Remediation of acid rock drainage through the use of a constructed passive treatment system which simulates natural processes
by Theodore George Schmidt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University


Abstract:
Acid rock drainage (ARD) exists at many active and abandoned mine sites throughout the Northern Rocky Mountain region. ARD forms when sulfide minerals in rocks are exposed to oxidizing conditions. The conventional treatment of ARD at active mine sites is expensive and may potentially require continuation after the mine is decommissioned. Abandoned mine sites may be located at remote or inaccessible locations where the required infrastructure to treat ARD by conventional methods is not economically or environmentally feasible.

The simulation of natural processes may be a viable alternative to mechanical treatments as these processes do not require extensive operation and maintenance needs and are not manpower intensive after construction. Constructed wetlands attempt to mimic natural processes; however, constructed wetlands in Montana have typically failed to effectively remediate ARD. These failures are primarily attributable to the pretreatment processes or geotechnical design flaws.

A true passive treatment system successfully mimics all natural processes typically involved with the ARD problem; that is, the precipitation of metals and resultant improvement of ARD when contacting good quality, neutral pH water. Additionally, a properly constructed anaerobic wetland, placed down gradient from a metal - precipitating source, will further reduce metal contamination through redox processes and metal retention resulting in a high quality effluent.

Bench-scale tests indicate that a 100:1 mixture of neutral-to-alkaline good quality water with ARD is an effective pretreatment. The metal and sulfate constituents contained in ARD are reduced to near state compliance levels through precipitation as oxides and oxy-hydroxides. Other metals not precipitated in this form may co-precipitate with the metal oxides.

Bench-scale tests indicate that the sludge generated by an oxidation/sedimentation pretreatment pond with a 100:1 ratio will not exceed the maximum permissible levels, as indicated by a TCLP test. Therefore, the sludge may be disposed of in accordance with the mine's operating permit and will not have to be placed in a RCRA approved repository, unless it is generated at a NPL Superfund site or an abandoned mine.

Anaerobic wetlands are able to function at reduced pH levels and function through winter months as a result of stored elemental sulfur and polysulfides which will react with dissolved metals. A constructed anaerobic wetland, in combination with a pretreatment oxidation/sedimentation pond may serve two purposes: 1) the wetland should provide a final polishing step prior to the release of the treated ARD, and; 2) the wetland should provide the necessary treatment of the oxidation/sedimentation pond effluent should the pond's mixture ratio decrease from the designed 100:1 ratio.

# REMEDIATION OF ACID ROCK DRAINAGE THROUGH THE USE OF A CONSTRUCTED PASSIVE TREATMENT SYSTEM WHICH SIMULATES NATURAL PROCESSES

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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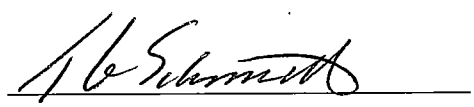
Signature 

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The simulation of natural processes may be a viable alternative to mechanical treatments as these processes do not require extensive operation and maintenance needs and are not manpower intensive after construction. Constructed wetlands attempt to mimic natural processes; however, constructed wetlands in Montana have typically failed to effectively remediate ARD. These failures are primarily attributable to the pretreatment processes or geotechnical design flaws.

A true passive treatment system successfully mimics all natural processes typically involved with the ARD problem; that is, the precipitation of metals and resultant improvement of ARD when contacting good quality, neutral pH water. Additionally, a properly constructed anaerobic wetland, placed down gradient from a metal - precipitating source, will further reduce metal contamination through redox processes and metal retention resulting in a high quality effluent.

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# 1.0 Introduction

## 1.1 Research overview and goals

Golden Sunlight Mines, Inc. (GSM), Whitehall, Montana, provided access to a historic, naturally occurring acid rock drainage (ARD) site, the Midas Spring, and logistical arrangements for research to develop a non-traditional alternative method of treating ARD. The research focused on developing a truly passive and non-manpower intensive constructed water treatment system which mimics natural processes and uses locally and readily available materials.

The specific goals of the research project include:

- ◊ The development of a passive treatment system for ARD
- ◊ Low operation and maintenance requirements
- ◊ The utilization of on-site or locally available materials
- ◊ Long-term effectiveness
- ◊ Compliance with any applicable Montana water quality requirements for livestock, wildlife, and irrigation

## 1.2 Water quality goals

The primary research goal is to produce a final effluent which meets Montana water quality requirements and/or guidelines. Specifically, the target water quality goals for the treated Midas ARD is for livestock/wildlife watering, irrigation, or other agricultural uses.

Standard treatment systems typically utilize lime or lime equivalents to raise the pH of the ARD causing dissolved metals to precipitate out of solution as a sludge. Lime treatment facilities may be in the form of anoxic limestone drains (ALD), oxidation or sediment ponds with limestone substrates, or lime and lime slurry injection systems. Each system is designed to neutralize target contaminants and exhibit varying degrees of metal reduction and acid

neutralization dependent upon the quality of the water treated. However, one commonality exists for all the systems; the need for continuous monitoring and/or renewing of the lime amendment. The science of liming is still evolving and its effectiveness continues to improve. However, a primary drawback to liming methods is the initial infrastructure needed for the treatment system and subsequent operation and maintenance requirements. The attainment of the stated goals may have direct applicability at remote ARD sites or current and proposed mining operations where an extensive treatment infrastructure is not feasible or desirable and would be less environmentally damaging than the construction of mechanized facilities requiring constant maintenance.

Natural wetland systems function as a filtering system which cleanse surface and ground water either through the percolation of surface water through wetland substrates or by removing particulate matter and contaminants prior to returning the water to a lotic system (Dennison and Berry 1993). Additionally, wetland vegetation such as cattails (*Typha spp.*), blue-green algae (e.g.; *Oscillatoria spp.*), and moss (e.g.; *Sphagnum spp.*) have demonstrated an ability to reduce metal contamination through the biological uptake of metals (Kepler 1988; Sencindiver and Bhumbla 1988; Spratt and Wieder 1988).

In areas of natural and man-caused ARD, metals precipitate out of solution when contacting natural, neutral lotic water systems. This is best illustrated by the presence of yellowboy (iron oxyhydroxide precipitates) immediately downstream from the confluence of ARD flow and a natural flow. The objective of this research is to mimic the naturally occurring oxidation and wetland reduction processes, thereby achieving the research goals.

# 2.0 Development of a System to Treat ARD

## 2.1 Background

### 2.1.1 ARD chemistry

Acid rock drainage can occur naturally and in disturbed areas at mine sites, both hard rock and coal, throughout the Rocky Mountain states (Jennings and Dollhopf 1995). Acid rock drainage is generated by the oxidation of pyritic rock, containing sulfide minerals, through exposure to oxygen and water (Jennings and Dollhopf 1995). Iron sulfide minerals present in this material are oxidized producing acidic water with the attendant high concentrations of sulfate, metals (typically iron, aluminum, and manganese), and elevated total dissolved solids (Brodie et al. 1988). The reactions for the oxidation of pyrite by oxygen and water may be written as (Skousen 1995):

$$FeS_2 + 3.5\ O_2 + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad \text{Reaction [1]}$$

$$Fe^{2+} + 0.25\ O_2 + H^+ = Fe^{3+} + 0.5\ H_2O \qquad \text{Reaction [2]}$$

$$Fe^{3+}\ 3\ H_2O = Fe(OH)_3 + 3\ H^+ \qquad \text{Reaction [3]}$$

The three equations may be expressed as (Jennings and Dollhopf 1995; Skousen 1995):

$$FeS_{2(s)} + 15/4\ O_2 + 7/2\ H_2O = Fe(OH)_3 + 2SO_4^{2-} + 4\ H^+ \qquad \text{Reaction [4]}$$

The oxidation of pyrite resulting in the generation of acid is accelerated by the presence of ferric iron, $Fe^{3+}$. At a pH less than 3.5, the ferric iron oxidation of pyrite may become the dominant process. This is expressed by the equation:

$$FeS_{2(s)} + 14\ Fe^{3+} + 8\ H_2O = 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \qquad \text{Reaction [5]}$$

Four moles of $H^+$ are produced per mole of $FeS_2$ and are oxidized by oxygen and water as illustrated by Reaction 1. Sixteen moles of $H^+$ are produced per mole of $FeS_2$ and are oxidized by ferric iron and water as illustrated by Reaction 5. Reaction 5 occurs rapidly and once

initiated, is self-perpetuating or autocatalytic (Jennings and Dollhopf 1995).

Ferric iron precipitates out of solution at a pH greater than 5.0 forming yellow-orange ferric hydroxides (yellowboy) or more complicated oxy-hydroxides (Penn Environmental Consultants 1983; Skousen et al. 1990). Ferrous iron precipitates at a pH greater than 8.0 forming a blue-green ferrous hydroxide (Penn Environmental Consultants 1983; Skousen et al. 1990). It is therefore advantageous to oxidize ferrous iron to ferric iron, rather than rely on the precipitation of ferrous iron at an elevated pH. Manganese oxidizes and hydrolyzes to manganese oxide or hydroxide and precipitates as a black particulate while aluminum precipitates as a white particulate. The extent of these reactions is governed by the pH of the water: little precipitation of manganese occurs at a pH less than 6.0; aluminum less than 4.0, and; iron less than 3.0.

2.1.2 Constructed wetland systems

Constructed wetland treatment systems are divided into three designs (Whitthar 1993):

1) Free-water surface systems (FWS). A FWS consists of water flowing at a low velocity over the top of the substrate and through the vegetation in shallow basins or channels.

2) Subsurface flow systems (SFS). This system is similar to a FWS; however, the water flows through the substrate. A SFS requires less land area but is more difficult to maintain.

3) Aquatic plant systems (APS). An APS is similar in function to a FWS; however, the water is in deeper ponds and the vegetation consists of floating or submerged plants. An APS requires greater maintenance than a FWS.

Free-water systems and aquatic plant systems are considered aerobic wetlands. Aerobic

FWS and APS constructed wetland systems rely on chemical oxidation to remove ARD constituents while anaerobic SFS constructed wetlands rely on reduction processes to remove the constituents. Additionally, aerobic wetland characteristics include: the formation of oxide precipitates; processes which may lower the effluent pH; the potential to freeze or short-circuit during winter months; a required inflow water pH greater than 5.5, and; the ability to remove iron.

Anaerobic SFS constructed wetland characteristics, in addition to reducing processes, include: the ability to precipitate sulfides; processes which may raise effluent pH; a pH requirement greater than 2.5, and; the potential to operate successfully through the winter months. Constructed anaerobic SFS wetlands possess ARD remediation capabilities superior to FWS and APS systems with a significantly improved effluent water quality (Dietz and Stidinger 1996).

### 2.1.3 ARD pretreatment options

#### 2.1.3.1 Anoxic limestone drains

Anoxic limestone drains are employed as a method to increase the pH of the mine drainage while keeping the drainage in an oxygen free state to eliminate the potential for limestone armoring through the oxidation of ferrous iron to ferric iron. Treatment of ARD with this method involves the dissolution of limestone which generates alkalinity by directly neutralizing proton acidity ($H^+$) and producing bicarbonate. The flow of ARD with ferric iron over limestone in an aerobic environment results in limited dissolution as the limestone is quickly armored by ferric hydroxides (Hedin and Watzlaf 1994; Hedin et al. 1991). As limestone dissolves, the hydraulic integrity of the ALD decreases (Hedin and Watzlaf 1994). If the ALD is expected to remove acidity and generate alkalinity through the retention of ferric

iron and aluminum, the demands of the reactions on calcite dissolution should be added to the ALD sizing calculations. The effects on the generation of alkalinity and longevity of the ALD by ferric iron and aluminum hydroxide precipitation and retention can not be confidently predicted and the presence of ferric iron and aluminum in the raw mine water has the potential to significantly and adversely affect an ALD performance (Hedin and Watzlaf 1994). In an anaerobic environment, where iron typically exists in a ferrous state, armoring doesn't occur (Hedin et al. 1991; Schafer and Associates 1994).

The State of Montana, Abandoned Mine Lands, constructed ALDs to be used as a pretreatment for constructed wetlands designed to treat ARD at abandoned mines at Centerville and Stockett, in the Great Falls coal fields. The ALDs all failed due to limestone armoring by metal precipitates and the fouling of buried pipe systems with inorganic precipitates. The ARD at these sites contained elevated concentrations of ferric iron, aluminum, and sulfate which were too high for effective ALD treatment (Schafer and Associates 1994). Skousen (1991) indicates that effluent requirements which may affect the use of ALDs are:

- Flows of less than 100 gpm
- Dissolved oxygen (DO) content less than 2 ppm
- Iron in a ferrous state (Ferric iron precipitates as iron hydroxide in the presence of an elevated alkalinity)
- Aluminum concentrations less than 25 ppm

2.1.3.2 Other lime pretreatments

Dry lime feeders and lime slurry (slaking) feeders are two pretreatment systems utilized to increase the pH of ARD thereby facilitating the precipitation of metals. Dry lime feeders consist of two main parts: a feeder hopper, typically with a throat at the bottom through which

the lime is gravity fed, and; a feeding element (i.e., screw) that can be adjusted to yield varying rates of lime feeding (Penn Environmental Consultants 1983). The feed rate may be adjusted by volume or weight. A volumetric feeder will be constant where the feed rate determined by weight may vary.

Slaking refers to the combination of varying proportions of water and quicklime which yields a milk of lime (slurry) or a viscous lime paste (Penn Environmental Consultants 1983). Considerations for slaking include:

- The reactivity time of the quicklime dependant upon whether the lime is hard, soft, or medium burned
- The particle size and gradation of the quicklime
- Utilization of the optimum amount of water; too little or much will slow the reaction thereby reducing efficiency
- An optimum water temperature
- An even flow of water into the slaking chamber and the proper agitation of the water and quicklime

## 2.2 Research Focus

### 2.2.1 Oxidation/sedimentation pond

The Midas Spring ARD possesses a seasonal ferric iron concentration of 978 mg/L compared to the ferrous iron concentration of 3 mg/L (R. Lazuk, pers. comm.). The use of an ALD was eliminated from research consideration because the elevated ferric iron concentration would render it useless for long-term use.

The other lime pretreatment systems were discounted for the Midas site due to operation and maintenance requirements which are inconsistent with the research goals. Additionally,

precise measurements of the liming material are required to maintain the balance between metal precipitation and the potential for metal resolubilization.

The proposed pretreatment of the Midas Spring consists of an oxidation/sedimentation pond where natural, neutral to alkaline spring, surface flow, or ground water would mix with the ARD resulting in the oxidation of metals. The metal precipitates would settle on and in the pond's substrate resulting in a higher quality effluent. The water mixing within in the pond would mimic the natural chemical processes which occur when ARD mixes with a natural body of water.

It is unknown whether the reduction of dissolved metal concentrations in ARD has been attempted by mixing ARD with neutral pH water flows as a pretreatment system. Extensive literature reviews revealed a paucity of information regarding this subject. A pretreatment settling pond utilizing uncontaminated surface flows was constructed near Boulder, Colorado; however, the ARD passed through an ALD prior to entering the surface flow fed settling pond (Ganse et al. 1993). Implementation of the Upper Blackfoot Mining Complex remediation plan involves construction of a settling pond prior to piping the mine drainage to a constructed wetland complex; however, the mine drainage is pretreated with lime prior to entering the settling pond (McCulley, Frick, and Gilman 1995) in a similar fashion to the Boulder complex. Oxidation or polishing ponds have been utilized as the final step in treating constructed wetland effluent (Ganse et al. 1993). The polishing ponds are aerobic in function and are designed to increase DO content of the drainage to facilitate the final precipitation of any metals remaining in solution prior to release.

### 2.2.2 Constructed anaerobic wetland

The precipitation of metals in a wetland occurs when ARD encounters a natural flow with a neutral or alkaline pH and normal dissolved oxygen content (DO is dependent upon water turbulence and temperature), or when the wetlands act as a filter. Both of these are viewed as natural, passive processes. When these processes are artificially created through a constructed wetland, the desired effect is a passive treatment system.

Studies of constructed anaerobic wetlands show that acid is neutralized and metals precipitate in the substrate where bacterial reductions in sulfate yield alkalinity and sulfide as biochemical by-products (Mudder et al. 1995). The sulfide may precipitate metals as sulfates; yielding low residual dissolved concentrations and high metal removal rates approaching 99 percent.

Winter freeze-up and sulfate reduction are considered the primary concerns for the constructed wetland to treat the Midas Spring ARD. The oxidation/sedimentation pond is anticipated to precipitate out of solution the majority of iron, aluminum, copper, and other metals as oxides, oxyhydroxides, or potentially as sulfides, similar to the naturally occurring oxidation processes. Ferric iron and aluminum precipitate as hydroxides in the form of a gelatinous solid that act as a scavenger with a strong capability of adsorbing other metal ions onto their surface (Wildeman et al. 1993). Consequently, the additional benefit of iron and aluminum removal includes the removal of additional metals.

The Midas Spring ARD contains high concentrations of sulfate ranging from approximately 20,000 mg/L to over 40,000 mg/L. This high sulfate concentration may potentially aid the anaerobic wetland processes in several ways. Dissimilatory sulfate reduction (DSR) is a microbial process commonly occurring in anoxic environments (Hedin et al. 1988).

By-products of DSR are hydrogen sulfide, which reacts with dissolved metals to form sulfide precipitates, and carbonate alkalinity which facilitates the neutralization of ARD acidity. Dissimilatory sulfate reduction is accomplished by heterotrophic bacteria (*Desulfovibrio desulfuricans* and other species) which, in the absence of oxygen, decompose simple organic compounds utilizing sulfate as a terminal electron acceptor (Hedin et al. 1988; Mudder et al. 1995).

The basic sulfate reduction reaction may be stated as (Mudder et al. 1995):

$$SO_4^{-2} + 2C_2H_4O_3^{-1}\ (lactate) = 2C_2H_4O_2^{-1}\ (acetate) + 2\ CO_3^{-2}\ (gas) + S^0 \qquad \text{Reaction [6]}$$

One mole of sulfate is reduced to hydrogen sulfide for every two moles of carbon oxidized. Depending upon the chemical environment, hydrogen sulfide is released as a gas, ionized to $HS^-$ and $S^{2-}$, or precipitated as a polysulfide, elemental sulfur, or iron sulfides (Hedin et al. 1988). Limiting factors affecting DSR in anoxic environments are the availability of suitable organic matter, dissolved sulfate less than 30 ppm, and a pH less than 5.0. Although DSR activity may decrease during winter months (Hedin et al. 1988), the high sulfate concentrations in the Midas ARD should result in high summer DSR activity with the resultant elevated accumulation of elemental sulfur and polysulfides which will react with dissolved metals during the winter period. An additional benefit resulting from the Midas Spring's ARD characteristics is the ability for the constructed wetland to operate at a lower pH as a direct consequence of the high ferric iron content: ferrous iron requires a pH approaching 8.5 to precipitate out of solution (Skousen et al. 1990).

# 3.0 Research Methods

## 3.1 Research site selection and description

The Midas Spring (Figure 1), located on Golden Sunlight Mine property near Whitehall, Montana, was selected for the project research because it provides a perennial flow of water exhibiting the chemical characteristics of ARD (Table 1). The Midas Spring is located at the head of a gulch with approximate seasonal flow rates of between 3.8 - 22.8 liters per minute (LPM) (Lazuk, pers. comm.). The Midas Spring water is presently captured, treated, and used in the ore processing circuit. Historically, the surface flow from the Midas Spring would infiltrate within as few as five meters (m) from where the water surfaced. Ground water monitored through a series of wells constructed in the aquifer down gradient of the spring does not exhibit the characteristics of ARD. The calcareous soil in the area is believed to naturally buffer the ARD emanating from the Midas Spring (Lazuk, pers. comm.). The soil surrounding the Midas Spring is classified as an aridisol possessing the calcareous great groups of calciorthid and torriorthent (Montagne et al. 1982). No soil analysis exists for the Midas Spring area; however, several soil analyses have been conducted in the vicinity of the Midas Spring and the soils possess a pH range from 7.4 to 7.8 (Lazuk, pers. communication).

