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Office of Solid Waste and Emergency Response
Office of Superfund Remediation and
Technology Innovation

Optimization Review
Gilt Edge Mine Superfund Site
Water Treatment Plant

Lawrence County, South Dakota

OPTIMIZATION REVIEW

GILT EDGE MINE SUPERFUND SITE
WATER TREATMENT PLANT
LAWRENCE COUNTY, SOUTH DAKOTA

Report of the Optimization Review
Site Visit Conducted at the Gilt Edge Superfund Site
July 11, 2012

December 14, 2012

EXECUTIVE SUMMARY

OPTIMIZATION BACKGROUND

U.S. Environmental Protection Agency's definition of optimization is as follows:

"Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase. Such actions may also improve the remedy's protectiveness and long-term implementation which may facilitate progress towards site completion. To identify these opportunities, regions may use a systematic site review by a team of independent technical experts, apply techniques or principles from Green Remediation or Triad, or apply other approaches to identify opportunities for greater efficiency and effectiveness."[1]

An optimization review considers the goals of the remedy, available site data, conceptual site model (CSM), remedy performance, protectiveness, cost-effectiveness and closure strategy. A strong interest in sustainability has also developed in the private sector and within Federal, State, and Municipal governments. Consistent with this interest, optimization now routinely considers green remediation and environmental footprint reduction during optimization reviews.

An optimization review includes reviewing site documents, interviewing site stakeholders, potentially visiting the site for one day and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Environmental footprint reduction

The recommendations are intended to help the site team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent review, and represent the opinions of the optimization review team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the EPA Region and other site stakeholders. Also note that while the recommendations may provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP).

[1] U.S. Environmental Protection Agency (EPA). 2012. Memorandum: Transmittal of the National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10). Office of Solid Waste and Emergency Response (OSWER) 9200.3-75. September 28.

SITE-SPECIFIC BACKGROUND

The Gilt Edge Mine Superfund Site (Site) is located in the northern Black Hills of South Dakota. The primary mine disturbance area covers approximately 360 acres. The Site is divided into three Operable Units (OUs). Operable Unit 1 (OU1) includes the acid rock drainage (ARD) sources within the primary mine disturbance area such as acid-generating waste rock and fills, spent ore, exposed acid-generating bedrock and sludge. Operable Unit 2 (OU2) includes collection and treatment, groundwater contamination, contaminant sources, surface water and sediments in the Strawberry Creek area. Operable Unit 3 (OU3) includes the Ruby Waste Rock Dump, which is one of the largest sources of ARD at the Site.

Contaminants of concern (COC) in soil, sediments, surface water and groundwater are arsenic, selenium, silver, weak acid dissociable cyanide, nitrate, sulfate, total dissolved solids (TDS), total suspended solids (TSS), pH, cadmium, chromium, copper, iron, manganese, lead, mercury, nickel and zinc. The proposed remedy in the November 2001 Interim Record of Decision (ROD) for OU2 included reducing the migration of metal contaminants and acid water to surface water by collecting and conveying ARD seep and surface water flow to the water treatment plant (WTP), and treating ARD at the WTP with a lime-based precipitation process. An additional purpose of the Interim ROD actions was to reduce WTP operating costs. The ARD collection and WTP operation are the focus of this review. The WTP was converted from a sodium hydroxide-based process to a lime-based process in 2003 and has operated since that time at a flow rate up to about 325 gallons per minute (gpm). Until 2010, the system was used to treat ARD seep and surface water runoff as well as reduce the volume of ARD stored in Site impoundments. Since 2011, the WTP has operated intermittently as the impoundments have been drawn down.

The WTP and Site are staffed 24 hours per day by a minimum of two operators. Most WTP collection and treatment equipment operates automatically but upgrades to alarms, pumps and generators would provide more fail-safes. An OU1 remedy is in the design phase and will affect the OU2 remedy by diverting clean stormwater prior to contact with ARD-generating material thus reducing the volume of ARD requiring treatment. The Site team plans to upgrade the WTP upon completion of the OU1 remedy. These upgrades may address treatment to selenium and TDS discharge limits, which are currently waived.

The ARD collection includes three separate areas: Ruby Repository, Strawberry Creek (includes heap leach pad and pit/pond drainage) and Hoodoo Gulch. Conveyance directly to the WTP is only from the Strawberry Creek pumping station; water from the other collection areas is directed through Site impoundments to the Strawberry Creek pumping station.

The majority of ARD is captured and treated, and the effluent is discharged to Strawberry Creek. However, a portion of ARD generated on-site has high sulfate content and cannot be treated efficiently in the current WTP; therefore, it is blended with more dilute ARD. Collection systems on-site operate well, but are not capable of intercepting all of the ARD. Traces of ARD-related contamination that are present in surface water outside of the collection system have not been targeted for collection.

SUMMARY OF CSM

The CSM for the Site was not evaluated because this optimization review focuses on the operations of the WTP and collection systems.

SUMMARY OF FINDINGS

Key findings from this optimization review include:

- The WTP effectively treats the ARD-impacted influent at a flow rate of up to 325 gpm. WTP operation has reduced ARD stored at the Site so that continuous treatment is no longer needed and the WTP can now be operated periodically. As of May 27, 2012, 222.9 million gallons (MG) of storage capacity was available; 12.0 MG of high-sulfate ARD and 4.1 MG of low-sulfate ARD were in storage. At the time of the July 2012 site visit, the WTP had been operating for 2 months. Based on the average annual precipitation and current ARD generation from precipitation, the WTP would be expected to operate about 8 months of the year. OU1 implementation is expected to reduce ARD generation and collection by over 67percent. As part of the OU1 remedy implementation, the Site team is planning to add a groundwater collection system in the Dakota Maid Pit area; this flow is included in the total flow estimate.

- The Ruby Repository and Strawberry Creek collection facilities have substantial holding capacity, redundant pumps and high-level remote alarms. The Hoodoo Gulch collection facility only includes one pump, a relatively small pump suction well, a manual-start generator and no remote alarm; therefore, it is the only collection facility at the Site that presents a high risk of an uncontrolled release if it is not checked on a daily basis.

- The three existing collection facilities capture a significant portion of ARD from the Site and have reduced ARD impact in surface water nearly to South Dakota Surface Water Quality Standards (SDSWQS); however, ARD releases from un-captured seeps to surface water remain.

- The WTP effluent generally meets listed discharge standards; however, a waiver is in place to allow effluent selenium and TDS above current SDSWQS and effluent cadmium and conductivity levels contribute to periodic SDSWQS exceedances in Strawberry Creek.

- The WTP is staffed seven days a week, 24 hours per day with a total of ten full-time staff, including the Site Manager, eight operators and one maintenance person. Complete system rounds are performed twice per day. Labor costs are approximately $1,441,000 per year and other direct costs, including heavy equipment and vehicle leases and maintenance, are about $225,000 per year.

- Power costs are approximately $151,000 per year, equivalent to a demand of approximately 434 kilowatts (KW). Large consumers of electricity in the system include the Ruby and Strawberry Creek feed pumps, filter feed and backwash pumps and Reactor A and Reactor B mixers. The Site also has fuel costs of $79,000 per year and propane heating costs of about $24,000 per year.

- The primary materials usage is the lime and polymer consumption. Approximately 1.24 tons of lime are used in the WTP per day at a current cost of about $110 per ton including transportation, or about $33,000 per year for the eight months of WTP operation required for current conditions. Polymer costs for flocculation are about $8,000 per year. Waste sludge disposal is to an on-site basin.

- Monitoring requirements include about 352 samples per year. Additional sampling and analysis is expected for quality assurance (QA) and unforeseen testing. Annual sampling, laboratory and reporting costs are about $125,000 per year.

- Changes anticipated for the WTP as noted by the Site team include:
    - Short-term improvements include re-routing the power for backwash.
    - Long-term improvements include potential relocation of the WTP to eliminate double pumping; upgrading to allow treatment for selenium, TDS, and sulfate reduction; and the addition of groundwater collection near the Dakota Maid Pit.
    - Operate the WTP on a campaign basis (i.e., operate for a few months of the year), or operate at full capacity for only a portion of the year as allowed by future lower flows.
    - Install an additional thickener to provide longer detention time in an attempt to reduce scaling problems in the filters. This would improve the WTP's ability to handle high-sulfate concentration ARD.

SUMMARY OF RECOMMENDATIONS

The following recommendations are provided to improve remedy effectiveness, reduce cost and provide technical improvement:

Improving effectiveness:

- Consider alternative treatment options for remaining high-sulfate ARD:
    - Consider treating the high-sulfate water in the pits rather than pumping it out for treatment in the WTP. Such treatment could include adding lime, mixing using floating mixers, decanting and pumping clarified water to the WTP with much lower sulfate concentration. The settled gypsum would combine with the existing sludge in the pits. This option could avoid processing higher sulfate water in the WTP. The cost for this is undetermined because it could be accomplished to varying degrees to reduce the amount of blending with "clean" water required prior to WTP treatment. Any effort to treat the existing 12 MG in the pits should cost less than $500,000.
    - If treatment in the pits is not feasible, and the need for high sulfate concentration removal is long-term, consider the use of an ion exchange system as an alternative to the proposed additional thickener for more effective and reliable treatment. An ion exchange system such as the Sulf-IX™ process developed by BioteQ Environmental Technologies, Inc., would remove high levels of sulfate, would be regenerated with sulfuric acid and lime, and would produce only gypsum as a waste product (no waste brine solution). The cost for a 100 gpm system would be approximately $4 million capital and $115,000 annual operation and maintenance (O&M) cost for 30 MG total flow.
- Upgrade the Hoodoo Gulch collection facility and other collection and WTP facilities prior to implementation of the OU1 remedy:
    - As soon as possible, implement the proposed OU1 remedy-related upgrades to the Hoodoo Gulch collection facility (i.e., drain improvements, an impoundment with high level alarms, redundant discharge pumps and an auto-start generator) to alleviate potential risks and eliminate the need for maintaining a 24-hour/day labor force. If the OU1-related upgrades cannot be accomplished within 6 months, implement immediate

short-term improvements to the collection system. Specifically and in order of importance add the following:

1. A high-level alarm with battery backup and a transmitter that notifies the Site operator of a water level above the normal operating level.

2. A larger or additional collection tank/basin to add storage capacity: the current 3,400-gallon tank provides about 1 hour of capacity in a worst case (50 gpm) flow. The optimization review team recommends at least 20,000 gallon total capacity for a greater than 6-hour worst case scenario.

3. A new duplex submersible pump system or a second submersible pump to supplement the existing pump; also provide appropriate level controls for backup pump operation: with an alarm and extra storage capacity, a backup mobile pump kept at the Hoodoo system would be sufficient for short-term operation.

4. An auto-start generator: with the alarm and extra storage capacity this is not critical.

When these improvements are made, system pipe supports should be improved and the fencing should be altered to improve access to equipment.

- Provide other minor control improvements and redundant alarms to the other two collection systems.

- In the WTP, add more tank level indicators, redundant pumps (especially the filter feed) and a remote start capability for backup units and provide the ability to monitor the plant's Supervisory Control and Data Acquisition (SCADA) system remotely via the internet for fully automatic, unmanned WTP operation.

About $200,000 of additional costs may be incurred for doing this work in a separate contract before OU1 remedy implementation (some cost savings during OU1 remedy implementation will result); these additional costs are far outweighed by the labor cost savings.

Reducing cost:

- Eliminate overnight staffing, reduce labor force and operate the WTP in batch mode:

  - Immediately reduce redundant and excessive system checks. The collection facilities can be allowed to run at most times with inspections completed twice per week rather than twice daily.

  - Alter WTP operation and contracting to provide standard, single-shift, daily working hours when there is water to treat and more staffing flexibility (reduced hours) when the WTP is not operating. Contract for, and track separately, work done outside of the WTP, such as snow clearing and other Site maintenance. Total Site staffing can be reduced by at least 50 percent to a maximum of five full-time staff, similar to sites such as Bunker Hill Mining and Metallurgical Complex Superfund Site, which treats about 1,200 gpm around the clock. This would result in approximately $700,000 of savings per year. It is likely that staffing can be reduced even further once the OU1 remedy is implemented.

- Run the plant in batch mode with either overnight unmanned operation or staffed, 12-hour daily shifts. The WTP process, once fully automated (per the above recommendations to improve effectiveness), is suitable for unstaffed operation. In addition, the WTP had been off for 2 months as of July 2012 and with low volume of ARD in storage (and the eventual OU1-related flow reduction), it could be off for over 6 months this year and in future years.

- Reduce vehicle leases, supplies and fuel costs with the reduction in staffing; this should reduce costs at least $50,000 per year.

- Reduce the sampling frequency of the WTP influent, and surface water monitoring points CP001 and CP003 from weekly to monthly as this sampling is excessive and not required for regulatory compliance or WTP operation. This frequency reduction will eliminate 120 samples per year and reduce costs by about $40,000 per year.

- Do not add/rebuild/replace/relocate the WTP:

    - Consider a phased approach for WTP changes once the OU1 remedy has been completed given that the current plant is effectively treating the ARD and meeting discharge limits. WTP modifications (addition of another thickener and reaction tank) should not be made given the uncertainty regarding the OU1 remedy implementation schedule, changes in discharge limits, expected decreases in ARD flows and anticipated reduction in sulfate content with the draining/reclamation of the pits.

    - Lower ARD flows are expected once the OU1 remedy has been completed, which will lead to lower pumping costs, allow batch operation and provide greater opportunity for blending using non-ARD sources if needed, should sulfate loading remain a concern.

    - Evaluate WTP performance and surface water quality following OU1 remedy implementation prior to any potential WTP upgrade for selenium and/or TDS removal. ARD generation will be significantly reduced, and concentrations of rinsate water generated from contact with newly exposed ground are expected to improve over time during the rinse period. System performance and ambient surface water quality under various conditions can then be evaluated for an extended period of time to determine the applicability, cost and benefit of additional system modifications such as ion exchange.

    - Pumping of the additional ARD groundwater collection system planned as part of the OU1 remedy implementation to be installed near the Dakota Maid Pit may not be necessary or provide significant benefit for surface water quality. The Site team should regularly reconsider the need to pump at the planned system based on surface water quality. Groundwater monitoring wells do not currently show a high risk from off-site migration and OU1 remedy implementation, not including additional groundwater collection, will improve groundwater conditions.

Technical improvement:

- Implement minor WTP changes:

    - Consider feeding lime only at Reactor A to simplify the control of the WTP and to optimize lime dosing;

- Install orifice plates in the influent lines to each filter to control rates; and,
- Install a backup filter feed pump.

Site closure:

No site closure recommendations are provided. WTP operation will continue after implementation of the OU1 remedy until a "rinse period" is complete and newly generated ARD volumes and concentrations are not sufficient to impact surface water and groundwater quality above goals. The Site team estimates that the rinse period will last at least 10 years and potentially much longer. Each collection system should be considered individually for termination of active pumping when ARD volumes and concentrations decrease.

