ZORTMAN-LANDUSKY: CHALLENGES IN A DECADE OF CLOSURE

R. David Williams[2], Joan Gabelman, Shannon Shaw, Wayne Jepson, Chris Gammons, and John Kill Eagle

Abstract. The Zortman Landusky mines in Montana, USA, produced gold and silver from a mineralized syenite intrusion. Although mining in the area began over 100 years ago, the most extensive production was from open pit mining and heap leach cyanide processing that occurred from 1977 until 1998. Zortman Landusky is where valley-fill-heap-leach cyanide processing was first used for gold production and is the first large-scale gold mine where unexpected consequences of acid rock drainage occurred. Neither the mining industry nor the agencies anticipated the problems, which developed at the mine. Subsequently Zortman/Landusky is where many of the best management practices for mining and new reclamation techniques were developed. In 1998, the operator declared bankruptcy and the site was taken over by the U.S. Bureau of Land Management and the Montana Department of Environmental Quality. This paper details the history of acid rock drainage issues at the site from the first recognition that acidic drainage was a problem, through initial characterization and prediction work, to final reclamation and water treatment. Closure costs to date include approximately US$42M for site reclamation and approximately US$15M for water treatment facilities. Work continues on residual impacts many of which were not fully recognized until well into the closure phase. These include characterization and treatment strategies for acid mine drainage in Swift Gulch, a small stream whose headwaters originate on the mine property and which eventually flows onto adjacent tribal lands

Some of the lessons that Zortman/Landusky are that detailed characterization and closure planning before and throughout the mine life are critical. This project also highlights the importance of having adequate financial guarantee mechanisms available to support both the anticipated reclamation throughout the project life and any potential water treatment.

Additional Key Words: Acid drainage, reclamation, water treatment

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INTRODUCTION

The Zortman-Landusky mines are located in the Little Rocky Mountains in North-Central Montana, U.S.A. The deposits were first discovered as a placer gold deposit at Zortman. Shortly after placer gold was discovered in 1884, the Fort Belknap Indian Reservation, home to the Gros Ventre and Assiniboine tribes, was created in 1888. The original southern boundary of the reservation was the divide between the Milk River to the north and the Missouri River to the south, along the crest of the Little Rocky Mountains as shown in Fig. 1. The mine locations are highlighted in green.

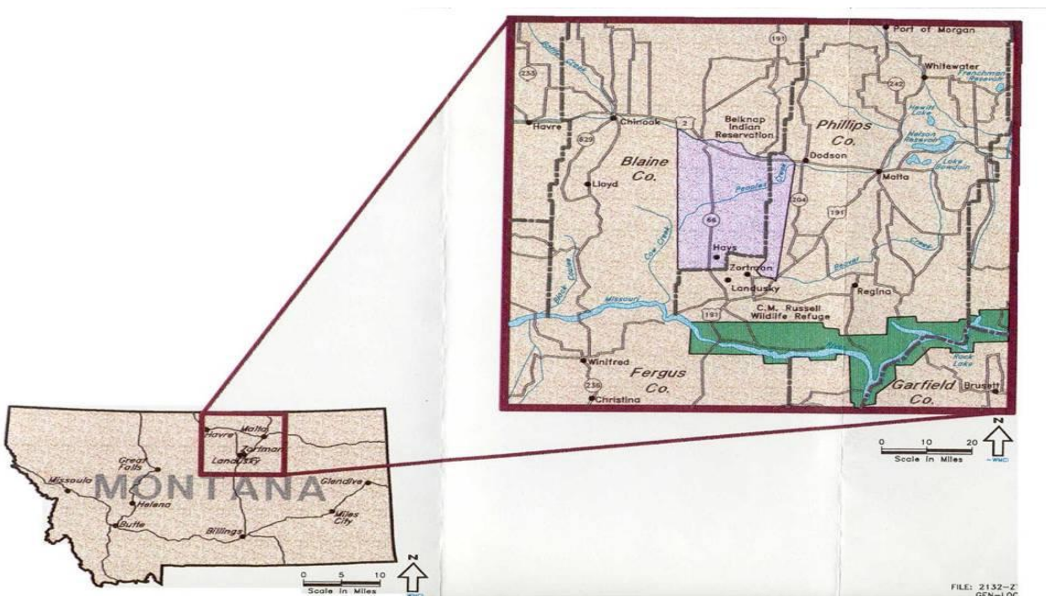

Figure 1. General location of Zortman-Landusky,

Gold and Ag produced over the life-of-mine were approximately 47 million grams and 200 million grams respectively. Approximately 195million tonnes of waste and ore were mined at the site.