The Midas Spring site is south of Sheep Rock Spring in Township 2 N, Range 3 W, Section 20, at an elevation of approximately 1832 m. Sheep Rock Spring (Figure 1) is north and in close proximity (approximately 90 m) to the research site, and does not exhibit ARD characteristics (Table 1). The general terrain contains gently rolling hills with upland vegetation. The slope aspect of the Midas site is east-to-southeast. Foothills adjacent to the site slope toward the southeast.

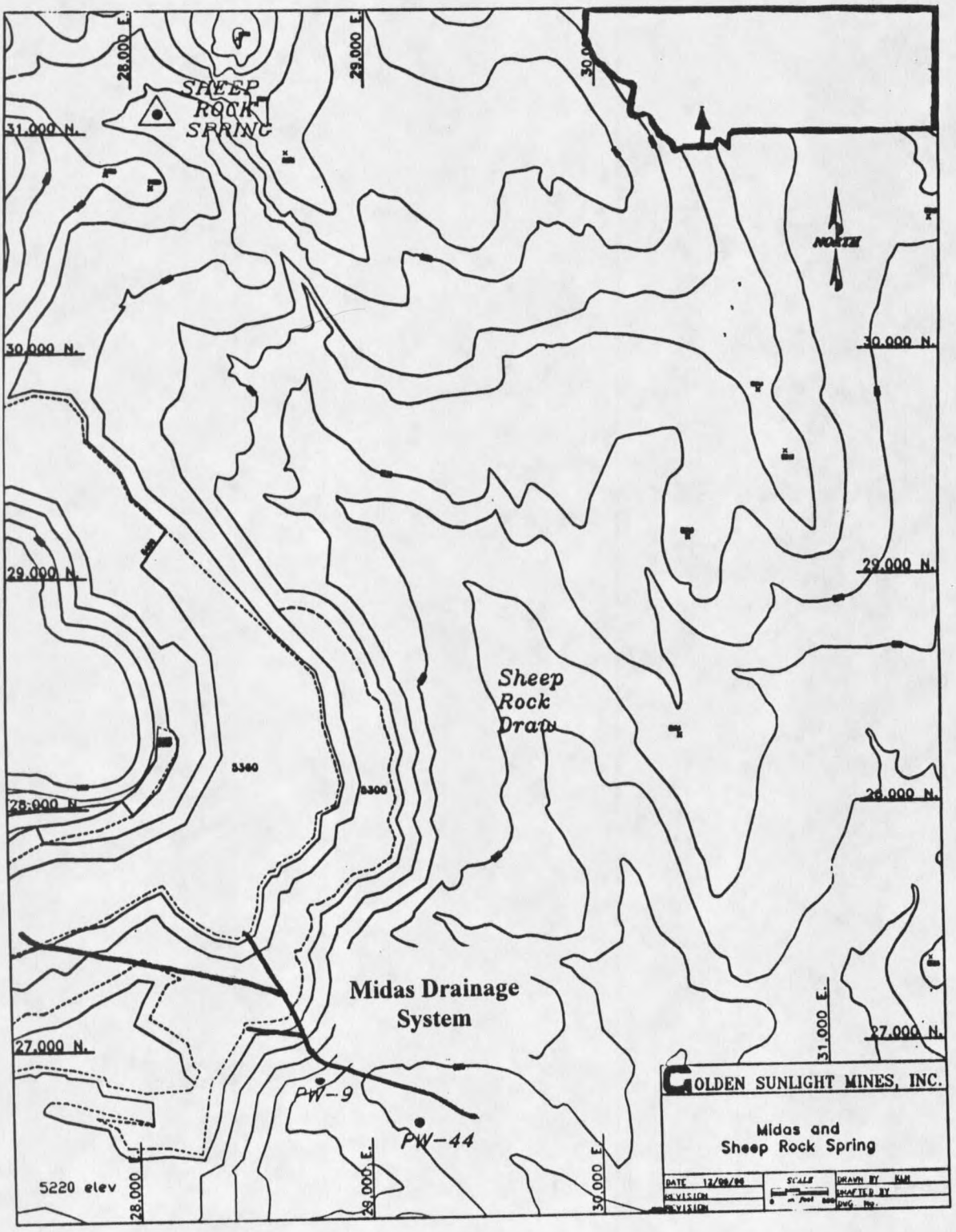


**Figure 1:** **Midas and Sheep Rock Springs**

**Table 1:** **Midas and Sheep Rock Springs water analyses compared to Montana Human Health Standards** ( Energy Labs 1995a,b,c).

| Parameter | Midas Spring Water Sampled 5/95 (mg/L) | Midas Spring Water Sampled 9/95 (mg/L) | Sheep Rock Spring Water Sampled 9/95 (mg/L) | Montana Human Health Standards[2] (converted to mg/L) |
|---|---|---|---|---|
| Sulfate | 41,200 | 23,100 | 164.0 | ---- |
| TDS | 43,500 | 35,500 | 521.0 | ---- |
| pH (su) | 2.3 | Not analyzed | Not analyzed | ---- |
| Aluminum | 5440 | 2820 | <0.1 | .030 |
| Arsenic | 5.7 | 1.5 | <0.001 | .018 |
| Barium | Not analyzed | <0.1 | 0.088 | 1.00 |
| Beryllium | Not analyzed | 0.05 | <0.001 | .040 |
| Cadmium | 0.029 | 0.121 | 0.0001 | .005 |
| Chromium | Not analyzed | 0.7 | <0.001 | 0.10 |
| Copper | 271.0 | 118.0 | <0.001 | 1.00 |
| Iron | 4660 | 1300 | 0.026 | 0.30 |
| Lead | <0.02[1] | 0.044 | <0.002 | 0.015 |
| Manganese | 77.0 | 39.0 | 0.032 | 0.050 |
| Nickel | 23.0 | 11.7 | <0.01 | 0.10 |
| Selenium | 0.010 | 0.039 | <0.001 | 0.050 |
| Zinc | 69.0 | 26.9 | 0.02 | 5.00 |

Note: Dissolved metal analyses.
[1]Detection limit was raised due to sample matrix interference.
[2]Montana Dept. of Environmental Quality 1995

Climatic conditions are typical of semi-arid southwest Montana. Site-specific annual precipitation is approximately 33.8 centimeters (cm) with the majority falling as rain (Scharf, pers. comm.). The maximum 24-hour rainfall is approximately 7.6 (cm). Winter low temperatures may approach minus 40° C, typically higher, with summer high temperatures

ranging to 35° C. The prevailing wind direction is from the south to southwest, although wind direction may be seasonably variable and related to storm events.

## 3.2 Bench-scale tests

### 3.2.1 Oxidation and precipitation

#### 3.2.1.1 Initial bench-scale test

Bench-scale testing was conducted to determine the feasibility of an oxidation/sedimentation pond and the optimum neutral water to ARD ratio. In April, 1996, samples of the Midas Spring and Sheep Rock Spring discharges were collected by GSM personnel for use in testing. These samples were mixed at five ratios of Sheep Rock Spring water to Midas Spring water. The mixing ratios were 1:1, 10:1, 20:1, 50:1, and 100:1.

Four hundred milliliters (ml) of Sheep Rock Spring water was placed in four 500 ml Erlenmeyer flasks. Two hundred fifty ml of Sheep Rock Spring water was placed in the fifth flask. The spring water was then agitated by shaking the flasks to diffuse as much oxygen as possible into solution. After agitation, the Midas Spring water was poured into the flasks in amounts equal to the previously stated ratios. The unused Midas water was retained for future testing. The mixed water was allowed to stand for 120 hours. At this time, the 100:1 mixture was decanted and analyzed for four parameters: sulfate; dissolved aluminum; dissolved iron, and; dissolved manganese. The filtered metal precipitates were retained and air dried for analysis utilizing a scanning electron microscope/energy dispersive analysis of x-rays (SEM/EDAX).

#### 3.2.1.2 Second bench-scale test

The results of the initial bench-scale test suggested a second test using a larger quantity of water to facilitate an analysis for total recoverable metals, in accordance with a list of key parameters in the Montana Department of Environmental Quality (DEQ) Circular WQB-7,

December, 1995 (Montana Numeric Water Quality Standards).

The initial test indicated that the 100:1 mixture generated the greatest amount of precipitate; therefore, only a 100:1 mixture was prepared. Additional Sheep Rock Spring water was collected by GSM personnel May, 1996, for the test. The previously collected Midas Spring water was used. 4500 ml of Sheep Rock Spring water was divided equally into two flasks and agitated to diffuse oxygen into solution. The DO was measured with a Hach water chemistry kit utilizing standard fisheries titration techniques. The DO was approximately 9 mg/L at a room temperature of 25° C. This represents almost total saturation at room temperature as DO saturation is dependent upon temperature with an increased saturation occurring a lower water temperatures. For instance, a DO content of 14 to 15 mg/L at 0° C would represent almost total saturation (Cole 1983). Forty-five ml of the Midas water was then divided equally into the flasks.

After 42 hours, the test mixture was transferred to plastic sample bottles utilizing a peristaltic pump to avoid the resuspension of precipitated metals. The sample was preserved with $HNO_3$ for analysis. Additionally, unmixed samples of Sheep Rock Spring and Midas Spring water were preserved and analyzed to facilitate a complete comparison of the test results.

3.2.1.3 Third bench-scale and TCLP test

A third bench-scale test was performed to determine the dissolved metal concentrations in the test water and to generate enough precipitated sludge to allow for a Toxic Characteristics Leaching Procedure (TCLP) analysis. A TCLP test was required as the Resource Conservation Recovery Act of 1976 (RCRA) mandates that sludge generated from treatments be tested to determine whether the sludge will require storage in a RCRA-approved repository. The TCLP test consists of an evaluation of eight metal extracted from the precipitated sludge: arsenic as

As; barium as Ba; cadmium as Cd; chromium as Cr; lead as Pb; mercury as Hg; selenium as Se, and; silver as Ag. Maximum values have been established and the exceedance of any one of the measured parameters would result in the deposition of the sludge in an appropriate RCRA repository.

As with the second bench-scale test, only a 100:1 mixture of Sheep Rock Spring to Midas Spring water was created. Approximately 37.85 liters (L) of Sheep Rock water was mixed in two buckets with 378.5 ml of Midas Spring water. After 24 hours, the test water was decanted and approximately 0.95 L of sludge was placed in a plastic container. The test water was not preserved or filtered until it was received by the testing laboratory. The precipitate sludge was analyzed in accordance with SW-846, Test Methods for Evaluating Solid Waste (updates I, II, IIA, and IIB).

## 4.0 Analysis Results

### 4.1 Initial bench-scale test results

Subsequent to the five mixings of the Sheep Rock and Midas Spring waters, a pH determination was made using field testing equipment. The pH of Sheep Rock Spring was 7.69 while the Midas Spring water had a pH of 2.40. Immediately after mixing, the pH of the test water was highly variable, dependent upon the ratio of Sheep Rock to Midas Spring water. The pH of the mixed water ranged from 2.69 to 6.40 with visible reactions (Table 2).

**Table 2: Initial observations and pH levels of the five Sheep Rock and Midas Spring mixing ratios.**

| Water Ratios Sheep Rock:Midas (Volume Basis) | pH (su) 10 Minutes After Mixing | Observations |
|---|---|---|
| No mixing | Midas 2.40<br>Sheep Rock 7.69 | The Midas water has an orange tint. The Sheep Rock water is clear. |
| 1:1 | 2.69 | The water was slightly clearer than the Midas but still very orange. Some flocculent was evident. No precipitation was visible. |
| 10:1 | 3.02 | The water was slightly clearer than the 1:1 mixture, but still cloudy and the same orange color. Some flocculent evident. Precipitation of iron was visible. |
| 20:1 | 3.77 | The water was a light yellow-white color. Iron precipitation evident on the flask bottom. Suspended solids were visible. |
| 50:1 | 4.22 | The water was white and slightly cloudy. Iron precipitates visible on the bottom of the flask. suspended solids were visible. |
| 100:1 | 6.40 | The water was a very light white and slightly cloudy. Iron (orange) and aluminum (white) precipitates highly visible on the bottom of the flask. The suspended solids were barely visible. |

The retention time in the oxidation/sedimentation pond is critical for oxidation reactions to occur. The initial bench-scale test indicated that visible iron precipitation occurs almost instantaneously at mixture ratios greater than 10:1. Aluminum, in mixture ratios greater than 20:1, was observed to precipitate at approximately the same rate; however, the precipitates remained suspended for a longer period of time. All the aluminum precipitates settled within 24 hours. For the purpose of determining the optimum retention time, the mixed water was allowed to stand for 120 hours. The pH was measured and visual observations recorded after 24, 48, and 120 hours (Table 3).

**Table 3: pH measurements and visual observations after 24, 48, and 120 hours.**

| Water Ratios Sheep Rock:Midas (Volume Basis) | pH @ 24 Hrs. (su) | pH @ 48 Hrs. (su) | pH @ 120 Hrs. (su) | Observations After 24 Hours* |
|---|---|---|---|---|
| 1:1 | 2.52 | 2.44 | 2.44 | No visible change during the test period. |
| 10:1 | 2.91 | 2.82 | 2.81 | The test water appeared slightly clearer with some iron precipitates evident. |
| 20:1 | 3.60 | 3.50 | 3.49 | The top ½ of the test water was clear with no visible suspended solids. Iron precipitate evident. |
| 50:1 | 4.04 | 3.99 | 4.02 | The top ½ of the test water was clear with no visible suspended solids. Iron and some aluminum precipitation evident. |
| 100:1 | 6.03 | 5.79 | 6.21 | The top 2/3 of the test water was very clear with no suspended solids evident. Iron and aluminum precipitates highly visible. |

* Note: no visible changes occurred after the first 24 hour period.

The 100:1 test water was the only sample to consistently maintain a pH level elevated enough to precipitate the aluminum (little aluminum precipitation occurs at a pH less than 4.0). The pH of the 100:1 sample ranged from 5.9 to 6.40. The testing also suggests that the designed oxidation/sedimentation pond would need to maintain a high (> 50:1) neutral spring water to Midas ratio for enhanced and prolonged precipitation results.

The 100:1 test water mixture was decanted and analyzed. The test water was analyzed for dissolved iron, aluminum, and manganese. Sulfate and other metals were not analyzed as they were not anticipated to have been notably reduced by the mixing. The Midas sample was analyzed for the same dissolved metals as the test mixture (Table 4).

**Table 4:** **Metal constituents present and percent of reduction occurring during the first bench-scale test** (Energy Labs 1996).

| Constituent Analyzed | Midas Spring Water (mg/L) | 100:1 Test Water Sheep Rock:Midas (mg/L) | % Reduction |
|---|---|---|---|
| Dissolved Aluminum | 4,070 | 0.30 | 99.99 |
| Dissolved Iron | 1580 | 0.11 | 99.99 |
| Dissolved Manganese | 96.4 | 0.80 | 99.17 |

After the mixture was decanted, the precipitates were filtered and air dried for analysis utilizing a SEM/EDAX. The elemental components of the SEM/EDAX analysis include oxygen, aluminum, silicon, sulfur, calcium, iron, copper, and phosphorus (Table 5). Manganese was not present in the elemental analysis despite the fact that a 99.17 percent reduction occurred during the water test. This may be a result of the initial concentration being too low for detection by the SEM/EDAX. The detection limits are approximately 0.5 percent by weight or 5000 mg/kg. Aluminum represented the greatest elemental percentage of metals present while iron

**Table 5: Approximate element concentrations present in the precipitate generated by the first bench-scale test.**

| Element Present | Element Concentration % |
|---|---|
| Oxygen | 57.75 |
| Aluminum | 23.01 |
| Silicon | 1.80 |
| Sulfur | 5.13 |
| Calcium | 0.51 |
| Iron | 10.76 |
| Copper | 0.84 |
| Phosphorus | 0.20 |

was the second highest. This is not surprising as past analyses (Table 1) indicate high concentrations of dissolved iron and aluminum.

The elevated concentrations of dissolved aluminum and iron likely precipitated as oxy-hydroxides in the test solution as indicated by the high amount of elemental oxygen; however the presence of elemental sulfur indicates that some precipitation of metal sulfides or sulfates also may have occurred. The reduction of manganese and copper may be a result of scavenging by iron and aluminum hydroxides (i.e., adsorbing the metal ions onto their surfaces). In addition, the effects of dilution may also have importance in lowering the concentrations of the constituents.

### 4.2 Second bench-scale test results

The 100:1 mixture test water was analyzed following a partial list of key parameters in the Montana Department of Environmental Quality (DEQ) Circular WQB-7, December, 1995, (Montana Numeric Water Quality Standards). In addition to the test water, Midas Spring and

Sheep Rock Spring water samples were also analyzed for the same parameters, facilitating a side-by-side comparison. The laboratory analysis included total recoverable metals, nutrients, sulfate, and other parameters (Appendix B). The pH of the test water was recorded after the initial mixing had occurred. The pH was remeasured after 24 and 42 hours. Visual observations were also recorded (Table 6).

The visual observations of the second bench-scale test were consistent with the previous test observations. The SEM/EDAX analysis of the initial bench-scale test precipitates (Table 5) indicated the presence of aluminum, iron, copper, and sulfur and it was anticipated that major reductions of total recoverable metals and other constituents would occur.

**Table 6: pH measurements and visual observations of the second bench-scale test.**

| Test Time (Hours) | pH Measurements (su) | Observations |
|---|---|---|
| 0.5 | 6.14 | Immediate formation of iron precipitate on the bottom of the flask with a milky white (aluminum precipitate) solution appearance. Suspended solids visible in the water. |
| 24.0 | 6.45 | Iron and aluminum precipitates highly visible on the bottom of the flask. The water was clear with no visible suspended solids. |
| 42.0 | 6.28 | No change from the 24 hour observation |

The highest reductions occurred in the total recoverable iron (> 99.99%), aluminum (> 99.99%), manganese (99.49%), copper (99.70%), zinc (99.44%), and lead (> 70.0%). Reductions in sulfate (98.72%), electrical conductivity (95.35%), and total dissolved solids (98.63%) also occurred and may be considered as a partial reduction through dilution. With the notable exceptions of copper and zinc, all the measured parameters of the treated Midas Spring

water comply with State of Montana Circular WQB-7 (12/95) Aquatic Life Standards (Table 7).

The aquatic life standards are included in Table 7 for comparison purposes only, as no surface release of the treated water is proposed at the constructed anaerobic wetland site. The comparison does provide a good indication of the potential effectiveness of an oxidation/sedimentation pond as a passive pretreatment facility.