Environmental footprint:

The Site team completed an energy optimization study in 2011 and has implemented some of the associated recommendations (e.g., negotiated a lower rate electric rate). The optimization review team has no further recommendations.

NOTICE

Work described herein including preparation of this report was performed by Tetra Tech GEO for the U.S. Environmental Protection Agency under Work Assignment #2-58 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared as part of a national strategy to expand Superfund optimization from remedial investigation to site completion implemented by the EPA Office of Superfund Remediation and Technology Innovation (OSRTI). The project contacts are as follows:

Organization	Key Contact	Contact Information
EPA Office of Superfund Remediation and Technology Innovation (OSRTI)	Kathy Yager	EPA Technology Innovation and Field Services Division (TIFSD) 11 Technology Drive (ECA/OEME) North Chelmsford, MA 01863 yager.kathleen@epa.gov phone: 617-918-8362
Tetra Tech EM, Inc. (Contractor to EPA)	Jody Edwards, P.G.	Tetra Tech EM Inc. 1881 Campus Commons Drive Suite 200 Reston, VA 20191 jody.edwards@tetratech.com phone: 802-288-9485
Tetra Tech GEO (Contractor to Tetra Tech EM, Inc.)	Doug Sutton, PhD, P.E.	Tetra Tech GEO 2 Paragon Way Freehold, NJ 07728 doug.sutton@tetratech.com phone: 732-409-0344

LIST OF ACRONYMS

%	percent
µg/L	micrograms per liter
ARD	acid rock drainage
BMP	best management practices
BOD	basis of design
Btu	British thermal unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
CO_{2e}	carbon dioxide equivalents of global warming potential
COC	contaminants of concern
CSM	conceptual site model
EPA	U.S. Environmental Protection Agency
ft^2	square feet
GHG	greenhouse gas
gpd	gallons per day
gpd/ft^2	gallons per day per square feet
gpm	gallons per minute
HAP	Total Hazardous Air Pollutant Emissions
HDS	high-density sludge
HDPE	high-density polyethylene
HLP	heap leach pad
hp	horsepower
KW	kilowatts
lb	pound
LTM	long-term monitoring
LTMO	long-term monitoring optimization
mg/L	milligrams per liter
MG	million gallons
NOx	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NREL	National Renewable Energy Laboratory
NTU	Nephelometric Turbidity Units
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
OU	operable unit
P&T	pump and treat
PM	particulate matter
QA	quality assurance
QAPP	Quality Assurance Project Plan
RAO	remedial action objective
ROD	Record of Decision
RSE	remediation system evaluation
SEFA	Spreadsheets for Environmental Footprint Analysis

SD DENR	South Dakota Department of Environment and Natural Resources
SDSWQS	South Dakota Surface Water Quality Standards
SOx	sulfur oxides
s.u.	standard units
TIFSD	Technology Innovation and Field Services Division
TtGEO	Tetra Tech GEO
TDS	total dissolved solids
TSS	total suspended solids
VFD	variable frequency drive
WAD	weak acid dissociable
WTP	water treatment plant

TABLE OF CONTENTS

LIST OF TABLES

APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

During fiscal years 2000 and 2001 independent site optimization reviews called Remediation System Evaluations (RSE) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (i.e., those sites with P&T systems funded and managed by Superfund and the States). Due to the opportunities for system optimization that arose from those RSEs, the U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (OSRTI) has incorporated RSEs into a larger post-construction complete strategy for Fund-lead remedies as documented in *Office of Solid Waste and Emergency Response (OSWER) Directive No. 9283.1-25, Action Plan for Ground Water Remedy Optimization*. Concurrently, the EPA developed and applied the Triad Approach to optimize site characterization and development of a conceptual site model (CSM). The EPA has since expanded the definition of optimization to encompass investigation stage optimization using Triad Approach best management practices (BMP), optimization during design and RSEs. The EPA's definition of optimization is as follows:

> *"Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase. Such actions may also improve the remedy's protectiveness and long-term implementation which may facilitate progress towards site completion. To identify these opportunities, regions may use a systematic site review by a team of independent technical experts, apply techniques or principles from Green Remediation or Triad, or apply other approaches to identify opportunities for greater efficiency and effectiveness."* [1]

As stated in the definition, optimization refers to a "systematic site review", indicating that the site as a whole is often considered in the review. Optimization can be applied to a specific aspect of the remedy (e.g., focus on long-term monitoring [LTM] optimization or focus on one particular operable unit [OU]), but other site or remedy components are still considered to the degree that they affect the focus of the optimization. An optimization review considers the goals of the remedy, available site data, CSM, remedy performance, protectiveness, cost-effectiveness and closure strategy. A strong interest in sustainability has also developed in the private sector and within Federal, State and Municipal governments. Consistent with this interest, OSRTI has developed a Green Remediation Primer (www.cluin.org/greenremediation), and now routinely considers green remediation and environmental footprint reduction during optimization evaluations.

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[1] U.S. Environmental Protection Agency (EPA). 2012. Memorandum: Transmittal of the National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10). Office of Solid Waste and Emergency Response (OSWER) 9200.3-75. September 28.

The optimization review includes reviewing site documents, potentially visiting the site for one day and compiling this report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Environmental footprint reduction

The recommendations are intended to help the site team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the optimization review team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the EPA Region and other site stakeholders. Also note that while the recommendations may provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP).

The national optimization strategy includes a system for tracking consideration and implementation of the optimization review recommendations and includes a provision for follow-up technical assistance from the optimization review team as mutually agreed upon by the site management team and EPA OSRTI.

Purpose of Optimization at the Gilt Edge Mine Superfund Site – Water Treatment Plant (WTP)

Environmental contamination of surface water, groundwater, soil and sediment occurred at the Gilt Edge Mine Superfund Site (Site) as a result of mining activities. Contaminants of concern (COC) in the impacted media are arsenic, selenium, silver, weak acid dissociable (WAD) cyanide, nitrate, sulfate, cadmium, copper, chromium, iron, manganese, lead, mercury, nickel, zinc, total dissolved solids (TDS), total suspended solids (TSS) and pH. The surface water and groundwater remedy consists of the WTP, which treats acid rock drainage (ARD) collected at the Site. ARD is acidic metal laden water that results from oxidation of metal sulfides in the rock when due to mining activities the rock surface is exposed to air and water.

The Site was selected by the EPA OSRTI for optimization based on a nomination from the EPA's Abandoned Mine Lands Team. The optimization review is focused on current ARD collection and WTP operations and proposed upgrades. The optimization review includes discussion and evaluation of influent sources, metals mass loading, discharge criteria, solids handling and an operating cost breakdown. Other components of the Site remedy are considered only as they relate to ARD collection and treatment.

1.2 TEAM COMPOSITION

The optimization review team consists of the following individuals:

Table 1: Optimization Review Team Composition

Name	Affiliation	Phone	Email
Peter Rich	Tetra Tech GEO	410-990-4607	Peter.Rich@tetratech.com
John Nemcik	Tetra Tech, Inc.	720-931-9307	John.Nemcik@tetratech.com
Doug Sutton*	Tetra Tech GEO	732-409-0344	Doug.Sutton@tetratech.com
Carolyn Pitera*	Tetra Tech, Inc.	703-390-0621	Carolyn.Pitera@tetratech.com

*Did not attend site visit.

In addition, the following individual from the EPA Headquarters – Technology Innovation and Field Services Division (TIFSD) participated in the optimization site visit:

- Kathy Yager, EPA TIFSD

1.3 DOCUMENTS REVIEWED

The following documents were reviewed in support of the optimization review. The reader is directed to these documents for additional Site information that is not provided in this report.

- *Early Action – Interim Record Of Decision, Operable Unit 2 Water Treatment Operations, Gilt Edge Mine National Priorities List (NPL) Site Lawrence County, South Dakota*, EPA, April 2001
- *Interim Record of Decision, Operable Unit 3, Ruby Gulch Waste Rock Dump, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*, EPA, August 2001
- *Interim Record of Decision, Operable Unit 2, Interim Water Treatment Operations, Gilt Edge Mine NPL Site, Lawrence County, South Dakota*, EPA, November 2001
- *First Five-Year Review Report for Gilt Edge Mine Superfund Site, Operable Units 2 and 3*, Lawrence County, South Dakota, EPA, April 2007
- *Final Remedial Investigation Report for the Gilt Edge Superfund Site, Lawrence County, South Dakota*, CDM Federal Programs Corporation, February 2008
- *Evaluation of Water Treatment System Improvements for the Gilt Edge Superfund Site, Lawrence County, South Dakota,* CDM Federal Programs Corporation, May 2008
- *Water Treatment Plant Basis of Design Report for OU1, CDM, February 2010*
- *Surface Water and Groundwater Summary Report, Summer 2009 Update, CDM, March 3, 2010*
- *Estimated Electrical Savings after Implementation of Energy Conservation Measures, March 8, 2012*

- *Second Five-Year Review Report for Gilt Edge Mine Superfund Site*, Lawrence County, South Dakota, EPA, June 2012
- *Gilt Edge Mine NPL Site Monthly Report*, CDM, various dates
- *Gilt Edge Mine NPL Site Weekly Report*, CDM, various dates

1.4 Quality Assurance

This optimization review utilizes existing environmental data to evaluate remedy performance, and to make recommendations to improve the remedy. The quality of the existing data is evaluated by the optimization review team before the data are used for these purposes. The evaluation for data quality includes a brief review of how the data were collected and managed (where practical, the Site QAPP is considered), the consistency of the data with other Site data and the use of the data in the optimization review. Data that are of suspect quality are either not used as part of the optimization review or are used with the quality concerns noted. Where appropriate, this report provides recommendations to improve data quality.

1.5 Persons Contacted

The following individuals associated with the Site were present for the Site visit:

Table 2: Persons Contacted During Optimization Evaluation

Name	Affiliation	Email
Joy Jenkins	EPA Region 8	jenkins.joy@epa.gov
Mark Lawrensen	South Dakota Department of Environment and Natural Resources (SD DENR)	mark.lawrensen@state.sd.us
Mike Cepak	SD DENR	mike.cepak@state.sd.us
Paul Hight	CDM Smith	hightpk@cdm.com

The EPA contracts CDM Smith to operate the WTP, including all collection and conveyance systems and Site maintenance.

2.0 SITE BACKGROUND

2.1 LOCATION

The Site is located in the northern Black Hills of South Dakota, approximately 6 miles south-southeast from the city of Lead. The Site includes about 360 acres of primary mine disturbance area, i.e., the area with the largest accumulation of contaminant sources. The Site is divided into three OUs as follows:

- OU1 addresses ARD sources (acid-generating waste rock and fills, spent ore, exposed acid-generating bedrock and sludge) in the primary mine disturbance area.
- OU2 addresses ARD collection and treatment, groundwater contamination, contaminant sources, surface water, and sediments in the Strawberry Creek area.
- OU3 addresses the Ruby Waste Rock Dump, which is one of the largest sources of ARD at the Site.

2.2 SITE HISTORY

2.2.1 Historic Land use and Facility Operations

Mining activities began at the Site in 1876. A number of owners and operators have conducted a variety of mining and mineral processing activities at the Site since the late 1800s. Major periods of mining activity occurred from 1938 to 1941 and from approximately 1986 to 1997. During earlier mining periods, mine tailings were disposed in Strawberry Creek and Bear Butte Creek or other Site surface water drainage ways. During the 1980s and 1990s, the Site was operated as a large-scale, open-pit heap-leach gold mine. The Sunday Pit and Dakota Maid Pit were mined from 1986 to 1992. The operator abandoned the Site in July 1999.

The WTP was constructed around 1985 and used caustic soda and ferric salts to precipitate dissolved metals. The plant was converted to the high-density sludge (HDS) process by 2004 to increase capacity and effectiveness and attempt to reduce operating costs. The HDS process is a conventional lime neutralization water treatment process whose key feature is the addition of lime to recycled sludge in a lime/sludge mix tank (Reactor A) at the head of the system. The Site operational strategy has been to operate the WTP at the highest practical capacity to reduce the volume of ARD stored on-site. ARD volume in storage was significantly reduced by 2011, thus high capacity treatment is no longer a key WTP requirement.

The major WTP operational concern is the high-sulfate concentration that causes severe scale build-up in the plant process units and plugs the filters. Currently, high-sulfate concentration water (12 million gallons (MG) as of May 27, 2012) is stored in the Sunday Pit and Dakota Maid Pit. High-sulfate concentration water is blended with dilute ARD during the current operation to ensure that the sulfate concentrations stay below levels that cause the severe scaling (1,800 milligrams per liter [mg/L]). Presently, plant effluent sulfate is not regulated.

2.2.2 Chronology of Enforcement and Remedial Activities

In 1991, cyanide leaked from the mineral processing circuit and affected Strawberry Creek and Bear Butte Creek. An EPA inspection in 1992 found unpermitted discharges of acidic and metal-laden waters. In 1993, the EPA issued a National Pollutant Discharge Elimination System (NPDES) permit addressing the discharges. Several NPDES permit violations subsequently occurred before mining operations ceased. Beginning in 1993, over 150,000 tons of tailings were removed from upper Strawberry Creek. The Site was listed on the NPL in December 2000.

As a result of the August 2001 and November 2001 Interim Records of Decisions (ROD) for OU3 and OU2, respectively, ARD collection systems were upgraded or constructed for Hoodoo Gulch, Strawberry Creek (Ponds C and E) and Ruby Gulch. In addition, the Ruby Gulch Waste Rock Dump was capped to reduce the ARD quantity requiring collection and treatment.

Planning and studies have been underway for several years for the OU1 remedy, a large earthwork effort that will reduce ARD generation. The schedule for this work is unknown and the upgraded WTP design flow rate and sources to be treated have not been finalized. The OU1 remedy will include filling and capping existing open pits in an attempt to reduce ARD flow. The Site team expects that the metals concentrations in the ARD will increase as flows decrease. In addition, there will be a reduction in overall storage capacity for ARD from about 253 MG to about 70 MG and a reduction in the volume of dilute ARD captured that could be used for blending purposes.

Under current conditions, approximately 3.3 MG of ARD are generated per inch of precipitation. This is about 92 MG per year for recent years. With OU1 remedy construction, ARD generation is expected to decrease to about 30 MG per year (57 gallons per minute (gpm) based on continuous operation). There are many potential changes to WTP operation that may be implemented once the OU1 remedy construction is complete and the OU2 remedy is finalized, including changing standard operation to batch mode, and the removal of TDS and selenium discharge waivers potentially requiring greater treatment efficiency.

2.3 Potential Human and Ecological Receptors

There have been documented impacts to benthic macroinvertebrate communities along Strawberry Creek due to ARD discharge from the Site. The primary potential receptors are downstream fisheries (Bear Butte Creek and beyond). There is no immediate threat to residential and municipal water users. There is a potential to impact downstream wells constructed in the alluvium from a large untreated release of ARD; however, based on the Site location and current status this is unlikely.

