting a significant water source at the bottom of the shaft. Deep bedrock aquifers are less subject to sudden changes in outflows and infiltration rates, especially if they have not been affected by an outside force that penetrates the aquifer. Since the aquifer is not typically subjected to sudden changes, it is unlikely the inflows from this aquifer increased effecting the water levels in the Orphan Boy and Orphan Girl shafts.

An increase in surface water infiltration is another potential source of the increased water levels. From the new structures built on the Montana Tech, surface water could flow to a more centralized location that infiltrates into the drifts that flow directly into the shafts instead of following the natural flow paths that existed the watershed. This could be the result of new parking lots and buildings built creating impermeable areas that surface water will flow to a low spot that is within the watershed of the Orphan Boy and Orphan Girl, or where the surface water will infiltrate into a working that flows into the shafts. This theory corelates with the precipitation amounts for each year, which still does not account for the total increase in water levels.

Another possibility is historical workings shifting, such as a bulkhead, drift, or a dam collapsing, and a previous obstruction shifting. With any of these incidents occurring, the water flow path would change resulting in a more direct or new flow path to the Orphan Girl and Orphan Boy. With the 2017 earthquake with the epicenter in Lincoln, MT with effects felt in Butte, MT, it was possible that the water saturated workings collapsed after over 50 years of unuse. Due to the waves that reached Butte were surface waves, it is unlikely the collapsed workings that opened a new flow path would be directly related to the earthquake. However, with the years of unuse, the dams and bulkheads in place to restrict the water flows may have collapsed due to time and water saturation.

If the workings collapsed, it could also create a blockage from the previous draining flow path, result in more pooling, and potential drainage into the Orphan Boy and Orphan Girl shafts instead of opening new flow paths. If a working collapsed, it is likely on the western side of the shafts where the hypothesized drainage flows (Gammons, 2020). There also could be the combination of collapsing structures obstructing flow paths and collapsing structures opening flow paths.

5.2. Orphan Boy and Orphan Girl Pumping and Outflows

Multiple “bucket method” outflow measurements were taken from the discharge point of the Orphan Boy and Orphan Girl pumping to determine the average outflow. The calculations shown in Table 1 indicate an overage of 0.10 cubic feet per second (cfs) or 43.04 gallons per minutes (gpm). Using the hydrograph from the previous section (Figure 10) it appears that pumping was resumed in the Orphan Boy in late September and was pumped in seven-hour increments (Roos, 2020). Water is piped out of the Orphan Boy shaft through a 3-inch HDPE pipe, using this information the rate of recharge within the Orphan Boy shaft can be back calculated to determine water inflows.

Table 1: Collected and calculated values from the Orphan Boy pumping outflows

Test #	Time	Gallons	Gallons/sec	Gallons/Min	cfs
1	6.97	5	0.72	43.04	0.10
2	6.37	5	0.78	47.10	0.10
3	7.24	5	0.69	41.44	0.09
4	6.76	5	0.74	44.38	0.10
5	6.2	5	0.81	48.39	0.11
6	6.57	5	0.76	45.66	0.10
Average	6.685	5	0.75	45.00	0.10

6. Conclusion

By using the stope books, potential water flow paths can be monitored, and other potential paths can be eliminated based on bulkhead construction, provided that the bulkheads are still structurally sound and there is no other flow paths that have opened from collapsing structures. This can be used to eliminate the possibility of water flowing through the Orphan Girl connection to mines on the East side of the rhyolite intrusion. The bulkhead eliminating this connection is a hydrostatic concrete bulkhead, which were specifically designed to eliminate water flows. Based on the thickness of this bulkhead it is most likely a double bulkhead seals, which is constructed from two retaining bulkheads with an impermeable seal between the two bulkheads (Chekan, 1985). This bulkhead design was mostly used in the Eastern United States as a part of the Federal and State acid mine drainage research and abatement programs (Chekan, 1985).