The guidelines for specific metals including cadmium, copper, lead, nickel, and zinc are dependent upon the total hardness (mg/L, $CaCO_3$) of the water. The standards provided in the text of Circular WQB-7 are based on a hardness of 100 mg/L, $CaCO_3$. Where the hardness is other than this value, a formula is provided to derive the appropriate standard. The formula for acute standards is:

$$\text{Acute} = \exp\{ma[\ln(\text{hardness})] + ba\}$$

The formula for chronic standards is:

$$\text{Chronic} = \exp\{mc[\ln(\text{hardness})] + bc\}$$

The factors for ma, ba, mc, and bc are given for the formula relative to each metal. Where the hardness is greater than or equal to 400 mg/L of $CaCO_3$, 400 mg/L shall be used in the calculation (DEQ 1995). The standards in Table 7 were developed utilizing the above referenced formulas. The calculation for the aquatic life standards for zinc is:

$$\begin{aligned}\text{Acute} &= \exp\{0.8473[\ln(400)] + 0.8604\} \\ &= \exp\{0.8473(5.9914) + 0.8604\} \\ &= \exp(5.9369) \\ &= 378.7846 \text{ (or } 379 \mu g/L)\end{aligned}$$

$$\begin{aligned}\text{Chronic} &= \exp\{0.8473[\ln(400) + 0.7614 \\ &= \exp\{0.8473(5.9914) + 0.7614 \\ &= \exp(5.8379) \\ &= 343.0626 \text{ (or } 343 \ \mu g/L)\end{aligned}$$

**Table 7:** **Total recoverable metal analysis of the second bench-scale test water compared with Aquatic Life Standards** (Maxim Technologies, 1996a).

| | | | Comparison to Standards | |
|---|---|---|---|---|
| **Parameter** | **Midas Water (mg/L)** | **Water Mixture 100:1 (Sheep Rock: Midas) (mg/L)** | **Water Mixture 100:1 (Sheep Rock: Midas) ($\mu$g/L)** | **WQB-7 Aquatic Life Standards ($\mu$g/L) Acute/Chronic** |
| Acidity/$CaCO_3$ | 27,500 | <2 | not applicable | ---- |
| Sulfate | 33,400 | 427 | not applicable | ---- |
| EC ($\mu$mhos/cm) | 19,100 | 887 | not applicable | ---- |
| pH (su) | 2.6 | 6.2 | 6.2 | ----/6.5-9.0 |
| TDS | 50,700 | 694 | not applicable | ---- |
| Aluminum | 8750 | 0.5 | 500 | 750/87 |
| Arsenic | 1.2 | <0.003 | <3.0 | 360/190 |
| Barium | 0.36 | 0.076 | 76 | ---- |
| Beryllium | 0.25 | <0.001 | <1.0 | ---- |
| Cadmium | 0.39 | 0.002 | 2.0 | 19/3 |
| Chromium | 1.2 | <0.001 | <1.0 | ---- |
| Copper | 286 | 0.86 | 860 | 65/35 |
| Iron | 2540 | 0.05 | 50 | ----/1000 |
| Lead | <0.01 | <0.003 | <3.0 | 477/18 |
| Manganese | 135 | 0.69 | 690 | ---- |
| Nickel | 24.0 | 0.13 | 130 | 4582/509 |
| Selenium | 0.030 | 0.001 | 1.0 | 20/5 |
| Zinc | 70.2 | 0.39 | 390 | 379/343 |

---- No standards have been developed

Each treated water constituent analyzed was less than the chronic levels for Aquatic Life with the exception of aluminum, copper, and zinc. Aluminum was higher than the chronic level but well below the acute standards. Zinc exceeded the acute standards by a small percent (<3%). Copper was considerably higher than the acute standards. A required reduction in copper, zinc, and other metal levels may be accomplished through an additional, successive oxidation/sedimentation pond or through the use of a constructed anaerobic wetland. However, if a second oxidation/sedimentation pond is utilized, the potential for the pH to increase to a level where aluminum would resolubilize may exist. This is highly unlikely as it would require an increase in the pH of the Sheep Rock Spring water. It is considered that aluminum will resolubilize at pH levels approaching 8.5 (Penn Environmental Consultants, Inc. 1983; Skousen et al. 1990).

### 4.3 Third bench-scale test results

One of the stated research goals is that effluent quality meet Montana water quality requirements. One potential use of the treated Midas Spring water is for development as a livestock/wildlife watering pond or as a water source for irrigation. No specific dissolved metal standards exist in Montana regarding livestock and wildlife or irrigation use; however, several states and countries have developed specific guidelines regarding livestock, wildlife, and irrigation water quality.

In a comparison with the May, 1995, Midas Spring water analysis, the test water contained substantially reduced levels of sulfate and dissolved metals. The comparison and percent of reduction for selected constituents is contained in Table 8.

The effluent entering an unlined livestock/wildlife watering pond may potentially seep to the underlying ground water. Table 9 compares the analysis of the third bench-scale test water

(Appendix A) with livestock/wildlife guidelines, irrigation guidelines, and ground water human health standards. Human health standards are included in Table 9 since any impounded water could percolate downward toward the underlying ground water supplies. The 100:1 mixture test water meets the established guidelines for livestock/wildlife and irrigation water. However, the treated water fails to meet the established human health standards for aluminum, manganese, and nickel. The other analyzed parameters are well within Circular WQB-7 standards for ground water and human use.

**Table 8:** **Comparison of the May, 1995, Midas Spring water analysis with the third bench-scale test water analysis** (Maxim Technologies 1996b; Energy Labs 1995a).

| Parameter | Midas Spring Water mg/L | Test Water mg/L | Percent of Reduction |
|---|---|---|---|
| Sulfate | 41,200 | 477 | 98.8 |
| TDS | 43,500 | 735 | 98.3 |
| pH (su) | 2.3 | 6.3 | N/A |
| Aluminum | 5440 | <0.1 | >99.9 |
| Arsenic | 5.7 | <0.003 | >99.9 |
| Cadmium | 0.029 | <0.0005 | 98.2 |
| Copper | 271 | 0.37 | 99.9 |
| Iron | 4660 | <0.02 - 0.1 | >99.9 |
| Lead | <0.02 | 0.013 | unknown |
| Manganese | 77.0 | 1.21 | 98.4 |
| Nickel | 23 | 0.25 | 98.9 |
| Zinc | 69 | 0.51 | 99.3 |

**Table 9:** **Analysis of the third bench-scale test compared with livestock/wildlife and irrigation guidelines, and human health ground water standards** (Maxim Technologies, 1996b).

| | | | | Comparison to Standards | |
|---|---|---|---|---|---|
| Parameter (Dissolved) | Mixture 100:1 (Sheep Rock: Midas) (mg/L) | Irrigation Guideline Range[1] (mg/L) | Stock/Wildlife Guideline Range[2] (mg/L) | Mixture 100:1 Sheep Rock:Midas) ($\mu$g/L) | Circular WQB-7 Human Health Standards ($\mu$g/L) |
| Acidity | <2 | ---- | ---- | <2 | ---- |
| Sulfate | 477 | 200 - 1000 | 1000 - 5000 | 477 | ---- |
| EC ($\mu$mhos/cm) | 947 | 750 - 2250 | ---- | 947 | ---- |
| pH (su) | 6.3 | 4.5 - 9.0 | 5.6 - 9.0 | 6.3 | ---- |
| TDS | 735 | 500 - 1500 | 5000 - 7000 | 735 | ---- |
| Aluminum | <0.1 | ---- | ---- | <100 | 30 |
| Arsenic | <0.003 | 0.1 - 5.0 | 1.0 - ---- | <3.0 | 18 |
| Barium | 0.089 | ---- | ---- | 89 | 1000 |
| Beryllium | <0.002 | ---- | ---- | <2.0 | 40 |
| Cadmium | <0.0005 | 0.05 | .01 - 5.0 | <0.5 | 5 |
| Chromium | <0.002 | 5.0 | 1.0 - ---- | <2.0 | 100 |
| Copper | 0.37 | 0.2 - 5.0 | 1.0 - 5.0 | 370 | 1000 |
| Iron* | <0.02 - 0.1 | 20.0 | ---- | <20 - 100 | 300 |
| Lead | 0.013 | 5.0 - 10.0 | 0.1 - ---- | 13 | 15 |
| Manganese | 1.21 | 10.0 | ---- | 1210 | 50 |
| Nickel | 0.25 | 0.5 - 2.0 | 5.0 - ---- | 250 | 100 |
| Selenium | <0.001 | 0.05 | 0.05 - 0.01 | <1.0 | 50 |
| Zinc | 0.51 | 5.0 | 5.0 - 25 | 510 | 5000 |

* Iron results were tested three times with two separate results. 0.02 appears valid but not reproducible

---- No standards have been developed

[1]Clark 1978

[2]Schafer and Associates 1994; Clark 1978; Environment Canada 1979-1983

## 4.4 TCLP test results

Approximately 0.95 L of precipitate sludge was generated through the mixing of 37.85 L of Sheep Rock Spring water and the Midas water at a 100:1 mixing ratio. The TCLP analysis results (Maxim Technologies 1996c) are summarized in Table 10 and presented in Appendix C.

**Table 10: TCLP analysis results of the precipitate sludge generated through the mixing of 37.85 L of Sheep Rock Springs water with 378.5 ml of Midas Spring water.**

| Test Parameter | Measured Value as mg/L (100:1 Mixture) | Maximum Permissible Limits as mg/L[1] |
|---|---|---|
| Arsenic as As | 0.008 | 5.0 |
| Barium as Ba | 0.21 | 100.0 |
| Cadmium as Cd | 0.95 | 1.0 |
| Chromium as Cr | <0.02 | 5.0 |
| Lead as Pb | <0.01 | 5.0 |
| Mercury as Hg | 0.006 | 0.02 |
| Selenium as Se | 0.03 | 1.0 |
| Silver as Ag | <0.05 | 5.0 |

[1]EPA SW-846, Test Methods for Evaluating Solid Waste, Method 1311.

All the constituents were found to be well within the maximum permissible limits. Only cadmium, with a measured value 0.05 mg/L less than the permissible limit, may present a potential storage problem. The need for additional testing is indicated by this result as the 0.95 mg/L of cadmium is essentially identical to the maximum permissible limit.

# 5.0 Oxidation/sedimentation Pretreatment Pond Design for the Midas Spring Water

## 5.1 Pond design

The simulation of natural processes utilizing the oxidation/sedimentation pond requires several components: 1) an adequate year-round supply of water of similar quality as Sheep Rock Spring; 2) the ability to maintain a high neutralization water to ARD ratio, and; 3) the ability to diffuse and maintain an elevated DO content. Additionally, potential sidehill runoff resulting in sedimentation of the pond, winter freeze-up, and the resuspension of solids by wind are of concern. Studies in Colorado indicate that the ultimate success of the system may depend more upon the geotechnical design rather than the optimization of the chemical processes (Ganse et al. 1993).

Very large ponds may assume the limnological properties of a small lake and experience spring and fall turnover (Penn Environmental Consultants, Inc. 1983). During the summer period, the epilimnion warms with freely circulating water and a decreased DO content. A decrease in the DO content reduces the effectiveness of oxidation/sedimentation ponds through a reduction in the oxidation of influent dissolved metals. The thermocline contained within the metalimnion exhibits a rapid decrease in temperature relative to an increase in depth terminating in a cold hypolimnion. The temperature and density of the water becomes uniform during autumn and the slightest wind may circulate the water and resuspend the sediments. However, this is rare in smaller impoundments.

One important limnological feature of iron is its seasonal behavior in the hypolimnion. In well-oxygenated waters, ferric iron is rare due to its insolubility. During spring over-turn, ferric iron is contained in the sediments. Iron exists in the sediments, or profundal ooze, as ferric hydroxide, ferric phosphate, and possibly as ferric silicate and ferric carbonate complex (Cole

1983). During summer stagnation in an oligotrophic lake, an oxidized microzone of iron-containing molecules in a complex colloidal layer seals the sediments preventing escapement to the overlying water. Copper and zinc behave similarly to iron; these metals are insoluble in oxidized states and form sulfides. Copper in the form of $CuSO_4 \cdot 5H_2O$ has been used as an aquatic algicide for years (Cole 1983). The formation of copper sulfate precipitates in the oxidation/sedimentation pond may assist in keeping the pond in an oligotrophic state.

The oxidation/sedimentation pond may experience oxygen depletion during winter ice cover. Ice formation inhibits the gaseous exchange with the atmosphere. This, coupled with the lack of photosynthesis in the oligotrophic pond, creates an oxygen deficiency which may potentially be detrimental to the desired function of the pond.

Bench-scale test analyses indicate that a spring water to ARD ratio of 100:1 will markedly improve the quality of the Midas water. The Midas seep flows at a rate approximating 3.8 to 22.8 LPM, dependent upon climatic conditions. By using the maximum flow rate of 22.8 LPM, the daily flow is extrapolated to 32,832 liters per day (LPD). A ratio of 100:1 equates to a pond containing 3,283,200 L of spring water. A pond containing this volume of water would have to be approximately 3168 $m^3$ in size, or approximately 66 X 16 X 3 m in size. The creation of a pond of this magnitude would not be difficult and the removed soils could be utilized as berms to lessen wind action and eliminate sidehill runoff sedimentation. The length and width dimensions of 66 m and 16 m were selected because it is considered that the optimum length-to-width ratio for settling ponds 4:1 (Penn Environmental Consultants, Inc. 1983). The long, narrow pond allows the metals to precipitate prior to reaching the outlet; thereby reducing the potential for metal sludge fouling of the outlet plumbing. Construction of a wedge-shaped pond bottom (Figure 2), with the deepest portion adjacent to the inflow, would allow storage for

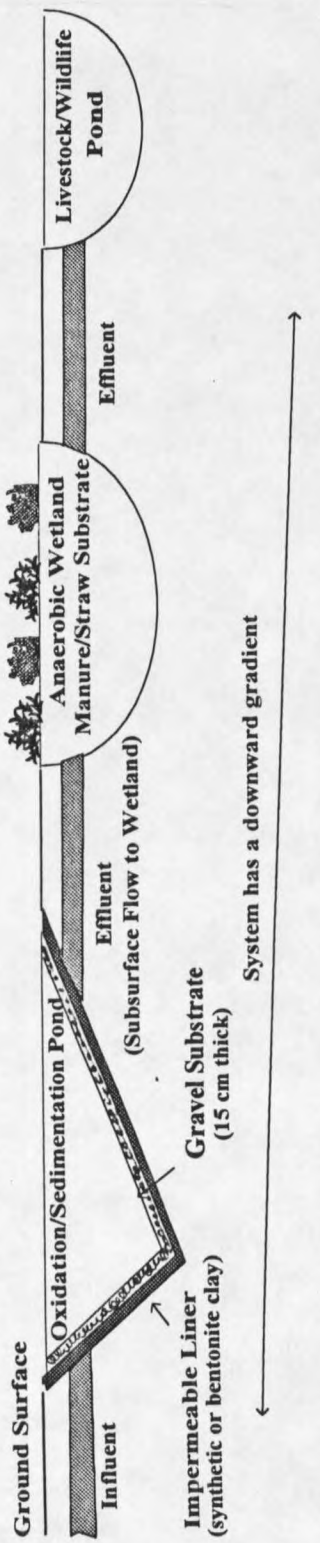


**Figure 2:** **Conceptual drawing of the pond/wetland system (side view)**

precipitates. The three m depth is an average and does not reflect an even-depth pond (i.e.; the deep portion next to the inflow pipes may be 4.5 m deep while the far end of the pond may be 1.5 m deep, with a gradual upward pond substrate gradient). Precipitate settling velocities are typically one m per day and a pond designed with a retention time of 12 to 48 hours is adequate for the removal of iron (McCulley, Frick, and Gilman, Inc. 1993) and other metals. The first two bench-scale tests indicated an immediate visible precipitation of metals. The second test demonstrated an increase in the pH of the treated water after 24 hours which then decreased after 42 hours. The pH after a 24 hour period decreased slightly during the first test; however, the amount of test water was considerably less than the second test and it is anticipated that the treated pond water would experience a pH increase similar to the second test. Therefore, the pond should have a minimum retention time of 24 hours which may facilitate an increase in the pH of the pond water and sufficient precipitation of the metals. However, the retention time and pond volume requirements are determined by three considerations: 1) the time required to oxidize iron in solution; 2) the time required for precipitated solids to settle, and; 3) the volume size required for sludge storage. The third bench-scale test demonstrated that approximately 0.95 L of hydrated precipitate sludge is generated for every 37.85 L of 100:1 mixed water. Therefore, every 3,283,200 L of mixed (at a 100:1 ratio) water would generate approximately 82,080 L of hydrated sludge (as suspended solids) per day. If this were the actual volume of sludge generated daily, it would equate to approximately 82 $m^3$ of required daily sludge storage space in the pond.

The first and second bench-scale tests generated 1.1 grams (g) of dried precipitates from 1.4 L of 100:1 ratio test water. This equates to approximately 0.79 g precipitates/L. The volume of the dried precipitates was 0.942 $cm^3$. This is equal to 1.17 g precipitates/$cm^3$. When these figures are applied to the total volume of water contained in the oxidation/sedimentation pond,

approximately 2,593,728 g of precipitates will be generated per day. This extrapolates to approximately 2,216861 $cm^3$ or 2.22 $m^3$ of dried or settled precipitates per day. The deeper portion of the pond would approximate 4.5 m in depth with an area of 495 $m^2$ for an approximate total of 2002 $m^3$. Approximately one-half, or 1001 $m^3$ would be available for precipitate storage. The initial mixing of the Midas water and Sheep Rock Spring water would exceed the 100:1 ratio and potentially yield a greater amount of sludge; however, over a period of time, the ratio would decrease, with a corresponding decrease in precipitate sludge and 100:1 would become an average ratio. It is unknown how long the oxidation/sedimentation pond would operate before the excavation of the precipitates is required; however, if the mixing ratio is maintained at 100:1, it is estimated that the precipitates would fill the available storage space in approximately 450 days. Additionally, the pH of the oxidation/sedimentation pond may potentially be reduced by the accumulation of the Midas Spring water with a corresponding decrease in the amount of precipitated sludge. Approximately 33 days after the introduction of the Midas water into the new oxidation/precipitation pond, unless the 100:1 ratio can be maintained (based on volumetric flow rate calculations derived from the total inflow, outflow, and pond capacity), the pond will diminish in its efficiency. If the ratio decreases to 10:1 or less, the sludge deposition will be reduced and the pond's sludge retention time will be increased. The quality of the pond effluent flow to the constructed anaerobic wetland will be decreased; however, the wetland should be fully function at this time and able to compensate for the pond's decreased treatment capacity.

As previously referenced, the physical creation of a pond of this size is feasible, based on available space at the Midas site; however, supplying the amount of water necessary to treat the volume of ARD is more difficult. Sheep Rock Spring flows at a seasonal rate approximating

that of the Midas seep, 3.8 to 22.8 LPM (Lazuk, pers. comm.). This means that the pond would require 100 days to fill to the required volume. Wells exist in close proximity to the project site and augmentation of the spring water may be possible by utilizing the wells. However, the use of electric pumps is not considered in this project and a more passive form of pumping is required. As the wind, however variable, is a constant at GSM, the potential for water-pumping windmills may exist. Two of the three wells in the project vicinity possess characteristics similar to those of the Sheep Rock Spring (Table 11). Alternatively, GSM may elect to lessen the flow of the Midas Spring to the pond by diverting a portion of the flow which may reduce the spring water and pond size requirements. The Sheep Rock Spring water flow and pond size may be retained to maintain the 100:1 mixing ratio if the Midas flow is decreased. Augmentation of the Sheep Rock Spring flow with well water would further enhance the mixing ratio if the Midas flow were lessened.

Regardless of the size of the treatment pond, design characteristics remain the same. Implementation of windbreaks either through the construction of high berms and/or the planting of shelter belts would minimize any wind-derived wave action which may resuspend solids. Although wind action is a primary vehicle for diffusing oxygen into the water, it is not desired in this application.

