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ENVIRONMENTAL METAL MINE

WASTE MANAGEMENT:

TEN YEAR RESEARCH PLAN

November, 1998

Minnesota Department of Natural Resources
Division of Minerals
Reclamation Section

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EXECUTIVE SUMMARY

1. TEN YEAR RESEARCH PLAN RATIONALE

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Among the responsibilities of the Reclamation Section is research directed at environmentally sound management of ferrous and non-ferrous mining wastes. Under the present research program a number of ferrous and non-ferrous projects have been completed, while others remain in progress. However, new research needs are arising and the complexity of mine waste research has increased substantially since the research program was initiated. *These developments require more effort, much of which is at a highly technical level, in order to evaluate, advance, and apply state-of- the-art techniques of environmentally sound mine waste management in Minnesota.*

Several new developments have occurred in the ferrous mining sector. In-pit taconite tailings disposal has become of interest to the industry. This disposal method reduces the amount of land required for disposal, energy requirements for tailings pumping, and the potential for dust generation and tailings dike failure. However, the geochemistry of tailings in an anoxic environment and the subsequent transport of dissolved components must be understood to ensure that ground water quality is not adversely impacted. Remaining current with developments in this area is time-consuming and requires expertise which is neither readily available nor easily attained.

The use of waste products as amendments to enhance vegetative growth on taconite tailings is of interest for reducing costs of reclamation and waste disposal. Development of wetlands on abandoned tailings basins, to replace those disturbed by mining activities, is another mine waste management approach of benefit to the industry. Research and monitoring programs on these topics were not a concern five years ago

Studies of extended duration are often required in the field of environmental management of nonferrous mine wastes. Research on the environmentally sound management of nonferrous mine waste began in Minnesota in the mid-1970s, at which time little information on the subject was available. As part of an effort to address concerns over environmental impacts of copper-nickel mining, field studies were begun at the AMAX site. Over a period of 17 years these studies produced data on waste rock drainage quality and quantity from well-characterized mine waste and effectiveness of various mitigation techniques. These studies were, and are today, unique and valuable to the field of environmentally sound mine waste management.

In the years which followed it became clear that studies of mine waste dissolution and drainage quality mitigation often required a long duration. Such studies are required to understand the dissolution behavior of mine wastes in the extended period of concern after mine abandonment and to determine the longevity of some mitigation methods. Consequently, long-term studies were initiated to address these issues and their results remain relevant today. Several of these studies remain in progress as part of core Reclamation Research. Included in these studies are those which examine the long-term dissolution behavior of Minnesota mine wastes and prevention of drainage quality problems by these wastes. *It is clear, however, that there is a vast amount of additional information which must be understood in order to maintain a productive research program.*

The information available on applied environmental mine waste management has vastly increased over the past decade. The extent of field research on environmental mine waste management increased in the late 1980s. Studies at mining operations were initiated as part of the MEND program in Canada. Developing technologies were applied at operations in Canada, the US, and Europe. Developing technologies will continue to be applied at mining operations around the world. To remain abreast of state-of-the-art methods of environmental mine waste management, the progress of field research and operational applications around the world must be tracked. This requires both time and expertise in the engineering and scientific principles on which the mine waste management methods are based, as well as research projects to test the effectiveness of mine waste management techniques in Minnesota.

The fundamental scientific background required for a sound understanding of environmental mine waste management in 1998 is far more complex than that in 1980. In addition to the Canadian MEND program, national efforts have been initiated in Sweden and Australia. Mining company representatives have also begun an international effort to prevent acid mine drainage. The relevance of principles of geology, chemistry, physics, and biology to mine waste problems has been recognized. As a result geochemical computer modeling and physical modeling have been used to describe the environmental behavior of mine wastes and to evaluate the effectiveness of proposed mitigation techniques. A waste rock dissolution model is also being developed by the University of Utah as part of a project with the US Bureau of Land Management. Research in various areas of mineral dissolution has also become more complex due, in part, to development of instruments capable of more precisely defining aspects of mineral surfaces and composition. A sound understanding of these modeling tools and scientific fundamentals is essential for interpreting reported research, evaluating the relevance of research to mining in Minnesota, as well as designing and interpreting appropriate research projects. This requires both time and expertise.

2. TEN YEAR PLAN FOR METALLIC MINERAL RECLAMATION RESEARCH

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2.1. INTRODUCTION

Permitting metallic mineral mines in Minnesota requires state of the art information on 1) site characteristics; 2) predicted mine waste drainage quality; 3) cost effective techniques for prevention, control, and treatment of problematic drainage, as well as mine land reclamation. The Department of Natural Resources has compiled and developed a substantial amount of information on these topics, particularly for iron mining. In addition, it is the Department's experience that an ongoing research and demonstration program is essential to the development and implementation of environmentally sound mine waste management techniques in Minnesota. These techniques must consider the geologic, climatic, and geographic conditions specific to the state. The Department has, therefore, been conducting environmental mine waste management research and demonstration studies for over twenty years. The following outlines the goals, strategies, and approaches for the continuation of this program for metallic mineral reclamation research. Industrial mineral and peat are not addressed.

2.2 RESEARCH GOAL

The overall objective of the Department's Reclamation Research Program is to develop technical information which is necessary for addressing permitting issues and solving environmental problems related to current and future metallic mineral mining. The research program will produce a catalogue of technical alternatives for addressing environmental mine waste (waste rock, tailings, mine walls) management problems at present and future mining operations in Minnesota.

2.3. RESEARCH STRATEGIES

2.3.1. IRON MINING

Iron mining is a well established and reasonably understood industry from an environmental and permitting perspective. Reclamation research related to the taconite industry in Minnesota has historically focused on determining optimal species and fertilization rates to ensure compliance with three and ten year vegetation standards. For the past several years the studies have been specifically focusing on the application of various biosolids to coarse tailings to increase their water retention and fertility. Mining scale application of field study results are ongoing and annual reclamation reviews at operating companies allow the implementation of the new techniques to be closely monitored for long-term success.

Several new areas of reclamation research have evolved over the over the last few years. The recent interest in in-pit disposal of tailings has raised questions on possible impacts on ground water quality. Current studies are near completion but additional research may be necessary on a site specific basis as new in-pit disposal applications are made.

Another relatively new research topic is the establishment of wetlands on tailings basins. The Wetland Conservation Act requires that wetlands disturbed by any activities of man be replaced. Tailings basins have good potential for creation of wetland habitat after mining. Studies to determine cost effective methods to construct wetlands on tailings are on going.

Although not a new problem the reclamation of watersheds disturbed by mining is becoming a large and complex issue as mining operations expand and adjoin one another. Cooperative studies with industry and governmental agencies were initiated three years ago and will continue into the future in order to determine how to successfully re-establish watersheds interrupted by mining activities.

An important aspect of the Reclamation Research program is to continue to address evolving issues associated with iron mining. Mitigation of elevated sulfate concentrations in tailings basin water is one project presently under consideration . New or additional processing applications such as DRI may result in new reclamation research initiatives. As other new opportunities arise the Program will work cooperatively with industry and others to develop cost effective techniques. In this capacity the Program will:

1.) develop and maintain an understanding of relevant reclamation research and incorporate it in new studies;
2.) develop and maintain and understanding of physical, chemical, and biological fundamentals that ensure successful reclamation and apply them to research and regulatory decision making; and,
3.) conduct field and laboratory studies to develop cost effective and efficient reclamation techniques that sustain the mining industry and protect the environment.

2.3.2. NON-FERROUS MINING

With respect to the future mining of non-ferrous metallic minerals, research will focus on ensuring that future base and precious metal mining does not adversely impact the quality of natural waters in Minnesota. The specific technical areas to be addressed will be prediction, prevention, and control of problematic mine drainages with a lesser emphasis on water treatment. The intention of this strategy is to eliminate, to the extent practical, the generation of problematic drainage. This, if successful, would obviate the necessity of long term treatment of mine waste drainage. In this capacity the research program will:

1) develop and maintain an understanding of current research and applications of environmental mine waste management alternatives;
2) develop and maintain an understanding of physical, chemical, and biological fundamentals which influence the behavior of mine wastes and models which apply these fundamentals; and

3) conduct field and laboratory experiments to extend the understanding of existing applications and develop additional technologies for environmental mine waste management. In particular, field and laboratory experiments will focus on:

A) collection of information on the composition of potential ore bodies in Minnesota under exploration (e.g. Wabigoon subprovince with greenstone belts [base metals]; Wawa subprovince, including Ely greenstone belt [gold]; Soudan Mine greenstone [gold, base metals]; the East-Central proterozoic [base metals]; and the Duluth Complex [platinum, titanium, base metals]);
B) characterization of potential mine wastes and conducting laboratory and field dissolution tests to determine the variation of drainage quality with solid phase composition of individual rock types;
C) laboratory and field tests on methods of mitigating problematic mine waste drainage; and
D) comparison of laboratory and field data.

3. PROJECT EVALUATION

Research projects will be selected based on 1) their relevance within the context of previous research and application in environmental mine waste management; 2) the likelihood of success based on evaluation of chemical, physical, and biological principles; and 3) practical economic feasibility.

4. PRODUCTS

The key products of the Metallic Mineral Reclamation Research Program will be

1) a catalogue of environmental mine waste management technologies from which appropriate tools can be selected based on the ore, mining methods, geography, and hydrology of a specific site;
2) a staff which is knowledgable in most current effective methods of environmental mine waste management; and consequently,
3) the capacity for mining to proceed in Minnesota without adverse impact on other natural resources.

5. ISSUES TO BE RESOLVED BY MAY 1999

5.1. STAFFING

- On 1 July 1999 the level of staffing will be short 1.3 FTE research and development (scientific) personnel to continue existing programs. The personnel costs for FY 1999 and FY 2000 are presented in Tables 1 and 2, respectively. The differences are summarized in Table 3.

- Any new projects will require additional staffing, which will be dependent on securing additional funding from outside sources or matching monies from the Environmental Cooperative Research Program.

5.2. CAPITAL COSTS

Capital costs are significant and funding has yet to be secured. The following are potential sources.

- Capital budget
- Environmental Cooperative Research Program (requiring match)
- Outside grants

5.3. FUNDING NECESSARY FOR 10-YEAR PROJECTS

- Outside grants
- Environmental Cooperative Research
- General Fund appropriations

6.0. ATTACHED INFORMATION

Three attachments are appended to provide additional detail on research projects which are proposed (Attachment A), projects in progress as core research funded by the Division of Minerals (Attachment B), and projects in progress supported by outside funding (Attachment C). These attachments provide information on objectives, tasks, costs and, for projects in progress, results.

