pt 41

elevated metal concentrations in the upper Alamosa River from the headwaters to the outlet of Terrace Reservoir, south-central Colorado, April-September, 1993, in, Posey, H. H., Pendleton, J. A., and Van Zyl, D., eds: Summitville Forum Proceedings, Colorado Geological Survey, Special Publication 38, p. 160-170.

29. **Ward, E.C., and Walton-Day, K., 1995,** Seasonal variations in water quality in Wightman Fork of the Alamosa River, 1993, in, Posey, H. H., Pendleton, J. A., and Van Zyl, D., eds: Summitville Forum Proceedings, Colorado Geological Survey, Special Publication 38, p. 183-190.

Go to the top of this document
Go to the Branch of Geochemistry Home Page
Go to the U.S.Geological Survey Home Page

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
NUMBER 4, December 1995
This newsletter is for administrative use only.
It should not be quoted or cited as a publication.

OSM APPALACHIAN CLEAN STREAMS INITIATIVE--UPDATE

Submitted by Mike Robinson (OSM) and Chuck Cravotta (USGS)

The Office of Surface Mining Reclamation and Enforcement (OSM) "Appalachian Clean Streams Initiative" (ACSI), which began as a broad plan in the fall of 1994 to prevent and remediate acidic drainage from coal mines in the Appalachian Region, has evolved into two focused programs. The current ACSI coordinates governmental and private resources to clean up acidic drainage from abandoned coal mines in the eastern United States. The complementary "Prevention Initiative" of OSM has the goal to minimize new sources of acidic drainage from active coal mines. Together, these initiatives constitute OSM's Acid Mine Drainage (AMD) Program.

The ACSI has stimulated new interest in AMD remediation projects by the States that administer the abandoned mine land (AML) tax receipts generated by Title IV of the Surface Mining Control and Reclamation Act (SMCRA). Previously, AMD cleanup was conducted only incidentally with higher priority AML projects that were hazards, such as reclamation or stabilization of mine subsidence, landslides, or coal-waste embankments. In 1994, OSM Director Bob Uram clarified AML project priority to include AMD cleanup where degraded water quality affects the public welfare. Therefore, States can elect to fund AMD remediation projects with a portion of the approximately $136 million in AML grants that OSM provides annually to the States. In addition, President Clinton's fiscal 1996 budget request included an additional $11,000,000 that would go specifically to States' ACSI work. However, the $11,000,000 has not survived the House and Senate mark-ups as this article goes to press. Equally important to note as this article goes to press is that deep cuts are proposed in the FY 1996 budgets for both OSM and the U.S. Environmental Protection Agency (EPA). OSM is currently faced with a reduction in force of 370 of its 950 positions, whereas EPA is evaluating the cuts in programs and positions required because of a 34 percent cut in their FY 1996 appropriation. Obviously, if these levels of cuts occur, the mine-drainage efforts of the OSM and EPA will be severely limited. The following descriptions of OSM and EPA plans do not reflect the proposed budget cuts.

One of the intentions of the ACSI is to improve the efficiency of use of public funds to clean up AMD by facilitating and coordinating the exchange of information and by eliminating duplicative efforts among Federal, State, and local government agencies and private groups working on AMD problems. Given this mission and shared goals of the ACSI and the EPA Region III "Mine Drainage Program," OSM and EPA have developed a "Statement of Mutual Intent Strategic Plan" (SMISP) that identifies specific, shared objectives and tasks.

Following is a list of the eight objectives of the SMISP and the status of work to complete the objectives:

1. Cooperate as a clearinghouse to share and exchange data and information as they relate to identifying

mine-drainage sites and establishing techniques to restore and improve water quality within watersheds adversely affected by mine drainage.

OSM is developing a national clearinghouse and library in the OSM Appalachian Regional Coordinating Center in Pittsburgh, Pa. The EPA and OSM are evaluating data and information that reside at EPA for inclusion in the clearinghouse and library and are developing an electronic annotated bibliography. OSM has established the Internet address cleanstream@osmre.gov for the clearinghouse.

OSM and EPA are designing and developing a watershed-based AMD Geographic Information System (GIS) and identifying existing data sources that can be incorporated into the GIS. The AMD GIS ultimately will include "macro" data on AMD-impacted streams, AMD abatement projects, and watershed-based organizations, plus "micro" coverages of water quality/quantity, land use, active and abandoned mines, topography, geology, hydrography, infrastructure, and satellite or aerial images.