The wind at GSM is primarily from the south to southwest. However, the amount of wind that occurs at the Midas site is unknown. Therefore, construction of south and southwest aspect berms (Figure 3) high enough to deflect the wind over the pond may or may not be necessary. The berms would be constructed of excavated subsoil. The topsoil, or top 23 cm, will be utilized in the construction of the wetland. If needed, berms would divert the wind

**Table 11: Previous water analyses of two monitoring wells located in the project site area** (Energy Labs, 1993,4,5d).

| Parameter (Dissolved) | PW-9 Sampled 12/93 (mg/L) | PW-9 Sampled 4/94 (mg/L) | PW-44 Sampled 10/95 (mg/L) |
|---|---|---|---|
| Sulfate | 113.0 | 98.0 | 105.0 |
| TDS | 423.0 | 421.0 | 411.0 |
| pH (su) | 7.7 | 7.9 | Not available |
| Aluminum | <0.1 | <0.1 | <0.1 |
| Arsenic | 0.048 | 0.050 | 0.014 |
| Barium | Not analyzed | Not analyzed | 0.043 |
| Beryllium | Not analyzed | Not analyzed | <0.001 |
| Cadmium | <0.001 | <0.001 | <0.0001 |
| Chromium | <0.01 | Not analyzed | <0.001 |
| Copper | <0.01 | <0.01 | <0.001 |
| Iron | <0.03 | <0.01 | <0.01 |
| Lead | <0.01 | <0.01 | <0.002 |
| Manganese | 0.04 | 0.02 | 0.041 |
| Nickel | <0.01 | <0.01 | <0.02 |
| Selenium | 0.018 | 0.012 | 0.002 |
| Zinc | <0.01 | 0.06 | 0.08 |

sufficiently until planted shelter belts reach the growth stage where they become an effective windbreak. In the absence of wind-caused oxygen diffusion, other means need to be applied to oxygenate the pond. The creation of a turbulent inflow of both the Midas ARD and the spring water is the preferred method of oxygenation. This may be accomplished through the use of corrugated pipe, the installation of baffles within the pipe, or a larger diameter pipe with a series of step-downs not unlike step-down culverts utilized for fish passage. Regardless of the pipe

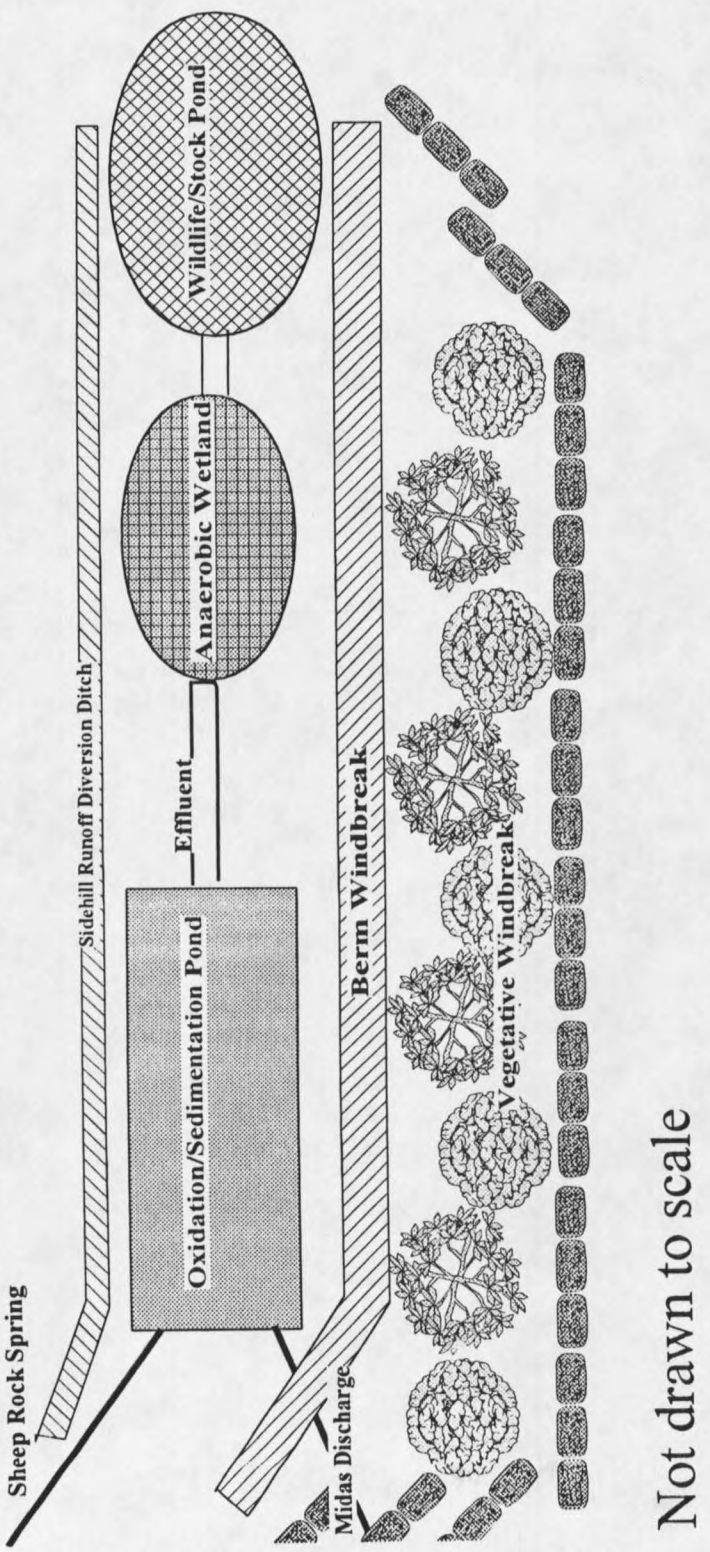


**Figure 3:** **Conceptual drawing of the pond/wetland system showing windbreak berms and vegetation (overhead view)**

system used, the slope should be of a sufficient enough angle to create a rapid flow, thereby aiding in the diffusion of oxygen through increased turbulence. In all instances, open stacks extending above the surface of the ground are required to allow oxygen to reach the flow. McCulley, Frick, and Gilman, Inc. (1993) recommend the stack placement not exceed 15.2 m increments. The pipes should be buried below the frost line to prevent ice formation on the pipe walls which would restrict flow rates.

The existing piping which captures the Midas ARD is sufficiently deep to avoid freezing. However, the installation of a diverter valve at the Y-junction where the ARD would enter into the pond system is required. Currently, Sheep Rock Spring is allowed to flow freely. The construction of an underground capture and pipe system is required for transport of the water to the pond site. As with the Midas piping, a diverter valve located at the spring site should be installed which would allow the spring to assume its natural flow during pond cleanup and other contingencies. If wells are used, underground piping at the well head should be installed. No diverter valve is required for this application as the pumping can be shut off, if required. Ice formation on the pond will occur during winter months; therefore, the piping should enter the pond approximately 30 cm below the surface. This depth is estimated based on similar projects in the Northern Rockies (i.e., the Mike Horse site on the upper Blackfoot [McCulley, Frick, and Gilman, Inc. 1995]); however, each site is elevationally and climatically variable in relation to the research site.

In addition to the construction of berms blocking the prevailing wind, berms designed to prevent sidehill water runoff from snow melt or rain events may be required to eliminate potential sedimentation of the pond (Ganse et al. 1993). The construction of diversion ditches at the base of the berms would facilitate directing the flow away from the earthen berms and

prevent berm erosion and water saturation which may permeate the berm and enter the pond. The water would be allowed to enter the ephemeral drainage below the pond and eventually enter into the ground water system. The berms would be constructed of the same excavated subsoil as the windbreak berms.

The pond liner should be impermeable to prevent seepage to the subsurface. This may be accomplished either through the use of a geotextile fabric (McCulley, Frick, and Gilman, Inc. 1993) or bentonite clay material. Since clay is readily available on-site, it is the preferred lining method. The clay should be a sodium dominated bentonite which swells when wetted. Polishing ponds typically utilize pea gravel as the substrate material (Ganse et al. 1993). Gravel substrates approximately 30 cm deep protect the pond liner from damage during excavation as the gravel is removed with the precipitate sludge. The gravel is then easily replaced. Gravel should be used in the oxidation/sedimentation pond at the Midas site and is readily and locally available.

The construction of a second, smaller oxidation/sedimentation pond may be desirable as a back-up pretreatment step to be utilized while the precipitate sludge is removed from the primary pond. This pond would not possess the same size requirements as it would be utilized periodically and for only a few days. Once the sludge excavation is completed, the Midas water and Sheep Rock Spring flow would be diverted to the main pond.

### 5.2 Precipitate sludge deposition

McCulley, Frick, and Gilman (1995) state that the precipitate sludge generated by the oxidation/sedimentation pond located at the Mike Horse site in the upper Blackfoot River drainage should pose no hazardous threat and has a low potential for remobilization of metals. However, the Resource Conservation Recovery Act of 1976 (RCRA) requires that potentially hazardous waste be analyzed using approved testing methods. The TCLP test determines

whether the sludge generated by a water treatment process requires storage in a RCRA approved repository. If the sludge generated by the treatment of ARD is determined to be within RCRA parameters, one of two scenarios may occur.

The first scenario involves active mining operations where the precipitate sludge is subject to the terms of the mining permit. If the permit states that treated sludge, even if it passes the TCLP test, is to be deposited in a lined repository or landfill, then all subsequent sludge generated on site is required to be deposited in a similar facility. However, if the active mine desires, a modification to the permit allowing on-site deposition of the sludge may be submitted. The mine permit takes precedence over any solid waste requirements, as detailed in MCA 75-10-214 (Pat Crowley, pers. comm.). The other scenario involves inactive mine and Superfund sites. At these sites, precipitated sludge is required to be deposited in a lined repository, landfill, or RCRA repository regardless of the TCLP analysis results (Pat Crowley, pers. comm.).

The analysis results of the precipitate sludge was found to be below RCRA maximum limits and the use of a RCRA repository may not be required for the disposal of the precipitate sludge. Therefore, the excavated sludge may be deposited in accordance with the mine's operating permit. However, subsequent testing of the sludge should be conducted to substantiate or disprove the initial test. As previously stated, the cadmium results are close to the maximum permissible levels and the potential for variations in test results exist.

### 5.3 Post-construction monitoring

The functional life expectancy of the oxidation/sedimentation pond is dependent upon two variables: first, the quantity of precipitate sludge deposition over time will dictate the timing of the sludge removal, and; second, the pH of the pond will determine the ability of the pond to oxidize and precipitate metals. Additionally, a slight potential for the Midas ARD to precipitate

metals into the pond delivery piping exists. Monitoring of the pond should address these concerns.

The monitoring protocol should be simple and easy to conduct on-site without time consuming, expensive, and labor-intensive sample collection and laboratory analysis. Monitoring protocol embracing these principles is in keeping with the overall goals of the system design. In addition, by keeping all monitoring simple and on-site, decisions regarding the pond's effectiveness and, if necessary, the implementation of appropriate corrective measures may be expedited.

The pH of the pond should be checked daily for approximately 33 days, which is the estimated time for the mixing ratio to reach its lowest level. After 33 days, the pH should be checked weekly to verify that the level is greater than 3.0. The pH can be measured by using either an electronic monitor, if available, or with a standard fisheries water quality kit. The components to measure pH may be purchased separately; however, it may be advantageous to purchase the whole water quality kit for future applications. Wind action should sufficiently mix the water so that the pH will be the same at the perimeter of the pond and its center. Therefore, water samples should be taken at three locations along the perimeter of the pond. The sample sites should be at the top or influent section, the middle section, and the bottom or effluent section. The pH monitoring protocol may have to be seasonally adjusted to accommodate for increased or decreased Midas and Sheep Rock Spring flows.

The rate of sludge deposition can be visually determined through the use of either a "dipstick" or a permanently installed measuring staff. The permanent staff is the preferred method since any placement of a dipstick or other portable device may potentially disturb the

precipitate sludge and cause it to move down gradient toward the outlet. Ice cover may hinder the visual reading of the staff, but if the pond is implemented during the spring or summer, sufficient sludge accumulation data will exist to preclude the use of the staff during ice cover periods. The sludge depth determination can be conducted concurrent with the pH testing.

The vent stacks providing oxygen to both inflows may be utilized to visually observe the piping to determine if any precipitate coating of the pipes transporting the Midas Spring water is occurring. If it appears that precipitates may be accumulating in the transport pipe, a test using a suitable length rod to scratch through the precipitates can be conducted to determine the extent of the deposition. The observation of the influent pipes can be conducted concurrent with the other two observations.

The results of the three observations should be recorded on waterproof paper and transcribed onto a permanent ledger for analysis and storage. Combined, the three monitoring steps can be performed by one person in less than one hour. After monitoring has occurred for a suitable length of time (to be determined during the monitoring phase), the frequency of monitoring may be decreased if demonstrable and predictable pond characteristics exist.

# 6.0 Constructed Wetland Design

## 6.1 Constructed wetland influent

To achieve maximum effectiveness, constructed wetlands must be designed and regarded as natural integrated ecosystems where: organisms are interdependent and integrated; multiple species diversity is more responsive to loading variations than monocultures; macrophytes should be kept in r-growth (r-selected) stages by intentional programmed disturbances, and; the hydrology should be used to maximize microbial access to dissolved organic matter, growth, and storage functions; areas where constructed wetlands can improve over typically channelized natural wetlands (Wetzel 1993).

The pond would initially be filled with sufficient Sheep Rock Spring water, or other similar water, to create an initial 100:1 or greater ratio. The Midas water would then be released into the pond concurrent with the release of the maximum available flow of the Sheep Rock Spring water. At this time, unless the 100:1 mixing ratio can be maintained, the effectiveness of the pond may slowly decrease. The second bench-scale test indicated an increase in pH after 24 hours. As the second test involved greater quantities of both the Midas and spring water, it may be inferred that the pH of the pond would exhibit similar results. The pH may rise during the 24-hour retention period. However, the pH of the pond may eventually decrease, since the 100:1 mixture can not be maintained without supplemental treatment water. Concurrent with the decrease in pH will be the decreased ability of the pond to treat the Midas discharge. Eventually a steady state mixing ratio of 2:1 will be reached (Table 12). The pond effluent will then flow via a subsurface piping system into a constructed anaerobic wetland system. The anaerobic wetland will then be the primary treatment facility.

**Table 12: Oxidation/sedimentation pond water budget reflecting the potential decrease in the mixture ratio (assuming the 100:1 ratio is not maintained).**

| Time Period | Maximum Midas Water Inflow (LPM/LPD) | Maximum Sheep Rock Spring Inflow (LPM/LPD) | Maximum Pond Effluent (LPM/LPD) | Pond Water Ratio |
|---|---|---|---|---|
| Initial mix | 22.8/32,832 | 22.8/32,832 | 45.6/65,664 | 101:1 |
| after 1st week | unchanged | unchanged | unchanged | 13.3:1 |
| after 2nd week | unchanged | unchanged | unchanged | 6.1:1 |
| after 3rd week | unchanged | unchanged | unchanged | 3.8:1 |
| after 4th week | unchanged | unchanged | unchanged | 2.6:1 |

The oxidation/sedimentation pond effluent will be of higher quality relative to the original Midas water. Anion, inorganic, and metal components of the Midas discharge are reduced by 70 to over 99 percent and the pH is improved from 2.6 to 6.3 at a mixing ratio of 100:1. At a 10:1 mixing ratio, the pH was improved to 3.02; high enough to precipitate iron and some aluminum, but not manganese; although other metals will co-precipitate with the iron and aluminum. At a 2:1 mixing ratio, the expected pH should be greater than the initial bench-scale test's 1:1 ratio pH of 2.69. However, little precipitation of metals other than a minimal amount of iron would occur at this pH. The initial characteristics (i.e; 100:1 mixing ratio) of the pond effluent are such that a constructed aerobic wetland would successfully treat the water. However, the decreasing efficiency of the oxidation/sedimentation pond coupled with the cold winters in the northern Rocky Mountains precludes the use of a free-water surface system (FWS) aerobic wetland. Therefore, construction of a subsurface flow system (SFS) anaerobic wetland

is required as it is considered that SFS anaerobic wetlands continue to operate efficiently in sub-freezing climates (Wildeman et al. 1993).

### 6.2 Properties of constructed SFS anaerobic wetlands

Constructed SFS anaerobic wetlands have been given final approval as the preferred remedial action for the mine drainage at the Bunker Hill Superfund Site, Kellogg, Idaho (McCulley, Frick, and Gilman 1994); however, implementation has not occurred. Anaerobic wetlands can remove metals from ARD without generating sludge requiring periodic removal. The deposition of divalent metals including zinc, cadmium, and copper in flooded anaerobic wetlands pose low and acceptable hazards to wetland-associated wildlife (McCulley, Frick, and Gilman 1994). Constructed anaerobic wetlands may therefore be considered as permanent repositories of retained metals.

The biogeochemical properties of constructed anaerobic SFS wetlands include:

- The precipitation of metals as sulfides
- An increase in pH through sulfate reduction and an increase in alkalinity
- The ability to function at pH 2.5 if sufficient dissolved sulfate (> 30 mg/L) and organic matter (OM) are present
- Will continue to operate during winter resultant of summer DSR activity yielding accumulations of elemental sulfur and polysulfides
- The presence of ferric iron allows the wetland to operate at a lower pH

### 6.3 Constructed wetland sizing to treat the oxidation/sedimentation pond effluent

The dimension requirements for a constructed anaerobic wetland are similar to those of the oxidation/sedimentation pond. The maximization of retention time and drainage contact with the substrate is important (Stillings et al. 1988) and requires a length to width ratio greater than

4:1 with some constructed wetlands approaching 96:1 (Whitthar 1993). The required size of constructed wetlands is variable dependent upon geographic location. The majority of sizing criteria have been developed in the eastern United States and are not applicable to sites in the northern Rocky Mountains. Constructed wetland sizes are almost entirely related to the flow of the effluent to be treated. The Tennessee Valley Authority (TVA) constructs wetlands sized from approximately nine $m^2$ to 144 $m^2$ per 3.8 LPM of effluent to be treated (Brodie et al. 1988). Other eastern wetlands range from 18 $m^2$ to over 360 $m^2$ , dependent on the metal content of the effluent (Brodie et al. 1988; Stillings et al. 1988; Whitthar 1993).The calculated minimum size for a constructed wetland in the Colorado Rocky Mountains is 90 $m^2$ per 3.8 LPM (Ganse et al. 1993).

The minimum depth of a truly anaerobic constructed wetland should be one m (Brodie et al. 1988; Whitthar 1993); however, some constructed wetlands possess variable depths up to 2.7 m (Whitthar 1993). Wetlands deeper than one m are typically anaerobic with some aerobic activity at lesser depths. Reducing environments exist at the greater depths where anaerobic bacteria utilize sulfate and ferric iron to oxidize organic matter (OM) in the anoxic environment (Whitthar 1993). Surface water depths are variable and range from 0 to 45 cm (Brodie et al. 1988; Whitthar 1993) with optimum anaerobic wetland functions occurring at depths less than 45 cm (Whitthar 1993); typically water depths are 15 to 30 cm (Brodie et al. 1988).

Effluent flow from the oxidation/sedimentation pond will be approximately two times that of the Midas discharge. Therefore, the constructed anaerobic wetland should be approximately 1080 $m^2$. This size was decided upon by multiplying the maximum flow rates of the Midas Spring discharge by two, dividing by 3.8, and then multiplying by 90. The length of

the constructed wetland should be approximately 76 m with the width approximating 15 m. This would give the wetland a length to width ratio of 5:1, which exceeds the minimum length to width ratio of 4:1. The constructed wetland substrate should be no less than one m deep with deeper portions throughout the system. The functioning anaerobic portion of the constructed wetland would then be a minimum of 1008 $m^3$. Irregular shaped constructed wetlands provide hydraulic discontinuity and enhance natural appearances (Brodie et al. 1988). Therefore, the wetland should not be a rectangle, but rather, an irregular shaped polygon. Hydraulic discontinuity will also be provided by the placement of straw bales in the substrate. The straw bales will also provide the OM and carbon required for anaerobic processes.