Table 1. SUMMARY OF PERSONNEL COSTS (FY99)

ACTIVITY	LAB and FIELD PERSONNEL				RESEARCH & DEVELOPMENT PERSONNEL			
	PERSON/ FTE's	GENERAL FUNDING	OUTSIDE FUNDING	ECR FUNDING	PERSON/ FTE's	GENERAL FUNDING	OUTSIDE FUNDING	ECR FUNDING
<u>BASELINE</u> High % Sulfur NF Weekly NF Oven WGA Humidity WGA Oven Particle Size Sub-Aqueous Flasks NF In-Pit Field NF In-Pit Columns Alkaline Addition Limestone Columns Sulfate Reduction Research & Development Research Site	ANNE/.15	4960			ANNE/.25	8268		
	PAT./60	19681			JON W./.50	18082		
	JOHN F./.20	6339			DAVID/.50	20818		
	GREG/.60	21473			PAUL/.05	3336		
	MIKE L./.30	9841			KIM/.40	26685		
					GLENN/.20	8920		
					LYN/.40			13062
					JENNIFER/.20			6757
TOTALS	1.85	62,294	0	0	2.50	86,109	0	19,819
<u>COOPERATIVE FUNDED PROJECTS</u> BLM Waste Characterization In-Pit Taconite Disposal Alternative Encapsulation Evtac Biosolids NSPC Dredge Spoils Dunka Wetlands Soudan Mine Evtac Dredge Spoils	JOHN F./.80		12678	12678	KIM/.30	20014		
	MICHELLE/1.0		10760	16140	DAVID/.30	12491		
	MIKE L./.20	6560			GLENN/.70	31220		
	GREG/.25	8947			JON W./.40	14466		
					PAUL/.80	53370		
					LYN/.60		19594	
TOTALS	2.25	15,497	23,438	28,818	3.10	131,561	19,594	0

Baseline: Lab + R&D = 4.35 FTE's
Coop: Lab + R&D = <u>5.35 FTE's</u>
TOTAL = 9.7 FTE's

Table 2. SUMMARY OF PERSONNEL COSTS (FY00)

ACTIVITY	LAB and FIELD PERSONNEL				RESEARCH & DEVELOPMENT PERSONNEL			
	PERSON/ FTE's	GENERAL FUNDING	OUTSIDE FUNDING	ECR FUNDING	PERSON/ FTE's	GENERAL FUNDING	OUTSIDE FUNDING	ECR FUNDING
<u>BASELINE</u> High % Sulfur NF Weekly NF Oven WGA Humidity WGA Oven Particle Size Sub-Aqueous Flasks NF In-Pit Field NF In-Pit Columns Alkaline Addition Limestone Columns Sulfate Reduction Research Site	ANNE/.15	4960			ANNE/.25	8268		
	PAT./60	19681			JON W./.50	18082		
	~~JOHN F./.20~~	~~6339~~			DAVID/.50	20818		
	GREG/.60	21473			PAUL/.05	3336		
	MIKE L./.30	9841			KIM/.40	26685		
					~~GLENN/.20~~	~~8920~~		
					~~LYN/.40~~			~~13062~~
					~~JENNIFER/.20~~			~~6757~~
TOTALS	1.65	55,955	0	0	1.70	77,189	0	0
<u>COOPERATIVE FUNDED PROJECTS</u> BLM Waste Characterization ~~In-Pit Taconite Disposal~~ Alternative Encapsulation ~~Evtac Biosolids~~ NSPC Dredge Spoils Dunka Wetlands ~~Soudan Mine~~ Evtac Dredge Spoils	~~JOHN F./.80~~		~~12678~~	~~12678~~	KIM/.30	20014		
	~~MICHELLE/1.0~~		~~10760~~	~~16140~~	DAVID/.30	12491		
	MIKE L./.20	6560			~~GLENN/.70~~	~~31220~~		
	GREG/.25	8947			JON W./.40	14466		
					PAUL/.80	53370		
					~~LYN/.60~~		~~19594~~	
TOTALS	.45	15,497	0	0	1.80	100,341	0	0
<u>TENYEAR PLAN PROJECTS</u> Range Hydrology (Funded) Biosoids ? Taconite in-pit ? Sulfate ? Non-Ferrous ? Non-Ferrous ? Non-Ferrous ?	JOE M./1.0		44,000		ANNE/.10	3070		
	LAB/1.2			39,074	DAVID/.10	4164		
					KIM/.15	16678		
					PAUL/.15	16678		
					JON W./.10	3616		
					R.A./.85			14695
TOTALS	2.20		44,000	39,074	1.45	44,206		14695

Baseline (3.35) + Coop (2.25) + Tenyear (3.65) = 9.25 FTE's

Table 3. PERSONNEL SUMMARY

FY99 Personnel (lab and R&D)		9.7 FTE's
Personnel ending on or before 6/30/98		4.1 FTE's
Glenn	.9 FTE's	
Michelle	1.0 FTE's	
John F.	1.0 FTE's	
Jennifer	.2 FTE's	
Lyn	1.0 FTE's	
Remaining personnel		5.6 FTE's
Discontinued projects (equivelent FTE's)		1.4 FTE's
In-Pit Taconite	.8 FTE's	
Evtac Biosolids	.3 FTE's	
Soudan Mine	.3 FTE's	
FY99 Personnel (9.7) minus discontinued projects (1.4) =		8.3 FTE's needed to run all exps.
Personnel needed to continue all experiments		8.3 FTE's
Available personnel		-5.6 FTE's
Personnel shortage		2.7 FTE's
Lab	1.4 FTE's	
R&D	1.3 FTE's	
FY00 funded projects (outside or ECR)		1.4 FTE'S (Lab personnel)
BLM	.4 FTE's	
NSPC Dredge	.2 FTE's	
Alt Cap	.2 FTE's	
Dunka	.2 FTE's	
Evtac Dredge	.4 FTE's	
Personnel not funded but needed to continue all exps.		1.3 FTE's (R&D personnel)
1.3 FTE's lost represent these personnel	Glenn .7	
	Lyn .4	
	Jennifer.2	

* Table does not include personnel associated with the ten year plan projects.

ATTACHMENT A

Potential Laboratory and Field Research Projects

INTRODUCTION

Considerable research on long-standing reclamation issues in the taconite industry has been conducted in the past, and results of this research have been applied by the companies in their reclamation practices. The long-term success of various approaches is monitored as part of reclamation permitting. New issues requiring research are also arising in the industry. Alternative reclamation amendments and tailings disposal approaches are being considered by the industry and research is required to assess these options. Additional research needs facing the industry include the quality of tailings basin water discharge as well as the determination and management of the hydrologic consequences of open pit mining. It should also be noted that wastes typical of nonferrous mining are encountered during ferrous mining (e.g. mineralized Duluth Complex and Virginia Formation hornfels waste rock), and research results directed at nonferrous mining can be applied to these wastes.

Future research on the environmental management of metallic mine wastes will focus on drainage quality prediction, as well as the prevention and control of problematic mine waste drainage. Previous drainage quality prediction studies on Minnesota rock associated with potential mineral resource recovery has been limited to a) Duluth Complex rock, b) mineralized Virginia Formation hornfels, and c) hydrothermal quartz-carbonate tailings, which might be associated with gold development in greenstones. Other areas presently under exploration must be identified and existing compositional data collected. If samples of potential waste rock or ore (which could be used to estimate tailing composition) are available, additional compositional characterization and dissolution tests can be conducted.

Mitigation studies will focus on the prevention and control of mine drainage problems. Previous prevention and control studies have addressed dry covers (standard reclamation, soil caps on waste rock, synthetic liner caps on waste rock), wet covers (subaqueous disposal of tailings and waste rock with and without additional oxygen barriers, wetlands on tailings), blending alkaline solids (rotary kiln fines, limestone) with fine rock, and blending Duluth Complex tailings and waste rock. Additional examination of the effectiveness of these techniques in Minnesota will be pursued. The treatment of mine waste drainage with wetlands has also been studied extensively.

FERROUS RESEARCH

Ferrous Proposal 1. Determination of mass balances for taconite plants and tailings basins.

The taconite industry has recently become interested in disposing taconite tailings in existing open pits as an alternative to traditional tailings disposal on land. Since 1996 the Division of Minerals, in concert with the University of Minnesota, has been examining the implications of in-pit disposal on ground water quality. In the course of this study 1) fluoride, manganese, arsenic, molybdenum, and boron have been identified as parameters of potential concern; 2) the background quality of the Biwabik Iron Formation ground water has been determined; 3) chemical reactions controlling the quality of water in tailings basins and the Biwabik Formation have been identified; and 4) mass balances for parameters of concern at the Inland plant and tailings basin have been developed. With this background, it is clear that a sound understanding of the mass balances in plants and tailings basins is essential to predicting ground water impacts of tailings disposal in open pits. Whereas the present study will continue through June 1999, additional questions will remain upon its completion.

Objective

Determine the sources and sinks of parameters of concern for processing plants and tailings basins at operations which may employ in-pit disposal of taconite tailings.

Tasks

1. Collect existing data on flow, water quality, and solid composition at participating plants.
2. Collect and analyze samples and flow data for one year.
3. Analyze data to identify and quantify sources and sinks for parameters of concern.
4. Collect verification data as necessary.

Duration

Two years.

Costs

Personnel: Rs analyst @ 50% for 2 years = ~$40,000
Analyses: 2 basins x 10 sites x 12 samples/yr x $80 = $19,200
2 plants x 16 sites x 2 water samples x $80 = $5120
2 plants x 16 sites x 2 solid samples x $80 = $5120
SUBTOTAL CONTRACT ANALYSES = $29,440
Travel: $5000
Equipment and supplies: $5000
TOTAL: $79,440

Ferrous Proposal 2. Alternatives for discharge of tailings basin waters with elevated sulfate concentrations.

USX may need to discharge water from its tailing basin to avoid exceeding the basin capacity. With regard to this need there is a concern for the impacts of high temperature water on a receiving water which is a trout stream. Furthermore, sSulfate concentrations in the tailings basin water are elevated, and there is concern that these sulfate levels may impact wild rice in the waters downstream from the basin. The potential for such impacts must be evaluated, as well as treatment and discharge alternatives if potential for impact exists.

Objectives

Determine the potential for impact of USX tailings basin discharge on wild rice and identify and evaluate alternatives for avoiding impact by discharge management and treatment.

Tasks

1. Review literature on sulfate impacts on wild rice.
2. Determine quality of water in USX tailings basin based on NPDES reports and, if necessary, additional sampling.
3. If potential for impact exists, identify methods of timing and locating discharge to minimize impact.
4. Evaluate potential treatment methods with regard to extent of lowering sulfate removal efficiency, retention time required, and mass removal capacity.

Duration

One year.

Costs

Research analyst at 60% for one year: $24K
Travel: $5000

Ferrous Proposal 3: Range Hydrology

Objective

Detailed hydrologic study of the Canisteo Mine. Potential outflow solutions and slope stability of high pit walls will be addressed. This pilot will serve as an example of how to address similar problems expected to arise at other locations on the Range.

Tasks

1. Development of bedrock topography and drift thickness maps.
2. Install elevation wells and begin groundwater data collection.
3. Assess pit wall stability and make recommendations.
4. Model Canisteo watershed for outflow at static water level.
5. Model Trout Lake and Holman Lake watersheds with inflow from Canisteo Pit.

Duration

Two years

Costs

300,000 for the biennium

Results

Model of Canisteo Mine Pit watershed with outlet selected and designed

Ferrous Proposal 4. Biosolids

Objective

Determine the suitability of dredge material to produce hybrid poplar tree plantations on taconite tailings basins.

Tasks

1. Design plot studies at EVTAC , using different amounts of dredge material and comparing incorporation of the material with covering the tailings.
2. Install suction lysimeters to measure the impact on water quality.
3. Measure tree growth.
4. Compare the cost of applying dredge material to the tailings to the profit obtained from the tree plantation.

Duration

Two years for design, construction and water quality monitoring. Annual monitoring of tree growth for 5 -10 years.