GEOLOGY AND MINERALIZATION

The Little Rocky Mountains (LRM) are one of several "Island Mountain Ranges" that rise above the Northern Great Plains east of the main Northern Rocky Mountains in Montana. They occur within the Great Falls Tectonic zone – a regional NW trending structural zone extending from the Idaho Batholith to southwest Saskatchewan (O'Neil and Lopez, 1985), which is coincident with all the significant ore bodies in Montana. The LRM are a plutonic complex that formed from by the emplacement of a series of Tertiary syenite and quartz monzonite porphyries into Archeanamphibolite-facies schists and gneiss and Paleozoic clastic and carbonate rocks. These units are overlain by Mesozoic sediments. Uplift and erosion resulted in the present day dome complexes.

Post intrusive hydrothermal and related tectonic activity formed mineralized brecciate veins and stockworks, higher grade zones are localized in regional shears and lower grades are in fracture zones marginal to the principal structural trends. These shears, faults, fractures, and associated jointing form a structural fabric that has had a major influence on not only mineralization, but also the associated regional alteration, and the development of acid rock drainage (both pre-mining and mining related (Russell 1991).

MINING HISTORY

From the original discovery in 1884 of placer gold deposits through the 1940s there were numerous attempts to develop the gold resources at Zortman and Landusky by small underground mines and vat leaching highlighted by the development of the Whitcomb Mill in 1905. An estimated 11.8 million grams of gold was produced from deposits in the Little Rocky Mountains prior to the 1970s.

In the 1970s, there was renewed interest in mining in the Little Rockies. Ed Schultz initiated a pilot heap leach project, *which* proved that heap leach technology could be profitable. This has been considered the birth of the now common low-grade heap leach technology for recovery of gold. In 1979, the State of Montana approved an Environmental Impact Statement for large-scale open-pit heap leach mining by both Zortman Mining Company (Gulf Resources) and Landusky Mining Company (Wharf Resources). In 1981 Pegasus Gold Corporation became the operator of both mines following the merger of Pegasus Limited and Arco Gold Corp. The BLM and the Montana Department of State Lands, now Montana Department of Environmental Quality (DEQ) have coordinated on administration of the Mine's Plan of Operations since 1981. Between 1979 and 1989, there were 11 amendments to the approved Plan of Operations generally expanding operations at both mine sites. The early emphasis on mining oxide ore and the relatively low percentage of pyrite (< 0.3%) in unoxidized ore led to the belief that the deposits had a low potential to generate acid rock drainage. What little work done on the sulfide mineralization present deeper in the deposits suggested there was potential for acid rock drainage only if mining proceeded to the deeper portions of the deposit.

Shears and their associated fracture zones are important pathways that have controlled mineralization and the associated ARD development. They form zones where hydrothermal breccias could be emplaced and subsequently oxidized in the upper portions of the ore bodies. These fractured oxidized zones were economically viable as they required only blasting, hauling, and leaching, no crushing was necessary. This extensive fracturing was also a contributing factor in the development of pre-mining sedimentary paleo-ferricrete deposits. Waters were able to infiltrate through mineralized altered fractured zones leaching the metals and depositing them as ferricrete breccias in stream beds and low areas. Additionally the recent decline in Swift Gulch water quality (see below) is directly related to mineralized fracture zones in the Landusky mine area.

The initial realization that acid rock drainage was an issue at the mine sites occurred in the early 1990s, when decreasing pH values in the headwaters of several drainages were noted. Initial attempts to mitigate acid rock drainage via lime amendments of waste rock were ineffective. Environmental reviews by the agencies after 1990 focused on reclamation of older dumps to attempt to address the ARD issues. By 1994, this led the U.S. Environmental Protection Agency (USEPA) and others to file suit against Pegasus in 1994 for water quality violations (Gabelman, 2009).