2.4 Existing Data and Information

2.4.1 Sources of Contamination

The primary source of contamination at the Site is the sulfide-containing rock materials that generate ARD, which subsequently contaminates both surface water and groundwater. These materials contain elevated levels of metals that could pose risks to humans, plants and animals. There are several categories of contaminant source materials: waste rock fills, heap-leach pad, spent ore, exposed rock surfaces, underground mine workings, tailings, soil stockpiles and sludge. These contaminant sources are widespread within the primary mine disturbance area, and most of the source materials have the potential to generate ARD.

2.4.2 Geology Setting and Hydrogeology

Local geology is comprised of bedrock ore which is of economic interest. Mining this bedrock ore contributes to the generation of ARD and the other contaminant source materials listed in Section 2.4.1.

Site groundwater occurs in alluvium and bedrock aquifers and discharges along slopes as seeps and into Site creeks and intermittent streams. ARD impacts to groundwater as indicated by low pH and inorganic constituents appear to be adequately delineated by the Site monitoring well network.

Detailed discussion of the geology and hydrogeology of the Site is beyond the scope of this review.

2.4.3 Soil Contamination

Discussion of soil contamination at the Site is beyond the scope of this review.

2.4.4 Soil Vapor Contamination

No soil vapor contamination is expected because the Site contaminants are ARD-related and do not include volatile compounds.

2.4.5 Groundwater Contamination

Groundwater impacted by ARD including low pH, metals and other inorganics contributes to surface water impacts in Strawberry Creek, the intermittent on-site tributaries (Hoodoo Gulch, Terrible Gulch, and Ruby Gulch) and Bear Butte Creek. Groundwater is strongly impacted by ARD contamination in the primary mine disturbance area. The detailed nature of the groundwater flow and its interaction with surface water are beyond the scope of this review.

ARD has infiltrated the groundwater in the alluvial and bedrock aquifers. ARD also migrates from the pit lakes and underground mine workings into groundwater and leads to surface water discharges in some locations. While groundwater is a significant route for contaminant migration, there is no indication that private wells outside of the Site boundary have been impacted.

2.4.6 Surface Water Contamination

Based on the water quality data provided through May 2012, the ARD collected at the Ruby, Hoodoo and Strawberry Creek collection facilities has consistently elevated concentrations of dissolved heavy metals. Copper (200 to 5,000 microgram per liter [µg/L] range), cadmium (30 to 200 µg/L range) and zinc (700 to 7,000 µg/L range) concentrations are approximately one order of magnitude higher than the South Dakota Surface Water Quality Standards (SDSWQS) for acute toxicity and pH is in the 3 to 5 standard unit (s.u.) range. The ARD collected by the Ruby, Hoodoo and Strawberry Creek collection facilities also has selenium concentrations periodically above the SDSWQS for acute toxicity (12.9 µg/L); collected ARD sulfate levels are typically below the 1,800 mg/L level that causes filter fouling. The collection system and WTP currently intercept a portion of the water contributing to the metals loading to surface water at the Site, treat the intercepted water, and discharge the treated water to surface water. The treated water from the WTP generally meets the SDSWQS except for waived limits and periodic elevated conductivity levels above the 30-day average limit of 2,500 micromhos per centimeter (umhos/cm) (this is related to high TDS – mainly sulfate levels) and average monthly selenium concentration consistently above the chronic SDSWQS of 4.6 µg/L.

Surface water continues to be impacted by ARD generated within the primary mine disturbance area and relic mine tailings. Some stream sediments are contaminated and ARD-affected groundwater is discharging to surface water due to extensive groundwater/surface water interactions. As indicated by sampling results at point CP003 in Ruby Gulch, for example, cadmium, copper and zinc periodically are above acute and chronic SDSWQS (selenium analysis is not conducted). Cadmium is regularly above the chronic SDSWQS at CP001 in Strawberry Creek and periodically above the same standard in the WTP effluent. The CP001 and CP003 locations are shown in Plate 3, provided in Appendix A.

Bear Butte Creek is located downstream of the three Site drainages: (1) Strawberry Creek, which includes Hoodoo Gulch as a tributary; (2) Terrible Gulch, which drains a small portion of the Site between Ruby Gulch and Hoodoo Gulch/Strawberry Creek; and (3) Ruby Gulch. Surface water quality in Bear Butte Creek downstream of its confluence with Strawberry Creek is being monitored for adverse impacts from the Site.

3.0 DESCRIPTION OF PLANNED OR EXISTING REMEDIES

3.1 REMEDY AND REMEDY COMPONENTS

The current operating systems at the Site include the following:

- Collection of ARD in three surface water drainage ways (Hoodoo Gulch, Ruby Repository and Strawberry Creek) and in a series of ponds/pits at the Site. These collection locations are shown on Plate 2a, provided in Appendix A (Plate 2a).

- Conveyance of ARD by multiple pumping systems and pits/ponds to the WTP influent pumping station at the Strawberry Creek collection facility at Pond E. The conveyance systems consist of buried and over-land high-density polyethylene (HDPE) pipe and include:

    a. The Ruby Repository and Hoodoo Gulch collection facilities, which pump to the Sunday Pit from which water is pumped to Pond D (in the Strawberry Creek collection facilities) which then drains to Pond E;

    b. Surface water from the heap leach pad (HLP) and nearby Site features, which drains to the Stormwater Pond and then to the Anchor Hill Pit; water is pumped from the Anchor Hill Pit to Pond D in the Strawberry Creek collection facilities;

    c. Surface water collected in Pond C, which drains to Pond D and is also periodically pumped to the Anchor Hill Pit; and

    d. Surface water collected in the Surge Pond and Dakota Maid Pit, which is periodically pumped to one of the other ponds/pits or the Strawberry Creek collection facilities.

  Flow from each source is managed to control WTP influent sulfate concentrations. The existing pits and ponds provide a storage capacity of about 253 MG. There are return lines that allow water to be pumped back for storage at the Anchor Hill Pit and Sunday Pit when needed.

- Influent is pumped to the WTP which is an HDS plant with filtration to precipitate metals and adjust pH.

- Sludge from the WTP is pumped to an on-site disposal impoundment near the HLP.

- Discharge from the WTP flows by gravity to Strawberry Creek.

Proposed ARD collection system and WTP modifications associated with the OU1 remedy include:

- A storage basin will be constructed at the Hoodoo collection facility so it can operate similarly to the Ruby Repository collection system; several of the Strawberry Creek collection facility ponds will be filled, but the pumping facility and basin will be largely unchanged. The Ruby Repository collection facility will remain as is.

- The existing ARD storage pits will be dewatered and backfilled and a multiple-cell storage basin will be constructed in the HLP area. The basin storage capacity will have a capacity of about 70 MG. ARD from the Ruby, Hoodoo and Strawberry collection facilities will likely be pumped to this new basin; ARD will drain from the new basin by gravity to the WTP.

- A collection system to control the groundwater level near the Dakota Maid Pit will be added with ARD-impacted groundwater pumped to the new basin prior to treatment.
- About 12 MG of ARD with sulfate >1,800 mg/L is currently (as of May 2012) stored in the pits; this ARD requires treatment by either blending with ARD or other water with lesser sulfate levels or by a separate treatment process. The Site team has tested several treatment options.

- Following OU1 remedy completion, generated ARD volumes requiring treatment are expected to be reduced by about 67percent as uncontaminated stormwater will be routed away from ARD collection facilities. ARD influent is expected to become more concentrated than current conditions immediately after OU1 remedy implementation because of the lack of dilution by stormwater. However, the influent will improve after a "rinse period". Based on sulfate data from the collection facilities, influent sulfate levels are expected to be well below the 1,800 mg/L that requires dilution prior to the WTP.

- The current waiver of selenium and TDS discharge limits may not be applicable to a "final" OU2 remedy which will be determined after the OU1 remedy is implemented.

- Assuming the current WTP remains in long-term operation, it would likely be most effectively operated in a batch mode with about 1,538 operating hours per year required for treating 30 MG/year at 325 gpm.

The following sections describe water collection and WTP features; these are shown in the figures included in Appendix A.

3.1.1 Collection

3.1.1.1 Ruby Repository

Pumping from the Ruby Repository collection facility (including wet well flow) has a base flow of about 10 gpm with a maximum flow in excess of 100 gpm; the facility includes a 54,000 gallon underground vault at the toe of the repository that collects ARD from the repository and wet well and a 600,000-gallon overflow pond, two 540-gpm pumps with 150 horsepower (hp) motors; a high-level alarm; and an auto-start generator. This storage capacity would provide 1 day of ARD storage in a worst-case scenario. No major changes are anticipated in either the facility or the flow rate as part of the OU1 remedy construction.

3.1.1.2 Hoodoo Gulch

The Hoodoo Gulch collection facility has a base flow of about 2 gpm and a maximum of about 50 gpm. ARD is collected from a constructed alluvial groundwater drain and surface water. The facility includes a 3,400-gallon tank, a single 300-gpm capacity sump pump, a generator with manual start and no remote alarm. As part of proposed OU1 remedy implementation, the drain system will be improved and a lined impoundment will be added. Due to the improvements in the collection system, some minor increase in flow is anticipated. An upgraded pump system and generator will be similar to the Ruby Repository facility with redundant pumps, an automatic starting generator and impoundment high-level alarm.

During the Site visit it was noted that the current pump station appeared to have been constructed as a temporary installation. The generator has no shelter or enclosure; the piping is supported with wooden blocking; and access to the equipment is impeded by fencing.

3.1.1.3 Strawberry Creek

The Strawberry Creek collection facility receives flow from the other collection facilities prior to pumping to the WTP. Overflow from Pond C alone can be over 1,000 gpm. The facility includes a 500,000-gallon pond (Pond E) as well as other ponds, a new 50 hp pump and two 150-gpm backups, all with variable frequency drive (VFD) motors. The system includes a manual start generator. The capacity of Pond E provides several hours of storage in a worst-case scenario under current conditions. As part of the proposed OU1 improvements, clean surface water collection and diversion facilities will be added in this area to reduce ARD flows. Pond E will be rebuilt and relined at the same location.

3.1.1.4 Impoundments and Conveyance

The Site ARD conveyance currently uses three large pits that are remnants of mining operations (Sunday Pit, Anchor Hill Pit and Dakota Maid Pit) and smaller ponds (Stormwater Pond, Surge Pond, Pond C, Pond D, Pond E, Last Chance Pond, and Ruby Repository Pond) for ARD collection and storage. Proposed OU1 work includes filling and capping Sunday Pit, Anchor Hill Pit and Dakota Maid Pit. A new approximately 70-MG capacity water storage basin with multiple cells is proposed to be built in the HLP area to replace a portion of the lost ARD storage. Water treatment efforts have reduced the ARD in storage at the Site. The WTP was not running at the time of the Site visit and had not been operating for over 2 months due to low precipitation. Over 200 MG of storage capacity was available at the Site; however, this volume is not considered necessary for future operation.

The WTP is at a high elevation at the Site and a large portion of the ARD is pumped twice prior to entering the WTP. The OU1 remedy-related upgrades should address pumping inefficiencies with ARD storage consolidated in one location.

3.1.2 Water Treatment Plant

Water treatment in the HDS system occurs in three primary units: the sludge/lime mix tank (Reactor A), the reaction tank (Reactor B) and the thickener. Sludge from the thickener is recycled to Reactor A. Lime feed to Reactor A is controlled to maintain a pH setpoint of approximately 10 s.u. in Reactor B (influent pH is approximately 3 s.u.).

The Basis of Design Report prepared by CDM Smith in February 2010 for OU1 ("*2010 OU1 BOD Report*") indicates that the lime addition rate is controlled by a feedback pH control loop from Reactor B and that lime is added to both Reactor A and Reactor B. This was not identified during the Site visit, and is a deviation from the typical HDS system layout where lime is fed only to Reactor A. The lime-treated recycle sludge from Reactor A and the plant influent are blended together in Reactor B. With lime being fed in two locations, the control of the lime dosing rate may not be optimal.

The plant has a control room in one corner of the building. A modern Supervisory Control and Data Acquisition (SCADA) system is provided for overseeing and controlling portions of the operation such as lime slurry batching and process pump speeds. The SCADA system cannot be accessed remotely via the internet. A radio transmitter auto-dialer is used to generate alarms and notify operators of problems during un-staffed periods.

3.1.2.1 Lime Feed

The lime storage and feed system includes a 55-ton silo, a volumetric feeder, a slaker, a slurry tank and centrifugal slurry feed pumps. The pumps run continuously and the slurry was reported to be approximately 20percent solids by weight. Other installations have reported benefits of operating the lime slurry system at this high concentration (20percent solids), most importantly having minimal scaling. The system appeared to be in good condition and fit for its purpose.

3.1.2.2 Reactor A

Reactor A is where the recycle sludge from the thickener and the lime slurry are mixed at the head of the plant. The tank capacity is 600 gallons. The Site Manager indicated that the recycle rate was 25 gpm, thus approximately 24 minutes of reaction time is provided in this tank, which appears adequate.

3.1.2.3 Reactor B

Slurry from Reactor A overflows by gravity to Reactor B where it mixes with the plant influent stream, neutralizing the acid and precipitating metal hydroxides and gypsum. Reactor B is aerated using a sparge ring and positive displacement blower to oxidize ferrous iron and some manganese. This tank has a capacity of 10,000 gallons and at a flow of 325 gpm offers 30 minutes of reaction time which appears adequate.

3.1.2.4 Thickener

The effluent from Reactor B flows by gravity to the center well of the thickener. Polymer is added to the flow stream in the thickener influent pipe to aide in floc formation and to enhance settling and thickening.

The thickener is a circular, carbon steel tank with a diameter of 25 feet and a sidewall depth of 10 feet. The design overflow rate is 700 gallons per day per square feet (gpd/ft^2) at an influent flow rate of 250 gpm. At the current flow rate of 325 gpm, the overflow rate is 950 gpd/ft^2. This does not include in-plant recycle streams such as filter backwash water, reagent dilution or motive water. There are over 1.5 hours of detention time in the thickener. The thickener contains no means of mixing or flocculating other than what can be achieved by the velocity and energy of the influent water, therefore it could be considered more of a “clarifier” than a thickener. The thickener is operated to achieve 10-15 Nephelometric Turbidity Units (NTU) effluent turbidity.

3.1.2.5 Polymer Addition

The polymer batching system automatically prepares a new batch of polymer solution when needed. Dry polymer is loaded manually into a hopper at the top of the mixing tank. The system uses fresh on-site water, which is pumped from the Oro Fino shaft located outside the mine disturbance area and stored at the plant. The polymer solution is metered to the process using a variable speed progressive cavity pump and diluted with treated water to a 10:1 ratio. It passes through a static mixer before entering the process stream. The system appears to be adequate for this purpose.