Costs

Personnel 20 % research analyst for 2 years	$15,000
Shipment of dredge material	$50,000
Analysis	$15,000
Supplies and Equipment	$6,000
Travel	$4,000
Total	$90,000

NONFERROUS CHARACTERIZATION AND PREDICTION

INTRODUCTION

In order to design and cost environmentally sound mine waste management alternatives in concurrently with mine development plans, prediction of mine waste drainage quality is required prior to mineral resource development. These predictions are required as part of Minnesota's Nonferrous Mining Rules. Mine waste drainage quality prediction involves determination of the relationship between solid-phase composition and drainage quality. The major drainage quality concern is whether or not a mine waste will produce acidic drainage. Key solid-phase variables are the amounts of exposed iron sulfide minerals (the oxidation of which leads to acid production) and calcium and magnesium carbonate minerals (the dissolution of which neutralizes acid). Predictive studies are best conducted on individual rock types, or lithologies, for which there is a degree of compositional homogeneity with respect to mineralogic composition and mineral grain size. There is, however, variability within rock types with regard to the iron sulfide and calcium and magnesium carbonate minerals, and this variability is critical to determining compositional thresholds for acid production.

To determine the relationship between solid-phase composition and drainage quality, a series of samples with a range of sulfur and carbonate contents are collected from a rock type which may be associated with future mining. The chemistry and mineralogy of the samples are then determined in detail. Samples are then subjected to laboratory dissolution experiments to determine the relationship between the solid-phase composition and drainage quality. Subjecting a variety of potential mine wastes is described in Proposal 1. Ideally field tests would also be conducted on a limited number of samples to allow correlation of laboratory and field results. Application of this approach for samples of Ely greenstone is presented in Proposal 2.

NONFERROUS PREDICTION PROJECT PROPOSALS

Proposal 1. Identify a variety of potential Minnesota metallic mine wastes and subject sets of samples to characterization and predictive dissolution testing.

Objective

Determine the relationship between solid-phase composition and laboratory drainage quality for a variety of potential mine wastes associated with future development of metallic minerals in Minnesota.

Tasks.

1. Identify areas of potential mineral resource development. This would include areas of Minnesota presently and previously under exploration. Among these area are the
   a. Wabigoon subprovince with greenstone belts (base metals);

   b. Wawa subprovince, including Ely greenstone belt (gold);
   c. Soudan Mine in the Ely greenstone (gold, base metals);
   d. East-Central proterozoic (base metals); and
   e. Duluth Complex
      i. platinum group elements
      ii. titanium
      iii. base metals
2. Briefly describe the geology of these seven areas as it relates to the characterization of potential future mine wastes.
3. Determine the availability of samples from rock units associated with potential mining.
4. Compile existing compositional data.
5. Collect a set of sixteen samples (ten pounds) which represent a range of compositions for each of the seven areas identified above (1a - 1e, iii). All will analyzed for sulfur species and carbon dioxide evolved. Ten of the sixteen samples will be selected for more detailed testing and six will be stored for potential later use. It is recognized that there will be duplication of the Wawa subprovince with the sampling at the Soudan mine. The target areas for the Duluth Complex will be associated with PGE, titanium, and base metals near the US Steel test pit. Thus a total of 48 samples will be collected from the Duluth Complex.
6. Determine the physical, chemical, and mineralogic composition of potential mine wastes. Ten of the sixteen samples from each area will be subjected to chemical and mineralogic analysis.
7. Conduct laboratory dissolution tests to determine the variation of drainage quality with solid-phase composition of individual rock types. Ten samples from each rock type will be subjected to testing. The additional six samples will be stored in case additional examination is warranted on the rock type.
8. Conduct laboratory dissolution tests to determine the variation of drainage quality with particle size of Ely greenstone rock from the Soudan mine. This information will aid in extrapolating laboratory results to field scale.
9. Analyze leached samples for sulfur species, evolved carbon dioxide, and mineral dissolution products.

Duration

The experimental duration would be three years. This consists of six months for sample collection and analysis; two years of dissolution testing; two months for analysis of leached samples; and four months for data compilation, analysis, and reporting.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Lab Set up	400				400
Solid Anal	7000			3000	10,000
DNR Lab	2575	5150	5150	2575	15,450
MDA Lab	4425	2760	2760	1490	11,435
Rs Analyst	4000	4000	4000	4000	16,000
Yrly Total	18,400	11,910	11,910	11,065	53,285

*DNR lab includes personnel and supplies on all cost estimates.

Proposal 2. Conduct field dissolution tests to allow extrapolation of laboratory test results on the prediction of drainage quality from Ely greenstone rock.

Objective

Conduct field dissolution experiments on Ely greenstone rock from the Soudan mine for calibration of the relationship between solid-phase composition and laboratory drainage quality. For most rock units associated with future metallic mineral development in Minnesota, the available samples will be limited to drill core. Study, therefore, will be limited to increasing the detail of characterization (compositional data) and conducting laboratory dissolution tests. The lithologies which will be excavated from the cavern under construction at the Soudan Mine represent potential hosts for mineralization and will be available in larger quantities. Therefore, this material will be an adequate source for small scale field tests, as well as laboratory tests.

Tasks.

1. Collect rock from cavern construction project and ship to Hibbing.
2. Characterize rock samples.
    a) Characterization information will be collected from existing analyses and analyses which will be conducted in the course of constructing the cavern.
    b) Additional analyses will be conducted as necessary.
3. Lined bins, approximately 10 feet square and a minimum of 6 feet deep, would be constructed of concrete, wood, or metal.
4. Conduct field tests on three different compositions of one rock type, with one composition run in duplicate.
5. Correlate laboratory and field data.

Duration

Tests would be conducted for ten years with a cost for years five through ten equal to year four.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Capital	13,000				13,000
DNR Lab	2025	3125	3125	3125	11,400
MDA Lab	600	900	900	900	3300
Rs Analyst	4000	4000	4000	4000	16,000
Yrly Total	19,625	8025	8025	8025	43,700

*Capital costs include bins and rock hauling.

MITIGATION

Mitigation alternatives can be categorized based on the stage of waste disposal at which they are implemented. First, to reduce or eliminate long-term problems from sulfide mineral oxidation, sulfide minerals can be removed from mine wastes prior to ultimate disposal (e.g. bioleaching). Second, the environment in which mine wastes are disposed can be selected to reduce access of oxygen and/or water to the sulfide minerals (e.g. subaqueous, waste rock within tailings basins). Third, mitigative materials can be incorporated during construction of the waste disposal facility to neutralize acid produced or limit the access of oxygen to sulfide minerals (e.g. blending of alkaline solids or oxygen consuming solids). Fourth, mine waste disposal facilities can be capped after construction (e.g. multilayer caps for tailings or waste rock, wetlands over tailings). Fifth, water treatment facilities can be constructed to mitigate mine waste drainage which does not meet water quality standards. The first four alternatives are referred to in this document as "Prevention and Control" options for mitigation generation of problematic drainage.

Mitigation Proposal 1. Prevent waste rock drainage problems by removing sulfide minerals by accelerated ***bioleaching*** *prior to disposal.*

If iron sulfide minerals can be removed prior to mine closure, the long term production of acid mine drainage will be reduced. Oxidation under normal environmental conditions occurs relatively slowly over many years. As a result, stockpiled material can produce water quality problems for hundreds of years. Recently there have been some reports of companies increasing the rate of bacterial oxidation of sulfide minerals in order to provide better metal recovery in leaching operations. If this technique could be used to remove most of the sulfides during the life of the mine, not only could the waste be reclaimed at the end of mining without threat to the environment, but additional metals could be recovered.

Objective

Determine if sufficient sulfides can be removed through bioleaching to produce a waste that can safely be reclaimed with standard reclamation techniques. Evaluate the economics of metal recovery.

Approach

Information on the feasibility of this approach will be collected from the literature and companies who have examined the process. Small scale laboratory experiment will be conducted to examine the feasibility of this approach. If results of the laboratory experiment look promising, small scale field experiments will be conducted using bins.

Duration

Initial laboratory experiments will be conducted for a period of at least 2 years. A minimum of 3 different rock compositions will be run in columns with and without bacteria. At least one set of columns will be run in duplicate. If laboratory work is successful small scale field tests will be built. This experiment would run for 5-10 years.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	2000*		13,000*			15000
Solid Anal	1800					1800
DNR Lab	4050	4050	4050	4050	4050	20250
MDA Lab	1030	685	685	685	685	3770
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	12,880	8735	21735	8735	8735	60820

*Capital costs in year 1 include initial laboratory setup and rock crushing.
*Capital costs in year 3 include bin construction.

*Mitigation Proposal 2. Prevention of acid drainage by **treating waste rock with biocides**.*

Bacteria play an important role in catalyzing the oxidation of sulfide minerals. In coal mining applications in the eastern United States, there has been some success in using a biocide to kill the bacteria and prevent or reduce the formation of acid drainage. This approach is not a long term solution, but might provide treatment during the active phase of mining. When mining is completed, the stockpile would be capped to provide long term containment.

Objective

Determine the effectiveness of commercial biocides to prevent acid mine drainage from mineralized stockpiles.

Approach

Information on various biocides and results from previous studies will be collected. Based on this information, small scale field trials in bins would be initiated. Acid forming rock from Soudan would be treated with biocide at rates prescribed by the supplier. The control bin would be part of the characterization study.

Duration

This project would continue as long as the water quality from the treated bins meets water quality standards.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	9500					9500
Solid Anal	1800					1800
DNR Lab	4350	4350	4350	4350	4350	21750
MDA Lab	2050	1350	1350	1350	1350	7450
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	21700	9700	9700	9700	9700	60,500

*Capital costs include bin construction and rock hauling.

Mitigation Proposal 3. Control acid generation by waste rock by disposing it in a ***subaqueous*** *environment.*

Subaqueous disposal of sulfide-bearing mine wastes has been recommended as the preferred option by some Canadian agencies. Such disposal limits the oxidation of sulfide minerals due to the low rate of oxygen diffusion through water. We are currently running an experiment with Arimetco rock (Duluth Complex) which has a sulfur content of about 0.65%, which is near the threshold for acid production. Data using higher percent sulfur rock (1.4%) would provide detailed information which would aid application of this approach for in-pit disposal of sulfidic waste rock. Greenstone from the Soudan mine is another option.

Objective

Determine the rate of sulfide mineral oxidation and net acid production in an under water environment relative to that in a subaerial environment.

Tasks

1. Locate and adequate supply (7 - 8 yd^3) of high-sulfur rock. Alternatives include Duluth Complex rock from the Research Site pile, stored hornfels rock, and rock from the Soudan mine cavern.
2. Crush and analyze rock.
3. Subject rock to laboratory tests and field tests in existing subaqueous tanks and on-land tanks at the Research Site.

Duration. Tests would be conducted for five years.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	9000					9000
Solid Anal	600					600
DNR Lab	4200	4200	4200	4200	4200	21,000
MDA Lab	2055	1370	1370	1370	1370	7535
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	19,855	9570	9570	9570	9570	58,135

*Capital costs include tank setup and rock crushing.

Mitigation Proposal 4. Control waste rock acid generation by disposing it in taconite tailings basins to inhibit transport of oxygen and water .

Taconite tailings are fine grained and can be an oxygen transport barrier, particularly if they retain moisture. Tailings may also contain some calcium and magnesium carbonates, the dissolution of which would neutralize acid. These attributes are conducive to limiting sulfide oxidation and maintaining neutral pH conditions.

Objective

Determine the rates of sulfide oxidation, net acid generation, and trace metal release for sulfidic rock inundated in taconite tailings, with and without limestone addition.

Tasks

1. Review hornfels disposal in LTV tailings basin and develop plan for additional monitoring.
2. Develop mathematical description of controlling factors.
3. Collect rock and tailings.
4. Crush and analyze rock and analyze tailings.
5. Set up and monitor four tanks at Research Site (two with and two without limestone addition). Tanks would be 4 feet in diameter and 7 feet deep. Each tank would have an outlet on the bottom to monitor water quality and internal wells to monitor percent oxygen saturation. Monitoring equipment would be similar to the on-land tanks currently being run. We currently have enough hornfels rock for 2 tanks, we would have to obtain more rock from Dunka and have all the rock crushed to minus 1".
6. Conduct analysis of leached solids.