In September 1996, a Consent Decree between Pegasus, the DEQ, USEPA, a citizen's group, and the Fort Belknap Tribes was signed. The Consent Decree obligated Pegasus to construct water collection systems and water treatment plants, bond for the immediate operation of the water treatment plants, and establish a trust reserve for their long-term operation and maintenance. It also provided for a penalty and required the company to perform ground water, aquatic, health studies, implement monitoring programs, and provide improvements to drinking water on the Fort Belknap reservation (Mitchell, 2004). By 1994, the total acreage disturbed at both sites was over 500 hectares.

Pegasus Bankruptcy

Following the Record of Decision in October of 1996 a reclamation bond of $67.3 million USD (a $45 million increase from the previous bond) was established by the BLM and DEQ. Appeals and court action after that led to a June 1997 decision that stayed the expansion of the mine but allowed ongoing remediation to continue. Six months later in January 1998, Pegasus Gold Corporation filed for Chapter 11 bankruptcy after investment in the proposed Mount Todd project in Australia proved disastrous. In May of 1998, the Agencies reissued a Record of Decision selecting Alternative 3 from the earlier EIS: Mine Expansion Not Approved Mitigated Reclamation. Subsequent legal actions regarding the permit were essentially co-opted by the bankruptcy proceedings. The bankruptcy proceedings were extended, but the end result was: 1) a Supplemental Environmental Impact Statement which was triggered by substantial changes to the proposed action outside the scope of what the original EIS envisioned; 2) substantial funding shortfalls due to the bond in place at the time of bankruptcy; 3) reclamation was performed using a variety of funding sources, including substantial public monies; and 4) the existing water treatment plants have continued to operate.

Closure and Reclamation

Major reclamation was completed by the agencies between 2002 and 2005 and involved resloping, pit backfilling, surface water control and revegetation of reclaimed areas as shown in Fig. 2, below.

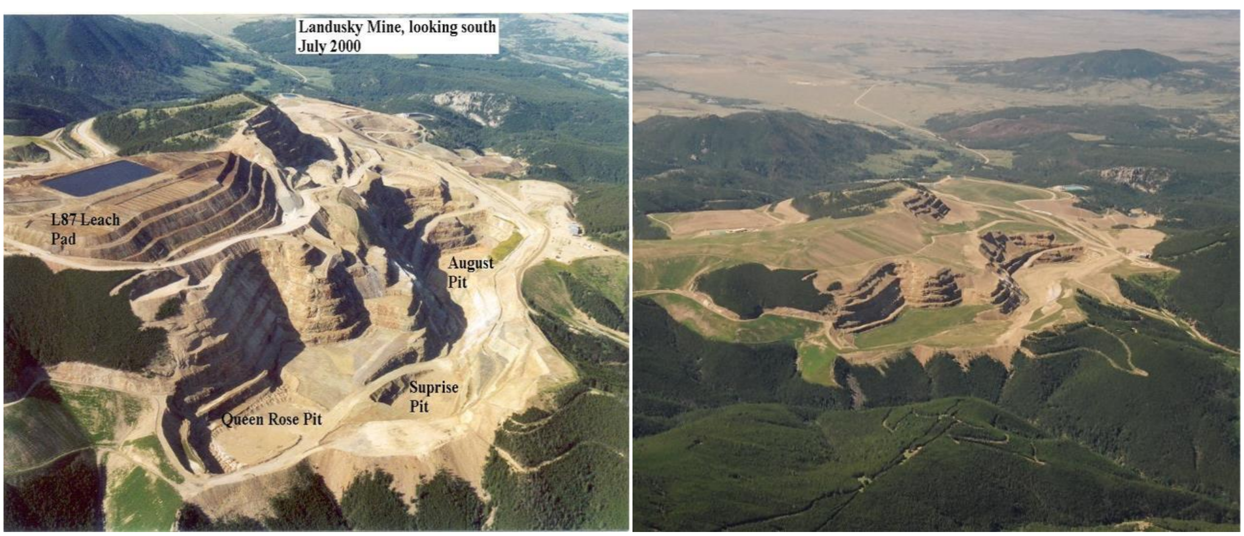

Figure 2. Comparison photos of before and after reclamation of the Landusky Queen Rose-Suprise Pits, 2000-2005. Swift Gulch is immediately below the mine as shown in the picture on the right.