The excavated pit encompassing the wetland will actually be deeper to accommodate the surface water and potential 24-hour storm events (Brodie et al. 1988). However, the berm protecting the wetland from sidehill runoff will eliminate most of the effects associated with a 24-hour storm event. Therefore, the pit edge should be a approximately 61 cm higher than the surface of the substrate: accommodating the 30 cm water surface and allowing for up to 7.6 cm of precipitation associated with a 24-hour storm event. No provision for accepting sidehill runoff is provided as the wetland will be bermed and have a diversion ditch similar to the oxidation sedimentation pond. Berm and pit wall stability will be accomplished through vegetative growth which will serve the dual purpose of reducing erosion and providing OM to the wetland substrate.

The oxidation/sedimentation pond effluent will be transported to the constructed wetland via a series of collection pipes terminating in two (or more) pipes located below the frost level and flowing into the base of the wetland substrate. The multiple wetland feeder pipes will reduce the likelihood of potential clogging by precipitates by dividing the flow and will prevent the

channelization of the substrate. The feeding of the effluent to the substrate base will facilitate maximum contact with the anaerobic substrate. Baffles or straw bales may enhance the distribution of the pond effluent throughout the substrate.

Recommended construction guidelines which facilitate optimal winter wetland operation are taken from Wildeman et al. (1993) and are as follows:

- Use the thermal energy contained in the mine drainage to best advantage by insuring that the delivery systems are insulated. Keep the inlet structure small and insulated.
- Place the wetlands cells so that they receive winter sun. If this is not feasible, insure that the outlets are in the sun.
- Insulate the top of the wetland cell with hay and plastic, or have excess surface flow.
- Insulate the wetland outlets and provide a method for directing the effluent away from places where freezing may occur.
- Design the wetland as a SFS. The thermal energy within the substrate will aid winter operation.

## 6.4 Constructed wetland substrate

### 6.4.1 Substrate suitability

Recent research indicates that vertical upflow anaerobic wetlands maximize the removal of sulfate and metals (Jones and Chapman 1995). A vertical upflow system enters the wetland at the base of the substrate and is allowed to flow upward and exit the wetland at the surface. Although water may be transmitted horizontally through the substrate, the hydraulic head is much larger and is more easily controlled in a vertical upflow system (Jones and Chapman

1995). A vertical upflow system can be designed with ten times higher flow rate than a properly sized horizontal system (Eger 1992). The life expectancy of a vertical upflow system is dependent upon the particulate matter which may plug flow paths and result in channelization or short-circuiting (Jones and Chapman 1995). Resultant of this, it is recommended that vertical upflow wetland cells be located downstream of the oxidation/sedimentation pond to minimize the concentration of particulates in the inflow. The placement of the wetland feeder pipes in the gravel substrate enhances the vertical upflow of the water through the wetland substrate.

The primary function of a substrate is to provide long-term support for plant growth, provide a medium for the propagation of bacteria, and provide uniform hydraulic conductivity (Schafer and Associates 1991). Materials utilized in constructed wetlands include: spent mushroom compost; peat; wood and wood/sewage; compost steer and chicken manure; Eko-Compost; carbonaceous materials such as hay and corn cobs; crushed limestone in combination with other materials; topsoil; natural wetland soil; clay; mine spoil, and; pea gravel (Whitthar 1993; Hedin et al. 1991; Schafer and Associates 1991). Spent mushroom compost, a combination of wheat straw, dried poultry waste, urea, canola, cottonseed meal, and gypsum, appears to be generally accepted as the best substrate medium as it contains 10 percent (dry weight) limestone and is rich in nitrogenous and carbonaceous materials with a maintainable pH of 6 to 7.8 (Barber, pers. comm.; Hedin et al. 1991; Schafer and Associates 1991). The TVA compared various constructed wetland substrates (topsoil, natural and acid wetland soil, clay, mine spoil, and pea gravel) and found similar reductions in iron and inconclusive reductions in manganese and pH (Whitthar 1993). The wetland design firm of Black and Veatch utilize the soil available on-site mixed with fertilizer and lime (Whitthar 1993). Wetland substrates of this composition may potentially reduce iron concentrations from 585 mg/L to 1.3 mg/L, aluminum

concentrations from 19.9 mg/L to 0.055 mg/L, and reduce total acidity from 375 mg/L to 0.0 mg/L, dependent upon wetland size and quantity of effluent to be treated (Dietz and Stidinger 1996; Whitthar 1993). In high elevation, cold climates in Colorado, it appears that the substrate material and the subsequent optimization of chemical processes is not as important as the geotechnical (construction) design of the constructed wetland (Ganse et al. 1993).

Regardless of the substrate material utilized, the physical characteristics of the substrate should include: a high hydraulic conductivity; elevated fiber content; a near neutral pH; high carbon and organic content, and; the ability to support hydrophytic vegetation both as a continued source of OM and carbon, and for the potential uptake of metals (Frostman 1996; Wildeman et al. 1993; Schafer and Associates 1991). Substrate material, as long as it has metal retention capabilities, may not be as important as the conditions created by wetland vegetation and the presence of an anaerobic zone (Skousen et al. 1995).

6.4.2 Substrate design for the Midas constructed wetland

Substrate combinations are numerous; however, a mixture of 50 percent manure, 30 percent hay, and 20 percent topsoil, including coarse fragments, placed on a 15 cm base of gravel should provide sufficient hydraulic conductivity, exchange capacity, and OM to produce a functional constructed anaerobic wetland (Skousen et al. 1995). For construction purposes, the top 23 cm of soil from the pond and wetland excavations should be lifted as topsoil. Fifteeen to 30 cm of topsoil will be placed on top of the substrate mixture to provide a growing medium for wetland vegetation. Utilization of the naturally calcareous soil present at the Midas site will add alkalinity to the wetland and aid in the neutralization of the pond effluent. These materials are locally available at GSM.

Approximately 378 $m^3$ of topsoil should be excavated from the oxidation sedimentation pond and wetland sites. The constructed wetland substrate will require 201.6 $m^3$ of soil, 302.4 $m^3$ of hay, and 504 $m^3$ of manure; mixed with a track or back hoe. Approximately 176.4 $m^3$ of topsoil will be left after the substrate is constructed. This material will be utilized as the growing medium and will provide approximately 15 cm of topsoil in a uniform coverage.

Two of the project goals are low operation and maintenance requirements, and the use of on-site or locally available materials. In keeping with these goals, aged cow manure or composted cow manure will be the principle substrate component. Cow manure composted with straw combined with a small amount of gravel would provide greater hydraulic conductivity and provide additional OM. The manure substrate will average approximately one m in thickness with a gravel base and a 15 cm layer of topsoil covering the manure. The topsoil will provide an enhanced growing medium for the wetland vegetation. Additionally, the calcareous topsoil (pH 7.4 to 7.8) may help offset the intentional lack of limestone in the substrate. The straw bales placed within the substrate to aid in hydraulic discontinuity will also function as an initial source of carbon and OM until the planted vegetation is able to provide the required quantity. If required, additional straw may be added to the substrate either by composting the straw with the manure or by hand-placement. The gravel substrate base will aid in hydraulic conductivity and provide for the up-flow of the oxidation/sedimentation pond effluent. The effluent will enter the constructed wetland through the gravel base. Thirty cm of cover water will keep the wetland in an anaerobic state. The entire constructed wetland will be lined with either an impermeable synthetic liner or locally available clay materials.

The initial effluent from the oxidation/sedimentation pond will possess reduced levels of iron, aluminum, manganese, zinc, copper, and other metals. Additionally, the sulfate content

will initially be reduced from over 30,000 mg/L to less than 500 mg/L with an increase in pH to 6.3. Approximately 33 days after introduction of the Midas and Sheep Rock Spring water, unless the 100:1 Sheep Rock Spring to Midas Spring water mixture can be maintained through either augmentation or a decrease in the Midas Spring flow, the pond effluent will diminish in quality; however, by this time the constructed wetland will be fully operational and inoculated with DSR facilitating bacteria and other microbiota rendering it capable of treating the increase in influent metals and sulfate, and the decrease in pH. Anaerobic wetlands will function at a pH as low as 2.5 provided a sulfate concentration greater than 30 mg/L is present.

### 6.5 Microbial seeding of the substrate

The desired anaerobic wetland reduction processes should occur prior to the reduction in the efficiency of the oxidation/sedimentation pond. Ideally, the wetland would posses the desired microbiota to commence anaerobic reduction processes immediately upon introduction of the pond effluent. This may be accomplished through microbial seeding, or "jump-starting", the substrate. Microbial seeding increases the initial sulfate removal process and enhances the start-up of the constructed wetland (Mudder et al. 1995). Potential site adapted microbial populations may develop where ARD and solid surfaces or soils have contacted for a period of time. The following is a list of materials used to prepare a seeding solution with a high probability of containing a viable population of sulfate reducing bacteria (Mudder et al. 1995):

- a 19 liter bucket of crushed ore
- a 3.8 liter plastic bag of sludge-like material collected from the soil-air-water interface in the tailings impoundment
- a liter bottle of sludge from the solid-water interface in the tailings impoundment

The above components are mixed in the 19 liter bucket and, after settling, the solution is transferred to a sprayer. The solution is then sprayed onto the substrate.

Alternatively, if a historic ARD site can be located in close proximity to the Midas site, the sludge or soil and vegetation contacting the ARD may be collected and substituted for the one gallon of sludge from the soil-air-water interface. If a quantity of ARD-contacted soil can be collected, then the soil may be placed directly in the substrate in several locations. The ARD-contacted soil will likely contain the desired microbial populations to enhance the start-up of the constructed wetland. The Midas Spring is a potential source of ARD-contacted soil and vegetation as it originates within the Midas Slump as a result of mining activities. The water flows from the base of the slump for one m before infiltrating into the ground. Wetland hydrology at this site is approximately nine $m^2$ (Western Technology and Engineering et al. 1995).

## 6.6 Wetland vegetation

### 6.6.1 Species, functions and characteristics

Emergent wetland vegetation has long been considered an effective vehicle for the removal of metals from the influent. However, less than five percent (one percent by *Typha* spp. [Skousen et al. 1995]) of the influent metals are actually incorporated into the plants (Jones and Chapman 1995). Instead, emergent vegetation enhances the removal of solutes by more indirect methods: plants reduce water velocities and lead to the sedimentation and trapping of metal particulates, and; provide a substrate for epiphytic algae (Jones and Chapman 1995). Additionally, wetland vegetation provides a long-term source of decaying organic matter (DOM) required to sustain sulfate reducing bacteria (Mueller 1996; Jones and Chapman 1995) and enhances aesthetic appeal.

Typical anaerobic wetland emergent vegetation functions and characteristics include (Wetzel 1993):

- major storage sites for carbon and nutrients
- wide fluctuations of nutrient content in plant tissues through the growth stages
- natural wetlands do not consist of monocultures. One or two species may dominate but there is typically a substantial understory
- most macrophytes, in natural wetlands, undergo continuous senescence and sloughing of a portion of their foliar and rooting tissues. Therefore, a primary function is to generate photosynthetically large amounts of organic carbon. Organic carbon enters the wetland as particulate matter into the rooting and detrital pools and organic matter is released as DOM, which may constitute up to 30 to 40 percent of the total net productivity.

Wetzel (1993) states that plants limited to r-growth stages are desired in constructed anaerobic wetlands. The primary benefit of this strategy is enhanced productivity as r-selected plants emphasize rapid development and early reproduction (Barbour et al. 1987). R-growth vegetation is typically maintained through winter mortality, wildlife related disturbances, or catastrophic mortality.

Cattails are regarded as the preferred wetland plant species (Brodie et al. 1988; Scendiver and Bhumbla 1988) because the species possess morphological adaptations including arenchyema tissues which aid in the transport of oxygen from above-ground plant parts to the roots which allows the plant to grow in highly reduced environments (Scendiver and Bhumbla 1988). Cattails influence a wetland's redox potential by creating a more reducing environment; cattails may lower the redox potential enough to precipitate iron in its sulfide form (Scendiver

and Bhumbla 1988).

In addition to cattails, other species commonly used in constructed wetlands include: sedge (*Carex* spp.); rush (*Juncus* spp.); horsetail (*Equisetum* spp.); spike rush (*Eleocharis* spp.), and moss (McCulley, Frick and Gilman 1994; Brodie et al. 1988; Spratt and Wieder 1988). Several of these species are utilized for eastern coal mine remediation and may not be adapted to higher elevations experiencing cold winters. *Carex* spp. are high elevation sedges growing to approximately one m with shallow creeping rhizomes. *C. aquatilis* is tolerant of low pH and high metal concentrations; however, poor growth is associated with elevated levels of copper, zinc, nickel, cadmium, and low potassium levels (Emerick et al. 1988). *Sphagnum* is beneficial in maintaining adequate substrate organic material levels and were one of the first plants used in constructed wetlands due to their ability to accumulate metals (Skousen et al. 1995). However, few, if any, of these original constructed wetlands remain effective because of the potential for total saturation of iron in the planted *Sphagnum* within one or two growing seasons (Skousen et al. 1995). *Sphagnum* may be impacted by dissolved iron levels exceeding 10 mg/L (Spratt and Wieder 1988). *Carex* spp., *Equisetum* spp., and *Juncus* spp. may also be considered as riparian plants in the Northern Rocky Mountain region. Selected species should be planted adjacent to the constructed wetland which would enhance the wetland to upland transition and the ecosystem approach important to wetlands constructed for wildlife use.

6.6.2 Vegetation selected for the constructed wetland at the Midas site

Two wetland plant species, cattails and sedges, should be planted to avoid the undesirable monoculture overstory. Riparian vegetation should be planted around the oxidation/ sedimentation pond, the constructed wetland, and the livestock/wildlife watering pond. The establishment of riparian vegetation will enhance an ecosystem approach to wetland

construction by creating a transitional habitat of riparian to upland vegetation, increase soil and berm stability thereby reducing the potential for erosion, provide habitat for avian and terrestrial wildlife, and function as a windbreak. Riparian plant species including rushes (*Juncus balticus*), horsetails (*Equisetum arvense*), and spike rushes (*Eleocharis palustris*) will be planted along the wetland fringe and protective berms. Willows (*Salex lutea*), currants (*Ribes* spp.), and aspen (*Populus tremuloides*) will provide an overstory component on the berms to provide habitat for avian species and function as a windbreak. The above referenced plants are present at various sites in the vicinity of the Midas Spring (Table 13) and are adapted to the existing climate and soil conditions. The transplantation of plants present in the vicinity of the Midas site should provide a high survival rate. The associated upland vegetation will not be disturbed and will be left in a natural state with no supplemental plantings.

Grass and forb species may be transplanted as sod from the various wetland sites at GSM. The sod mats may be cut using a sod-cutting machine or dug by hand. Alternatively, a seed mixture may be developed and sown using hand seeders or another low-impact seeding system. However, seeding the grasses and forbs may delay implementation of the system until the seeded vegetation reaches maturity. The use of sod would expedite implementation of the system and would provide site-adapted vegetation.

The grass and sedge species should be planted in the spring to make use of the available precipitation and provide soil stability. The willows may be planted during the spring. The revegetation of disturbed riparian areas in the west-slope of the Colorado Rocky Mountains using this technique has proven successful. However, planting of the cuttings may be performed during the winter following the flooding of the constructed wetland while snow cover is present. At this time, the cuttings should be placed as close to the wetland as possible and should contact

**Table 13:** **Wetland and riparian plant species present at GSM** (Western Technology and Engineering et al. 1995).

| | Plants Present at GSM Wetland and Riparian Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Cattail** | **Sedge** | **Rush** | **Horsetail** | **Spike rush** | **Aspen** | **Willow** | **Currant** |
| **Bunk-house Sp.** | X | X | X | | | | | |
| **Jefferson Slough** | X | | | | | | | |
| **Sheep Rock Sp.** | | | X | | X | | X | X |
| **West Tailing WL** | X | | | | | | | |
| **Beaver Sp.** | | | | X | | X | X | X |

ground water. Riparian willow establishment using this technique has been successful in high elevations (>2440 m) in northern Utah.

The plants will be hand dug to obtain the complete root ball and rhizomes. Transplanting should occur on the same day to insure viability and decrease transplant shock (Brodie et al. 1988). The plants should be placed on approximately 0.9 m centers. After planting, the cattail stems should be broken over above the water level to promote new growth and minimize

The desired understory of mosses, algae, and grasses should be planted with the root balls as topsoil and vegetative surface growth will be a part of the hand-dug root balls. Algae, like moss, is an important component of a constructed wetland's understory. Freshwater algae are common in eastern waters associated with coal mine drainage and are considered as effective accumulators of metals (Kepler 1988). Algae require iron and manganese as essential nutrients; however, concentrations of manganese greater than 1 mg/L may inhibit the growth of certain

blue-green and green algae species. However, algae in mine drainage systems have shown an accumulation of manganese as great as 56,000 mg/kg of dry plant tissue (Kepler 1988). Oxyhydroxide precipitates are commonly accumulated by algae in mine drainages; it is unknown whether this is assimilation or preferred precipitation but some strains of algae become orange with ferric iron coatings (Wildeman et al. 1993).

Prior to any wetland vegetation planting, the substrate should be saturated with good quality, neutral pH water. The treatment water utilized in the oxidation/sedimentation pond would be a good source as the transport and distribution plumbing would already be in place. The substrate should remain saturated to allow development of the desired anaerobic and reducing processes for a period of no less than two weeks. During this time, the substrate should be inoculated. After two weeks and substrate inoculation, the vegetation should be established and the oxidation/sedimentation pond effluent may be released into the constructed wetland.

The wetland construction site is in close proximity to an ephemeral drainage and located in an upland area. Therefore, plant species planted should be adapted to the general site area and, if possible, cuttings planted should be taken from the area surrounding the site. The riparian zone will initially be narrow as the soils will possess upland characteristics and the plant available water from the wetland associated water table will be minimal. However, with time the wetland derived plant available water will increase and the riparian zone should expand into the downslope upland.

The site selected for construction of the oxidation/sedimentation pond and anaerobic wetland slopes slightly in a southerly direction. More ground water will be available to the riparian vegetation on the downslope side. The upslope side of the constructed wetland complex

will be bermed to prevent sedimentation through sidehill runoff. The riparian zone at this location will consist primarily of grasses, sedges, and small shrubs.

### 6.7 Efficiencies of other constructed anaerobic wetlands

Anaerobic constructed wetlands require elevated levels of dissolved sulfate (> 30 mg/L) for DSR to occur. Two by-products of DSR are hydrogen sulfide, which reacts with dissolved metals to form sulfide precipitates, and carbonate alkalinity which facilitates the neutralization of any influent acidity. Metal removal rates are variable, dependent upon the wetland sizing, residence time, and substrate composition (including OM and carbon). Given the proper geotechnical design, a constructed anaerobic wetland should remove much of the metal component in the water. Table 14 details removal efficiencies of iron and aluminum for several constructed anaerobic wetlands. The Z and F anaerobic constructed wetland successfully reduced iron, aluminum, and sulfate, while manganese was reduced slightly. The W1D anaerobic complex successfully reduced copper, nickel, cobalt, and zinc. The Corsica wetland decreased acidity, iron, aluminum, and manganese while increasing alkalinity and pH.