Duration.
The experiment will run for four years.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Capital	5000				5000
Solid Anal	1200				1200
DNR Lab	4050	4050	4050	4050	16,200
MDA Lab	1370	900	900	900	4070
Rs Analyst	4000	4000	4000	4000	16,000
Yrly Total	15,620	8950	8950	8950	42,470

*Capital costs include tank setup and rock crushing.

Mitigation Proposal 5. Control acid generation by placing a multilayer cap on waste rock to inhibit ingress of oxygen and water.

Objectives

1. Determine the rate of oxygen diffusion through the cap.
2. Determine the rate of sulfide mineral oxidation, net acid production, and trace metal release relative to an uncapped scenario.

Tasks

1. Collect, prepare, and analyze sulfidic waste rock for experiment.
2. Review literature.
3. Develop mathematical description of controlling factors.
4. Construct two 10' square bins with 10' x 6' overburden side slope extensions at a 3:1 slope. The barrier design for the top and side slopes would consist of an 18" layer of low sulfur tailings sandwiched between 9" layers of overburden . The tailing layer would remain saturated which would reduce oxygen transport and water infiltration into the pile. Monitoring equipment would be obtained to measure oxygen flux through the cap and water quality and flow would be monitored.
5. Post-mortem analyses would be conducted on the materials.

Duration

Tests would be conducted for five years.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	9500					9500
Solid Anal	1800					1800
DNR Lab	4020	4020	4020	4020	4020	20,100
MDA Lab	1370	900	900	900	900	4970
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	20,690	8920	8920	8920	8920	56,370

*Capital costs include bin construction and rock hauling.

Mitigation Proposal 6. Control acid generation by placing a multilayer cap on tailings to inhibit ingress of oxygen and water.

Objectives

1. Determine the rate of oxygen diffusion through the cap.
2. Determine the rate of sulfide mineral oxidation, net acid production, and trace metal release relative to an uncapped scenario.

Tasks

1. Collect, prepare, and analyze sulfidic tailings for experiment.
2. Review literature.
3. Develop mathematical description of controlling factors.
4. Set up two tanks with Winston Lake tailings plus multi-layer cap. The cap would be placed above two feet of tailing (3.2 ft^3) and consist of an 18" layer of low sulfur tailings sandwiched between 9" layers of overburden . The tailing layer would remain saturated which would reduce oxygen transport and water infiltration into the pile. The tanks would be 48" in diameter and 72" tall. Each tank would have an outlet on the bottom to monitor water quality. Monitoring equipment would be similar to the on-land tanks currently being run. An oxygen sensor to measure the rate of oxygen consumption would have to be purchased. Six laboratory columns would be run to examine what affect different layer thicknesses have on oxygen diffusion.
5. Post-mortem analyses would be conducted on the materials.

Duration

Tests would be conducted for five years.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	5600					5600
Solid Anal	1800					1800
DNR Lab	4350	4350	4350	4350	4350	21,750
MDA Lab	2740	1825	1825	1825	1825	10,040
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	18,490	10,175	10,175	10,175	10,175	59,190

*Capital costs include tank setup, lab setup, and a new oxygen sensor.

Mitigation Proposal 7. Control acid generation by adding organic material to waste rock.

Limiting the access of oxygen to sulfide minerals can control the rate of oxidation and subsequent generation of acid mine drainage. Disposing sulfide waste in a saturated environment is currently the easiest way to minimize oxygen transport. For underground operations where there is a small amount of waste rock, disposing the rock in the tailings basin may be practical. However, for large open pit operations, the volume of waste rock may make tailings basin disposal impractical. Another approach to limit the oxygen transport might be to consume the oxygen with an organic material. In addition to consuming oxygen, some of these materials are waste products containing alkalinity and may help to maintain pH within the stockpile. Potential materials include: lime stabilized sludge, Nviro soil (sewage mixed with alkaline materials) and paper processing sludge.

Objective
Determine the rates of sulfide mineral oxidation, net acid production, and trace metal release from a mixture of waste rock and organic material.

Approach
Initially laboratory experiments will be conducted to determine the feasibility of this approach. Organic materials will be assessed for their ability to consume oxygen and loading factors estimated. Columns containing acid generating rock from Soudan will be mixed with organic material selected from the initial screening tests. A minimum of 2 different materials at 3 different loading rates will be used. Laboratory experiments will run for at least 2 years, at which time the best material will be selected for small scale field trials. This study will use four bins.

Duration
Laboratory feasibility experiments will run for 2-3 years. Some columns would continue to run, while those not successful would be stopped. Field experiments would run from 5 - 10 years or until drainage quality from the treated bins no longer meets water quality standards.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	2000		13000			15000
Solid Anal	1200		1800			3000
DNR Lab	7875	7125	4350	4350	4350	28050
MDA Lab	4000	3000	1000	1000	1000	10000
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	19075	14125	24150	9350	9350	76050

*Capital costs include bin construction and rock hauling.

Mitigation Proposal 8. Control acid generation by ***blending limestone with waste rock.***

Objective

Determine the rates of sulfide mineral oxidation, net acid production, and trace metal release from a mixture of waste rock and manufactured limestone sand.

Tasks

1. Review existing data.
2. Collect rock from cavern excavation at Soudan Mine.
3. Construct four bins (10 feet square). Two low sulfur and two high sulfur rock would be mixed with lime sand at a 3:1 ratio. Would also run four reactors in the laboratory.

Duration

The project would continue as long as drainage quality from the treated bins meets water quality standards.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Capital	17,800				17,800
Solid Anal	2400				2400
DNR Lab	6225	6225	6225	6225	24,900
MDA Lab	2050	1350	1350	1350	6100
Rs Analyst	4000	4000	4000	4000	16,000
Yrly Total	32,475	11,575	11,575	11,575	67,200

*Capital costs include bin construction and rock hauling.

Mitigation Proposal 9. Control acid genera6tion by ***blending limestone with tailings.***

Objectives

1. Determine the rates of sulfide oxidation, net acid production, and trace metal release from mixtures of limestone and tailings.
2. Determine variation of oxygen with depth.
3. Compare laboratory and field data.

Tasks

1. Obtain manufactured limestone sand.
2. Set up two tanks with Winston Lake tailing and mix in limestone at an NP:AP (neutralization potential: acid production potential) ratio of 1:1 in the upper one foot of tailings. Run 10 laboratory reactors using two different tailing types and five different mixing ratios. Set up two additional tanks to look at underwater disposal of tailing mixed with limestone. Tailing would be Winston Lake tailing (mainly pyrite) and another tailing (mainly pyrrhotite). Monitoring equipment would be similar to the on-land tanks currently being run.

Duration

The experiment would continue as long as drainage quality remained acceptable.

Costs

ITEM	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Capital	8600				8600
Solid Anal	1800				1800
DNR Lab	6675	6675	6675	6675	26,700
MDA Lab	4100	2725	2725	2725	12,275
Rs Analyst	4000	4000	4000	4000	16,000
Yrly Total	25,175	13,400	13,400	13,400	65,375

*Capital costs include tank setup and lab setup.

*Mitigation Proposal 10. Treat acidic mine drainage using two different **sulfate reduction/wetland treatment** systems.*

Although the best approach to protect the environment is to prevent the formation of mine drainage which does not meet water quality standards, this goal is not always achievable. Capping systems are not 100% effective and even if acid conditions are prevented, residual water may contain elevated levels of trace metals. Passive treatment systems have the potential to offer long term treatment at much lower costs than water treatment plants. The major questions related to the use of these systems is their lifetime and winter performance.

Objectives

Determine the effectiveness of two wetland treatment systems to treat acid mine drainage

Approach

The first system will be a two stage treatment: a sulfate reduction cell, which will be built using a small tank (approximately 4' in diameter and 7' tall) and a prefabricated overland flow wetland (approximately 3' wide by 15' long). The second system will be a subsurface flow system built in a prefabricated cell. Input and output flow and water quality will be measured to determine overall metal removal and treatment effectiveness.

Duration

The project will continue for 5-10 years or until water quality standards are exceeded.

Costs

ITEM	YEAR_1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
Capital	8500					8500
Solid Anal	600					600
DNR Lab	6000	6000	6000	6000	6000	30,000
MDA Lab	1500	1000	1000	1000	1000	5500
Rs Analyst	4000	4000	4000	4000	4000	20,000
Yrly Total	20,600	11,000	11,000	11,000	11,000	64,600

*Capital costs include tank, pre-fab cells, substrate, and equipment.

NOTES

- Bin construction costs are based on the capital budget estimate by Chuck French.
- The rock used in all bins mentioned above would not require crushing. Instrumentation for all bins would consist of a sump, pump, and flow meter similar to the ones used at AMAX.
- Crushing costs obtained from Midland are for a two stage crushing, if only one stage is needed the cost would be cut in half.
- Solids analysis could be less depending on what experiments are run.
- Rock hauling costs obtained from Hoover construction are for loading at Tower and transporting to Hibbing.
- Personnel costs are based on a Project Analyst position.
- DNR lab costs are based on $75/sample point.
- MDA lab costs are based on the current MOU which is $4.25/parameter and seven parameters per sample with twenty sample points the initial year of an experiment and twelve for the remaining years.

Table 4. SUMMARY OF ANNUAL COSTS FOR PROPOSED EXPERIMENTS

EXPERIMENT	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL	PRIORITY
FERROUS							
IN-PIT MASS BALANCES	39,720	39,720	NA	NA	NA	79,440	A
TAILINGS BASIN SULFATE	29,000	NA	NA	NA	NA	29,000	A
RANGE HYDROLOGY	150,000	150,000	NA	NA	NA	300,000	A
BIOSOLIDS	45,000	45,000	NA	NA	NA	90,000	A
PREDICTION							
LABORATORY[1] PREDICTION	18,400	11,910	11,910	11,065	NA	53,285	A
FIELD PREDICTION[2]	19,625	8025	80250	8025	8025	51,725	A
MITIGATION							
BIOLEACHING	12,880	8735	21735	8735	8735	60,820	B
BIOCIDE	21700	9700	9700	9700	9700	60,500	B
SUBAQUEOUS DISPOSAL	19,855	9,570	9,570	9,570	9,570	58,135	B
TAILINGS BASIN DISPOSAL	15,620	8,950	8,950	8,950	NA	42,470	C
MULTI LAYER CAP (ROCK)	20,690	8,920	8,920	8,920	8,920	56,370	A
MULTI LAYER CAP (TAILING)	18,490	10,175	10,175	10,175	10,175	59,190	C
ORGANICS ADDITION	19075	14125	24150	9350	9350	76,050	A
LIMESTONE ADDITION (ROCK)	32,475	11,575	11,575	11,575	NA	67,200	A
LIMESTONE ADDITION (TAILING)	25,175	13,400	13,400	13,400	NA	65,375	B
WETLAND TREATMENT	20,600	11,000	11,000	11,000	11,000	64,600	C

1 - Costs are for one rock type (10 samples).

2- This experiment is slated to run for ten years. At 9,250/year for years 6 - 10 the total would be 93,625.