Prior to undertaking this reclamation, a new geochemical evaluation was undertaken to evaluate the limited availability of suitable reclamation material on site as was proposed in the Environmental Impact Statement (EIS) (US DOI and MT DEQ, 1996) and stipulated in the Record of Decision (ROD) (MT DEQ and US DOI, 1998). This geochemical evaluation had two primary objectives; first, to prioritize reclamation efforts by identifying the location, extent, and probable current and future contaminant loads from the various facilities on the site. The second objective was to identify candidate sources on site for use as construction materials in cover and remediation purposes.

The geochemical characterization program was comprised of an assessment of historic information, a field reconnaissance survey, a drilling campaign and laboratory testing. Confirmation lab testwork conducted included paste pH and paste conductivity measurements on the as-received ‘fines’, modified acid base accounting (ABA) tests, inorganic carbon and leach extraction analyses, forward acid titration (of Acid Buffering Characteristic Curves), multi-element ICP, net acid generation (NAG) tests and sieve analyses.

The evaluation clearly showed that the rock with total sulfur contents greater than 0.2% had become acidic when weathered, with field paste pH values less than 5.0 (Shaw, 2000). Very little neutralization or buffering capacity was available in the associated rock types, other than what had been added to the heap leach pads in the form of lime and/or caustic soda. Acid Potential or AP values were relatively low, 0 to 30 kg $CaCO_3$/tonne, typically < 20 $CaCO_3$/tonne; however NP values were also negligible 0 to 30 kg $CaCO_3$/tonne, typically < 10 $CaCO_3$/tonne, with the result that any acidity production from oxidation of pyrite was immediately translated into runoff with low pH and high dissolved metal concentrations (Shaw,2000).

The results were used to map the ARD/Metal Leaching (ML) potential for various facilities and to provide a mass loading evaluation of these facilities (Shaw, 2000). Reclamation efforts have been focused on reducing infiltration and therefore contaminant loading from the various waste facilities, while relying on and optimizing water management, collection and treatment. The only drainage on Landusky that did not have an existing seepage collection system at the time of these evaluations was Swift Gulch, which is discussed below.

Water Treatment

Water treatment plants were constructed in 1994 (Zortman) and 1997 (Landusky) to treat waters impacting the major drainages, Ruby Gulch and Mill Gulch and have continued to operate since then. The Zortman water treatment plant treats an average of 360 million liters of water per year at an average cost of \$0.002/L. The Landusky plant treats an average of 790 million liters of water per year at an average cost of \$0.0004/L. Both treatment plants use standard lime addition technology to treat the impacted water. Average influent and effluent values for selected contaminants of concern are shown in Tables 1 and 2.

Table 1. Average influent and effluent values for the Zortman Water Treatment plant

Zortman Mine Water Treatment Plant Water Quality			
Parameter	**Typical Captured Water**	**Typical WTP Treated Water**	**Water Quality Standard**
pH (s.u.)	3.7	7.0	6.5 – 8.5
TSS (mg/l)	20	25	20
Sulfate (mg/l)	3000	2600	N/A
Cyanide (mg/l)	ND	ND	0.0052
Arsenic (mg/l)	0.227	0.0013	0.010
Copper (mg/l)	6.95	0.011	0.031
Cadmium (mg/l)	0.218	0.007	0.005
Iron (mg/l)	40	0.5	1.0
Lead (mg/l)	0.005	<0.003	0.015
Manganese (mg/l)	35	3.5	N/A
Mercury (mg/l)	ND	ND	0.00005
Selenium (mg/l)	0.012	0.009	0.005
Zinc (mg/l)	7.02	0.02	0.388

In 2002 a bioreactor was constructed at Landusky for removal of NO_3, CN, and Se from leach pad solutions. The biological treatment plant has required modification on several occasions: first due to rapid decline in pH of the leach pad waters, and associated increase in metal concentrations (notably Al) that was much faster than expected requiring pre-treatment for NO_3 reduction. Pre-treatment via NaOH addition and a settling pond was added in 2002 for neutralization and sludge removal. This pre-treatment method has proven inadequate due to ineffective settling of solids, and is anticipated to be replaced by a $Ca(OH)_2$ neutralization process and an additional clarifier. The bioreactor plant treats an average of 144 million L of water per year at an average cost of $0.003/L.