Metal reduction rates for anaerobic wetlands range from approximately 20 percent for manganese (Faulkner and Skousen 1995) to over 95 percent for iron, aluminum, and nickel (Eger et al. 1996; McCulley, Frick, and Gilman 1993). The Midas water contains elevated metal concentrations greater than the wetland influents detailed in Table 12. However, the oxidation/sedimentation pond will reduce the metal levels, even at a reduced 2:1 mixing ratio. Adsorption of other metals by iron and aluminum precipitates will occur with a reduced mixing ratio (Jones and Chapman 1995), as long as the pH remains high enough to cause iron and aluminum to precipitate. Factors controlling the adsorption include the amount of precipitate. Given the elevated levels of iron and aluminum, it is likely that enough precipitate will be

**Table 14:** **Metal removal efficiencies of constructed anaerobic wetlands** (Dietz and Stidinger 1996; Eger et al. 1996; Faulkner and Skousen 1995).

| Cold-climate Constructed Anaerobic Wetland Efficiencies Influent/Effluent (mg/L) | | | |
|---|---|---|---|
| | Wetland and Location | | |
| **Parameter** | **Z&F (WVa)** | **W1D (Mn)** | **Corsica (Pa)** |
| pH (su) | 2.5/3.5 | 7.1/7.1 | 3.41/6.62 |
| Sulfate | 2821.0/1662.0 | ---- | 1555.0/1496.0 |
| Acidity | ---- | ---- | 375.0/0.0 |
| Alkalinity | ---- | ---- | 0.0/112.3 |
| Iron | 376.0/86.0 | ---- | 11.13/0.511 |
| Aluminum | 206.0/76.0 | ---- | 0.055/0.026 |
| Manganese | 51.0/40.0 | ---- | 38.21/33.72 |
| Copper | ---- | 0.068/0.010 | ---- |
| Nickel | ---- | 3.94/0.38 | ---- |
| Cobalt | ---- | 0.032/0.010 | ---- |
| Zinc | ---- | 0.051/0.012 | ---- |

present to allow the adsorption process. The co-precipitation of other metals is also likely to occur (Jones and Chapman 1995).

## 6.8 Post-construction monitoring

The survival and continued growth of the wetland vegetation is critical to the success of the constructed wetland. The vegetation used in the constructed wetland will be transplanted from wetlands and riparian zones in the vicinity of the Midas Spring. Although the plants will be site-adapted, the potential for transplant shock may exist. Therefore, the transplanted vegetation should be visually monitored daily during the two week adaptation period prior to

the introduction of the oxidation/sedimentation pond effluent. If the vegetation exhibits any symptoms of transplant shock, appropriate measures should be taken to alleviate the symptoms before the pond effluent is introduced. Subsequent to the introduction of the pond effluent, the vegetation should be visually monitored every day, concurrent with the first month of oxidation/sedimentation pond monitoring. After the first month, weekly visual observations should be sufficient.

After the first winter and during the growing season, the vegetation density and diversity should be visually estimated. The visual estimation is required as the potential for substrate damage through compaction exists if personnel were allowed to walk on the substrate. If it appears that winter mortality or avian wildlife damage has not kept the wetland vegetation in r-growth stages, then the vegetation should be knocked down or broken over by personnel using long rods or other devices designed to break the vegetation. Continued wetland vegetation monitoring should not be required once it is determined that the vegetation is functioning as desired.

The potential for the short-circuiting of the substrate exists and steps should be taken to guard against this occurrence. Calculations to estimate actual residence time may be used to determine if short-circuiting has occurred. One such calculation is is derived from the division of the total inflow rate by the average volume of water stored in the wetland. This yields a renewal rate where the residence time is equal to the reciprocal of the renewal rate. However, this is a theoretical residence time and the actual residence time may be less (Mitsch and Gosselink 1993). Visual observations may be useful in determining whether short-circuiting has occurred. Short-circuiting frequently is in the form of channelization which may be apparent to the observer.

The constructed anaerobic wetland effluent (the total treatment system effluent) should be analyzed to determine the suitability of the effluent water for either livestock wildlife or irrigation. Frequent laboratory analysis is not consistent with all the goals of the treatment system; however, it is necessary to determine the effectiveness of the system. Grab samples of the wetland effluent should be taken bi-weekly for the first month. After that, bi-monthly samples should be taken for the first year of operation. This sample frequency will facilitate the analysis of the effectiveness of the treatment system through winter as well as during the warmer months. After one year, baseline information and trends will be established and the sampling frequency may be reduced.

The wetland monitoring protocol is consistent with the project goals, with the exception of the effluent analysis, and may be conducted concurrent with the monitoring of the oxidation/sedimentation pond. The total time for the monitoring of the pond and wetland should not exceed two man-hours.

# 7.0 Potential System Failures

## 7.1 Potential oxidation/sedimentation pond failures

Proper construction techniques should minimize any potential pond failures. However, one failure associated with the transport of the Midas Spring water into the pond may potentially occur during normal pond operation. The pipe transporting the Midas water will directly contact the pond treatment water and the potential exists for the pipe to become fouled or plugged over a period of time by premature precipitation of metals in the mouth of the pipe. This should not occur because the Midas water will undergo a series of velocity and turbulence increasing processes and the velocity will be such that it will flow forcibly into the pond and the Midas concentration will disperse after flowing a short distance into the pond. Bench-scale tests indicate that metal precipitation, as flocculate, occurs instantly with the contact of treatment water. The flocculate forms a cloud and the metal precipitants start to settle within minutes. As the Midas inflow will be continuous with an increased velocity, no back flushing of the precipitates or flocculate into the pipe is anticipated. If the 100:1 ratio is not maintained, the potential for fouling is decreased as a reduction in the amount of metal precipitates will occur. No problems are anticipated with the transport piping delivering the spring water to the oxidation/sedimentation pond.

## 7.2 Potential constructed wetland failures

Two areas for potential constructed wetland failures exist: 1) improper construction of the wetland cell, and; 2) lack of substrate maintenance. Experience in the Colorado Rocky Mountain region indicates that the success of a constructed system may depend more upon the geotechnical design rather than the optimization of the desired chemical processes (Ganse et al. 1993). The principle component of substrate maintenance is the ability to maintain substrate

capabilities (i.e, prevent the substrate from wearing out). Wildeman et al. (1993) state four reasons for a constructed wetland substrate to become depleted:

- The precipitated metal sulfides occupying the void spaces
- The consumption of OM and substrate carbon
- The humification of OM
- The loss of permeability which may be related to OM conditions and/or compaction from substrate settlement.

As the pond effluent should not contain appreciable quantities of ferric iron or aluminum, no clogging of the wetland influent plumbing system is anticipated.

Mitigation measures to prevent depletion or failure of the constructed wetland substrate include (Wildeman et al. 1993):

- The maintenance of the surface plant community to provide a continuous source of OM and carbon.
- Periodic additions of OM as a solid on the surface. This may be as simple as adding straw using mulch-spreading machines.
- Periodic removal of finer grained materials which may lower substrate permeability.
- The continuous maintenance of substrate saturation even if the wetland is temporarily idle. Permeability restoration through substrate drying is temporary and may result in the oxidation of precipitated metals and the subsequent remobilization of the metals when flows are re-established. Additionally, drying exacerbates OM breakdown and decreases hydraulic conductivity through substrate compression.

- Prohibition of machinery and personnel on the substrate surface.

Constructed wetland vegetation may experience decreased vigor or die if metal concentrations in the substrate are elevated. The use of the oxidation/sedimentation pond ensures that reduced quantities of metals will be contained in the pond effluent and subsequently the wetland. The vegetation should flourish and ensure a continued source of OM and carbon. The continued maintenance of the vegetation should also reduce or eliminate the potential to add additional OM and carbon in the form of straw mulch. Finer-grained materials, in the form of metal precipitates occupying void spaces, should not require removal as the pretreatment process reduces the metals and sulfate the wetland will be receiving. The constructed wetland is not expected to remain idle for a long period of time, if at all. No maintenance of the wetland is anticipated and any maintenance of the oxidation/sedimentation pond should be short in duration. If a second, smaller pond is built to offset annual primary pond maintenance, then the wetland will not be inactive. As the wetland will not be inactive or dewatered, no need for machinery or personnel on the substrate is required; thereby eliminating the potential for substrate compaction.

The proper placement of straw bales as flow desynchronization baffles and suitable gravel placement within the substrate should eliminate potential short-circuiting and ensure adequate hydraulic conductivity and residence time. The proper establishment (i.e., waiting for any transplant shock effects to end) of wetland vegetation prior to releasing the pond effluent should ensure long-term productivity and a continued source of OM. The above referenced principles combined with the implementation of previously detailed construction parameters should eliminate the potential for the constructed wetland to fail.

# 8.0 Conclusions and Recommendations

## 8.1 Conclusions

The development and successful implementation of the oxidation/sedimentation pond and constructed anaerobic wetland complex would simulate two natural processes. First, the precipitation of metals through the formation of hydroxides or oxyhydroxides. This process has been well documented and is chemically and visually evident at historic unremediated mine sites where ARD contacts natural flows. Second, the further filtering of metal contaminants through the use of a constructed anaerobic wetland which would simulate the natural anaerobic function of removing particulate material and pollutants through reduction processes.

The implementation of this truly passive treatment system attains each project goal as detailed below:

- The development of a passive treatment system for ARD: The operation of the oxidation/sedimentation pond wetland complex requires no mechanical (fuel or electric powered) equipment or chemical treatments and only periodic visual and rudimentary chemistry monitoring.
- Low operation and maintenance requirements: When the system is functioning, only periodic inspection is required. The oxidation/sedimentation pond will require excavation; however, the length of time required before excavation is not completely estimable and will require field determination during the first weeks of operation. As no equipment is utilized, the use of repair and maintenance personnel is negated.
- The utilization of on-site or locally available materials: With the possible exception of synthetic lining material (which the mine may have on-site), all

components of the system are locally available. Plumbing materials are available at home improvement stores and the wetland substrate components are readily obtained through excavation and nearby ranching operations.

- Long-term effectiveness: An uninterrupted and continuous flow of neutral to alkaline spring or ground treatment water coupled with periodic sludge removal should ensure the long-term effectiveness of the oxidation/sedimentation pond. If the pond were to experience decreased effectiveness associated with a decreased mixing ratio, iron and aluminum will still precipitate as the pH of the pond would approximate 3.0. The additional metals will be adsorbed by or co-precipitate with the iron and aluminum. Proper design and construction of the anaerobic wetland should eliminate potential short-circuiting or channelization of the wetland substrate. The wetland will be receiving improved water and the potential for metal loading will be minimized. These two factors should provide for an extended life expectancy of the constructed wetland.
- Compliance with Montana water quality standards for wildlife and livestock: No standards currently exist; however, guidelines delineating the maximum recommended metal concentrations exist. Table 9 illustrated that the 100:1 pond effluent exceeds the guidelines for livestock and wildlife as well as irrigation guidelines. As the pond's efficiency is decreased, the anaerobic wetland should effectively remove metals and sulfate while increasing pH and alkalinity; thereby maintaining compliance with the water quality standards.

The use of an oxidation/sedimentation pond as the only pretreatment for water entering an anaerobic constructed wetland appears to be unique in the northern Rocky Mountain region.

However, bench-scale tests indicate a high probability of success if the 100:1 mixture of Sheep Rock Spring water to Midas Spring water can be maintained. Even with a reduced ratio, the pond effluent will possess reduced levels of metals and have a sulfate concentration and pH high enough to allow the wetland to successfully treat the water. Constructed wetlands in Montana have not functioned with a high degree of success. However, failures are principally related to the pretreatment processes or improper construction techniques. Constructed anaerobic wetlands in cold climates in the eastern United States have demonstrated an ability to cleanse acid mine drainages and produce an improved effluent. The potential for the success of the constructed anaerobic wetland at the Midas site is high as it will be receiving water with reduced metal concentrations and will be designed for maximum life expectancy. The treatment system developed in this paper mimics natural processes and should provide for a passive, low-maintenance ARD treatment system.

## 8.2 Recommendations

### 8.2.1 Oxidation/sedimentation pond

The construction phase of the treatment system is critical to the successful operation of the oxidation/sedimentation pond and the anaerobic wetland. Proper sizing of both the pond and the wetland is important; however, as long as the length-to-width ratio remains at least 4:1, some variation in the overall sizing is permissible. The wetland should possess an irregular shape, not a rectangle, to enhance residence time and maximize metal removal through increased contact with the substrate. Both the pond and the wetland, along with the pipe placement should be delineated prior to excavation. On-site supervision by personnel familiar with the system is necessary to determine the adequate depths and slopes of the pond and wetland. Excavated topsoil should be stored separately from the subsoil as the topsoil will be utilized as part of the

wetland substrate. The topsoil should not be stored for longer than one or two weeks; therefore, no soil amendments or plantings to maintain the integrity of the topsoil will be required.

The piping transporting the Sheep Rock Spring and Midas water to the oxidation/sedimentation pond should be deeper than the frost level. Additionally, turbulence enhancing devices to increase the DO content in the water should be installed. These devices should be a series of step-downs contained within the piping coupled with vent stacks to allow oxygen into the piping. The inflows from both water sources should be designed in this manner. A large part of the pond's treatment capabilities is derived from the oxygen content within the water; the metals will precipitate as oxides or oxyhydroxides.

Bench-scale tests indicate that a 100:1 or greater ratio of Sheep Rock Spring or comparable water to Midas water is effective at removing contaminants from ARD. The effectiveness of the oxidation/sedimentation pond will eventually decrease as the inflows decrease the water ratio. The pH of the pond should be checked daily for approximately 33 days (the time required for the mixing ratio to become the lowest). This will provide a reference trend for future applications and monitoring. After 33 days, the pH should be measured weekly to insure that the level has not decreased appreciably lower than 3.0. The monitoring of the pH may require seasonal adjustment as the flows will be seasonally variable. If additional water sources are available, then augmentation of the Sheep Rock flow with the additional water would maintain the mixing ratio at a high level and increase the efficiency of the pond. The size of the wetland and the pond may require up-sizing to accommodate the additional flow. Alternatively, the mixing ratio could be maintained at a higher level by reducing the Midas flow to the pond. This would require that the retained Midas flow continue to be mechanically treated and used in the ore processing circuit. The creation of a second, smaller pond may be desirable to allow

the continued operation of the system during the clean-out of the pond. Additionally, the second pond may be used in conjunction with the main pond to determine possible combinations of pretreatment and efficiencies.

8.2.2 Constructed anaerobic wetland

The piping transporting the pond effluent to the anaerobic wetland should capture the pond effluent at a depth, approximately halfway between the surface and the substrate, where no precipitates would pass into the wetland or clog the pipe. The effluent transport pipe should enter the wetland at the base of the substrate, under the gravel. This is essential as the wetland is designed to function in the upflow mode to maximize residence time and maximize contact with the substrate. The wetland effluent will spill over into the livestock/wildlife or irrigation pond via a surface culvert or weir.

The proper planting of the wetland and riparian vegetation along with the minimization of transplant shock is critical to the long term maintenance of the wetland substrate. Although wetland vegetation accounts for a small percentage of metals removed, their primary role is to provide OM and carbon to the wetland substrate to enhance DSR bacteria populations. Additionally, cattail roots are considered to enhance reducing conditions within the wetland substrate. The riparian vegetation will provide necessary berm stabilization and taller shrubs and trees will function as windbreaks. The root balls should be hand-dug to ensure complete root capture and immediately hand-planted to reduce the potential of mortality or shock. Cattails, after planting, should be broken over at the water level to promote new growth and increase the amount of available OM. Transplanting should occur during the spring or early summer. Subsequent to the transplanting, the wetland should be saturated for two weeks to allow the vegetation to recover from any shock before the Midas water is introduced.

Substrate material, as long as it possesses metal retention capabilities, is not as important as the substrate conditions created by the wetland vegetation and the presence of an anaerobic zone. However, proper hydraulic continuity is required to maximize substrate contact and prevent short-circuiting of the substrate. Without hydraulic continuity, as a result of compaction or substrate saturation, the water to be treated will find its own way past the substrate and no treatment benefits will be realized. On-site or locally available materials including gravel, composted steer manure, hay, and topsoil excavated from the oxidation/sedimentation pond and the wetland construction will be utilized in the wetland. Paramount in the construction of the wetland is the avoidance of machinery or excessive foot traffic on the substrate. The gravel should be placed along the base of the wetland at a depth of 15 cm, which allows the influent piping to be covered and allows the water to percolate upward. The manure, hay, and topsoil mixture should be placed on the gravel with 15 to 30 cm of topsoil on the substrate. At this point, compaction may occur through the operation of machinery or excessive foot traffic; only the personnel responsible for transplanting the vegetation and inoculating the substrate should be allowed on the substrate material. The potential compaction of the berms is not a concern.

Hydraulic discontinuity is important to create a functional anaerobic wetland. Discontinuity is accomplished through the placement of hay bales within the substrate, typically on the gravel where the pattern is readily laid out. After the placement of the hay bales, the substrate material may be installed. Additionally, the hay bales will provide additional OM to aid in DSR bacteria growth. If a need for additional hay bales arises during the operation of the wetland, a track hoe or back hoe could create an opening in the substrate for the placement of the bales.

The wetland effluent should be monitored after the livestock/wildlife watering or irrigation pond is partially filled. This should include an analysis of dissolved metals, as this pond will be unlined and designed to allow the downward infiltration of the water. Subsequent to the water analysis, the pH should be taken weekly to determine whether any metals may resolubilize and to determine whether the pH meets Montana standards. No specific state standards exist for either livestock/wildlife or irrigation; however, a range of guidelines exists and compliance with these guidelines is required for the planned use of the wetland effluent. Dependent upon the results of the pH testing, additional laboratory analysis for dissolved metals may be required.

8.2.3 Bench-scale test replications

This study was intended as a preliminary step in the development of an alternative method to remediate ARD. Prior to any construction activities, additional bench-scale testing should be conducted to verify the initial results. Although a test replication was conducted using dissolved metal parameters, additional testing is warranted. Greater quantities of both ARD and spring water using the 100:1 and other mixing ratios should be tested to determine the consistency of the results. In particular, the TCLP results for cadmium require verification to insure that the pond-generated sludge will consistently meet RCRA standands.

If this passive treatment system were to be built, it is expected to function as designed without any major modifications during construction or operation. The design is based upon current constructed anaerobic wetland technology coupled with initial bench-scale testing which demonstrates the feasibility of using an oxidation/sedimentation pond as a passive and non-manpower intensive method for the remediation of ARD.

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# APPENDICES

# Appendix A:
# Water Analysis - Dissolved Metals

**Maxim**
600 South 25th Street
P O Box 30615
Billings, MT 59107
(406) 248-9161
FAX (406) 248-9282

# TECHNICAL REPORT

**REPORT TO:** ATTN: TED SCHMIDT
ANTLER BIOLOGICAL SERVICES
4766 ASPEN LANE
BOZEMAN MT 59715

**DATE:** August 22, 1996
**JOB NUMBER:** 96-928
**SHEET:** 1 of 2
**INVOICE NO.:** 035974

**REPORT OF:** Water Analysis - Golden Sunlight

---

**SAMPLE IDENTIFICATION:**

On August 5, 1996, this water sample (laboratory number 177271) was received in our laboratory for analysis. Tests were conducted in accordance with EPA/4-79-020 *"Methods for Chemical Analysis of Water and Wastes"* and *"Standard Methods for the Examination of Water and Wastewater,"* 18th Edition.

The condition of the sample upon receipt at the laboratory is noted on the attached sample receipt checklist. Chain of custody documentation is enclosed.

The results of the analyses are shown on the following page.

A < sign indicates the value reported was the practical quantitation limit for this sample using the method described. Concentrations of analyte, if present, below this were not quantifiable.

Reviewed by Kathleen A. Ahti

Attachment: Chain of Custody
Sample Receipt Checklist

rmr

**Maxim**
600 South 25th Street
P O Box 30615
Billings, MT 59107
(406) 248-9161
FAX (406) 248-9282

# TECHNICAL REPORT

Revised: September 20, 1996

**REPORT TO:** ATTN: TED SCHMIDT
ANTLER BIOLOGICAL SERVICES
4766 ASPEN LANE
BOZEMAN MT 59715

**DATE:** August 22, 1996
**JOB NUMBER:** 96-928
**SHEET:** 1 of 2
**INVOICE NO.:** 035974

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**SAMPLE IDENTIFICATION:**

On August 5, 1996, this water sample (laboratory number 177271) was received in our laboratory for analysis. Tests were conducted in accordance with EPA/4-79-020 *"Methods for Chemical Analysis of Water and Wastes"* and *"Standard Methods for the Examination of Water and Wastewater,"* 18th Edition.