3.1.2.6 Filtration, pH Adjustment and Discharge

The thickener effluent flows by gravity to the filter influent tank and is treated with carbon dioxide to adjust the pH to approximately 8.5 s.u. The carbon dioxide feed system appeared to be in good condition.

From the filter influent storage tank, the water is pumped to the filters by a single pump with no backup. The filtration system consists of five vertical pressure filters using multimedia for final suspended solids removal. The filters are operated to reduce turbidity to about 4 NTU which results in TSS of about 10 mg/L. The filters are backwashed manually based on head loss across the media. Typically six to seven filter backwashes (approximately 18 hours between backwashes per filter) are completed in a full day of operation; each backwash takes about 1 hour. Air scour is provided to enhance the backwash effectiveness. Dirty backwash water is discharged to a backwash waste tank. The content of the tank is returned to Reactor B on a controlled basis.

The filters operate in parallel and there is no apparent means for controlling the rate through any given filter (rate of flow control valve or orifice plates). When a filter is returned to service following a backwash it likely receives a higher portion of the total plant flow. Any type of filter operates most effectively when its flow rate is controlled. Excessive flows tend to prematurely blind the upper portion of the filter media resulting in shorter filter runs and more frequent backwashing. The filter effluent flows by gravity through an 8-inch diameter HDPE outfall pipe to Strawberry Creek.

3.1.2.7 Sludge Recycle and Disposal

The thickener underflow reportedly contains 20 to 30 percent solids, which is continuously recycled back to Reactor A. As the sludge inventory builds up, a portion of the sludge is pumped from the thickener to the sludge disposal cell located on the northeast portion of the HLP.

3.1.3 WTP Operation

Since the HDS process was implemented, the Site operational strategy has been to operate the WTP at the highest practical capacity to reduce the volume of ARD stored on-site. For the past year, the stored ARD volume and precipitation have been low so the WTP has operated only intermittently.

The major operational concern is the high-sulfate concentration that causes severe scale build-up in the plant process units and plugs the filters. The current configuration of the WTP does not effectively reduce influent sulfate concentration. When the influent sulfate concentration approaches 1,800 mg/L, the sulfate reduction through the thickener is only about 200 mg/L. When treating influent water with sulfate concentrations over 1,800 mg/L, the effluent from Reactor B and thickener is supersaturated with gypsum, and scaling in the filter media becomes a major problem. The filter media becomes cemented together and it is a difficult task to remove the damaged media. The Site team blends ARD influent to keep sulfate concentrations below 1,800 mg/L.

The existing WTP was designed to treat a continuous flow of 250 gpm of ARD feed water transferred to Strawberry Pond (Pond E) from various ARD storage locations on the Site. The plant throughput rate was increased to approximately 325 gpm while maintaining successful treatment results. This has been determined to be the maximum hydraulic and treatment capacity of the WTP, with the limiting factors being hydraulic capacities of the plant pumps, piping, filters and thickener. One of the key limitations is that there is only one filter feed pump that is pumping at its maximum capacity of about 325 gpm.

While the WTP is designed to operate as an HDS process, the recycle rate from the thickener to Reactor A may not be as high as the typical 20:1 ratio recommended for the HDS process. The actual recycle rate was not available at the time of the Site visit.

3.2 REMEDIAL ACTION OBJECTIVES AND STANDARDS

The November 2001 *OU2 Interim ROD* identified the following remedial action objectives (RAOs):

- Prevent direct exposure of human and environmental receptors to elevated concentrations of contaminants in surface water drainage from the Site.
- Reduce or eliminate ARD water flow into Ruby Gulch, Strawberry Creek and Bear Butte Creek.
- Achieve compliance, to the extent possible and practicable for the interim, with currently applicable water quality standards.
- Minimize waste and waste disposal requirements.
- Integrate water treatment with overall Site closure and reclamation activities.
- Maintain compatibility with the site-wide RAOs and final water treatment remedial action.
- Minimize expenditures for water treatment at the Site during closure activities.

The *2010 OU1 BOD Report* has RAOs related to reducing the volume of ARD generated at the Site and reducing the risk of uncontrolled releases. The *2010 OU1 BOD Report* also states that a final OU2 remedy will be identified and implemented after the OU1 remedy effectiveness is determined. Collection and treatment of the ARD would continue with the current discharge waivers for TDS and selenium until the final OU2 remedy is selected.

3.3 PERFORMANCE MONITORING PROGRAMS

The Site team currently conducts quarterly sampling at 17 monitoring wells and seven (7) surface water locations for metals, other inorganics and indicator parameters. There are about 60 monitoring wells at the Site but most are not sampled regularly.

WTP process samples and surface water samples taken on a more frequent schedule include: WTP influent, WTP effluent, Strawberry surface water monitoring point CP001 and Ruby Gulch surface water monitoring point CP003 on a weekly basis; and Ruby Toe, Ruby Wet Well, Hoodoo Gulch and Pond C to Pond D flow on a monthly basis. In addition to laboratory analysis, WTP operators field check flow rates and analyze for pH at multiple points on a daily basis.

3.3.1 Treatment Plant Operation Standards

The standards for discharging the water treated at the WTP to surface water are based on current SDSWQS as included in Table 4 in the 2012 Five Year Review Report and are summarized in Table 3:

Table 3: Current WTP Effluent Limits

Parameter	Chronic Standard (based on 400 mg/L hardness as applicable) or 30-Day Average (μg/L except where noted)
Arsenic	340
Cadmium	0.648
Chromium III	230.79
Chromium VI	11
Copper	29.31
Lead	10.911
Mercury	0.77
Nickel	168.012
Selenium	Waived (4.6)
Silver	34.96 (acute: no chronic standard)
Zinc	379.37 (acute: acute < chronic)
Conductivity	2,500 umhos/cm
Total Dissolved Solids (TDS)	Waived (2,500,000)
Total Suspended Solids (TSS)	10,000
pH	6.5SU to 9.0 SU

During normal operation, the WTP effectively meets these discharge limits. However, the effluent periodically exceeds the 30-day average conductivity standard (related to sulfate/TDS levels) and the standard cadmium standard for chronic conditions. Limits for selenium and TDS have been waived for the interim remedy; the chronic SDSWQS (4.6 μg/L) for selenium is periodically exceeded, TDS analysis is not conducted. There are no discharge limits for sulfate, nitrate and manganese.

4.0 CONCEPTUAL SITE MODEL

This optimization review focuses on current ARD collection and WTP operations. Discussion of a CSM including ARD sources, transport and fate are beyond the scope of this review.

5.0 FINDINGS

The observations provided below are the interpretations of the optimization review team and are not intended to imply a deficiency in the work of the system designers, system operators, or site managers rather are offered as constructive suggestions in the best interest of the EPA and the public. These observations have the benefit of being formulated based upon operational data unavailable to the original designers. Furthermore, it is likely that site conditions and general knowledge of treatment have changed over time.

5.1 GENERAL FINDINGS

- The plant is staffed 7 days a week, 24 hours per day with a total of ten full-time staff employed including the Site Manager, eight operators and one maintenance person. The Site Manager noted that in addition to operating the plant, there are significant labor activities associated with managing water on-site. Snow removal is a major labor-intensive task in the winter. With the WTP at its current location, there is a long access road that must be maintained to allow personnel access and chemical truck delivery.

- In section 5.1.2.2 of the *2010 OU1 BOD Report* there is a statement that lime demand increased during the high flow, high-sulfate operations and that the capacity of the lime system should be re-evaluated. Since the projected ARD collection rate after the OU1 remedy improvements are made is anticipated to drop to below 100 gpm, it is very likely that the existing lime system will be capable of meeting the dosage requirements in the future.

- A general concept of the OU1 remedy is to keep separate the uncontaminated surface runoff water from the ARD-generating material. The schedule for the OU1 improvements was indeterminate when this optimization review was completed.

- Changes anticipated for the WTP as noted by the Site team include:

    - Short-term improvements: re-routing power for backwash.

    - Long-term improvements: potential relocation of the plant to eliminate double pumping, upgrading to allow treatment for selenium and TDS, and sulfate reduction.

    - Future lower flows may allow for the WTP to be operated on a campaign basis (i.e., operate for a few months of the year).

    - Providing an additional thickener will allow greater retention time and reduced scaling in the filters.

5.2 INFLUENT COLLECTION

ARD in surface water and shallow groundwater is intercepted at three locations: Ruby Repository, Hoodoo Gulch and Strawberry Creek. The existing Hoodoo Gulch collection facility has only one pump, a relatively small collection tank, a manual-start generator and no remote alarm. Of the three collection facilities, this is the only one that presents a high risk of an uncontrolled release if it is not checked on a daily basis. The Ruby Repository and Strawberry Creek collection facilities have substantial holding capacity, redundant pumps and high-level remote alarms. The three collection facilities capture a significant portion of ARD from the Site and have reduced ARD impact in surface water to near SDSWQS; however ARD releases from un-captured seeps to surface water remain.

5.3 CURRENT WTP PERFORMANCE AND REGULATORY COMPLIANCE

The WTP effectively treats ARD-impacted influent at a flow rate up to 325 gpm. WTP operation has reduced ARD water stored at the Site so that continuous treatment is no longer needed and the WTP can now be operated intermittently. As of May 27, 2012, only 12.0 MG of high-sulfate ARD and 4.1 MG of low-sulfate ARD were in storage out of the 253 MG capacity. Under current ARD-generating conditions, the WTP would have to operate approximately 200 days per year at 325 gpm to treat the ARD volume generated each year. Following completion of the OU1 remedy, ARD generation is expected to be reduced by over 67 percent so WTP operation could be reduced to fewer than 70 days per year.

WTP effluent generally meets required discharge standards; however, a waiver is in place to allow effluent selenium and TDS above current SDSWQS and effluent cadmium levels contribute to periodic SDSWQS exceedances in Strawberry Creek.

5.4 COMPONENTS OR PROCESSES THAT ACCOUNT FOR MAJORITY OF ANNUAL COSTS

Table 4 provides a breakdown of the approximate annual cost estimates for operating this remedy based on total costs and energy costs provided by the Site team and estimates by the optimization review team based on information provided by the Site team.

Table 4: Summary of Annual Operating Costs

Item	Approximate Annual Cost
Project Management	$191,000
Routine Operations and Maintenance Labor	$1,441,000
Routine Maintenance – Other Direct Costs/Subcontractors	$225,000
Process and Groundwater Sampling and Analysis	$125,000
Fuel and Propane	$103,000
Electricity	$151,000
Lime, Polymer and CO_2	$48,000
Potable Water, Phone and Office Supplies	$13,000
Equipment Replacement / Non-Routine Maintenance	$53,000
Total	**$2,350,000**

5.4.1 Utilities

Power costs are approximately $151,000 per year, including operation of the WTP for about 8 of 12 months, based on an approximate rate of $0.0398 per kilowatt hour (kWh) from Black Hills Power. This represents a demand of approximately 434 KW. Large consumers of electricity in the system include the Ruby and Strawberry Creek feed pumps, filter feed and backwash pumps and Reactor A and Reactor B mixers.

Propane costs for building heat total about $24,000 per year, and fuel costs for vehicles, heavy equipment and generators are about $79,000 per year. Potable water brought to the Site, telephone service and office supply costs total about $13,000 per year.

5.4.2 Non-Utility Consumables

Approximately 1.24 tons of lime are used in the WTP per day at a current cost of about $110 per ton including transportation. With about 8 months of WTP operation required for treatment of the average flows generated with current conditions, the annual cost is about $33,000. Polymer costs for flocculation are about $8,000 per year.

5.4.3 Labor

Project management costs include labor for financial management, planning, quality assurance, plan updates and material and subcontractor procurement. These costs total about $191,000 per year. Costs for EPA and State management are not included. Costs for the EPA contractor related to testing and design for WTP upgrades are not included.

The ten full-time operating staff includes the Site Manager, eight full-time operators and one maintenance person. Two staff are on-site at all times, whether or not the WTP is running, completing inspections/checks; collection and conveyance system O&M; and vehicle, equipment and site maintenance, including snow clearing. During WTP operations, pH and turbidity checks, backwash monitoring, lime feed monitoring, sludge wasting and recycling monitoring are key added activities. Complete system rounds are performed twice per day. These frequent system checks are completed because staff is available; however, there are no frequent system upsets or extreme consequences that would indicate the need for such frequency. WTP O&M labor costs are about $1,441,000 per year.

Similar sites and WTPs with continuous flow to treat ARD metals operate with one system inspection round per day and unmanned overnight operation using a total of four to five full-time staff. With the intermittent treatment requirements of 2011 and 2012 and expected further reduced flow in the future, a staff of 3.5 full-time equivalent operators would be reasonable, with the part-time operator mainly assisting during spring high flows. Similar collection facilities with high-level alarms are often operated with weekly and sometimes less frequent checks.

5.4.4 Other Direct Costs

The main components of non-labor costs for routine maintenance are vehicle and heavy equipment leases and associated supplies. These costs total about $225,000 per year.

5.4.5 Chemical Analysis

The monitoring requirements (Section 3.3) include about 352 samples per year. Samples analyzed by contract laboratories cost about $300 per sample. Additional sampling and analysis is expected for QA and unforeseen testing. Annual laboratory costs are about $107,000 per year with an additional $18,000 per year spent on sampling supplies, data validation and reporting.

5.4.6 Equipment And Non-Routine Maintenance

A $53,000 annual allowance for equipment replacement and non-routine maintenance is used by the Site team.

5.5 APPROXIMATE ENVIRONMENTAL FOOTPRINT ASSOCIATED WITH REMEDY

The following subsections describe the environmental footprint of the site remedies, considering the five core elements of green remediation defined by EPA (www.cluin.org/greenremediation).

5.5.1 Energy, Air Emissions, and Greenhouse Gases

The primary contributor to the energy footprint is the electricity usage of about 3.7 million kWh of electricity per year. Black Hills Power is the electricity provider for the Site, and based on a preliminary review of Black Hills Corporation 2011 Annual Report, it appears that approximately 61.3% of the electricity is generated from coal, 16.3% from natural gas, 20.4% from gas/oil and 2% from diesel #1-5 oil. Based on this generation mix, the electricity is also a major contributor to the greenhouse gas (GHG) and other air emissions associated with WTP operation. The other largest contributor to the GHG and other emissions is associated with lime mining/manufacturing and transportation to the Site and on-site fuel use.

The EPA Spreadsheets for Environmental Footprint Analysis (SEFA) were used to estimate the energy and air footprints. The results for key energy and air footprint metrics are summarized in Table 5.