Table 2. Average influent and effluent values for the Landusky Water Treatment Plant.

Landusky Mine Water Treatment Plant Water Quality			
Parameter	**Typical Captured Water**	**Typical WTP Treated Water**	**Water Quality Standard**
pH (s.u.)	5.0	7.7	6.5 – 8.5
TSS (mg/l)	20	7	20
Sulfate (mg/l)	991	900	N/A
Cyanide$_{(total)}$ (mg/l)	<0.005	ND	0.0052
Arsenic (mg/l)	0.15	0.008	0.010
Copper (mg/l)	0.11	0.004	0.031
Cadmium (mg/l)	0.04	0.002	0.005
Iron (mg/l)	18.8	0.3	1.0
Lead (mg/l)	0.004	<0.003	0.015
Manganese (mg/l)	7.6	3.0	N/A
Mercury (mg/l)	ND	ND	0.00005
Selenium (mg/l)	0.004	0.004	0.005
Zinc (mg/l)	1.72	0.07	0.388

Since reclamation was completed in 2005, ongoing work has consisted of continual operation of the three water treatment plants and routine upkeep of the existing reclaimed facilities. For most of the minesite this work has proven to be quite effective at accomplishing the goals of preventing off-site water quality impacts via capture and treatment, and improving wildlife habitat via revegetation. The average collective cost per year of maintaining the water treatment plans and reclamation has been US$1.5M. Combined state and federal agency funding to support the reclamation and water treatment expenses to date have totaled approximately US$9.5M. These expenses are public funds above and beyond funds available through the pre-existing bond and bankruptcy settlement. Funding has been coordinated between Montana DEQ and BLM but is not assured into the future.

Swift Gulch

Swift Gulch is a small headwater stream, which drains the area north of the Queen Rose-Surprise pits as noted in Fig. 2 above and Fig. 4 below. It was the only drainage in which there was not a pre-existing seepage collection system, and therefore relied solely on source control provided by covers to reduce infiltration. Subsequent to mine closure ARD issues have developed in Swift Gulch. This gulch contains a small headwater stream which drains from north of the Queen Rose and Surprise pits on the northern end of the Landusky mine to the Fort Belknap reservation. Typical average flow for Swift Gulch is < 50 L/sec. Ferricrete deposits, which formed before mining began, have been recognized in Swift Gulch (Fig. 3).