Table 5. **SUMMARY**

Proposed Experiments (10 yr. Plan)

- Prioritized internally
- Need a cooperator which may change priorities
- Costs may vary depending on which experiments are run

ACTIVITY	PERSONNEL*		ESTIMATED COSTS			RECLAMATION STAFF
	(hrs./week)	Salary	Capital[1]	DNR Lab	MDA Lab	
1. In-Pit Mass Balance[1]	24	20,000	NA	ND	ND	
2. Tailings Basin Sulfate[1]	20	24,000	NA	NA	NA	
3. Range Hydrology[1]	40	44,000	NA	NA	NA	
4. Biosolids[1]	8	7800	NA	ND	ND	
5. Laboratory Prediction[1]	10	9700	4700	1250	4425	
6. Field Prediction[1]	6	5850	13,000	1275	600	
7. Organics Addition[1]	12	11,700	16,200	175	4000	
8. Limestone Addition (rock)	10	9700	20,200	525	2050	
9. Limestone Addition (tailing)	10	9700	10,400	975	4100	
10. Subaqueous Disposal	8	7800	9600	400	2055	
11. Tailings Basin Disposal	8	7800	6200	250	1370	
12. Multi-layer Cap (rock)	8	7800	11,300	220	1370	
13. Multi-layer Cap (tailing)	8	7800	7400	550	2740	
14. Bio-leaching	8	7800	16,800	350	1030	
15. Biocide Application	8	7800	11,300	550	2050	
16. Wetland Treatment	10	9700	9100	300	1500	
TOTAL	**198**	**$198,850**	**$136,200**	**$6820**	**$27,290**	

*Personnel breakdown - Project Analyst (lab and field work)
Research Analyst (data manipulation and report writing)

Anne
David
Kim
Paul
Jon W.
Greg
Mike L.

1 - FTE's required to run these experiments (priorities listed in table 2)

TOTAL FTE'S (LAB, FIELD, and R&D PERSONNEL)	=	2.2
INDIRECT SUPPORT PERSONNEL FTE'S	=	1.45
TOTAL TEN YEAR PLAN EXPERIMENTS FTE'S	**=**	**3.65**

NA - Not applicable
ND - Not determined

ATTACHMENT B

Minerals Division Laboratory Experiments in Progress

PREDICTION OF DRAINAGE QUALITY FROM MINNESOTA MINE WASTES

Duluth Complex Rock Drainage Quality Prediction

Objective

Determine the release of acid and trace metals from Duluth Complex rock as a function of solid-phase S content and time of dissolution.

Tasks

1. Started: 14 February 1989. Current week (8/4/98):
2. 498 weeks: 0.18, 0.22, 0.40, 0.41, 0.51, 0.58, 0.71, 1.63% S (Dunka blast holes)
   417 weeks: 1.16, 1.44% S (Dunka blast holes)
   55 weeks: 0.26, 0.28, 0.42, 0.42, 0.47, 0.99% S (Arimetco (0.26% S), AMAX core).
3. 16 reactors sampled weekly and analyzed for metals and sulfate monthly.
4. Analyze leached solids upon termination of reactor.

Costs

7 person hours/week.
DNR LAB = $1200 annual total = 16 reactors x $75/reactor
MDA LAB = $2652 = 624 parameters

Results

For samples begun in 1989, as the sulfur content of the rock increased, the rate of sulfate release increased and pH decreased. Rocks with S $\leq$ 0.4% generated drainage pH of at least 6.0, and their drainage quality tended to stabilize after roughly 100-200 weeks of reaction. Rocks with S > 0.4% generated drainage pH < 6.0. The pH of drainage from these rocks typically decreased over the initial 275 weeks, stabilized for 25 to 125 weeks, then increased. Sulfide oxidation for all samples increased during the summer of 1995, when temperature and humidity were elevated.

For samples begun in 1997, the 0.26% S Arimetco rock generated drainage pH as low as 4.6, considerably lower than expected from the relationship between sulfur content and drainage pH observed for the Dunka blast hole samples. Similarly, the 0.28% S AMAX drill core sample has generated a drainage pH of 5.9, slightly lower that expected based on the Dunka blast hole samples and earlier work on AMAX drill core samples. The drainage from two of the four higher sulfur samples has remained above pH 6.0, most likely due to small amounts of carbonate minerals present, as indicated by evolved carbon dioxide data. It appears the relationship between solid-phase sulfur content and drainage quality may be somewhat spatially variable within the Duluth Complex.

Hydrothermal Quartz Carbonate Tailings Drainage Quality Prediction

Objective

Subject ten hydrothermal quartz-carbonate tailings samples (T1-T10) to compositional characterization (particle size, chemistry, mineralogy) and dissolution testing to determine the relationships between the solid phase characteristics and long-term drainage quality.

Tasks

1. Started: 6 June 1990. Current week: 430 (9/2/98)
2. Four reactors (T2, T6, T9, T10) sampled weekly, and analyzed for Ca, Mg, SO_4 monthly.

Costs

2.5 person hour/week.
DNR LAB = $300 annual total = 4 reactors x $75/reactor
MDA LAB = $663 = 156 parameters

Results (through week 430)

The oxidation of iron sulfide minerals in the tailings led to acid production, while dissolution of calcium and magnesium carbonate minerals neutralize the acid produced. Drainage from the tailings remained neutral as long as calcium/magnesium carbonates were present. Drainage pH decreased below 6.0 for T9 (122 weeks, presently high 2s and low 3s), T6 (284 weeks), and T10 (429 weeks). T2 pH shows a slight decreasing trend to mid to high 7s, alkalinity has decreased from about 75 to 55, and SC has decreased from about 250 to 150. This demonstrates that the quality of drainage generated in short term dissolution experiments may not accurately reflect the drainage quality generated by mine wastes over a longer time frame. The six remaining tailings were unlikely to produce acidic drainage, based on solid-phase characteristics and drainage quality over time. The comparison of oxidation rates with solid phase sulfur contents indicated that no solid-phase variables other than pyrite surface area were controlling rates of iron sulfide oxidation in this experiment (Lapakko and Wessels 1994, 1995; Lapakko 1993c). Barium, zinc, arsenic, antimony, and molybdenum were the most commonly released trace metals. The laboratory data provided a good indication of potential for trace metal release in the field. Particularly for arsenic, molybdenum and zinc. Barium concentrations in mine waste drainage in the field, where sulfate concentrations are typically high, would probably be controlled by the limited solubility of barium sulfate. Arsenic, antimony, and molybdenum, when occurring in elevated concentrations as sulfide minerals, may produce elevated concentrations even if drainage is neutral.

Elevated Temperature Prediction of Hydrothermal Quartz-Carbonate Tailings Drainage Quality.

Objective

Determine the extent and rates of release for acid and trace metals from hydrothermal quartz carbonate hosted gold tailings at 100°C. Compare these results with those at ambient temperature.

Tasks

1. Started: 4 February 1992. Current week: 343 (9/2/98).Two reactors (T2, T8) sampled weekly and analyzed for metals and sulfate monthly.

Costs

2 person hours/week
DNR LAB = $150 annual total = 2 reactors x $75/reactor
MDA LAB = $335 = 78 parameters

Results (through week 343)

In addition to dissolution testing at room temperature, most of these samples were subjected to dissolution testing at 100°C. Sample T9 produced acidic drainage in only eight weeks, compared to 122 weeks at room temperature (Lapakko 1993c). Sample T2, which has not acidified after 342 weeks of dissolution at room temperature, began to produce acidic drainage after week 60 at the elevated temperature (MN DNR Hibbing Laboratory 1997, unpublished data). Drainage pH is presently in the range of 3.8 to 4.2. The pH of drainage from T8 has decreased into the approximate range of 5.5 to 6.5. Alkalinity and specific conductance are presently around 5 mg/L (as $CaCO_3$) and 25 uS. In summary, dissolution tests at elevated temperatures may predict the quality of drainage from mine wastes much more rapidly than dissolution tests at lower temperatures. However, these tests are not typical of the reaction environment in the field.

Effects of Particle Size on Waste Rock Drainage Quality Prediction

Objective

Determine the influence of the particle size of three different rock types on 1) sulfate, calcium, and magnesium release rates and 2) capacities for acid release and acid neutralization, and compare results for covered and uncovered (drier) reactors.

Tasks

1. Started: 6 December 1993. Current week: 247 (8/27/98).
2. Fourteen reactors sampled weekly and analyzed for metals and sulfate monthly.

Costs

6.5 person hours/week.
DNR LAB = $1050 annual total = 14 reactors x $75/reactor
MDA LAB = $2321 = 546 parameters

Results (through week 247)

To determine the effects of particle size on drainage quality, each of the three rock types were separated into six different size fractions, and subjected to dissolution testing (Lapakko et al. 1995). The effects of rock particle size on drainage pH were variable. For RK3 drainage from all particle size fractions was neutral, and specific conductance generally increased as particle size increased. For RK4 the two largest particle sizes (-0.75 inch/+0.25 inch; -0.25 inch/+10 mesh) produced acidic drainage immediately. The drainage pH for the -10/+35 mesh rock decreased below 6.0 after 240 weeks and reached 4.5 at week 250. The pH from drainage in the smaller size fractions (-35/+100, -100/+270, -270 mesh) has been in the mid- to high-sevens. For RK5 drainage pH increased and specific conductance decreased with increasing particle size. Drainage pH from the smaller particles was in the lower fours, as compared to the upper fives to lower sixes for the large particles.

Prediction of Drainage Quality from Various Mine Wastes

Objective

Determine the long-term drainage quality, capacities for acid production and acid neutralization, and rates of acid production and neutralization for a variety of base and precious metal mine wastes.

Tasks

1. Started: 30 April 1992. Current week: 384 (9/10/98)
2. Eight reactors (RK1, RK2, RK3, RK4, RK5, TL1, TL4, TL5) sampled weekly and analyzed for metals and sulfate monthly.

Costs

4.75 person hours/week.
DNR LAB = $600 annual total = 8 reactors x $75/reactor
MDA LAB = $1326 = 312 parameters

Results

The focus of this project is the long-term dissolution behavior of a variety of mine waste samples. Samples RK1, RK2, RK3, and TL1 produced neutral drainage for the present duration of about 400 weeks. The pH of drainage from RK5 has stabilized in the range of 5.8 to 6.2. In contrast, sample TL5 produced acidic drainage immediately and has been in the upper twos for an extended period.

The remaining five samples produced acidic drainage after fairly long periods of neutral drainage. These samples, and their associated "lag times" to acidification, are RK4 (167 weeks, pH~ 3.4 at 390 weeks), TL2 (233 weeks, pH~3 when terminated at 333 weeks), TL3 (258 weeks, pH~4 at when terminated at 333 weeks), TL4 (203 weeks, pH~3 at 253 weeks), and TL6 (256 weeks, pH~2.7 when terminated at 333 weeks). Detailed analysis of both unleached and leached phases would help identify the reactions controlling the quality of drainage from these samples. In turn, this would aid extrapolation of the data for prediction of drainage quality from other mine wastes.

Elevated Temperature Prediction of Drainage Quality from Various Mine Wastes

Objective

Compare the rates of release and capacities for acid production and acid neutralization with those at ambient temperature.

Tasks

1. Started 30 April, 7 May 1991 (start staggered for convenience). Current week: 381 (9/3/98)
2. Four reactors (RK3, TL1, TL2, TL3) sampled bi-weekly; metals, sulfate analyzed monthly.