The Butte mining district has unique mine water geochemistry that is not common in other mining districts with similar geological structures. This creates some difficulties when doing literature reviews, the research scope is almost limited completely to the Butte mining district. Other papers that could potentially be helpful include mining districts that contain geothermally warm waters that show upwelling flows of these waters into abandoned mine workings. Substantial inflows, more than what can result from surface water infiltration, are entering the shafts as displayed in the provided hydrographs.

There are several possibilities for the increased inflows into the Orphan Girl and Orphan Boy shafts, including collapsed structures and/or drifts creating new openings or blockages that create or end historic flow paths, a deep bedrock aquifer, and an increase in the surface water infiltration.

7. Future Work

Substantial field work will be necessary to further understand the groundwater and mine working interactions in Outer Camp. This also includes finishing the stope book work that connects and displays the connections between different mines and the Orphan Girl and Orphan Boy. The continuation of the stope book work will include the Minnie Jane workings located to the west of the Orphan Girl and Orphan Boy shafts and workings. The Orphan Girl connects to the Minnie Jane workings on the 500 level of the Minnie Jane workings and the 100 level of the Orphan Girl. Following these connections will allow for a full picture of possible inflows from different drifts and shafts to the Orphan Boy and Girl shafts, but will also display the possible outflow directions, potentially verifying the connections to the Green Seep. Another connection to further investigate is the 2,600 or 2,800 level of the Orphan Girl that potentially displays a connection between West and East Camp.

Displaying the stope work done can be expanded by creating 3D models of these workings with relevant elevations and locations by using a combination of AutoCAD and a mining software. This will also assist the Montana Bureau of Mines and Geology with their stope book work and further their research as well to a more in-depth and interactive display of historical workings.

Collecting samples at approximately 1,500 feet and deeper, halfway down the Orphan Boy shaft to determine if water inflows differentiate from water near top of the mine shaft to support theory of deep bedrock aquifer inflows supplying water to the historic workings and adding to the water flooding the UMEC. Previously, water samples were limited to 1,500 feet due to an obstruction within the shaft and equipment length (Gammons Chris H., 2009), since the time of the initial sampling, the obstruction may have shifted allowing for deeper sampling. An aquifer test conducted using the Anselmo Mine, the connection bulkheaded off from the Orphan Girl shaft, using the Orphan Boy or Orphan Girl shaft as an observation well to determine if there is intermixing between West Camp and Outer Camp. This would also give an indication if the bulkhead on the 1,500 Sill of the Orphan Girl is still in place or if it has collapsed. Taking isotopic samples of shafts in both West Camp and Outer Camp would give an indication if the waters of these camps are mixing and how much mixing is occurring.

With the state of the historical workings, it is unlikely to take preventative measures to eliminate a source of inflow to the Orphan Boy and Orphan Girl shafts, understanding the hydrogeology of the groundwater system will allow for more strategic pumping methods.

Further literature reviews into mining districts that possess similar characteristics to that of the Butte mining district. Due to the uniqueness of the Butte mining district there are not many mining districts that display the same characteristics, because of this, further literature research would isolate characteristics. These characteristics could include similar working infrastructure, similar materials mined, and/or mine water interactions.

8. References Cited

Braly, N. B. (1914). Shaft-Sinking Methods of Butte. In SME, *Transactions of the American Institute of Mining Engineers (Montana Edition)* (pp. 151-176). New York, N.Y.: The Institute.

Chekan, G. J. (1985). *Design of Bulkheads for Controlling Water in Underground Mines.* United States Department of the Interior.

Duaime, T. (2019, October). Green Seep and Hydrograph Data Discussion. (E. Doucette, Interviewer)

Duaime, T. (2020, January). Hydrogeologist. (E. Doucette, Interviewer)

Dunshee, B. (1914). Timbering in the Butte Mines. In SME, *Transactions of the American Institute of Mining Engineers (Montana Edition)* (pp. 137-150). New York, N.Y.: the Institute.