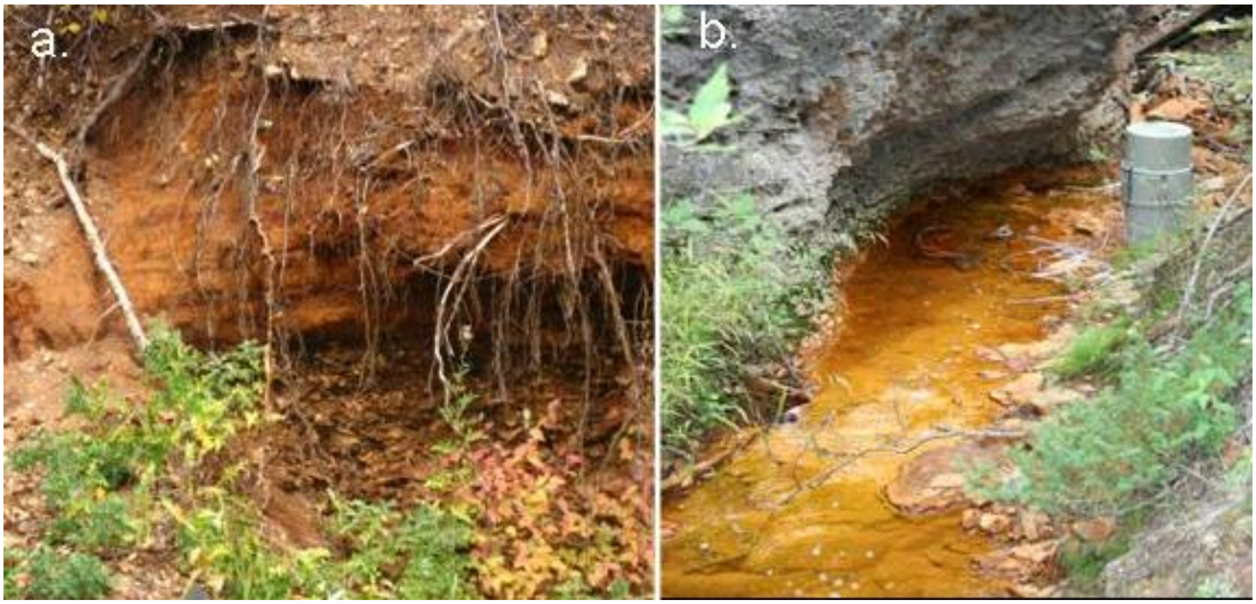

Figure 3. Photographs of Swift Gulch: a) ancient ferricrete-cemented soil forming a bench above the modern streambed; b) the stream during late summer baseflow conditions at monitoring station L-19 (the automated sampler in the background is roughly 1 m tall).

These deposits were carbon dated at 10,350 years before present by (Gabelman et al., 2005). The effects of mine-related ARD/ML on water quality in Swift Gulch were identified during reclamation of the site, although impacts at that time were considered low relative to other issues and it was hoped that reclamation measures on the site would further reduce and ideally arrest impacts to the drainage. Higher ARD contamination associated with this shear zone has appeared in the last 10 years in Swift Gulch. Nimick et al. (2009) subsequently recognized that based on a detailed comparison of the trace element concentration in the ancient and modern Fe-oxide precipitates; the present-day loading of metals and acidity in Swift Gulch is much greater than pre-mining conditions. The presence disseminated sulfides in the Swift Gulch porphyry and the correlation with fractures and shears of the Landusky zone are an influence on the gulch. Clearly ARD issues in Swift Gulch are complicated and have occurred significantly before mining and after mining. Because Swift Gulch flows onto the Fort Belknap Indian Reservation, this decline in water quality is a particularly sensitive issue and has resulted in detailed studies to better understand the reason(s) for the decline in water quality and to search for potential treatment options.

Studies conducted in Swift Gulch have shown that concentrations of Fe, Zn, and other contaminants of concern (As, Cu, Ni, Mn) in Swift Gulch and in a prominent spring referred to as BKSP2E have increased steadily since 1999 (Fig. 4). A zone of intense fracturing, shearing, and hydrothermal alteration is believed to form a hydraulic connection between mineralized rock at Landusky and upper Swift Gulch. In addition to Swift Gulch being an area of high fracturing and hydraulic conductivity, the rock contains up to several percent sulfide, particularly below the water table where the sulfides have not been oxidized. It is conceivable that as mining occurred the water table was lowered which allowed for the oxidation of in-situ sulfides and that when mining ceased the rebounding water table flushed the oxidation products from the sulfides out towards Swift Gulch. Evidence for the influence of the shear /fracture zones on the geochemistry of Swift Gulch is that the stream gains a large volume of water where the shear zone crosses the stream, with a 10x increase in flow over a 500 m reach (Kill Eagle et al., submitted) and that much of this discharging groundwater has very high metal concentrations (e.g., up to 490 mg/L Fe, 22 mg/L Zn). Most of the Fe in the springs is Fe^{2+}, but oxidation and hydrolysis occur rapidly upon exposure to air, causing a rapid decrease in stream pH from values above 6 to values below 3.5. The overall reaction can be written as follows:

$$Fe^{2+} + 5/2H_2O + 1/4O_2 = Fe(OH)_3(s) + 2H^+ \qquad (1)$$

Lower Swift Gulch is naturally a losing stream, and historically would cease to flow for many months of the year. However, the hydrous ferric oxide precipitates formed via reaction (1) have created an impermeable seal on the bottom of the streambed, allowing the AMD-contaminated waters to progress further downstream with each passing year. This is of particular concern because the Swift Gulch drainage enters the Fort Belknap Reservation less than 3 km below L-19, near the left edge of Fig. 4.

Some of the studies in Swift Gulch used geophysical work that have involved the use of two electrical geophysical techniques: Residual Potential Mapping (RPM™), and High Resolution

Resistivity (HRR™) 3D resistivity. This work was completed in autumn of 2008 and has identified locations of conductive shear zones bisecting zones of sulfide bedrock which form a direct conduit from the mine pit to Swift Gulch. This information was used to target drill holes intersecting one of the principal shear zones.