Costs

2.5 person hours/week
DNR LAB = $300 annual total = 4 reactors x $75/reactor
MDA LAB = $663 = 156 parameters

Results

Drainage pH values from RK3, TL2 and TL1 decreased permanently below 6.0, respectively, after 20 (present range 3.4-3.7), 53 (3.7-4.2), and 223 (4.5-5.3) weeks of reaction. Drainage from TL3 decreased below pH 6.0 at week 279 but has occasionally oscillated above pH 6.0 through week 387. Most recently the typical range has been 4.8 to 7. All ten of the solids subjected to the Elevated Temperature Test produced acidic drainage. In contrast, only six produced acidic drainage at ambient temperature. TL5 produced acidic drainage immediately in both tests. The remaining five solids which acidified in both tests had lag times of 16 to 271 weeks. In four of these cases the lag time at elevated temperature was 93 to 181 weeks shorter than that at ambient temperature. Curiously, for sample TL3 the lag time was slightly shorter in testing at ambient temperature (258 vs 271 weeks). Nonetheless, the Elevated Temperature Test accelerated sulfide oxidation for most samples. Unfortunately the test yielded some erratic results, such as those observed for sample TL3. It remains to be seen if the erratic results can be accurately interpreted so that the time frame required for predictive dissolution testing can be decreased by increasing the temperature of the reaction environment.

MITIGATION

PREVENTION/CONTROL

SUBAQUEOUS DISPOSAL

Two completed experiments revealed that separating sulfidic mine waste from the atmosphere with a layer of water would reduce the rate of oxidation of sulfide minerals present (Appendix D). Furthermore, the depth of sulfidic rock at which oxygen transport became rate limiting was determined for fine and coarse solids. However, oxidation would continue and possibly produce acidic waters. Consequently, various modifications to subaqueous disposal are being examined.

Oxidation of partially leached sulfide rock under a compost layer in a subaqueous environment.

Objective

Determine the rates of sulfate, acid, and trace metal release for partially leached sulfidic rock which is covered with a layer of yard-waste compost in a subaqueous environment.

Tasks

1. Started on 4 April 1995. Currently at week 179.
2. Two control reactors and 6 flasks sampled bi-monthly for laboratory parameters and monthly for metals and sulfate.

Costs:

3.0 person hours/week
DNR LAB = $540/year annual total = 12 reactors x $75/reactor
MDA LAB = $1193=280 parameters

Results

After approximately 4.5 years the addition of alkalinity to the flasks was terminated (see subaqueous flask experiment, Appendix D), and 75 grams of yard waste compost was added to one of each pair of duplicate reactors [treatment 1) unmodified subaqueous, treatment 2) subaqueous with alkaline addition, treatment 3) rock rinsed and neutralized, subaqueous with alkaline addition]. The quality of water was monitored for 179 weeks, at which time the pH of water in the three reactors receiving no compost was in the range of 3.2 to 4.0. For reactors receiving compost, the pH remained near seven or, in the case of the initial unmodified subaqueous treatment, increased to this level shortly after the addition. After 179 weeks pH for the first two treatments remained above 6.0. In contrast, the pH in treatment 3 with compost addition decreased below pH 6.0 after 27 weeks and into the mid-fours after 34 weeks. An additional 75 grams of compost was added to this flask on week 58 and pH has remained in the mid- to upper-sevens. The higher level of effectiveness for the first two treatments may have been influenced by a layer of iron precipitate which had accumulated at the solids water interface during the previous stage of the experiment. Rates of sulfide oxidation were calculated for the different disposal techniques based on the rate of sulfate appearance in solution. The aqueous concentrations of phosphorous, ammonia-ammonium nitrogen, total Kjeldahl nitrogen, nitrate, and nitrite from the organic substrate were also determined.

Oxidation of fresh sulfide rock under a yard-waste compost cover in a subaqueous environment.

Objective

Determine the rates of sulfate, acid, trace metal, and nutrient release for fresh sulfidic rock which is covered with a layer of yard-waste compost in a subaqueous environment.

Tasks

1. Control flasks started on 12 December 1995, and amended flasks on 15 May 1996. Flasks 11-14 are currently at week 121.
2. Sampled on a bi-monthly for laboratory parameters and monthly for metals and sulfate.

Costs

2.5 person hours/week
DNR LAB = $360/year annual total
MDA LAB = $796=188 parameters

Results (through week 179)

The compost controls (containing compost only, Flasks 9, 10) ran for 20 weeks. Solution pH was 7.5 to 7.75 and typical conductivity was 500 to 550. pH values for the rock-only controls decreased from the upper fours initially to a range 3-3.1. SC presently ranges from 500 to 600 uS. For the flasks with compost (flasks 13, 14) initial pH was in the mid sevens with SC from 600 to 800. pH dropped below six at week 133 (both flasks). Subsequently pH has decreased to the mid fives with SC of 500 to 600. In contrast, the solids subjected to an initial subaqueous oxidation have maintained pH above 6 for 179 weeks. It is possible that some of the more reactive sulfides were removed during the 224-238 weeks of previous oxidation. The difference in effectiveness may also be due to differences in the initial composition of the rock and/or compost in the two experiments.

In-Pit Disposal of Sulfidic Waste Rock Column Test

Objective

In a subaqueous environment determine the effect of tailings, tailings/limestone, and tailings/organic cap layers on the release of acid and trace metals from Duluth Complex rock.

Tasks

1. Date started: 3/12/97. Current week: 80.
2. The experiment consists of 17 columns with 120 cm of rock (to the nearest 100g) in each column. Six columns with tailings layers of 0, 1, 2, 3, 5, and 10 cm, three with tailings layers of 1, 3, and 10 cm covered with a 0.5 cm layer of limestone screened to 10 to 30 mesh, three with tailings layers of 1, 3, and 10 cm mixed with 1% composted yardwaste, two with 3 cm of tailings mixed with 3% and 5% composted yard waste, one with the original unsceened rock, and one unsaturated with screened rock. The bottom port of the columns are sampled monthly and the rock/water interface every six weeks for laboratory parameters, metals, and sulfate.

Costs

5 person hours/week
DNR LAB = $1275/year annual total = 17 columns x $75/reactor
MDA LAB = $7586 = 1785 parameters

Results

Results indicate that sulfate released during the first 42 weeks was that which had accumulated after the rock was rinsed. Samples through week 79 (9 samples) will be submitted for sulfate analysis and mass release rates will be determined to see if oxidation rates vary among the treatments. SC has gradually decreased since week 42 in all amended columns and subaqueous controls, but not in the unsaturated control. SC is fairly constant among the treated columns.

In-Pit Disposal of Sulfidic Rock Field Tests

Objective

1) Compare rates of acid production and acid neutralization by Duluth Complex rock in a subaqueous environment with those in an on-land environment and 2) in a subaqueous environment determine the effect of tailings, tailings/limestone, and tailings/organic cap layers on the release of acid and trace metals from Duluth Complex rock.

Tasks

1 Date started: 12/19/96-8/21/97, restarted after amendments on 9/4/97. Current week: 54
2. 4 field tanks with three sample ports and two on-land tanks with one sample port are sampled monthly for lab parameters, metals, and sulfate.
3. Compare laboratory and field data.

Costs

5.5 person hours/week
DNR LAB = $450/year annual total = 6 tanks x $75/tank
MDA LAB = $6188 = 1456 parameters

Results

The tanks were filled to a depth of 48 inches with -3/4-inch Duluth Complex rock from the second Arimetco bulk sample site with sulfur content averaging 0.66 percent (range of 0.63 to 0.69%). To the control tank, water was added to a level one foot from the top of the tank. To the remaining three tanks, the amendments were added prior to filling the tanks to this level. A 53 liter (14 gallons) volume of each amendment was added, representing an amendment depth of approximately 4.4 cm (1.75 inches). The mass additions of limestone, tailings, and tailings plus compost were 87 kg, 81 kg, and 81 kg, respectively (191, 179, 179 lbs). The tailings/compost mixture contained 0.406 kg dry compost, or five percent of the mixture. Two unsaturated tanks (d = 48 in., h = 42 in.) were also established to generate comparative water quality data for an on-land disposal scenario. At week 55 the pH of drainage from the on-land tanks was 5.6, while pH for all subaqueous treatments was above 7. As depth in the subaqueous tanks increased, pH decreased an specific conductance increased.

USE OF ALKALINE SOLIDS

Alkaline Addition

Objective

Determine the potential of adding alkaline solids to acid-producing mine waste to provide 1) short-term mitigation by neutralizing acid produced by iron sulfide oxidation and 2) long-term mitigation by facilitating the passivation of iron sulfide mineral surfaces.

Tasks

1. Started: 17 May 1988. Current week: 538 (9/8/98)
2. Presently 9 reactors (initially 23), running for about 10.5 years, are sampled weekly and analyzed for metals and sulfate monthly.

Costs

5.5 person hours/week
DNR LAB = \$825 annual total = 11 reactors x \$75
MDA LAB = \$1823 = 429 parameters

Results

Rotary kiln fines (RK fines; a waste product generated by the conversion of limestone to lime), -10 mesh limestone, and +10 mesh/-0.25 inch limestone were each mixed with finely-crushed Duluth Complex rock ($0.053 < d \leq 0.149$ mm, 2.1% S) to examine their effectiveness in reducing the release of acid and trace metals in drainage from the rock. The pH of drainage from the rock alone decreased below 6.0, a common minimum water quality standard, after 8 weeks and reached a minimum of 3.3 in 117 weeks, at which time the controls were terminated. Maximum copper and nickel concentrations ranged from 1 to 2 ppm. The sulfate release did not decrease over time. The minus 0.25-inch/+10 mesh limestone treatment produced drainage similar to that of the controls and was discontinued after 40 weeks.

In contrast, the RK fines and -10 mesh limestone maintained drainage pH above 6.0 for 75 to 397 (in progress) weeks. While pH was in this range, sulfate concentrations decreased and trace metal concentrations were typically three to ten percent of those observed in drainage from the controls. The pH of drainage from the lowest -10 mesh limestone loading was initially neutral, decreased below 6.0 after 109 weeks, reached a minimum of 5.0 at week 116, and subsequently increased to a typical range of 5.5 to 6.3 through week 397. This is in contrast to the pH from the lower loadings of RK fines, for which pH continued to decline after falling below 6.0. The lack of more extreme acidification was due to an 84 percent decrease in the rate of sulfide oxidation. Drainage pH from the higher limestone loadings remained above 6.0 and sulfate concentrations decreased with time.

TREATMENT

Limestone Columns

Objective

The objectives of this experiment are to determine 1) the rate at which limestone will neutralize the acid present in three different mine waste drainages and 2) the neutralization capacity of the limestone bed for each of the three drainages. (i.e. How much drainage can the column effectively treat?)

Tasks

1. Started: 4 April 1988. Last week 1996:
2. One column (simulated FL3/FL6 drainage) is sampled bi-weekly for lab parameters and monthly for lab parameters, metals, and sulfate.

Costs

1.5 person hours/week
DNR LAB = $75 annual total = 1 column x $75/column
MDA LAB = $847 = 208 parameters

Results

Triplicate columns containing 780 grams of minus 0.25-inch/ +10 mesh high calcium limestone were used to successfully treat each of three different drainages. The median influent pH and mean net alkalinity of the three drainages were FL6: 4.15, -600 mg/L; FL3: 4.9, -210 mg/L; Seep 1: 5.25, -22 mg/L, respectively. The corresponding effluent values were FL6: 7.8, 120 mg/L; FL3: 7.9, 37 mg/L; Seep1: 7.5, 20mg/L, respectively. The flow rates (adjusted to maintain excess alkalinity early in the experiment) required to maintain an effluent alkalinity in excess of effluent acidity were 0.53, 0.16 and 4.88 bed volumes per day, respectively. Copper concentrations were reduced from 85 to 99%. Nickel, cobalt and zinc concentrations were reduced to a lesser extent. These results indicate that limestone beds are capable of neutralizing these stockpile drainages and substantially reducing copper concentrations if adequate detention time is allowed. Problems with maintaining flow, due to cementation of the bed, were encountered. Use of larger particles would reduce potential for such problems in the field. Additional detail is available in status reports (Lapakko and Antonson 1989b, 1990a; Lapakko et al. in progress b) as well as a shorter technical publication (Lapakko and Antonson 1990d).