Gammons C. H., e. (2016). New investigations of the mineralogy of silver in the world-class porphyry-lode deposits of Butte, MT. *Mining Engineering*, 2-9.

Gammons Chris H., S. e. (2009). Geochemistry and Stable Isotopes of the Flooded underground Mine Workings of Butte, Montana. *Economic Geology*, 1213-1234.

Gammons, C. H. (2020, March 3). Professor. (E. Doucette, Interviewer)

Guy D. Faugue, L. L. (2012). Sulfer-Reducing Bacteria. *Advances in Microbial Physiology*.

Metesh, J. J. (1990). Aquifer Testing and Evaluation at the Travona Mine and Marget Ann Mine Butte, Montana. *Library of Montana College of Mineral Science and Technology* , 191.

Montana Bureau of Mines and Geology. (2020). Outer Camp Sites.

Montana Department of Environmental Quality. (n.d.). *DEQ Historic Context*. Retrieved August 26, 2020, from https://deq.mt.gov/Land/AbandonedMines/linkdocs/183tech

Montana Resources . (2020).

Montana Technological Engineering. (2020). *World Class Mining Engineering* . Retrieved August 21, 2020, from https://www.mtech.edu/mining-engineering/index.html

Pit Watch. (2020). *Pit Watch Protective Water Level*. Retrieved August 20, 2020, from https://pitwatch.org/protective-water-level/

Pit Water. (2009, June 6). *Pit Watch*. Retrieved October 2020, from https://pitwatch.org/west-camp-also-part-of-mine-flooding-site/2/

Roos, C. (2020, October 22). Orphan Boy Pumping Information. (E. Doucette, Interviewer)

Rosenthal, S., & Knudsen, P. (2018). *Montana Tech's Underground Mine Education Center.* Butte: Digital Commons @ Montana Tech.

Roth, A. (2019, September). Stope Books. (E. Doucette, Interviewer)

Standard Staff. (2004, June 27). *Some facts about Montana Resources*. Retrieved October 12, 2020, from https://mtstandard.com/news/local/some-facts-about-montana-resources/article_da1555ab-d481-5236-b320-25f8d254676c.html

The Montana National Register Sign Program. (n.d.). *Orphan Girl Mine* . Retrieved August 24, 2020, from https://historicmt.org/items/show/36

USGS. (n.d.). *Minnie Jane Mine*. Retrieved September 26, 2020, from https://mrdata.usgs.gov/mrds/show-mrds.php?dep_id=10019804

Water Treatment Services. (2020). *Closed Loop & Closed Circuit Heating & Cooling*. Retrieved October 12, 2020, from https://watertreatmentservices.co.uk/water/closed-loop-water-systems-

2/#:~:text=Closed%20circuits%20operate%20as%20a,suffer%20only%20negligible%20water%20losses.

Watson, B., & Burkholder, S. (2015). Butte Montana: A Case For the Mining Metropolis. *Scenario Journal*, 05.

9. Appendix A: Stope Book Images

Figure 12:Focus area and stope books used to construct connections of the Orphan Girl on the 1500 Sill. Grid system is based on Figure 8.