The condition of the sample upon receipt at the laboratory is noted on the attached sample receipt checklist. Chain of custody documentation is enclosed.

The results of the analyses are shown on the following page.

A < sign indicates the value reported was the practical quantitation limit for this sample using the method described. Concentrations of analyte, if present, below this were not quantifiable.

Reviewed by Denise Jensen

Attachment: Chain of Custody
Sample Receipt Checklist

rmr

Client Name: ANTLER BIOLOGICAL SERVICES
Project No.: 96-928
Laboratory No.: 177271
Sample Name: WATER SAMPLE
Sample Date: NONE GIVEN
Collected by: NONE GIVEN
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <2 | mg/l | 305.1 | 08/07/96 |
| Alkalinity Bicarbonate as HCO3 | 45 | mg/l | 2320B | 08/07/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 08/07/96 |
| Alkalinity Total as CaCO3 | 37 | mg/l | 2320B | 08/07/96 |
| Chloride as Cl | 9 | mg/l | 325.3 | 08/15/96 |
| Fluoride (undistilled) | 0.36 | mg/l | 340.2 | 08/19/96 |
| Sulfate as SO4 | 477 | mg/l | 375.2 | 08/06/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 91 | mg/l | 3500 | 08/07/96 |
| Magnesium as Mg | 78 | mg/l | 3500 | 08/07/96 |
| Potassium as K | 7 | mg/l | 258.1 | 08/08/96 |
| Sodium as Na | 18 | mg/l | 273.1 | 08/08/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 947 | umhos/cm | 120.1 | 08/06/96 |
| pH | 6.3 | S.U. | 150.1 | 08/05/96 |
| Total Dissolved Solids | 735 | mg/l | 160.1 | 08/08/96 |
| **METALS** | | | | |
| Aluminum as Al (Dissolved) | <0.1 | mg/l | 200.7 | 09/05/96 |
| Arsenic as As (Dissolved) | <0.003 | mg/l | 206.3 | 08/13/96 |
| Barium as Ba (Dissolved) | 0.089 | mg/l | 200.7 | 09/05/96 |
| Beryllium as Be (Dissolved) | <0.001 | mg/l | 210.2 | 08/14/96 |
| Cadmium as Cd (Dissolved) | <0.0005 | mg/l | 213.2 | 09/05/96 |
| Chromium as Cr (Dissolved) | <0.002 | mg/l | 218.2 | 08/21/96 |
| Copper as Cu (Dissolved) | 0.37 | mg/l | 200.7 | 09/05/96 |
| Iron as Fe (Dissolved) | 0.10 | mg/l | 200.7 | 09/05/96 |
| Lead as Pb (Dissolved) | 0.013 | mg/l | 239.2 | 09/05/96 |
| Manganese as Mn (Dissolved) | 1.21 | mg/l | 200.7 | 09/05/96 |
| Nickel as Ni (Dissolved) | 0.25 | mg/l | 200.7 | 09/05/96 |
| Selenium as Se (Dissolved) | <0.001 | mg/l | 270.3 | 08/21/96 |
| Zinc as Zn (Dissolved) | 0.55 | mg/l | 200.7 | 08/20/96 |

Client Name: ANTLER BIOLOGICAL SERVICES
Project No.: 96-928
Laboratory No.: 177271
Sample Name: WATER SAMPLE
Sample Date: NONE GIVEN
Collected by: NONE GIVEN
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <2 | mg/l | 305.1 | 08/07/96 |
| Alkalinity Bicarbonate as HCO3 | 45 | mg/l | 2320B | 08/07/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 08/07/96 |
| Alkalinity Total as CaCO3 | 37 | mg/l | 2320B | 08/07/96 |
| Chloride as Cl | 9 | mg/l | 325.3 | 08/15/96 |
| Fluoride (undistilled) | 0.36 | mg/l | 340.2 | 08/19/96 |
| Sulfate as SO4 | 477 | mg/l | 375.2 | 08/06/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 91 | mg/l | 3500 | 08/07/96 |
| Magnesium as Mg | 78 | mg/l | 3500 | 08/07/96 |
| Potassium as K | 7 | mg/l | 258.1 | 08/08/96 |
| Sodium as Na | 18 | mg/l | 273.1 | 08/08/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 947 | umhos/cm | 120.1 | 08/06/96 |
| pH | 6.3 | S.U. | 150.1 | 08/05/96 |
| Total Dissolved Solids | 735 | mg/l | 160.1 | 08/08/96 |
| **METALS** | | | | |
| Aluminum as Al (Dissolved) | <0.1 | mg/l | 200.7 | 08/20/96 |
| Arsenic as As (Dissolved) | <0.003 | mg/l | 206.3 | 08/13/96 |
| Barium as Ba (Dissolved) | 0.032 | mg/l | 200.7 | 08/15/96 |
| Beryllium as Be (Dissolved) | <0.001 | mg/l | 210.2 | 08/14/96 |
| Cadmium as Cd (Dissolved) | 0.009 | mg/l | 200.7 | 08/20/96 |
| Chromium as Cr (Dissolved) | <0.002 | mg/l | 218.2 | 08/21/96 |
| Copper as Cu (Dissolved) | 1.02 | mg/l | 200.7 | 08/21/96 |
| Iron as Fe (Dissolved) | 0.02 | mg/l | 200.7 | 08/20/96 |
| Lead as Pb (Dissolved) | 1.3 | mg/l | 200.7 | 08/20/96 |
| Manganese as Mn (Dissolved) | 1.10 | mg/l | 200.7 | 08/20/96 |
| Nickel as Ni (Dissolved) | 0.23 | mg/l | 200.7 | 08/20/96 |
| Selenium as Se (Dissolved) | <0.001 | mg/l | 270.3 | 08/21/96 |
| Zinc as Zn (Dissolved) | 0.55 | mg/l | 200.7 | 08/20/96 |

MAXIM TECHNOLOGIES INC

## SAMPLE RECEIPT CHECKLIST

Client Name: Antea Biological
Project: Golden Sunlight
Laboratory number(s): 177271
Checklist completed by: [Initials] / 8/5 [Date]

Date/Time Received: 8/5/96 (Date) / 1345 (Time)
Received by: C. Jensen
Carrier name: Hand Delivered
Sample Type: Water

| | | YES | NO |
|---|---|---|---|
| 1. | Shipping container in good condition? | N | A |
| 2. | Custody seals present on shipping container? | N | A |
| 3. | Condition: Intact ____ Broken ____ | | |
| 4. | Chain of custody present? | ✓ | — |
| 5. | Chain of custody signed when relinquished and received? | ✓ | — |
| 6. | Chain of custody agrees with sample labels? | — | ✓ |
| 7. | Custody seals on sample bottles? | — | ✓ |
| 8. | Condition: Intact ____ Broken ____ | | |
| 9. | Samples in proper container/bottle? | ✓ | — |
| 10. | Samples intact? | ✓ | — |
| 11. | Sufficient sample volume for indicated test? | ✓ | — |
| 12. | VOA vials have zero headspace? | N | A |
| 13. | Trip Blank received? | — | ✓ |
| 14. | Ice/Frozen Blue Ice present in shipping container? (circle one) | — | ✓ |
| 15. | Container temperature 1. ____ 2. ____ 3. ____ | | |

| | | YES | NO |
|---|---|---|---|
| 16. | All samples rec'd within holding time? | N | A |
| | Preservation | | |
| 17. | pH check performed by: CC | | |
| 18. | Metals bottle(s) pH <2? | * | — |
| 19. | Nutrient bottle(s) pH <2? | N | A |
| 20. | Cyanide bottle(s) pH >12? | — | — |
| 21. | Sulfide bottle(s) pH >9? | — | — |
| 22. | Oil & grease bottle(s) pH <2? | — | — |
| 23. | TOC bottle(s) pH <2? | — | — |
| 24. | DRO/418.1 bottle(s) pH <2? | — | — |
| 25. | Phenolics bottle(s) pH <2? | — | ✓ |
| 26. | Volatiles (VOA) pH <2? (VOA pH checked by analyst) | — | — |
| 27. | Client contacted? | — | — |
| 28. | Person contacted | | |
| 29. | Date contacted | | |
| 30. | Contacted by | | |
| 31. | Regarding? | | |

**Note: Samples may be affected when not transported at the temperature recommended by the EPA for the test you've selected. Please contact the lab if you have concerns about the temperature of your samples.**

COMMENTS: #6 No ID on sample
* filtered & preserved with 1+1 $HNO_3$ CC

# CHAIN OF CUSTODY RECORD

**MAXIM TECHNOLOGIES INC**

600 South 25th Street
Billings, Montana 59101
Phone (406) 248-9161 • Fax (406) 248-9282

Golden Sunlight
Project or Site Name

Project Number

Sampler Name (Printed)

~~Gold~~ Ted Schmidt 16-434
Contact Name Antler Biological Services
4766 Aspen Lane
Report to (Firm or Agency)
Bozeman MT 59715
Address

Sampler Signature

| DATE COLLECTED | TIME COLLECTED | SAMPLE LOCATION OR DESCRIPTION | COMP OR GRAB | SAMPLE MATRIX | NO. OF CONTAINERS | ANALYSIS REQUIRED | NOTES | LAB NUMBER |
|---|---|---|---|---|---|---|---|---|
| none given | | water sample | | | | X Dissolved Metals, X Conventionals, X Cyanide | see attached parameter list for metals & required detection limits<br><br>fax when complete 406-582-1889 | 177271 |

Relinquished by: Ted Schmidt — Date 8/5/96 — Time 1305 — Received by: D. Jensen.

Relinquished by: D. Jensen — Date 8/5/96 — Time 1305 — Received by:

Relinquished by: — Date — Time — Received by:

Relinquished by: — Date — Time — Received by:

Remarks: filter at preserve a portion of the water for dissolved metals

MT

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# Appendix B:
## Water Analysis - Total Recoverable Metals

**Note: ABS01 refers to the treated water;**
**ABS02 refers to the Midas discharge, and;**
**ABS03 refers to Sheep Rock Spring water**

**Maxim**
600 South 25th Street
P O Box 30615
Billings, MT 59107
(406) 248-9161
FAX (406) 248-9282

# TECHNICAL REPORT

**REPORT TO:** ATTN: LEMOINE WEIDMAN
GOLDEN SUNLIGHT MINES, INC.
453 MT HWY 2 EAST
WHITEHALL MT 59759

**DATE:** May 31, 1996
**JOB NUMBER:** 90-929
**SHEET:** 1 of 11
**INVOICE NO.:** 034399

**REPORT OF:** Water Analysis

---

**SAMPLE IDENTIFICATION:**

On May 20, 1996, these water samples (our laboratory numbers 174383 through 174385) were received in our laboratory for analysis. Tests were conducted in accordance with EPA/600/4-79-020 *"Methods for Chemical Analysis of Water and Wastes"*.

The condition of the samples upon receipt at the laboratory is noted on the attached sample receipt checklist. Chain of custody documentation is enclosed.

The results of the analysis are shown on the following pages.

A < sign indicates the value reported was the practical quantitation limit for this sample using the method described. Concentrations of analyte, if present, below this were not quantifiable.

Reviewed by _____

cc: Ted Schmidt
4766 Aspen Lane
Bozeman, MT 59715

Attachments: Chain of Custody
Sample Receipt Checklist

caj

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174383
Sample Name: ABS01 TREATED
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <2 | mg/l | 305.1 | 05/29/96 |
| Alkalinity Bicarbonate as HCO3 | 80 | mg/l | 2320B | 05/29/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 05/29/96 |
| Alkalinity Total as CaCO3 | 66 | mg/l | 2320B | 05/29/96 |
| Chloride as Cl | 9 | mg/l | 353.2 | 05/23/96 |
| Fluoride (undistilled) | 0.49 | mg/l | 340.2 | 05/23/96 |
| Sulfate as SO4 | 427 | mg/l | 375.2 | 05/29/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 90 | mg/l | 200.7 | 05/20/96 |
| Hardness as CaCO3 | 484 | mg/l | 2340B | 05/20/96 |
| Magnesium as Mg | 63 | mg/l | 200.7 | 05/21/96 |
| Potassium as K | 6 | mg/l | 258.1 | 05/22/96 |
| Sodium as Na | 12 | mg/l | 200.7 | 05/20/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 887 | umhos/cm | 120.1 | 05/30/96 |
| pH | 6.2 | S.U. | 150.1 | 05/20/96 |
| Total Dissolved Solids | 694 | mg/l | 160.1 | 05/23/96 |
| **METALS** | | | | |
| Aluminum as Al (Total Recoverable) | 0.5 | mg/l | 200.7 | 05/23/96 |
| Arsenic as As (Total Recoverable) | <0.003 | mg/l | 206.3 | 05/29/96 |
| Barium as Ba (Total Recoverable) | 0.076 | mg/l | 200.7 | 05/22/96 |
| Beryllium as Be (Total Recoverable) | <0.001 | mg/l | 210.2 | 05/29/96 |
| Cadmium as Cd (Total Recoverable) | 0.002 | mg/l | 213.2 | 05/29/96 |
| Chromium as Cr (Total Recoverable) | <0.001 | mg/l | 218.2 | 05/29/96 |
| Copper as Cu (Total Recoverable) | 0.86 | mg/l | 200.7 | 05/23/96 |
| Iron as Fe (Total Recoverable) | 0.05 | mg/l | 200.7 | 05/22/96 |
| Lead as Pb (Total Recoverable) | <0.003 | mg/l | 239.2 | 05/29/96 |
| Manganese as Mn (Total Recoverable) | 0.69 | mg/l | 200.7 | 05/22/96 |
| Nickel as Ni (Total Recoverable) | 0.13 | mg/l | 200.7 | 05/22/96 |
| Selenium as Se (Total Recoverable) | 0.001 | mg/l | 270.3 | 05/28/96 |
| Zinc as Zn (Total Recoverable) | 0.39 | mg/l | 200.7 | 05/22/96 |
| **Nutrients** | | | | |
| Ammonia (Undistilled) as N | <0.05 | mg/l | 350.1 | 05/22/96 |
| Nitrate + Nitrite as N | 0.20 | mg/l | 353.2 | 05/24/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174383
Sample Name: ABS01
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| Phosphorous Ortho | 0.02 | mg/l | 365.1 | 05/21/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174384
Sample Name: ABS02 MW-5 B5
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | 27500 | mg/l | 305.1 | 05/29/96 |
| Alkalinity Bicarbonate as HCO3 | <1 | mg/l | 2320B | 05/29/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 05/29/96 |
| Alkalinity Total as CaCO3 | <1 | mg/l | 2320B | 05/29/96 |
| Chloride as Cl | 582 | mg/l | 353.2 | 05/23/96 |
| Fluoride (undistilled) | <0.05 | mg/l | 340.2 | 05/23/96 |
| Sulfate as SO4 | 33400 | mg/l | 375.2 | 05/29/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 480 | mg/l | 200.7 | 05/20/96 |
| Hardness as CaCO3 | 9435 | mg/l | 2340B | 05/20/96 |
| Magnesium as Mg | 2000 | mg/l | 200.7 | 05/21/96 |
| Potassium as K | 2 | mg/l | 258.1 | 05/22/96 |
| Sodium as Na | 105 | mg/l | 200.7 | 05/20/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 19,100 | umhos/cm | 120.1 | 05/30/96 |
| pH | 2.6 | S.U. | 150.1 | 05/20/96 |
| Total Dissolved Solids | 50700 | mg/l | 160.1 | 05/23/96 |
| **METALS** | | | | |
| Aluminum as Al (Total Recoverable) | 8750 | mg/l | 200.7 | 05/23/96 |
| Arsenic as As (Total Recoverable) | 1.2 | mg/l | 206.3 | 05/29/96 |
| Barium as Ba (Total Recoverable) | 0.36 | mg/l | 200.7 | 05/22/96 |
| Beryllium as Be (Total Recoverable) | 0.25 | mg/l | 210.2 | 05/29/96 |
| Cadmium as Cd (Total Recoverable) | 0.39 | mg/l | 200.7 | 05/22/96 |
| Chromium as Cr (Total Recoverable) | 1.2 | mg/l | 218.2 | 05/29/96 |
| Copper as Cu (Total Recoverable) | 286 | mg/l | 200.7 | 05/23/96 |
| Iron as Fe (Total Recoverable) | 2540 | mg/l | 200.7 | 05/22/96 |
| Lead as Pb (Total Recoverable) | <0.01 | mg/l | 239.2 | 05/29/96 |
| Manganese as Mn (Total Recoverable) | 135 | mg/l | 200.7 | 05/22/96 |
| Nickel as Ni (Total Recoverable) | 24.0 | mg/l | 200.7 | 05/22/96 |
| Selenium as Se (Total Recoverable) | 0.030 | mg/l | 270.3 | 05/28/96 |
| Zinc as Zn (Total Recoverable) | 70.2 | mg/l | 200.7 | 05/22/96 |
| **Nutrients** | | | | |
| Ammonia (Undistilled) as N | 3.36 | mg/l | 350.1 | 05/22/96 |
| Nitrate + Nitrite as N | 5.7 | mg/l | 353.2 | 05/24/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174384
Sample Name: ABS02
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| Phosphorous Ortho | 0.08 | mg/l | 365.1 | 05/21/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174385
Sample Name: ABS03 SWEEP 12UL
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <2 | mg/l | 305.1 | 05/29/96 |
| Alkalinity Bicarbonate as HCO3 | 317 | mg/l | 2320B | 05/29/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 05/29/96 |
| Alkalinity Total as CaCO3 | 260 | mg/l | 2320B | 05/29/96 |
| Chloride as Cl | 6 | mg/l | 353.2 | 05/23/96 |
| Fluoride (undistilled) | 0.40 | mg/l | 340.2 | 05/23/96 |
| Sulfate as SO4 | 167 | mg/l | 375.2 | 05/29/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 89 | mg/l | 200.7 | 05/30/96 |
| Hardness as CaCO3 | 408 | mg/l | 2340B | 05/20/96 |
| Magnesium as Mg | 45 | mg/l | 200.7 | 05/21/96 |
| Potassium as K | 6 | mg/l | 258.1 | 05/22/96 |
| Sodium as Na | 11 | mg/l | 200.7 | 05/20/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 774 | umhos/cm | 120.1 | 05/30/96 |
| pH | 8.2 | S.U. | 150.1 | 05/20/96 |
| Total Dissolved Solids | 552 | mg/l | 160.1 | 05/23/96 |
| **METALS** | | | | |
| Aluminum as Al (Total Recoverable) | 0.1 | mg/l | 200.7 | 05/23/96 |
| Arsenic as As (Total Recoverable) | <0.003 | mg/l | 206.3 | 05/29/96 |
| Barium as Ba (Total Recoverable) | 0.084 | mg/l | 200.7 | 05/22/96 |
| Beryllium as Be (Total Recoverable) | <0.001 | mg/l | 210.2 | 05/29/96 |
| Cadmium as Cd (Total Recoverable) | <0.0001 | mg/l | 213.2 | 05/29/96 |
| Chromium as Cr (Total Recoverable) | <0.001 | mg/l | 218.2 | 05/29/96 |
| Copper as Cu (Total Recoverable) | 0.002 | mg/l | 220.2 | 05/20/96 |
| Iron as Fe (Total Recoverable) | 0.14 | mg/l | 200.7 | 05/22/96 |
| Lead as Pb (Total Recoverable) | <0.003 | mg/l | 239.2 | 05/29/96 |
| Manganese as Mn (Total Recoverable) | 0.035 | mg/l | 200.7 | 05/22/96 |
| Nickel as Ni (Total Recoverable) | <0.02 | mg/l | 200.7 | 05/22/96 |
| Selenium as Se (Total Recoverable) | 0.001 | mg/l | 270.3 | 05/28/96 |
| Zinc as Zn (Total Recoverable) | 0.10 | mg/l | 200.7 | 05/22/96 |
| **Nutrients** | | | | |
| Ammonia (Undistilled) as N | <0.05 | mg/l | 350.1 | 05/22/96 |
| Nitrate + Nitrite as N | 0.14 | mg/l | 353.2 | 05/24/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174385
Sample Name: ABS03
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| Phosphorous Ortho | 0.02 | mg/l | 365.1 | 05/21/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174386
Sample Name: DUPLICATE 174383 ABS01
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <2 | mg/l | 305.1 | 05/29/96 |
| Alkalinity Bicarbonate as HCO3 | 81 | mg/l | 2320B | 05/29/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 05/29/96 |
| Alkalinity Total as CaCO3 | 66 | mg/l | 2320B | 05/29/96 |
| Chloride as Cl | 8 | mg/l | 353.2 | 05/23/96 |
| Fluoride (undistilled) | 0.52 | mg/l | 340.2 | 05/23/96 |
| Sulfate as SO4 | 448 | mg/l | 375.2 | 05/29/96 |
| **CATIONS** | | | | |
| Calcium as Ca | 80 | mg/l | 200.7 | 05/20/96 |
| Hardness as CaCO3 | 459 | mg/l | 2340B | 05/20/96 |
| Magnesium as Mg | 63 | mg/l | 200.7 | 05/21/96 |
| Potassium as K | 5 | mg/l | 258.1 | 05/22/96 |
| Sodium as Na | 13 | mg/l | 200.7 | 05/20/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | 873 | umhos/cm | 120.1 | 05/30/96 |
| pH | 6.2 | S.U. | 150.1 | 05/20/96 |
| Total Dissolved Solids | 697 | mg/l | 160.1 | 05/23/96 |
| **METALS** | | | | |
| Aluminum as Al (Total Recoverable) | 0.5 | mg/l | 200.7 | 05/23/96 |
| Arsenic as As (Total Recoverable) | <0.003 | mg/l | 206.3 | 05/29/96 |
| Barium as Ba (Total Recoverable) | 0.077 | mg/l | 200.7 | 05/22/96 |
| Beryllium as Be (Total Recoverable) | <0.001 | mg/l | 210.2 | 05/29/96 |
| Cadmium as Cd (Total Recoverable) | 0.002 | mg/l | 213.2 | 05/29/96 |
| Chromium as Cr (Total Recoverable) | <0.001 | mg/l | 218.2 | 05/29/96 |
| Copper as Cu (Total Recoverable) | 0.90 | mg/l | 200.7 | 05/23/96 |
| Iron as Fe (Total Recoverable) | 0.05 | mg/l | 200.7 | 05/22/96 |
| Lead as Pb (Total Recoverable) | <0.003 | mg/l | 239.2 | 05/29/96 |
| Manganese as Mn (Total Recoverable) | 0.69 | mg/l | 200.7 | 05/22/96 |
| Nickel as Ni (Total Recoverable) | 0.12 | mg/l | 200.7 | 05/22/96 |
| Selenium as Se (Total Recoverable) | 0.001 | mg/l | 270.3 | 05/28/96 |
| Zinc as Zn (Total Recoverable) | 0.38 | mg/l | 200.7 | 05/22/96 |
| **Nutrients** | | | | |
| Ammonia (Undistilled) as N | <0.05 | mg/l | 350.1 | 05/22/96 |
| Nitrate + Nitrite as N | 0.19 | mg/l | 353.2 | 05/24/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174386
Sample Name: DUPLICATE 174383 ABS01
Sample Date: 05/17/96
Collected by: TED SCHMIDT
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| Phosphorous Ortho | 0.01 | mg/l | 365.1 | 05/21/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174387
Sample Name: METHOD BLANK
Sample Date: NONE GIVEN
Collected by: NONE GIVEN
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| **ANIONS** | | | | |
| Acidity as CaCO3 | <1 | mg/l | 305.1 | 05/29/96 |
| Alkalinity Bicarbonate as HCO3 | <1 | mg/l | 2320B | 05/29/96 |
| Alkalinity Carbonate as CO3 | 0 | mg/l | 2320B | 05/29/96 |
| Alkalinity Total as CaCO3 | <1 | mg/l | 2320B | 05/29/96 |
| Chloride as Cl | <1 | mg/l | 353.2 | 05/23/96 |
| Fluoride (undistilled) | <0.05 | mg/l | 340.2 | 05/23/96 |
| Sulfate as SO4 | <15 | mg/l | 375.2 | 05/28/96 |
| **CATIONS** | | | | |
| Calcium as Ca | <1 | mg/l | 200.7 | 05/20/96 |
| Hardness as CaCO3 | <7 | mg/l | 2340B | 05/21/96 |
| Magnesium as Mg | <1 | mg/l | 200.7 | 05/21/96 |
| Potassium as K | <1 | mg/l | 258.1 | 05/22/96 |
| Sodium as Na | <1 | mg/l | 200.7 | 05/20/96 |
| **INORGANICS** | | | | |
| Electrical Conductivity | NA | umhos/cm | 120.1 | |
| pH | NA | S.U. | 150.1 | |
| Total Dissolved Solids | <10 | mg/l | 160.1 | 05/23/96 |
| **METALS** | | | | |
| Aluminum as Al (Total Recoverable) | <0.1 | mg/l | 200.7 | 05/23/96 |
| Arsenic as As (Total Recoverable) | <0.003 | mg/l | 206.3 | 05/29/96 |
| Barium as Ba (Total Recoverable) | <0.005 | mg/l | 200.7 | 05/22/96 |
| Beryllium as Be (Total Recoverable) | <0.001 | mg/l | 210.2 | 05/29/96 |
| Cadmium as Cd (Total Recoverable) | <0.0001 | mg/l | 213.2 | 05/29/96 |
| Chromium as Cr (Total Recoverable) | <0.001 | mg/l | 218.2 | 05/29/96 |
| Copper as Cu (Total Recoverable) | <0.001 | mg/l | 220.2 | 05/20/96 |
| Iron as Fe (Total Recoverable) | <0.01 | mg/l | 200.7 | 05/22/96 |
| Lead as Pb (Total Recoverable) | <0.003 | mg/l | 239.2 | 05/29/96 |
| Manganese as Mn (Total Recoverable) | <0.005 | mg/l | 200.7 | 05/22/96 |
| Nickel as Ni (Total Recoverable) | <0.02 | mg/l | 200.7 | 05/22/96 |
| Selenium as Se (Total Recoverable) | <0.001 | mg/l | 270.3 | 05/28/96 |
| Zinc as Zn (Total Recoverable) | <0.01 | mg/l | 200.7 | 05/22/96 |
| **Nutrients** | | | | |
| Ammonia (Undistilled) as N | <0.05 | mg/l | 350.1 | 05/22/96 |
| Nitrate + Nitrite as N | <0.05 | mg/l | 353.2 | 05/24/96 |