Sulfate Reduction Columns

Objective

Determination of the potential for composted organic material to raise the pH and reduce trace metal runoff from acid mine drainage through the biological process of sulfate reduction.

Tasks

1. Sample four columns weekly for lab parameters, sulfate, and metals.
2. Monitor treatment versus flow rate.

Costs

5 person hours per week
DNR LAB = $1400 annual total = 14 columns x $100/column
MDA LAB = $5525 = 1300 parameters

Results

In general, the columns have been effective in treating the input drainage. The substrates in the columns are subsamples of the original substrate from the field barrel experiment which began at the old Babbitt research site in 1990. The columns have been effective in removing essentially all the copper and until recently all of the nickel. The pH of the input has been raised from around 4.5 to over 6.5. Sulfate reduction rates have decreased and adjustments to flow rates have been made in an attempt to balance the rate of sulfate reduction with the input load of acidity. Sulfate reduction rates will be compared to an organic decomposition model in an attempt to estimate treatment lifetime.

LINKAGE WITH INDUSTRY PRACTICE, FIELD RESEARCH, AND SCIENTIFIC FUNDAMENTALS

Research and Development

Objectives

1. Collect, analyze, and summarize information on environmental mine waste management practices and the scientific fundamentals on which they are based, and
2. apply this information to the selection, design, and analysis of reclamation research.

Tasks

1. Contact industry personnel involved in environmental mine waste management and summarize information obtained.
2. Review trade literature and summarize environmental mine waste management practices relevant to Minnesota.
3. Review and summarize literature on scientific fundamentals on which environmental mine waste management practices are founded.
4. Identify tools (e.g. models) which assess the effectiveness of environmental mine waste management based on scientific fundamentals.
5. Attain and maintain the ability to apply models relevant to environmental mine waste management problems.
6. Maintain an organized compilation of research both outside and inside the Division of Minerals.

Costs

Personnel: 24 person hours/week = $25,000

Results

1. Literature citations have been entered into a bibliographic data base.
2. A literature review on the use of dry covers is in progress.
3. A literature review on iron sulfide oxidation is in progress.
4. Geochemical modeling was applied to results from field testing of limestone beds.
5. A summary of "lag time" to acidification of mine waste drainage is in progress.

MISCELLANEOUS

Field Research Site Maintenance Costs

A.	MgOH	1350
B.	Sludge disposal	500
C.	Supplies	1000
D.	Equipment	1000
		3850

Additional Research Costs

A.	Solids analysis	5000
B.	Contract laboratory	2000
C.	AMAX permit	1230
D.	MISC.	2350
		10580

Table 6.
MINERALS BASELINE FY99 LABORATORY AND FIELD COST SUMMARY

EXPERIMENT		PERSONNEL TIME (hr/week)	DNR LAB COST/YEAR	MDA LAB COST/YEAR	START DATE
DULUTH COMPLEX PREDICTION	pg. 31	7	1200	2652	02/89
QUARTZ-CARB. TAILING PREDICTION	pg. 32	2.5	300	663	06/90
QUARTZ-CARB. ELEVATED TEMP.	pg. 33	2	150	335	02/92
PARTICLE SIZE PREDICTION	pg. 33	6.5	1050	2321	12/93
VARIOUS MINE WASTE PREDICTION	pg. 34	4.75	600	1326	04/92
VARIOUS MINE WASTE ELEV. TEMP.	pg. 35	2.5	300	663	05/91
SUB-AQUEOUS LEACHED ROCK	pg. 36	5.5	900	1989	09/90
SUB-AQUEOUS FRESH ROCK	pg. 37	1.5	300	552	05/9
IN-PIT SULFIDE DISPOSAL COL	pg. 38	5	1275	7586	03/97
IN-PIT SLUFIDE DISPOSAL FIELD	pg. 39	5.5	450	6188	12/96
ALKALINE ADDITION	pg. 40	5.5	825	1823	05/88
LIMESTONE COLUMNS	pg. 41	1.5	75	847	04/88
SO4 REDUCTION	pg. 42	5	1400	5525	08/90
RESEARCH & DEVELOPMENT	pg. 43	24	0	0	
RESEARCH SITE	pg. 44	12	3850	0	
OTHER EXPENSES	pg. 44	0	10580	0	
LAB QA and MISC		7.25	0	1700	
TOTAL		9874	$23255	$34,170	

NOTES:

1. Personnel includes laboratory work and data entry.

2. DNR lab costs are based on a prorated total of supplies and equipment needed to run the experiments ($75/sample unit).

3. MDA lab costs are based on FY99 estimated sample load of 17,280 parameters and the DNR providing MDA with $73,440, which equates to $4.25/parameter.

4. The estimated time for the field site includes running and monitoring the active treatment system, monitoring the leach pile, monitoring the weather station, as well as miscellaneous tasks.

Table 7. **SUMMARY**

Minerals Baseline Exp.

- no outside support
- outgrowth of earlier cooperative projects
- evaluated on a yearly basis

ACTIVITY	**PERSONNEL*** (hrs./week)	**ESTIMATED COSTS** DNR Lab	MDA Lab	**RECLAMATION STAFF**
1. High % Sulfur	7	1200	2652	
2. NF Weekly	2.5	300	663	
3. NF Oven	2	150	335	
4. WGA Humidity	4.75	600	1326	
5. WGA Oven	2.5	300	663	
6. Particle Size	6.5	1050	2321	
7. Sub-Aqueous Flasks	5.5	900	1989	
8. Sub-Aqueous Col	1.5	300	552	
9. NF In-Pit Field	5.5	450	6188	
10. NF In-Pit Col	5	1275	7586	
11. Alkaline Addition	5.5	825	1823	
12. Limestone Col	1.5	75	847	
13. Lab QA and Misc.	7.25	0	400	
14. Sulfate Reduction	5	1400	5525	
15. Research Site	12	3850	0	
16. Research & Development	24	0	0	
17. Misc. Expenses	0	10,580	0	
TOTAL	**98**	**$23,255**	**$34,170**	

*Personnel breakdown -

Anne	15%
Pat	60%
John F.	20%[1]
Mike L.	30%
Greg	60%
Lyn	40%[2]
Jennifer	20%[2]

Reclamation Staff:

Anne	25%
Jon W.	50%
David	50%
Paul	5%
Kim	40%
Glenn	20%

TOTAL FTE'S (LAB & FIELD PERSONNEL)	=	2.45
INDIRECT SUPPORT PERSONNEL FTE'S	=	1.90
TOTAL BASELINE EXPERIMENTS FTE'S	=	**4.35**

1 - NF in-pit field & col, funded from lab budget, $7600

2 - Funded by Environmental Cooperative Research

ATTACHMENT C

Minerals Division Outside Funded Projects

In-Pit Disposal of Taconite Tailing

Objective

For disposal of taconite tailings in abandoned open pits, determine the influence of tailings dissolution, processing reagents, and other operational inputs on groundwater quality.

Tasks

1. Four field cylinders in operation since approximately 6/96.
2. One of five "buckets" is continuing in an experiment examining kinetics of Mn oxidation and precipitation.
3. Field sites are sampled quarterly.
4. Results from these studies and mass balances for the plant and tailings basin at Inland are being compiled and reported.

Cost

32 Person hours/week
DNR LAB + Personnel = $38,660
MDA LAB = $340 for manganese study

Results

Fluoride, manganese, arsenic, molybdenum, and boron were identified as potentially problematic parameters based on historical data, operational sampling, and column tests. Geochemical computer modeling was conducted to determine the solid phases controlling the aqueous concentrations of problematic parameters. Mass balances for the Inland tailings basin and plant were conducted to identify sources and sinks of these elements.

BLM Waste Characterization Study

Objective

1. Determine the rates of acid and trace metal release and capacities for acid production and acid neutralization as a function of solid-phase composition of individual mine waste lithologies.
2. Evaluate testing protocols for predictive dissolution testing of waste rock.

Tasks

2. Determine the physical, chemical, and mineralogic characteristics of a series of waste rock samples from a specific rock type.
3. Conduct dissolution tests using the standard ASTM protocol on the above set of samples.
4. Determine the relationship between solid-phase characteristics and drainage quality and chemical mass release rates.
5. Assess the reproducibility of the ASTM standard dissolution test protocol.
6. Use an alternative test protocol on selected samples and compare results from the standard ASTM protocol.

Costs

48 Person hours/week
DNR LAB + Personnel = $49,104
MDA LAB = $11,216 = 2639 parameters

Results

Twenty one siltite-argillite samples were characterized and subjected to dissolution testing. Sulfur in nine of the samples was present almost entirely as sulfate, while the sulfide content of the remaining 12 samples ranged from 0.14 to 5.75 percent. The sulfate release of the former group was due to slow dissolution of alunite and jarosite, as well as oxidation of trace amounts of iron sulfide. Iron sulfide oxidation released the majority of sulfate from the latter group.

Based on solid-phase sulfur speciation and sulfate release rates, four groups of rocks were identified: 1) sulfate rocks with low sulfate release; 2) sulfate rocks with high sulfate release; 3) sulfide rocks with low sulfate release; and 4) sulfide rocks with high sulfate release. In addition to sulfate release, characteristic ranges of calcium and magnesium release and drainage pH were associated with each group. Other than solid-phase sulfur speciation (sulfate rock vs sulfide rock), no solid-phase variables were identified as strongly influencing the rock dissolution. The weathering history of the rock in the field may have played a dominant role in the dissolution behavior of the rocks. In particular, high sulfate release was observed for rocks on which acidic reaction products had accumulated due to leaching in the environment. Similarly, sulfide rocks containing substantial carbonate minerals tended to have lower sulfate release rates, due partly to the pH elevation resulting from carbonate mineral dissolution.

The ASTM standard dissolution test method was reproducible within the MN DNR lab and between different laboratories. A modification of the rinsing procedure (using a flood rinse rather than the standard drip rinse) yielded comparable drainage pH and release rates roughly 15 percent higher than those for the standard method. Comparison of results from the ASTM standard dissolution tests method and a simplified protocol revealed no substantial difference.

Using Dredge Material for Wetland Creation at National Steel

Objective

Determine the feasibility of obtaining, shipping and applying large volumes of dredge material to create wetlands in a closed tailings basin.

Background

Mining companies are now required to replace all wetlands that are disturbed by their operation. Portions of tailings basins often have the hydrology needed to create a wetland but the lack of organic matter and the low fertility of the tailings limits vegetative success and diversity. The addition of an organic substrate will likely be required for successful wetland creation. A possible source of this organic material may be dredge material from Lake Superior.
The US Army Corps of Engineers is responsible for maintaining the shipping channel in Duluth harbor and its current disposal site is almost full. As a result the Corps has been involved in identifying potential beneficial reuse for the dredge material. Although the majority of the dredge material is sandy, a substantial quantity of silty material with high organic content exists. This material should provide a good growing media for wetland species. Contaminant concentrations in dredge material have decreased over time, as more and better pollution control strategies have been implemented in the watershed, and as a result, material with low levels of trace metals and organics exist within the Corps disposal facility.