Table 5: Summary of Energy and Air Annual Footprint Results

Green and Sustainable Remediation Parameter	Approximate Annual Value
Greenhouse Gas Emissions (carbon dioxide equivalents [CO_{2e}]	5,001 tons
Total Nitrogen oxides (NOx) + Sulfur Oxides (SOx) + Particulate Matter (PM) emissions	81,454 pounds
Total Hazardous Air Pollutant (HAP) Emissions	1,716 pounds
Total Energy Use	61,163 MMBtus
Voluntary Renewable Energy Use	NA

Notes: CO_2e = carbon dioxide equivalents of global warming potential
MMBtus = 1,000,000 Btus

Based on the assumptions made in SEFA, approximately 7percent (371 tons CO_2e) of the CO_2e footprint is from lime usage, 7 percent (340 tons of CO_2e) is from on-site fuel use, and approximately 86percent (4,290 tons CO_2e) is from electricity usage. Other contributions, including personnel transport and laboratory analysis are negligible contributors.

5.5.2 Water Resources

Site groundwater (not potable) is used for lime slaking, polymer batching and sanitary and cleaning purposes. Water that is intercepted as part of the remedy is discharged to surface water, which would be the natural fate of the water in the absence of the remedy. Potable water is brought to the Site from outside sources.

5.5.3 Land and Ecosystems

Operation of the remedy does not have secondary effects on local land and ecosystems.

5.5.4 Materials Usage and Waste Disposal

The primary materials usage is the lime and polymer consumption. Waste disposal associated with the WTP is to an on-site basin. Space is available for additional disposal basins adjacent to the current basin.

5.6 SAFETY RECORD

The Site team did not report any safety concerns or incidents.

6.0 RECOMMENDATIONS

Several recommendations are provided in this section related to remedy effectiveness, cost control and technical improvement. Note that while the recommendations provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and QAPPs.

Cost estimates provided herein have levels of certainty comparable to those done for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Feasibility Studies (-30%/+50%), and these cost estimates have been prepared in a manner generally consistent with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, July, 2000. A summary table of the recommendations with associated capital cost and changes in operating costs is included as Table 6.

Because this optimization review focused solely on the ARD collection and WTP operation, but it is impacted by potential (but uncertain in scope and timing) system changes associated with the planned OU1 remedy and a final OU2 ROD, costs for some recommendations are not quantified.

Currently planned improvements at the WTP by the Site team can be summarized as follows:

- Upgrades to the WTP are planned that will enable treatment of higher sulfate concentrations.
- The main upgrade components will include the addition of a second reactor tank with a mixer and aerator, and a thickener. A building expansion will also be required to house the new components.
- Collection, handling and treatment of contaminated water in the mine disturbance area and discharge of treated water in Strawberry Creek would continue under the current discharge waivers for selenium and TDS until a final remedy for OU2 is selected.

A key concern of the optimization review team is the uncertain schedule for future efforts associated with OU1 remedy implementation including treatment of the remaining 12 MG of high-sulfate ARD in storage pits. In addition, the potential requirement for a “final” remedy to meet SDWQDS for cadmium, TDS and selenium could lead to maintaining/continuing long-term excess labor costs to operate the existing WTP. This could be followed by a large capital expense for an “upgraded” system providing minimal contaminant load and risk reduction. The optimization review team therefore recommends a phased approach consisting of:

1. Reduce the Site labor force while the WTP is not needed (the WTP had not been operating for 2 months as of July 2012 and over 200 MG storage is still available, which is over 2 years of average ARD collection);
2. Conduct short-term reasonable system upgrades, especially at the Hoodoo Gulch collection facility, to allow low- risk automated operation of the collection systems and WTP with the reduced one-shift labor force;
3. Do not upgrade the WTP to treat a short-term sulfate issue but instead require pretreatment of the remaining high-sulfate ARD in the pits when the OU1 remedy is implemented; and

4. Evaluate WTP performance and surface water quality following OU1 remedy implementation including the 10-year rinse period and prior to any potential WTP upgrade for selenium and or TDS removal. ARD generation will be significantly reduced and concentrations are expected to improve over time during the rinse period. The Site team can evaluate system performance and ambient surface water quality under various conditions for an extended period of time to determine the applicability, cost and benefit of additional system modifications such as ion exchange. Any added ion exchange or similar system for tertiary treatment could potentially be sized for a flow much lower than 325 gpm.

6.1 Recommendations to Improve Effectiveness

6.1.1 Pretreat Remaining High-Sulfate ARD

The high-sulfate water in the lower portion of the Sunday Pit (about 7.7 MG) and the Dakota Maid Pit (about 4.3 MG) will have to be treated prior to or as part of the OU1 remedy implementation. Following dewatering, these pits will be reclaimed, filled and capped. After these pits are reclaimed, the contribution of high-sulfate ARD from these sources will be greatly reduced. Further, when the improvements are made in OU1, the site-wide ARD collection is expected to decrease from the current 175 gpm average to around 57 gpm; a significant reduction.

As an alternative to the Site team's proposed modification of the WTP for the likely short-term treatment of high-sulfate ARD, consideration should be given to treating the high-sulfate water in the pits rather than pumping it out for treatment in the WTP. Such treatment could include lime addition, mixing using floating mixers, decanting and pumping clarified water to the WTP with much lower sulfate concentration. The settled gypsum would combine with the existing sludge in the pits. This option could avoid processing this water in the WTP.

As an alternative to treating the high-sulfate ARD in the pits, consider the use of a specialty ion exchange system to treat the thickener effluent prior to the filters instead of the proposed additional thickener and expanded building. An ion exchange system that removes high levels of sulfate, is regenerated with sulfuric acid and lime, and produces only gypsum as a waste product (no waste brine solution) is offered by the Sulf-IX™ process developed by BioteQ Environmental Technologies, Inc. Informational brochures for the Sulf-IX™ process are included as Appendix B. This system would be more reliable than the proposed additional thickener at a similar cost. A 100-gpm Sulf-IX™ system would cost $4 million (capital) and $115,000 per year for O&M (power and reagent cost for 30 MG treated). However, if the need for treating high-sulfate water is truly short-term, it is unlikely that the cost of an ion-exchange treatment system, or the improvements proposed by the Site team, could be justified.

6.1.2 Upgrade Hoodoo Gulch Collection Facility Prior to Remainder of OU1 Remedy

The Hoodoo Gulch collection facility presents a relatively higher risk for an ARD release than the other collection facilities. The proposed OU1-related upgrades to the Hoodoo Gulch facility (drain improvements, an impoundment with high-level alarms, redundant discharge pumps and an auto-start generator) appear to be reasonable. These upgrades are basically a facility replacement with an installation similar to the Ruby Repository collection facilities and should be completed as soon as possible to alleviate potential risks and address a key concern that drives the need to maintain a 24-hour/day labor force.

If the OU1-related upgrades cannot be accomplished within 6 months, the optimization review team recommends immediate short-term improvements to the collection system, in order of importance adding:

1. A high level alarm with battery backup and a transmitter that notifies the site operator of a water level above the normal operating level.

2. A larger or additional collection tank/basin to add storage capacity: the current 3,400 gallon tank provides about 1 hour of capacity in a worst case (50 gpm) flow. We recommend a total of at least 20,000 gallons for greater than 6-hour worst case capacity.

3. Provide a new duplex submersible pump system or add a second submersible pump to the existing pump and provide appropriate level controls for backup pump operation: with an alarm and extra storage capacity, a backup mobile pump kept at the Hoodoo system would be sufficient for short-term operation.

4. An auto-start generator: with the alarm and extra storage capacity, this is not critical.

When these improvements are made, system pipe supports should be improved and the fencing should be altered to improve access to equipment.

Other minor control improvements and redundant level alarms should also be added to the other two collection systems now rather than waiting for the OU1 remedy. For fully automatic unmanned WTP operation more tank level indicators, more redundant pumps (especially the filter feed) and remote start capability for backup units should be added. The ability to monitor the plant SCADA system remotely via internet should also be provided.

About $200,000 of additional costs may be incurred for doing this work in a separate contract from the OU1 remedy implementation; these costs are far outweighed by the projected labor cost savings.

6.2 RECOMMENDATIONS TO REDUCE COSTS

6.2.1 Eliminate Overnight Staffing, Cut Labor Force and Operate in Batch Mode

The WTP had not been operating for 2 months at the time of the July 2012 Site visit, and with low ARD volume in storage (and the eventual OU1 remedy-related flow reduction), it could remain non-operating for over 6 months this year and future years. The Site and WTP does not require continuous staffing while the WTP is not operated. Collection facilities are currently adequate for unstaffed operation except for the Hoodoo Gulch collection facility (see above Section 6.1.2). WTP operation and contracting should be altered to provide standard, single shift, daily working hours when there is water to treat and more staffing flexibility (reduced hours) when the WTP is not operating. The plant should be run in batch mode with either overnight unstaffed operation or staffed 12-hour daily shifts. The collection facilities can be allowed to operate at most times with inspections twice per week. Staffing should be reduced by at least 50percent to a maximum of five full-time staff, similar to sites such as the Bunker Hill Mining and Metallurgical Complex Superfund Site which treats about 1,200 gpm around the clock. This would result in about $700,000 of savings in operator labor costs per year. It is likely that staffing can be reduced even further once the OU1 remedy is complete.

In addition to labor savings, the reduction in staffing should result in a reduction in vehicle leases, supplies and fuels costs of at least $50,000. Significant savings should also be possible by contracting some short-term heavy equipment and snow plowing needs rather than maintaining equipment year round.

6.2.2 Reduce Sampling Frequency

Weekly sampling of the WTP influent, CP001 and CP003 is not required for regulatory compliance or WTP operation. This sampling should be reduced to a monthly frequency eliminating 120 samples per year and saving about $40,000 per year.

6.2.3 Do not Add/rebuild/replace/relocate WTP and Regularly Evaluate Collection System Pumping Requirements

There are plans to modify the WTP through the addition of another thickener and reaction tank with the objective of treating high-sulfate influent expected after the OU1 remedy implementation. The expectation of higher sulfate concentrations in the Site ARD after the pits are closed is due to the proposed addition of a groundwater collection system in the Dakota Maid Pit area as part of the OU1 implementation. Pumping of the additional collection system may not be necessary or provide significant benefit for surface water quality. The site team should regularly reconsider the need to pump at the planned system based on surface water quality. Groundwater monitoring wells do not currently show a high risk from off-site migration and OU1 remedy implementation (earthwork, capping and other non-groundwater pumping items) will improve groundwater conditions.

The existing collection facility sulfate levels are below 1,800 mg/L and are expected to decrease further when OU1 remedy implementation is complete, offsetting expected high-sulfate concentrations in the collected groundwater. Even if sulfate concentrations from the combined ARD collection are an issue, lower ARD flows are expected which will allow batch operation and blending opportunities using non-ARD sources, if needed.

The current WTP is effectively treating the ARD and meeting discharge limits. With uncertainty regarding the OU1 remedy schedule; future groundwater pumping rates, concentrations and benefits; discharge limit changes; and decreasing ARD flows expected, the optimization review team recommends a phased approach rather than immediate major changes to the WTP. . The WTP modifications could be more effectively identified once the OU1 remedy has been completed. The cost savings for this recommendation are unknown, but it is presumed that capital costs would be reduced in the short-term and distributed over the long-term.

6.3 RECOMMENDATIONS FOR TECHNICAL IMPROVEMENT

6.3.1 Make Minor WTP Changes

The optimization review team recommends consideration of the following WTP operational changes:

- Feed lime only at Reactor A to simplify the control and to optimize lime dosing (no cost).

- Add rate controlling orifice plates for the filters; the addition of orifice plates in the influent lines to each filter would entail furnishing five orifice plates costing about $200 each, and inserting one in each of the influent lines at each filter. The plate could be inserted between two flanges. There is no need for power or monitoring devices on the plates. As the flow would tend to be higher when the filter is clean, the higher flow through the orifice would induce more head loss in that section of piping thereby tending to divert more flow to the other filters. The total cost for modifying all fiver filters would be approximately $10,000.

- Install a backup filter feed pump adjacent to the existing pump. The cost for pump materials and installation would be approximately $25,000.

6.4 Considerations for Gaining Site Close Out

The WTP operation will continue after OU1 remedy implementation until a "rinse period" is complete and ARD volume and concentrations are not being generated sufficiently to impact surface water quality. Each collection system should be considered individually for termination of active pumping when ARD volume and concentrations decrease so that surface water would not be impacted above standards.

It is clear that WTP operation will extend in some form for many years. Based on this fact, the Site team should make significant efforts to achieve consistent, cost-effective WTP operation. The optimization review team does not have further recommendations regarding site close out.

6.5 Recommendations Related to Environmental Footprint Reduction

An energy optimization study was completed in 2011 by the Site team and cost savings were summarized in a March 8, 2012 memo from CDM Smith. The following energy conservation measures were recommended and implemented:

- Install a smaller (50 hp) pump at the Strawberry Creek collection facility for WTP feed;

- Negotiate a lower rate electric rate based on energy conservation measures yielding a lower capacity requirement; and

- Install a bladder tank and pump for water supply (lime solution, cleaning, etc.) to the WTP.

The above measures are estimated to result in a cost savings of about $55,000 per year; the exact energy use reduction was not provided, but we estimate that it was about 10percent with the remaining savings due to the rate reduction.

Energy use should be further reduced with the simpler pumping scheme planned and reduced flows expected after OU1 remedy implementation.

Currently, the EPA is conducting a pilot wind energy study at the Site with support from the National Renewable Energy Laboratory (NREL) to determine the feasibility for utilizing wind turbines for energy generation for use on-site and as a location for a commercial wind farm. If implemented, it could lead to a further reduction to the environmental footprint. The wind study will be completed in early 2013.

The optimization review team has no further recommendations for environmental footprint reduction.