Client Name: GOLDEN SUNLIGHT MINES, INC.
Project No.: 90-929
Laboratory No.: 174387
Sample Name: METHOD BLANK
Sample Date: NONE GIVEN
Collected by: NONE GIVEN
Time Sampled: NONE GIVEN
Sample Type: WATER

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| Phosphorous Ortho | <0.01 | mg/l | 365.1 | 05/21/96 |

MAXIM TECHNOLOGIES INC

## SAMPLE RECEIPT CHECKLIST

Client Name: Golden Sunlight Mines
Project: 174383-85
Laboratory number(s):
Checklist completed by: KB 5/30 (Initials / Date)

Date/Time Received: 5/30/96 1100 (Date / Time)
Received by: KA Smith
Carrier name: Hand Delivered
Sample Type: Water

| | | YES | NO |
|---|---|---|---|
| 1. | Shipping container in good condition? | N | A |
| 2. | Custody seals present on shipping container? | N | A |
| 3. | Condition: Intact ____ Broken ____ | | |
| 4. | Chain of custody present? | ✓ | |
| 5. | Chain of custody signed when relinquished and received? | ✓ | |
| 6. | Chain of custody agrees with sample labels? | ✓ | |
| 7. | Custody seals on sample bottles? | | ✓ |
| 8. | Condition: Intact ____ Broken ____ | | |
| 9. | Samples in proper container/bottle? | ✓ | |
| 10. | Samples intact? | ✓ | |
| 11. | Sufficient sample volume for indicated test? | ✓ | |
| 12. | VOA vials have zero headspace? | N | A |
| 13. | Trip Blank received? | | ✓ |
| 14. | Ice/Frozen Blue Ice present in shipping container? (circle one) | N | A |
| 15. | Container temperature 1. ____ 2. ____ 3. ____ | | |

| | | YES | NO |
|---|---|---|---|
| 16. | All samples rec'd within holding time? | ✓ | |
| | Preservation | | |
| 17. | pH check performed by: KB | | |
| 18. | Metals bottle(s) pH <2? | ✓ | |
| 19. | Nutrient bottle(s) pH <2? | ✓ | |
| 20. | Cyanide bottle(s) pH >12? | N | A |
| 21. | Sulfide bottle(s) pH >9? | | |
| 22. | Oil & grease bottle(s) pH <2? | | |
| 23. | TOC bottle(s) pH <2? | | |
| 24. | DRO/418.1 bottle(s) pH <2? | | |
| 25. | Phenolics bottle(s) pH <2? | | ✓ |
| 26. | Volatiles (VOA) pH <2? (VOA pH checked by analyst) | | |
| 27. | Client contacted? | | |
| 28. | Person contacted | | |
| 29. | Date contacted | | |
| 30. | Contacted by | | |
| 31. | Regarding? | | |

**Note: Samples may be affected when not transported at the temperature recommended by the EPA for the test you've selected. Please contact the lab if you have concerns about the temperature of your samples.**

COMMENTS: _____

**GOLDEN SUNLIGHT MINES, INC.**
453 Mt. Hwy. 2 East Whitehall, Mt. 59759

## CHAIN OF CUSTODY RECORD FOR WATER QUALITY SAMPLES

SAMPLER SIGNATURE Ted Schmidt

CC: Ted Schmidt
4866 Aspenland
Bozeman MT 59715

| Sample I. D. | Date | No. of Containers | Parameter Group Number | Other Parameters and / or Comments |
|---|---|---|---|---|
| ABS #1 | 5/17/96 | 3 | 4 | TESTING FOR WQB-CIR. 7 SURFACE WATER |
| ABS #2 | 5/17/96 | 3 | 4 | TOTAL-RECOVERABLE METALS - NOT DISSOLVED |
| ABS #3 | 5/17/96 | 3 | 4 | PLEASE DO NOT TEST FOR METALS CROSSED OUT ON ATTACHED SHEET! |
| | | | | ALL OTHER TESTS REMAIN THE SAME |
| DP 174383 ABS01 | | | | THANKS |
| Method Blank | | | | |

5/20/96

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**Parameter Groups Are Listed Below** **NOTE: Detection limits are shown in parentheses as mg/L**

| | |
|---|---|
| **Parameter Group Number 1** | pH, SC, TDS ( 10), Ammonia as N (0.05), NO3 as N (0.05), Total CN - manual distillation(0.005) |
| **Parameter Group Number 2** | Total CN - manual distillation (0.005) **RUSH ANALYSIS** |
| **Parameter Group Number 3** | pH, SC, TDS (10), Ammonia as N (0.05), NO3 as N (0.05), Total Alkalinity as CaCO3 (1.0) Total Acidity as CaCO3 (1.0), Ca(1.0), Mg(1.0), Ortho-P(0.01), F(0.1), Na(1.0), K(1.0), SO4(5.0), Cl(1.0), HCO3(1.0), CO3(1.0), Dissolved Al(0.1), As(0.005), Ba(0.1), Cd(0.001), Cu(0.01), Fe(0.03), Mn(0.01), Zn(0.01) |
| **Parameter Group Number 4** (WQB Circular - 7 reporting values) | pH, SC, TDS(10), Ammonia as N(0.05), NO3 as N(0.01), Total Alkalinity as CaCO3(1.0), Total Acidity as CaCO3(1.0), Ca(1.0), Mg(1.0), Na(1.0), K(1.0), HCO3(1.0), CO3(1.0), Ortho- P(0.001), F(0.1), SO4(1.0), Cl(1.0) ~~Dissolved Ag(0.003)~~, Al(0.1), As(0.003), Ba(0.005), Be(0.001), Cd(0.0001), Cr(0.001), Cu(0.001) Fe(0.01), ~~Hg(0.0006)~~, Mn(0.005), Ni(0.02), Pb(0.003), ~~Sb(0.003)~~, Se(0.001), ~~Tl(0.003)~~, Zn(0.01) |
| Relinquished By (Signature) Ted Schmidt | Date 5/12/96 | Time 11:00 AM |
| Recieved By (Signature) [illegible] | Date 5/20/96 | Time 1100 hrs |

White - Return to Sender Yellow - Lab Copy Pink - Sender's Copy

# Appendix C:
# TCLP Metal Analysis

**Maxim**
600 South 25th Street
P O Box 30615
Billings, MT 59107
(406) 248-9161
FAX (406) 248-9282

# TECHNICAL REPORT

**REPORT TO:** ATTN: TED SCHMIDT
ANTLER BIOLOGICAL SERVICES
4766 ASPEN LN.
BOZEMAN MT 59715

**DATE:** August 14, 1996
**JOB NUMBER:** 96-928
**SHEET:** 1 of 2
**INVOICE NO.:** 035659

**REPORT OF:** Solid Waste Analysis

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**SAMPLE IDENTIFICATION:**

On July 25, 1996, this solid waste sample (laboratory number 176860) was received in our laboratory for analysis. The solids in the sample were allowed to settle. Then the liquid was decanted. The remaining solids were used as the sample for the TCLP extraction. The tests were conducted in accordance with SW-846, *"Test Methods for Evaluating Solid Waste,"* 3rd Edition, updates I, II, IIA, IIB.

The condition of the sample upon receipt at the laboratory is noted on the attached sample receipt checklist. Chain of custody documentation is enclosed.

The results of the analysis are shown on the following page.

A < sign indicates the value reported was the practical quantitation limit for this sample using the method described. Concentrations of analyte, if present, below this were not quantifiable.

Reviewed by Denise Jensen

Attachment: Chain of Custody
Sample Receipt Checklist

caj

Client Name: ANTLER BIOLOGICAL SERVICES
Project No.: 96-928
Laboratory No.: 176860
Sample Name: MIDAS ARD
Sample Date: 07/25/96
Collected by: TED SCHMIDT
Time Sampled: 0800
Sample Type: SLUDGE

| PARAMETER | MEASURED VALUE | | METHOD NUMBER | DATE ANALYZED |
|---|---|---|---|---|
| TCLP METALS | | | | |
| Arsenic as As | 0.008 | mg/l | 7062 | 08/08/96 |
| Barium as Ba | 0.21 | mg/l | 6010 | 08/12/96 |
| Cadmium as Cd | 0.95 | mg/l | 6010 | 08/12/96 |
| Chromium as Cr | <0.02 | mg/l | 6010 | 08/12/96 |
| Lead as Pb | <0.01 | mg/l | 6010 | 08/12/96 |
| Mercury as Hg | 0.006 | mg/l | 7470 | 08/12/96 |
| Selenium as Se | 0.03 | mg/l | 7742 | 08/09/96 |
| Silver as Ag | <0.05 | mg/l | 6010 | 08/12/96 |

MAXIM TECHNOLOGIES INC

## SAMPLE RECEIPT CHECKLIST

Client Name: Antler Biological

Project: Nome Stream

Laboratory number(s): 176860

Checklist completed by: JH 7/25 (Initials / Date)

Date/Time Received: 7/25/96 (Date) 1040 (Time)

Received by: S. Bradley

Carrier name: Hand Delivered

Sample Type: Sludge

| | | YES | NO |
|---|---|---|---|
| 1. | Shipping container in good condition? | ✓ | N/A |
| 2. | Custody seals present on shipping container? | ✓ | N/A |
| 3. | Condition: Intact ____ Broken ____ | | |
| 4. | Chain of custody present? | ✓ | — |
| 5. | Chain of custody signed when relinquished and received? | ✓ | — |
| 6. | Chain of custody agrees with sample labels? | — | ✓ |
| 7. | Custody seals on sample bottles? | — | ✓ |
| 8. | Condition: Intact ____ Broken ____ | | |
| 9. | Samples in proper container/bottle? | ✓ | — |
| 10. | Samples intact? | ✓ | — |
| 11. | Sufficient sample volume for indicated test? | ✓ | — |
| 12. | VOA vials have zero headspace? | ✓ | N/A |
| 13. | Trip Blank received? | — | ✓ |
| 14. | Ice/Frozen Blue Ice present in shipping container? (circle one) | ✓ | A |
| 15. | Container temperature 1. ____ 2. ____ 3. ____ | | |

| | | YES | NO |
|---|---|---|---|
| 16. | All samples rec'd within holding time? | ✓ | — |
| | Preservation | | |
| 17. | pH check performed by: ____ | | |
| 18. | Metals bottle(s) pH <2? | ✓ | N |
| 19. | Nutrient bottle(s) pH <2? | — | — |
| 20. | Cyanide bottle(s) pH >12? | — | — |
| 21. | Sulfide bottle(s) pH >9? | — | — |
| 22. | Oil & grease bottle(s) pH <2? | — | — |
| 23. | TOC bottle(s) pH <2? | — | — |
| 24. | DRO/418.1 bottle(s) pH <2? | — | — |
| 25. | Phenolics bottle(s) pH <2? | — | — |
| 26. | Volatiles (VOA) pH <2? (VOA pH checked by analyst) | NA | — |
| 27. | Client contacted? | — | — |
| 28. | Person contacted ____ | | |
| 29. | Date contacted ____ | | |
| 30. | Contacted by ____ | | |
| 31. | Regarding? ____ | | |

**Note: Samples may be affected when not transported at the temperature recommended by the EPA for the test you've selected. Please contact the lab if you have concerns about the temperature of your samples.**

COMMENTS: ____

96-928

# CHAIN OF CUSTODY RECORD

MAXIM TECHNOLOGIES INC

600 South 25th Street
Billings, Montana 59101
Phone (406) 248-9161 • Fax (406) 248-9282

Project or Site Name

Project Number

Sampler Name (Printed)

Ted Schmidt
Contact Name

Antler Biological Svcs.
Report to (Firm or Agency)

4766 Aspen Ln.
Address Bozeman, MT 59715

Ted Schmidt
Sampler Signature

FAX 406-582-1889
PR. 582-0379

| DATE COLLECTED | TIME COLLECTED | SAMPLE LOCATION OR DESCRIPTION | COMP OR GRAB | SAMPLE MATRIX | NO. OF CONTAINERS | ANALYSIS REQUIRED: TCLP Metals on Sludge | NOTES | LAB NUMBER |
|---|---|---|---|---|---|---|---|---|
| 7/25 | 0800 | MIDAS AIRD | | Sludge | | ✓ | | 176860 |

Send Results to Antler Biological Svcs

| Relinquished by: | Date | Time | Received by: |
|---|---|---|---|
| Ted Schmidt | 7/25 | 1040 | Peter Jackson |
| Peter Jackson | 7-25-96 | 10:40am | Shari Eudy 7/25/96 |
| Relinquished by: | Date | Time | Received by: |
| Relinquished by: | Date | Time | Received by: |

Remarks:

1040

results by 8/8/96 or sooner if possible.

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