Approach

Two small demonstration areas have been established. At the north site, dredge material will be seeded with a custom wetland seed mix and compared to a standard reclamation seeding on both the dredge and on a tailings control. Water quality samples will be collected from surface water and from water in within the layer of dredge material. At the south site, vegetative success will be measured on a variety of soil amendments including: 2 thicknesses of dredge material, local topsoil, glacial overburden, a peat and sand mixture (commercial black dirt), and a bare tailings control.

Tasks

1. Monitor water levels and overall conditions of plots
2. Collect water quality samples, 3 times per year.
3. Measure vegetative success annually. Measurement include percent cover, biomass and species prevalence.

Costs

Personnel	$6500
MDA Lab	$1100
Total	$7600

Carry over, estimate = $13000

Results

Vegetative success was truly impressive at the north site where percent cover for the dredge plots ranged from 94-98% and biomass was about 20 times that of the control. (Percent cover on the control, standard reclamation, was only 27%).
Overall cover was less at the south site but all amendments had better vegetative success than the control. Shoreline vegetation exceeded 70% cover for both dredge applications as well as for the local topsoil and black dirt. Percent cover for the control was only 18%.
Due to a dry summer, no water quality samples were collected.

Wetland Creation using Dredge Material

Objective

Evaluate the suitability of dredge material as a substrate for creating wetlands

Background

EVTAC will close Cell 1 of its tailing basin within the next year. Under an existing Corps of Engineers permit, the company must conduct a study of Cell 1 to determine how these areas can be reclaimed as wetlands. Based on the chemistry of the dredge material used at National Steel and the dramatic first year vegetation results, a proposal was developed and funded by the US EPA to determine the feasibility of using the dredge material from Lake Superior to reclaim 5-10 acres of this basin.

Approach

Using the results form the preliminary study at National, a five to ten acre portion of EVTAC's Cell 1 will be reclaimed using dredge spoil.

Tasks

1. Develop criteria for acceptable material, based on contaminant and soil fertility concentrations
2. Determine the feasibility and cost of shipping large amounts of dredge material from Duluth to the Iron Range.
3. Determine vegetative success and the effect of using dredge material on water quality within the tailings basin.

Costs

Personnel	$20,000
DNR Lab	3,000
Total	$23,000

Carryover estimate $23,000

Results

Project was approved in October 1998. Initial meetings with the Corps, EVTAC and the railroads will be held at the end of October.

Creating Wetlands on Acid Generating Tailings

Objective

Determine the feasibility of creating wetlands over acid generating tailings to produce an anoxic environment and reduce the release of acid and metals from the tailings

Background

For new mining projects, mine wastes will be stored in lined waste storage areas to prevent release of contaminants to surface and ground water. When the operation is over, the tailings must be isolated to prevent future water quality problems. One common approach is to drain the area and encapsulate the tailings with a barrier such as clay or plastic. Although the tailings may not be chemically stable in this type of environment, the presence of the barrier minimizes water infiltration into the tailings, and reduces the release of contaminates to the environment. When this approach is taken, the area must be permanently maintained to avoid the introduction of deep rooted species such as trees. If these species become established, the roots can puncture the overlying barrier layer, and the waste no longer isolated.
A better alternative may be to create a permanent wetland over the mine waste. By covering the waste with a saturated organic substrate, oxygen would be excluded from the acid producing material, and the residual sulfides present in the tailings should be permanently stable. If successful, additional wetland habitat will also be created.

Approach

A series of small test cells was constructed at the Hibbing research site to investigate the feasibility of establishing wetland vegetation and reducing waste quality problems associated with acid generating tailings. Cover material included: wetland soil, glacial overburden and tailings.
A water cover, with and without aquatic plants and an unsaturated control were also constructed. Each cell will be run in duplicate and water quality samples will be collected from surface water and water within the substrates.

Tasks

1. Monitor water levels weekly.
2. Collect water quality samples from surface water and from wells within the substrate and tailings.

Costs

Personnel	$7600
MDA Lab	$5600
Total	$13200

Carry over, estimate = $8550

Results

During the first year, the pH of the water in contact with the tailings in all the treated plots has been relatively stable and has remained above 6.2. The pH in the surface water was lowest in the plots with the wetland soil cover, due to the acidic nature of the peat itself and not acidification of the tailings. Zinc concentrations were about 2 mg/l in the plots with cattails planted directly into the tailings, and are above acceptable water quality standards. Zinc release may be occurring to the surface water in the plots with a water cover, but it does not appear that there has been any significant release from the plots that have a water cover with aquatic plants.
Due to a lack of rain and some problems with a leak in one of the control tanks only a single sample of the control was collected. This sample had a pH of 3 and an acidity of 7000. Trace metal data have not yet been received.
Treatments have been effective at initially decreasing acid generation and metal release but additional data is needed to determine if this approach will provide acceptable long term water quality.

Wetland treatment of mine drainage

Objective

Evaluate metal removal and estimate the lifetime of the wetland treatment systems at the Dunka Mine.

Background

Based on the successful results of a non-point wetland treatment project, LTV built several wetland treatment systems to remove metals from their mine drainage. Although these systems have been effective in removing up to 90% of the metal load, a key question is the longevity of the systems. This project will examine, in detail, the removal that has occurred in the wetlands, and develop guidelines for the lifetime of these type of treatment systems.

Approach

Although LTV Steel Mining Company has conducted regular monitoring of their wetland treatment systems for their NPDES permit, there has been no thorough analyses of the performance of these systems.
Total mass removed and the areal removal rates in each system will be calculated. Additional samples will be collected within the wetland to determine where the majority of the metal removal is occurring. Peat samples will be collected from selected areas in the wetlands and compared to peat concentrations calculated from mass removal estimates.
These metal values will be compared to the maximum metal concentrations which have been estimated from previous laboratory and field investigations. Based on these calculations, estimates of lifetime will be made for the various treatment systems

Tasks

1. Collect water quality and flow from designated sample sites.

Costs

Personnel	$6500
MDA Lab	$1400
Total	$7900

Carry over, estimate = $10700

Results

Dry conditions and low flows have made it difficult to collect all the data that was originally planned. Both study sites were constructed in 1992, and have reduced overall metal loads by 65-

to 90%. Peat samples were collected from within both treatment systems and contained up to 2% nickel and 0.6% copper. Flow monitoring equipment has been installed to examine the effectiveness of stockpile capping procedures and to estimate the reduction in load to the wetland systems.

The Use of Organic Amendments to Reclaim Coarse Taconite Tailings

Objective

Determine the suitability of various organic amendments to establish vegetation on coarse taconite tailings without impacting water quality.

Background

Mineland reclamation rules require that all lands disturbed by mining be reclaimed. In general, a 90% cover is required after 3 years, and a self sustaining vegetation is required after 10 years. Previous reclamation techniques have not been successful in reclaiming coarse taconite tailings and meeting these standards. Plot and small scale field tests have demonstrated that when organic material is added to the coarse tailings, successful reclamation can be achieved. Although a variety of organic amendments have been used on agricultural or forest soils, there is only limited data on their use on taconite tailings. Despite the fact that these amendments are generally low in trace organics and metals, there is still public concern regarding their use. This project will examine the use of various biosolids from paper manufacturing plants and municipal systems as well as municipal solid waste compost on the reclamation of a coarse taconite tailings dam. Vegetative success and the impact of these amendments on water quality will be determined.

Approach

A series of small plots was constructed to measure both the volume and quality of surface runoff and infiltration. Treatments included paper processing waste from Blandin and Consolidated paper, municipal sludge from the quad cities, municipal solid waste compost (MSW), and standard mineland reclamation. Samples will be collected and analyzed for general parameters, nutrients and metals. These results will be compared to water generated from standard reclamation plots and to applicable water quality standards. Vegetation success will be measured by percent cover and biomass.

Tasks

1. Monitor flow at plots after rain events.
2. Collect water quality samples 3 times per year.
3. Measure percent cover and biomass annually.

Costs

Personnel	$6500
MDA Lab	$5400
Total	$11,900

Carry over, estimate = -$900

Results

The plots were constructed in the fall of 1997 and the first set of water samples were collected in November. Water quality data from all plots was acceptable with the exception of an elevated value for arsenic and zinc in one of the municipal solid waste plots. There were no elevated values in any of the subsequent samples. Vegetation germinated in the spring and was growing satisfactorily until drought conditions developed in mid summer. Percent cover for all plots was low but was highest in the MSW plots which had an average value of 41%. Standard reclamation was one of the lowest at 18%.

Controlling Mine Drainage Problems at Soudan State Park

Objective

Develop a treatment system for a portion of the mine discharge.

Background

Elevated concentrations of copper and cobalt were measured in the discharge from Soudan State Park in the mid-1990's. Data was collected on flow and water quality through out the mine and the major sources of copper and cobalt were identified. The goal now is to design a treatment approach which will be cost effective yet protective of the environment. The current approach is to develop a pre-treatment system which will remove over 90% of the copper and to use the natural wetland downstream of the park (which has been receiving mine discharge for around 80 years) to remove any residual metals in the discharge.

Approach

Passive and active systems are currently being evaluated for the pre-treatment system. Wetland mitigation sites are being sought.

Tasks

1. Collect water quality samples and flow from designated sites.
2. Conduct laboratory and field trials on various treatment approaches.
3. Summarize results for report to PCA.
4. Identify appropriate sampling sites within the wetland and conduct a water quality survey.

Costs

Personnel	$6500
MDA Lab	$4012
Total	$10512

Results

Copper and cobalt removals of greater than 90% have been measured in laboratory tests of passive systems. A qualitative biological assessment of the receiving wetland did not reveal any serious impacts, and based on copper concentrations in the peat, only about 5 acres of the wetland has been affected by the discharge.

Table 8. **SUMMARY**

Outside Funded Projects

- Have outside support
- Have varying funding deadlines
- May become baseline at termination of funding
- Some have ECR funding

ACTIVITY	PERSONNEL* (hrs./week)	PERSONNEL* Salary	ESTIMATED COSTS DNR Lab	ESTIMATED COSTS MDA Lab	RECLAMATION STAFF
1. BLM Waste Characterization	16	15,213	10,254	11,216	
2. In-Pit Taconite Disposal	32	30,788	7872	340	
3. Alternative Encapsulation	8	7607	10,325	5566	
4. Evtac Biosolids	8	6456	-811	5355	
5. NSPC Dredge Spoils	8	6456	13,506	1063	
6. Dunka Wetlands	8	6456	12,141	1403	
7. Soudan Mine	8	6456	1000	4012	
8. Evtac Dredge Spoils	16	20,000	3000	0	
TOTAL	**104**	**$99,432**	**$57,287**	**$28,955**	

*Personnel breakdown -			Reclamation staff	
	John F.	80%	Kim	30%
	Michelle	100%	David	30%
	Lyn	60%	Glenn	70%
			Greg	25%
			Jon W.	40%
			Paul	80%
			Mike L.	20%

TOTAL FTE'S (LAB, FIELD, and R&D PERSONNEL) = 2.4
INDIRECT SUPPORT PERSONNEL FTE'S = 2.95
TOTAL OUTSIDE FUNDED EXPERIMENTS FTE'S = 5.35

NOTES: The Evtac Dredge Soils project has not started and the 16 hours of personnel time is not included in the total FTE'S.

Some projects may carry over to the next fiscal year which would result in a portion of the DNR and MDA lab funding being carried over also.

DNR lab costs represent the remaining budget for these projects after personnel and MDA costs (DNR lab, travel, etc.)

1 - Capital costs include experimental setup and solids analysis.