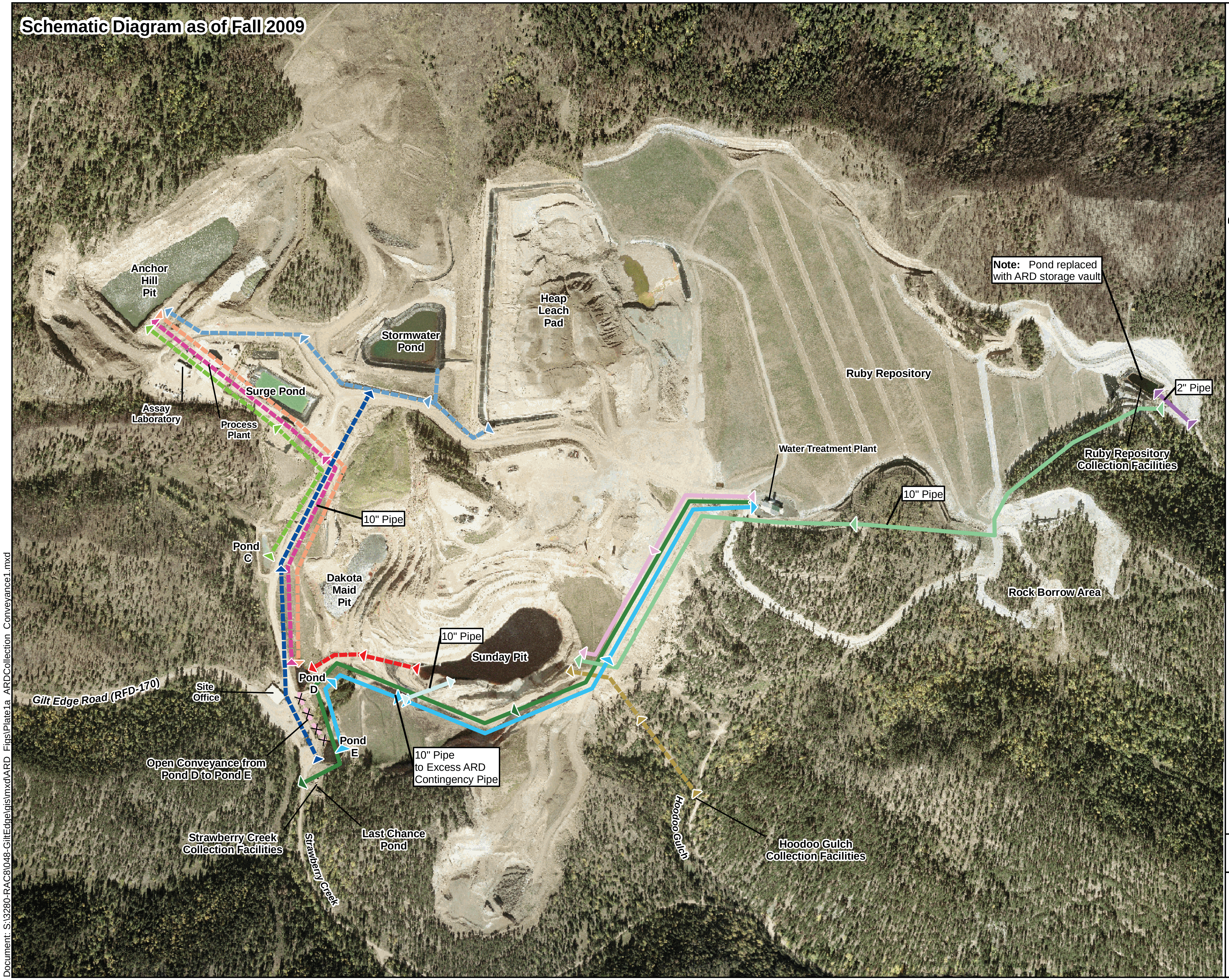
Table 6: Summary of Recommendations and Associated Costs

Recommendation	Reason	Change in Cost*
6.1.1 Pretreatment for Remaining High-Sulfate ARD	Effectiveness	Not Quantified
6.1.2 Upgrade Hoodoo Gulch Collection Facility Prior To Remainder of OU1 Remedy	Effectiveness	$200,000
6.2.1 Eliminate Overnight Staffing, Cut Labor Force and Operate WTP in Batch Mode (includes reduced vehicle leases)	Cost Reduction	($750,000)/year **
6.2.2 Reduce Sampling Frequency	Cost Reduction	($40,000)/year
6.2.3 Do Not Add/Rebuild/Replace/Relocate WTP and Regularly Evaluate Collection System Pumping Requirements	Cost Reduction	Not Quantified
6.3.1 Minor WTP Changes	Technical Improvement	$35,000

* Due to the nature and timing of this review (i.e., focus on the WTP and collection facilities with the separate OU1 remedy implementation pending), cost impacts were generally not quantified.
** Prior to OU1 remedy implementation; additional savings likely after OU1 remedy-related flow reductions are achieved.

APPENDIX A

Select Figures from Site Documents



Legend

Pipelines

Permanent (buried)

- Ruby Repository Pipe Line
- WTP Feed Pipe Line
- WTP Discharge Pipe Line (Treated Water)
- WTP Bypass Pipe Line
- Excess ARD Contingency
- Ruby Wet Well Pipe Line

Temporary (over land)

- Pond D Contingency Pipe Line
- Anchor Hill Return Pipe Line
- HLP Pipe Line
- Hoodoo Gulch Pipe Line
- Pond C Contingency Pipe Line
- Pond E Contingency Pipe Line
- Sunday Pit Return Pipe Line

Note: All pipes are 6 inch diameter unless otherwise noted. Arrows indicate flow direction

N
W E
S

Feet
500 250 0 500

CDM

PLATE 1a

Schematic Diagram of ARD Collection and Conveyance Facilities Pipe Line
GILT EDGE MINE SITE
LAWRENCE COUNTY, SOUTH DAKOTA

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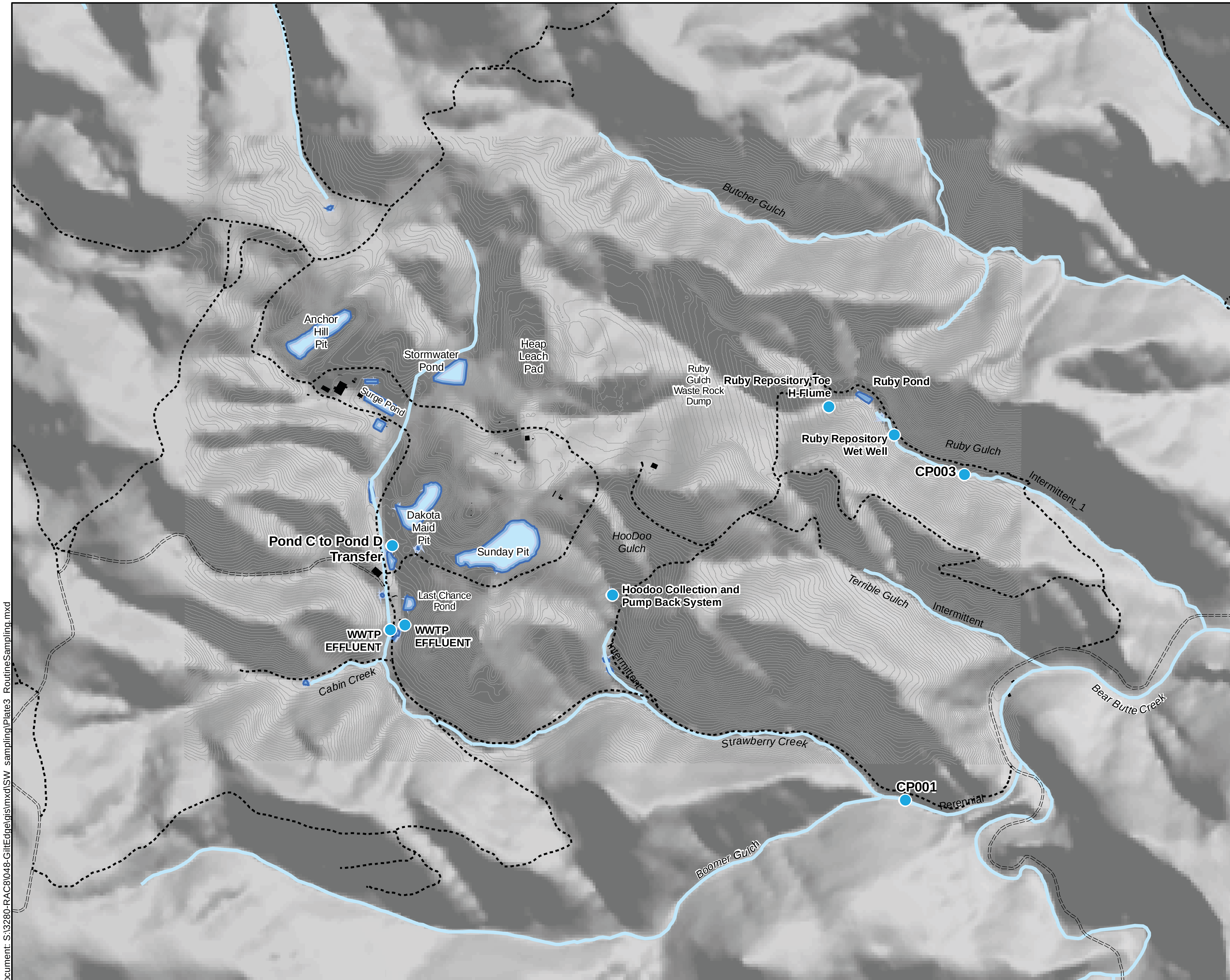

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Sampling Location

N
W E
S

CDM

PLATE 3

Routine Water Sampling

GILT EDGE MINE SITE
LAWRENCE COUNTY, SOUTH DAKOTA

APPENDIX B

Informational Brochures – BioteQ Sulf-IX™ Process

» **CASE STUDY**

Sulf-IX™ Plant, USA

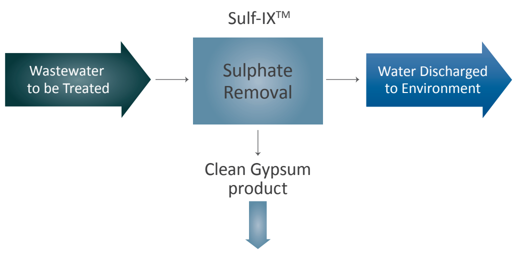
PROJECT OBJECTIVES	Remove calcium and sulphate from groundwater.
PROJECT SIZE	· 600 m^3/day flow
TECHNOLOGY	Sulf-IX™ for calcium and sulphate removal
COST	Confidential

In 2007, BioteQ entered into a development agreement with a US-based mining company to apply BioteQ's Sulf-IX™ process on a groundwater stream containing elevated sulphate. The objective of the project is to reduce the Total Dissolved Solids (TDS) in the wastewater by removing calcium and sulphate. The plant was designed and developed to meet strict effluent limits and improve the process operability and economics.

The process incorporates a cation exchange circuit and an anion exchange circuit using selective strong acid cationic ion exchange resins and weak base anion resins respectively, to produce clean water and a gypsum product.

BioteQ provided process design engineering review, plant commission, and operations support for the project. The plant is now being optimized after successful start-up in Q4 2010.

Figure 1: Sulf-IX™ Plant Process Flowsheet



The Sulf-IX™ Plant is designed to remove sulphate from groundwater.

With a design flow rate of more than 25 m^3/hr, the plant will treat water to produce clean water and a usable gypsum product.

Innovative water treatment reduces life cycle costs and contributes to sustainability in mining and power generation

DAVID KRATOCHVIL, DAVID SANGUINETTI, TERYL MURRAY
BioteQ Environmental Technologies Inc., Vancouver, BC

Regulations are tightening for wastewater treatment, water conservation and re-use, energy consumption, and carbon footprints. Regulatory compliance is increasingly connected with the need to operate more sustainably, particularly in the resource and power generation sectors. This is driving industry to review the "life cycle cost" of water treatment, which includes maximizing recovery of valuable resources including water itself, minimizing power consumption, and reducing the carbon footprint. This helps the development of new technologies that target compliance with today's standards and with future regulations. Example applications of the Sulf-IX™ water treatment process in the mining and power generation are presented. These case studies demonstrate reduced life cycle costs achieved through savings in capital and operating cost, including savings in water consumption and CO_2 emissions. The examples include 1) the removal of sulphate from flue gas scrubber blow-down to comply with new regulations, and 2) selective removal of calcium and sulphate from cooling tower blow-down to maximize water re-use and reduce energy consumption associated with Zero Liquid Discharge (ZLD) systems.

Keywords: water treatment, sulphate removal, life cycle costs, ZLD

Sulf-IX™ process

BioteQ has developed and successfully piloted a novel ion exchange process called Sulf-IX™ for the removal of sulphate and TDS from hard waters with high scaling potential and elevated levels of sulphate near or at gypsum saturation levels. Sulf-IX™ is a two stage process employing a Strongly Acidic Cation (SAC) resin and a Weakly Basic Anion (WBA) resin placed in two separate circuits operating in series, achieving an overall partial demineralization of the feed by selectively removing Ca^{2+} and SO_4^{2-} from the plant feed water. The feed is first directed to the cation circuit where Ca is removed in exchange for H^+. The effluent from the cation circuit is then directed to the anion circuit where dilute H_2SO_4 produced in the cationic circuit is taken up by the WBA resin. Ion exchange reactions during resin loading are identical to those utilized in conventional ion exchange systems.

The unique feature of the Sulf-IX™ process is the regeneration step that uses H_2SO_4 and lime as the regenerants for the cation and anion resins, respectively. In both cases solid gypsum is formed during resin regeneration. The cationic gypsum is then blended with the anionic gypsum to yield a final neutral gypsum product. The schematic of the Sulf-IX™ process is shown in Figure 1. The novel feature of the Sulf-IX™ process is that the spent regenerants from the cation and anion circuits are quantitatively recycled with only a small volume of concentrated sulphuric acid and lime added to the recycle stream to make-up for the acid and hydroxide consumed by the IX process.

This paper was presented at the 12th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, May 2010, Prague, Czech Republic

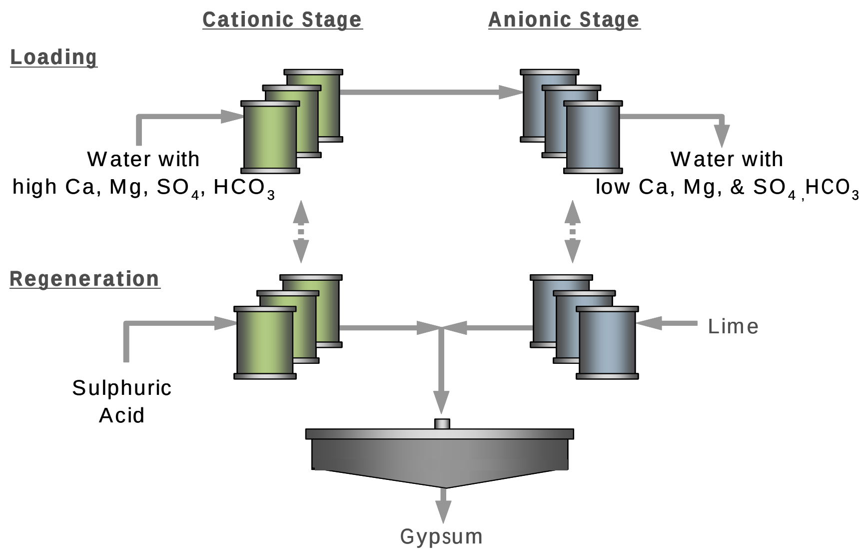


Figure 1 – Sulf-IX™ Process Schematic

The resin regeneration reactions taking place in the cation and anion stages can be described by reactions (1) and (2):

Cation Resin Regeneration (100% recycle of regenerant):

$$CaSO_4.2H_2O\ (aq) + Ca^{2+}(aq) + 2H^+(aq) + 2SO_4^{2-}(aq) + 2R_f\text{-}Ca(resin) + 2H_2O = 2R_f\text{-}H\ (resin) + Ca^{2+}(aq) + SO_4^{2-}(aq) + 2\ CaSO_4.2H_2O(s) \quad (1)$$

Anion Resin Regeneration (100% recycle of regenerant):

$$R_f.H_2SO_4(resin) + CaSO_4.2H_2O(aq) + 2Ca^{2+}(aq) + 2OH^-(aq) + SO_4^{2-}(aq) = R_f + Ca^{2+}(aq) + SO_4^{2-}(aq) + 2\ CaSO_4.2H_2O(s) \quad (2),$$

where (s), (aq), and (resin) stand for solid, solution, and resin/gel phases respectively, and R_f depicts the resin functional groups. The formula of undissociated gypsum species $CaSO_4.2H_2O$ (aq) is included on both sides of the reactions (1) and (2) in order to highlight the fact that as a result of the regenerant recycle, the regeneration of resins in Sulf-IX™ takes place under gypsum saturation conditions in the bulk of solution.