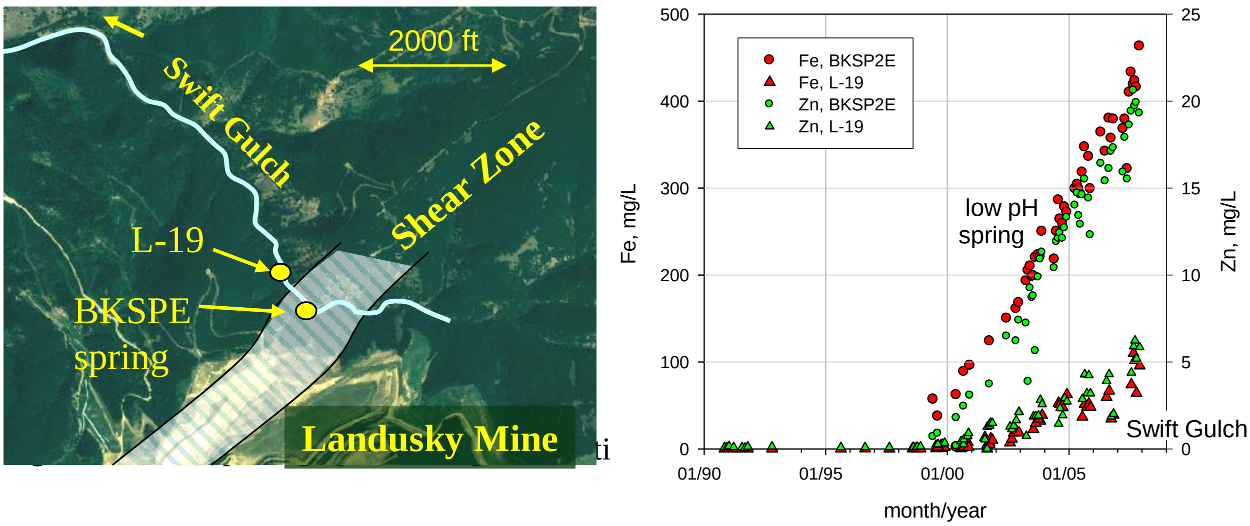

Figure 4. Aerial photograph showing the location of Swift Gulch and monitoring locations in relation to the Landusky Mine. The graph on the right shows long-term trends in concentrations of Fe and Zn at the BKSPE spring and Swift Gulch at L-19.

To mitigate the worsening situation in Swift Gulch, the State of Montana is moving quickly to set up a treatment plant downstream of station L-19 and before the stream enters the Reservation. Because of the remoteness of the location and the very steep terrain, the facility is currently being powered by a portable generator and must be visited weekly to restock fuel and lime. Different treatment technologies (e.g., lime, NaOH) are currently being tested, and management of the appreciable volumes of Fe-oxide sludge is proving to be a challenge. Nonetheless, preliminary tests involving the use of a generator-powered Rotating Cylinder Treatment System ™ (RCTS) show a dramatic improvement in water quality in lower Swift Gulch. Estimated operating parameters for the Swift Gulch RCTS unit are 90 million L per year treated at a cost of $0.0005/L.

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Water treatment options in Swift Gulch, as in many locations in the Mountain states are constricted by limited space in the narrow drainage and logistical considerations, as Swift Gulch is not supported by either the ready availability of power or good roads. The water treatment option being evaluated by the agencies mixes lime with water diverted from the stream, then discharges the treated water to an infiltration pond. The RCTS was installed in the fall of 2008 and initial reports show considerable promise with concentrations of all dissolved metals achieving water quality standards in the effluent.

CONCLUSIONS

The history of this project has demonstrated many lessons learned by both the mining industry and the regulatory agencies, most importantly, developing detailed geologic and geochemical characterization of the site for use in long-term mine planning and closure development. It illustrates the high financial and environmental costs of not addressing these issues up front. This project also highlights the importance of having an adequate financial guarantee mechanism in place to both perform the anticipated reclamation at the site and address water treatment. The long-term public costs for failure to adequately address these issues can substantial and continue for decades.

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