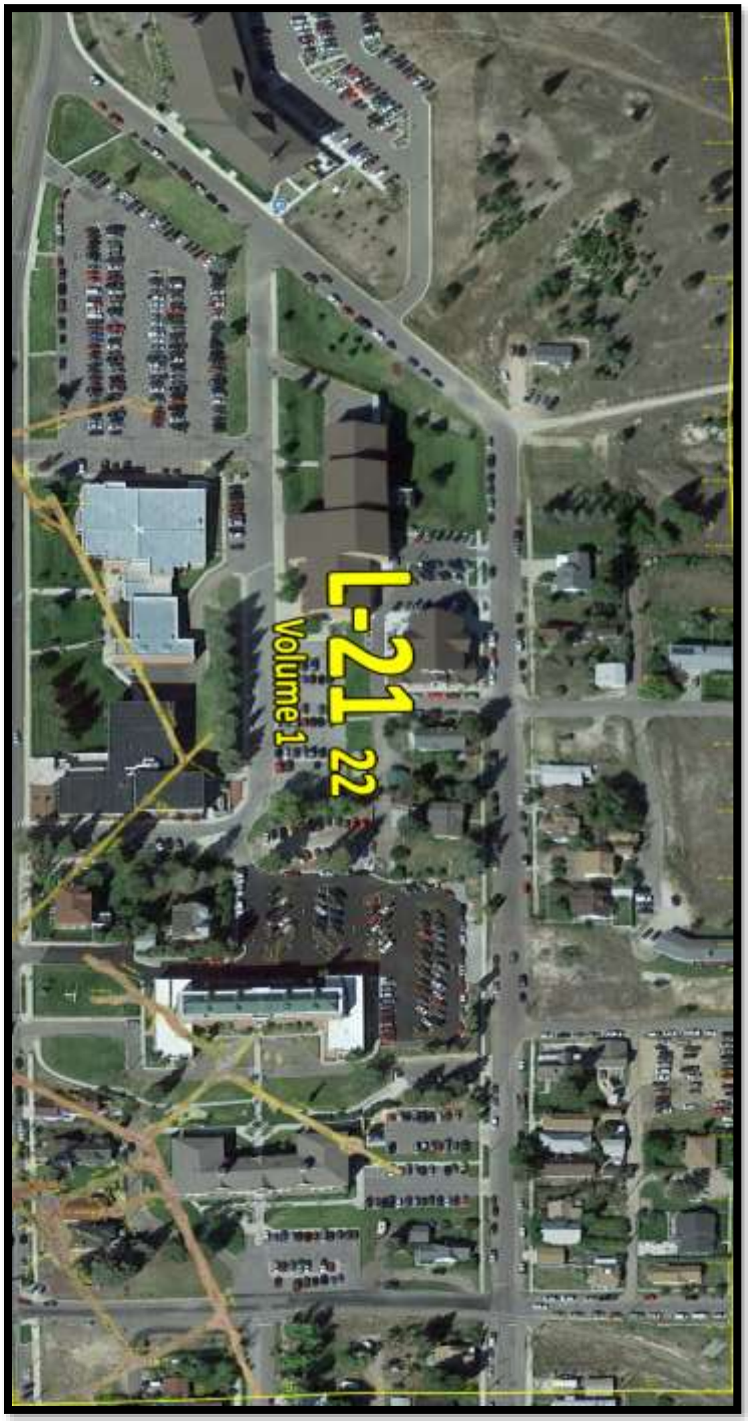

Figure 13:L-21 book Orphan Girl 1500 Sill with double sealed concrete hydrostatic bulkhead cutting off connection from West Camp to Outer Camp along the Orphan Girl workings. The red box indicates where the bulkhead is located, underneath the North end of the Mining and Geology Building on the Montana Tech campus.

Figure 14:Location of dam in red box on Orphan Girl 1500 Sill in book J-19. Dam location is near Orphan Girl shaft.

10. Appendix B: All Stope Book Sections

Figure 15: K-19/20 Workings of the Orphan Grill 1500 Sill

Figure 16: K-21/22 Orphan Girl 1500 Sill

Figure 17: J-17/18 of Orphan Girl 1500 Sill, farthest west extent of the 1500 Sill

Figure 18: J-19/20 page of Orphan Girl 1500 Sill. This section contains the Orphan Girl shaft

Figure 19: I-19/20 of Orphan Girl 1500 Sill. Cropped due to no other Orphan Girl 1500 Sill workings within the section

Figure 20: I-21/22 Orphan Girl 1500 Sill. Image cropped to highlight portions with workings.

Figure 21: H-21/22 cropped to display section containing Orphan Girl 1500 Sill

Figure 22: G-21/22 cropped view of the Orphan Girl 1500 Sill