The key advantages of Sulf-IX™ can be summarized as follows:

- Process operates on hard scaling water and in the presence of suspended solids directly without any pre-treatment.
- The process operates with fluidized bed of resins;
- Solids, i.e. gypsum and $Mg(OH)_2$ are the only waste by-products of the process. No brines are produced;
- Process achieves very high water recovery since the only water lost in the process is the pore water contained in the solids products;
- Process has lower reagent cost than conventional IX systems due to inexpensive regenerants, and low power consumption compared to membrane systems.

Case study# 1 - Removal of sulphate from flue gas scrubber blow-down

This case study describes the removal of sulphate from flue gas scrubber blow-down at a coal burning iron pelletizing plant where the flue gas produced from the pelletizing plant is scrubbed using lime slurry. The pelletizing plant is part of a large iron mine and ore processing plant complex. The overall process flow diagram is shown in Figure 2 which also shows the proposed application of Sulf-IX™ for the blow-down treatment. As can be seen from this figure, solids are separated from the blow-down solution in a conventional clarifier, and the clarifier overflow solution is then directed to an unlined tailings pond. Water reclaimed from tailings is returned for iron ore processing. The blow-down solution flow is 91 m^3/hr (400 USGPM) and the composition is shown in Table 1 below.

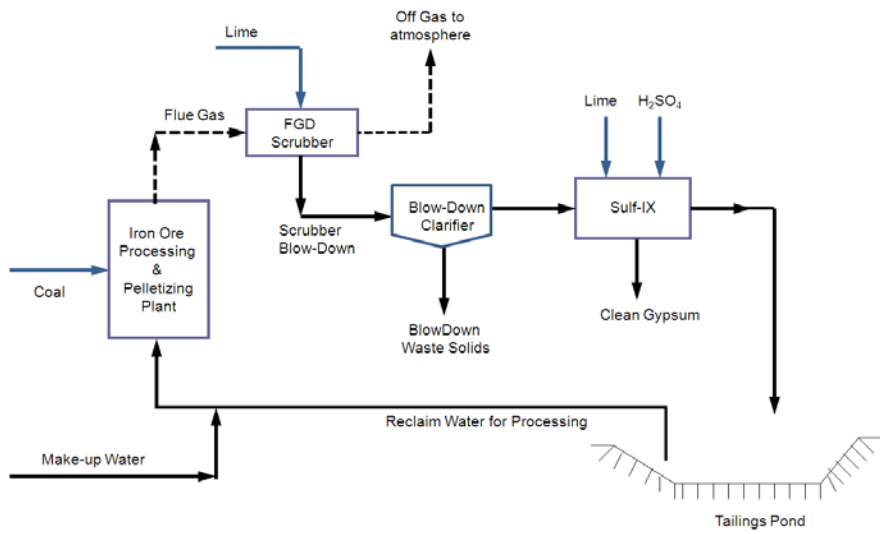


Figure 2: Sulphate Removal from Flue Gas Scrubber Blow-Down

Regulatory agencies are concerned about the steady rise in sulphate levels in the tailings pond and a new site environmental permit stipulates mandatory reductions in the concentration of SO_4 in tailings pond water. It has been determined that the flue gas scrubber blow-down is the main source of SO_4 contributing to the total SO_4 present in the tailings pond. The objective of the site owner is to reduce the sulphate load in the scrubber blow-down by 60% which, given the composition of the blow-down solution, translates into a 500 mg/L SO_4 discharge limit from a new blow-down water treatment plant.

Table 1: Sulf-IX™ Plant Feed & Discharge Composition

Constituent	Feed [mg/L]	Discharge [mg/L]
Sulfate	1,300	493
Alkalinity	39	0
Chloride	36	36
Calcium	514	168
Magnesium	28	26
Sodium	23	23
TDS	1,940	746

The following two water treatment process options are evaluated for achieving the 60% sulphate load reduction:

- Sulf-IX™ process; and
- Membrane treatment combined with conventional softening upstream of membranes, and evaporation-crystallization downstream of membranes treating the membrane reject stream.

The membrane process combined with soda ash softening and evaporator-crystallizer system was selected as the basis for the life cycle cost comparison with Sulf-IX™ because the individual process components of the conventional system are well known and their operation well understood which makes this treatment option appealing to risk averse site owners. The block diagram of the membrane treatment system with all its ancillaries is shown in Figure 3.

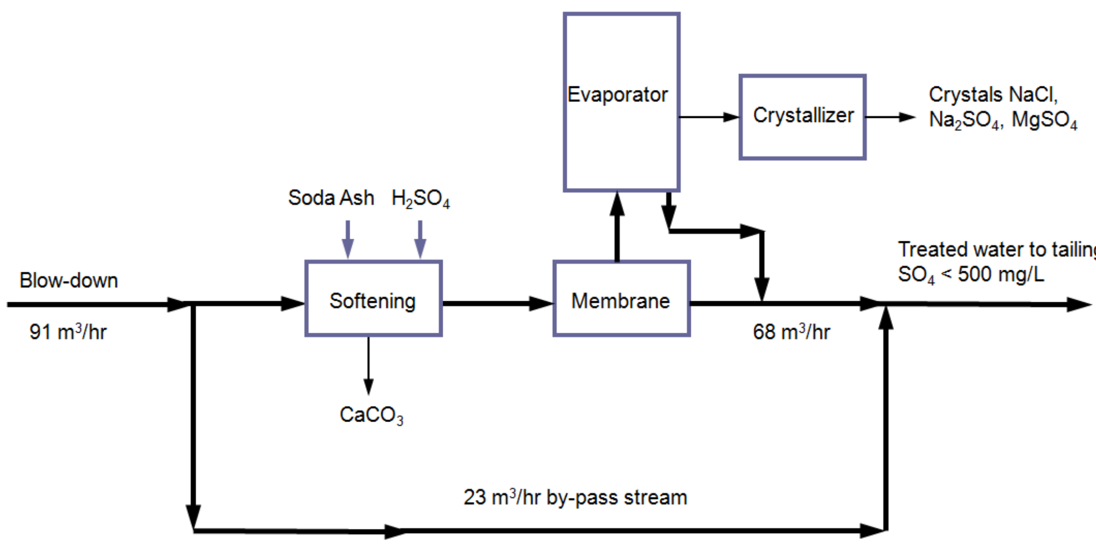


Figure 3: Membrane-Based Blow Down Treatment System

As can be seen from Figure 3, only 68 m^3/hr of the total blow-down flow passes through the membrane treatment while the remaining 23 m^3/hr bypass the treatment. This is because membranes produce treated water nearly free of sulphate which then opens the possibility to blend this high purity treated water with untreated blow-down to yield the discharge limit of 500 mg/L in the combined blended effluent.

The need for softening upstream of the membrane is driven by the fact that the blow-down solution contains elevated levels of dissolved calcium and sulphate which are near gypsum saturation thus causing problems with scaling inside membrane modules. The requirement for the evaporator-crystallizer system is driven by the need to cost effectively dispose of the membrane reject stream containing high concentration of sulphate. Due to the geographic location of the site, solar evaporation ponds that are sometimes used for the disposal of brines are not technically feasible. The recycle of the brine solution to process is not possible and there is no storage pond at the site that is large enough to continue receiving the membrane reject stream during the entire life of the project.

The detailed comparison of annual operating costs for the two treatment options is presented in Table 2. Unit reagent, power, waste disposal, and labour costs were provided by the site owner in 1Q 2010. The annual maintenance costs of the two water treatment plants are assumed to be equal to 4% of the purchase cost of process equipment. Plant amortization costs and costs of carbon dioxide emissions are excluded from the annual operating cost estimate.

As can be seen from Table 2, the Sulf-IX™ process is estimated to provide close to $600,000/year savings in operating costs compared to the membrane based treatment system. The savings in power constitute over 50% of the total savings, closely followed by the savings in the reagent costs.

Table 2: Comparison of Annual Operating Costs

OPERATING COST ITEM	**Unit Cost**	**Membrane-Evap.-Crystal.**	**Sulf-IX™**
Reagents	$/dmt		
Soda Ash	$ 580	$510,643	$0
H_2SO_4	$ 165	$17,518	$192,720
Lime	$125	$0	$109,500
Floc	$4,200	$5,013	$11,531
Membrane cleaning		$2,102	$0
Power	$/kWh		
RO	$ 0.10	$126,144	$0
Evaporator	$ 0.10	$211,391	$0
Crystallizer	$ 0.10	$30,646	$0
IX	$ 0.10	$0	$33,288
Waste Disposal	$/mt		
Na_2SO_4 crystals	$20	$33,744	$0
Softening cake ($CaCO_3$)	$20	$28,890	$0
Gypsum	$20	$0	$124,100
Membrane replacement (based on 3 year life)		$12,614	$0
Resin loss (based on 2 years of piloting)		$0	$2,650
Labour		$344,500	$344,500
Maintenance (4% of purchase cost)		$215,677	$124,000
Total Operating cost		**$1,538,883**	**$942,288**

Table 3 summarizes the carbon footprint of the two treatment options including emissions related to the running power, and lime, respectively. All electric power at site originates from coal burning power plants. Consequently, the blow-down water treatment plant running power is converted to tons of CO_2 using the average heating value of coal of 36 MJ/kg in combination with 36% efficiency of conversion of coal's heating value into electricity. The conversion of lime into CO_2 is fairly straightforward as one mol of CO_2 is emitted into the atmosphere for every mol of lime produced from limestone.

Table 3: Comparison of Carbon Footprint

Carbon Footprint		**M-E-C**	**Sulf-IX™**
Running Power	kW	420	38
	kWh/d	10,087	912
CO_2 emissions from running power dmt/a		4,355	394
Lime	tpd	0	2.4
CO2 emissions from lime dmt/a		0	521
Total CO_2 emissions	**dmt CO2/a**	**4,355**	**915**
Total Cost of CO_2 emissions	**$15/dmt CO_2**	**$ 65,322**	**$ 13,719**

As can be seen from Table 3, _Sulf-IX™ offers close to 80% reduction in carbon footprint compared to the membrane based treatment_. This reduction may not be important for the site owner at this stage, not only because CO_2 emissions are not subject to regulations but also because of the relatively small savings in the absolute tonnage of CO_2 emitted to the atmosphere given the small size of the water treatment plant treating less than 100 m^3/hr flow. However, _the significance of the savings in CO_2 emissions becomes very relevant for larger scale treatment plants especially in jurisdictions where CO_2 emissions are capped and/or emissions credits can be monetized._

Table 4 shows the life cycle cost comparison for the two treatment options. The life cycle costs are based on a 10-year Net Present Value (NPV) which combines the initial capital cost with operating costs discounted to the present at 7%. Various degrees of price escalations are applied to individual sub-components of the annual operating cost to reflect overall price escalation over the life of the project. The capital and operating costs of the softening-membrane-evaporators-crystallizer system are based on "actual capital and operating costs" of an existing system treating 65 m^3/hr of wastewater that is nearly identical to the one considered for blow-down treatment in this case study. The capital and operating cost estimates for the Sulf-IX™ plant are based on the feasibility level engineering estimates prepared in 1Q 2010 for the site owner by BioteQ.

Table 4: Comparison of Life Cycle Costs, Based on 10-Year NPV

	Annual Increase	**Membrane-Evap.- Crystal.**	**Sulf-IX™**
Capital Expenses		$10,783,833	$6,050,000
Power (10 year)	15%	$ 6,180,233	$ 558,767
Reagents (10 year)	8%	$ 6,684,300	$ 3,917,978
Other Operating Cost (excl. CO_2 cost) 10 yr	4%	$ 6,724,576	$ 6,299,408
Total (undiscounted)		$ 30,372,942	$16,826,153
Total 10 Year NPV		**$ 24,445,229**	**$ 13,650,463**

As can be seen from Table 4, the capital cost of the Sulf-IX™ plant is approximately $4 million lower than the cost of the membrane based treatment system. However, _the initial capital costs represent only about 36% of the total life cycle cost_. The remaining 64% of the life cycle cost is the accumulation of operating expenses over the life of the project. It is assumed that the cost of electricity, reagents, and all other operating costs will increase by

15%, 8%, and 4% respectively. What matters for the life cycle cost comparisons is the relative rate of price escalation that is applied to the individual sub-components of the total operating cost. From this perspective, it seems reasonable to assume that the cost of electricity will escalate faster than the cost of basic inorganic chemicals such as lime and soda ash and that these are likely to increase at a faster rate than the labour cost and administration costs.

Table 4 shows that using these assumptions, the life cycle cost of the Sulf-IX™ plant is \$13.6M compared to \$24.4M for the membrane based treatment. The potential net savings of \$10.8 M provide a good incentive for the site owner to implement a new water treatment technology.

Case study #2: Minimizing ZLD cost & reducing water consumption at power plants by selective removal of calcium and sulphate from cooling tower blow-down

It is well documented and understood that cooling tower make-up water accounts for the majority of the overall water demand by power plants and that the build-up of calcium and to certain degree also sulphate often limit the extent of water re-use in the cooling tower loops due to concerns related to scaling (EPA 2008; Merkle 2008). Consequently, levels of calcium and sulphate are controlled mainly through blow-down.

Blow-down is not a concern where water is abundant, as there is plenty of water to replace water lost in the blow-down. However, in areas with water scarcity, the minimization of cooling tower blow-down is usually seen as the key to reducing the overall water demand by power plants.

One of the direct consequences of blow-down minimization is the increase in the concentration of all dissolved constituents, i.e. Total Dissolved Solids (TDS), which makes the blow-down unfit for re-use elsewhere within the power plant, and at the same time unsuitable for discharge into the environment because of high concentrations of salts. Therefore, blow-downs are typically directed to ZLD systems that vary in complexity from solar evaporation ponds where all water contained in the blow-down is lost to atmosphere through evaporation, to mechanical evaporator crystallizer plants that recover clean distilled water from blow-downs for re-use in power plants.

Power generation facilities located in arid areas with water scarcity are likely to be at odds with achieving sustainability in that solar pond based ZLD systems do little to conserve water, and mechanical ZLDs that maximize water recovery can be very expensive and also result in a significant increase in the parasitic power consumption at the power plant. The increase in parasitic power not only negatively impacts sales of electricity and power production costs, but also increases the overall carbon footprint.

The following case study illustrates a potential niche application for the Sulf-IX™ technology by reducing the capital and operating cost of mechanical ZLD systems while maintaining a high degree of water re-use and minimizing parasitic power associated with mechanical ZLD.

The case study is for a 1,000 MW coal fired power plant where water is drawn from an aquifer approximately 500 ft below the surface and where the ground water contains elevated concentrations of Ca and SO_4. Currently, the plant uses a combination of sulphuric acid injection and soda ash softening to partially remove calcium and bicarbonate alkalinity from raw make-up water prior to the use of water in the cooling tower. The cooling tower loop operates with a calcium concentration limit of 300 mg/L that determines the blow-down which is currently set at 452 m^3/hr, and is directed to solar evaporation ponds with the total active wetted surface area of 1,034 m^2. The current cooling tower loop and solar ZLD system is depicted in Figure 4.

The case study compares the existing solar ZLD system to two alternate ZLD systems including 1) conventional mechanical ZLD, and 2) mechanical ZLD applied in combination with Sulf-IX™ treatment of cooling tower blow-down. These two alternate systems are depicted in Figures 5 and 6.

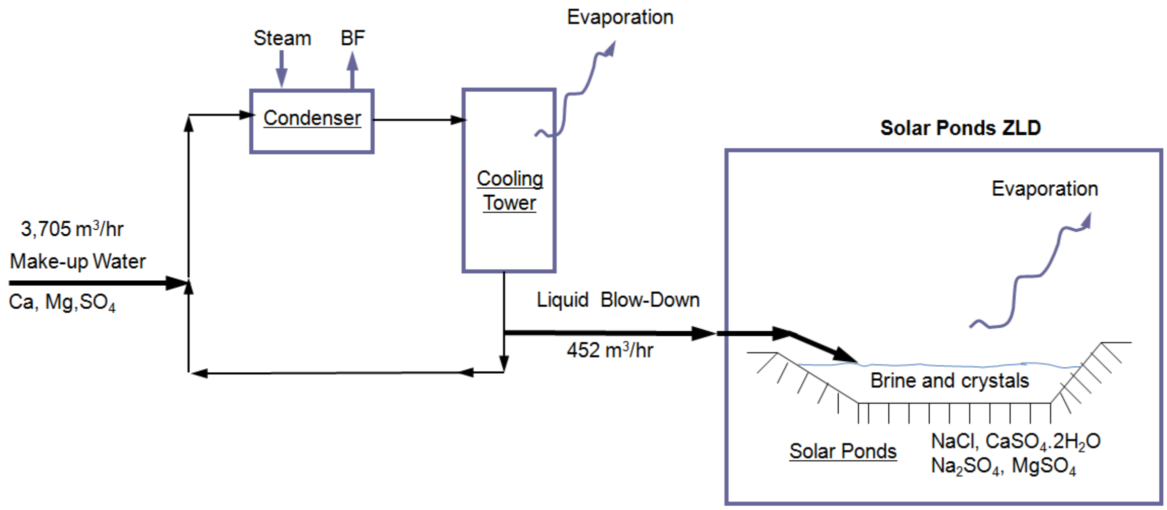


Figure 4: Cooling Tower Loop and Solar ZLD System

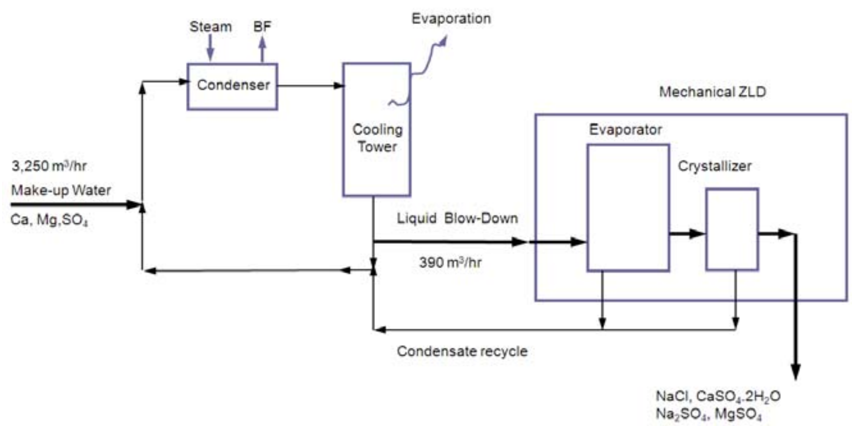


Figure 5: Conventional Mechanical ZLD

This paper was presented at the 12th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, May 2010, Prague, Czech Republic

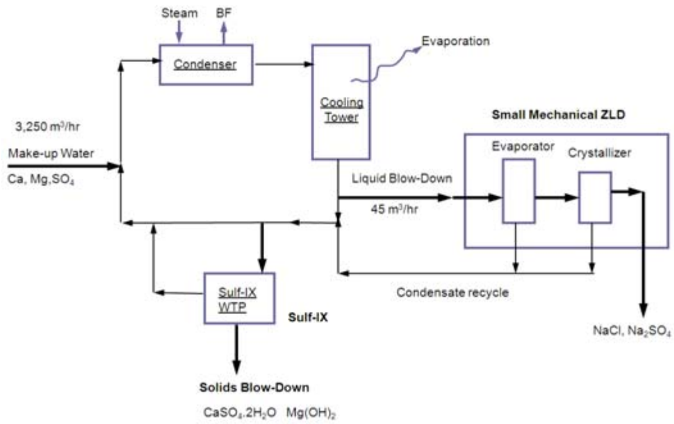


Figure 6: Mechanical ZLD in Combination with Sulf-IX™

Comparing the two systems shown in Figures 5 and 6, one can see that Sulf-IX™ treatment introduces a new concept of “solids blow-down”. This blow-down is composed mainly of solids and is achieved by the selective removal of calcium and sulphate from the cooling tower water by Sulf-IX™ which turns Ca and SO_4 removed from the loop into solid gypsum. Since there is little water of hydration associated with the gypsum, the gypsum stream becomes “solids blow-down”. All other constituents dissolved in the cooling water loop pass through the Sulf-IX plant as inert species.

In summary, Sulf-IX™ selectively extracts constituents that are of concern for scaling of the cooling tower loop and that limit the extent of water re-use, i.e. Ca and SO_4, while leaving other salts including Na, and Cl in the loop. The main benefit of the solids blow-down is the reduction in the liquid blow-down volume. As can be seen from Figures 4 and 6, the use of Sulf-IX™ can potentially reduce the liquid blow-down from 452 m^3/hr to 45 m^3/hr.

In effect, the application of Sulf-IX™ to cooling tower loops can be viewed as replacing the mechanical energy of conventional ZLD evaporators with chemical energy contained in lime and sulphuric acid used for IX resin regeneration to extract Ca and SO_4, from the cooling water loop. Furthermore, instead of producing very pure distilled water as a by-product of concentrating salts in ZLD evaporators, Sulf-IX™ allows cooling towers themselves to do the bulk of salts concentrating.

Although the conventional ZLD and the modified ZLD using Sulf-IX™ both achieve the same overall reduction in water demand by cooling towers, they achieve it through different means. While the conventional ZLD reduces the cooling tower make-up water requirements by recycling large volumes of distilled water from evaporators, Sulf-IX™ minimizes the make-up requirements by maximizing the extent of re-use of water already present in the cooling tower loop. Although many cooling towers are designed to operate at very high TDS including those operating on sea water, the increase in TDS level in cooling towers may be subject to permitting.

Table 5 compares annual operating costs of all three ZLD systems. The costs are based on the same power, reagent, and labour pricing as Case Study 1. The water cost of $0.70/m^3 reflects the power cost associated with lifting water by 500 ft from wells, and associated maintenance costs but excludes the cost of acquiring land and/or water rights to secure the water supply, and/or amortization costs for the wells and pumping infrastructure. The costs of soda ash and H_2SO_4 consumed during pre-treatment of raw well water are included in the operating costs for all three options in order to illustrate the savings resulting from the water recovery by mechanical ZLD and Sulf-IX™.

Table 5 shows that the solar ZLD appears to provide the lowest annual operating cost. Comparing the operating costs of the conventional mechanical ZLD, and Sulf-IX™/ZLD systems one can see that Sulf-IX™ offers $2.8M/year savings. Table 5 shows that the operating cost difference between the solar ZLD and Sulf-IX™/ZLD is $2.7 M/year while the incremental water cost for solar ZLD is $2.8M/year.

This means that if the cost of water were to rise to over $1.40/m^3 then Sulf-IX™/ZLD would provide the lowest overall annual operating cost. The cost of water can be $1.40 or higher in areas where water is pumped from depth that exceeds 1,000 ft or across a distance that would result in the total head loss of more than 1,000 ft. In addition, the price of water could rise based on the supply and demand market fundamentals in areas where water is "mined" from groundwater aquifers at a rate that exceeds the natural rate of aquifer recharge.

Table 5: Comparison of Annual Operating Costs

	Unit Cost	**Solar ZLD**	**Mechanical ZLD**	**Sulf-IX™ ZLD**
Reagents	$/dmt			
Soda Ash	$ 580.00	$2,287,019	$2,008,868	$2,008,868
H_2SO_4	$ 165.00	$754,471	$701,340	$2,168,743
Lime	$125	$0	$0	$766,211
Floc	$4,200	$0	$0	$17,520
Power	$/kWh			
Evaporator	$ 0.10	$0	$6,157,163	$618,336
Crystallizer	$ 0.10	$0	$480,160	$370,648
IX	$ 0.10	$0	$0	$177,828
Other	$ 0.10	$11,643	$0	$0
Waste Disposal	$/mt			
Na_2SO_4 crystals	$20	$0	$387,713	$299,286
Softening cake ($CaCO_3$)	$20	$74,399	$65,350	$65,350
Gypsum	$20	$0	$0	$391,429
Incremental Water Cost (Blow-down not recycled)	$0.70	$2,769,997	$0	$0
Resin loss		$0	$0	$24,820
Labour		$35,000	$400,000	$750,000
Maintenance (4% of purchase cost)	$/mt	$15,000	$1,282,340	$1,022,625
CO_2 emissions	$0		$0	$0
Total Operating Cost		**$5,947,530**	**$11,482,935**	**$8,681,663**

Total Cost per kWh electric output		$0.0007	$0.0013	$0.0010
Lost Power Sales due to loss of blow-down water		$26,337,087	$0	$0
Lost Power Sales due to parasytic power by ZLD		$0	$6,625,680	$1,155,168
Lost Cash Flow from Power Sales (15% of sales)		$3,950,563	$993,852	$173,275
Total Operating Cost Including the Cost of Lost Sales		**$9,898,093**	**$12,476,787**	**$8,854,939**

The operating costs shown in Table 5 do not include the cost of missed opportunities to sell incremental power due to either lack of water or high parasitic load. The concept of parasitic load is well understood in that every kWh that is consumed within the power plant represents kWh of lost sales. Revenue losses due to the lack of water stem from the fact that power plants need water to dissipate waste heat produced during electricity production. The higher the electric output the more heat needs to be dissipated and the higher the water consumption. In certain parts of North America, dry seasons characterized by the lack of water often coincide with the peak air conditioning season when power sells at a premium. Lost sales arise when a power plant cannot take advantage of the peak season due to the lack of water or must in fact cut back its output.

In Table 5, lost sales are assessed using $0.1/kWh sales price of electricity and 15% net profit margin on sales. The water consumption factor of 0.0037 m^3/ kWh (3,705 m^3/hr for 1,000 MW) is used to translate excess water consumed by solar ZLD into lost power sales. Finally, it is assumed that sales lost due to lack of water happen only during a 90 day window per year. As can be seen from Table 5, when the cost of lost sales are added to the total operating cost, Sulf-IX™/ZLD becomes the option with the lowest overall operating cost.

Table 6 compares the carbon footprint of all three ZLD systems. Clearly, the solar ponds ZLD system provides the lowest carbon footprint with the Sulf-IX™/ZLD in the second place emitting almost 63,000 tonnes of CO_2/year less than conventional mechanical ZLD.

Table 6: Comparison of Carbon Footprint

		Solar ZLD	**Mechanical ZLD**	**Sulf-IX™+ZLD**
Running Power	kW	280	7,577	1,332
	kWh/d	6,720	181,844	31,967
CO2 emissions from running power	dmt CO2/a	2,901	78,506	13,801
Lime	tpd	0	0	10.8
CO_2 emissions from lime	dmt CO2/a	0	0	2,344
Total CO_2 emissions	dmt CO2/a	2,901	78,506	16,145
Total Cost of CO_2 emissions	**$15/dmt CO_2**	**$ 43,517**	**$ 1,177,590**	**$ 242,173**

Table 7: Comparison of Life Cycle Costs, Based on 10-Year NPV

	Annual Increase	Solar ZLD	Mechanical ZLD	Sulf-IX™+ZLD
Capital Expenses		$ 7,729,987	$ 64,116,979	$ 33,585,952
Power (10 Year)	5%	$ 128,382.64	$ 73,186,868	$ 12,865,920
Water (10 Year)	25%	$ 71,472,364.34	$ 36	$ -
Other Operating Cost (excl CO_2 cost)	3%	$ 72,296,794.62	$ 59,323,733	$ 78,104,500
Total (undiscounted)		$ 151,627,528.10	$ 196,627,616	$ 124,556,372
Total 10 Year NPV		**$ 106,443,171**	**$ 158,326,361**	**$ 98,492,226**

Table 7 shows the Life Cycle Costs for all three ZLD systems where the cost of lost sales is included in the life cycle costs. As can be seen from this table, Sulf-IX™/ZLD system provides the lowest overall life cycle cost despite the fact that the initial capital expense is higher than that for solar ponds ZLD system. The capital costs for the existing ZLD was obtained from the site owner. The cost of the Sulf-IX™ plant was estimated internally based on the results of field piloting of Sulf-IX™, and the IX resin costs provided by Lanxess. The cost of evaporators-crystallizer systems are estimated based on adjusting the actual known installed cost for a 65 m^3/hr ZLD system, using the conventional rule of thumb 0.6 scaling factor to arrive at the approximate costs for 45 m^3/hr and 390 m^3/hr systems operating in combination with Sulf-IX™, and alone as the conventional mechanical ZLD, respectively.

Conclusions

The target niche application for the new ion exchange based Sulf-IX™ technology involves the treatment of waters with elevated hardness and sulphate levels at or near gypsum saturation. Based on the results of field piloting and engineering studies, the Sulf-IX™ process allows mining and power generation industries to comply with new SO_4 discharge regulations, conserve water, and reduce carbon footprint by up to 80% while reducing the life cycle cost of projects by up to 50% compared to membrane based technologies.

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