2. Raise the level of awareness of government agencies, private organizations, and the general public on the serious environmental problems associated with mine drainage from abandoned coal mines.

OSM has plans to support a periodic newsletter to be published by the National Mine Land Reclamation Center (NMLRC), Morgantown, W.V. The OSM and EPA have sponsored several AMD conferences and workshops for the interactive participation of these groups with panelists from a variety of public and private organizations. The EPA and OSM are forming a multi-organizational team to develop a Citizen's Guide to AMD and Reclamation. The guide will provide methods for evaluating watersheds and AMD sources, identifying remediation options, and identifying potential funding sources. OSM has been assembling a list of watershed organizations and has initiated efforts to promote technology transfer and program visibility. OSM will assist States in sponsoring forums to bring together private groups and representatives of industry and government agencies to exchange information and conduct tours of AMD sites and reclamation projects.

3. Work with Federal, State, and local government agencies, watershed organizations, environmental groups, and other public and private organizations to target streams and watersheds which have been degraded by mine drainage.

EPA has provided funding to Pennsylvania and West Virginia for the development of their programs to identify streams and watersheds for restoration. OSM has taken administrative action through the AML program to increase funds available to States for stream cleanup projects. Twelve projects for restoring aquatic resources have been identified by the International Association of Fish and Wildlife Agencies, and funding strategies under the ACSI are being developed. OSM and EPA are developing an index of potential government and private sources of funding for AMD projects and are compiling a directory of government and nongovernment representatives for AMD-related programs, projects, and other activities.

4. Work to increase the understanding and applications of the best technology available for remediating and preventing mine drainage and to support the development of new technologies.

EPA and OSM are currently identifying and listing any demonstration projects involving AMD sites. EPA and OSM also are working with the States, U.S. Bureau of Mines, NMLRC, industry, and environmental groups to identify needs for future mine- drainage research.

5. Support efforts to establish and implement an effective remining program that reclaims abandoned coal mines.

EPA and OSM will solicit information from government and nongovernment sources to determine the limiting factors that inhibit remining programs and the incentives that are needed to develop an effective remining program that promotes mining while protecting environmental quality.

6. Provide a forum for the purpose of transferring technologies and other information about improving, restoring, and preventing further harm to watersheds that have been degraded by mine drainage.

OSM will coordinate a Technical Notes section for technology transfer within the AMD newsletter to be edited and published by the NMLRC. The EPA is developing an AMD section to their existing Nonpoint Source Electronic Bulletin Board and evaluating potential Bulletin Board opportunities.

7. Develop shared information management systems to minimize overlap in data collection and development, to save resources, and maximize the usefulness of data developed.

This objective encompasses the Clearinghouse, AMD-GIS, and other projects to provide "one-stop" shopping for persons interested in AMD cleanup.

8. Prepare periodic reports describing the extent and severity of the mine-drainage problem and the current status of ongoing efforts to improve and restore degraded watersheds.

The EPA and OSM will produce an annual report that includes measures of success with respect to the SMISP. The EPA and OSM have initiated development of indicators of accountability, program successes, and program failures of the SMISP. The first annual report is in draft and will be finalized for distribution at the second annual Mine Drainage Workshop in Cincinatti, Ohio, in December 1995 (see announcement of Future Meetings of Interest in this newsletter).

The OSM also has established a list server for the ACSI. Internet users can subscribe to the list by sending email to majordomo@osmre.gov. The body of the message should contain the message "subscribe cleanstream (your Internet address)." If you would like to be added to a mailing list for more information, send your name and address to:

Appalachian Clean Streams Initiative
Office of Surface Mining
1951 Constitution Avenue
Washington, D.C. 20240

Questions can be directed to Mary Ann Miovas via telephone at 412-937-2883, or via email at mmiovas@osmre.gov.

Back to Mine Drainage Newsletter

Water Resources of California or USGS Water Resources

The URL for this page is <http://water.wr.usgs.gov/mine/sep/osm.html>.
If you have any questions or comments about this document contact:
Dale Alan Cox <dacox@usgs.gov>

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
NUMBER 4, December 1995

ACIDIC-MINE-DRAINAGE PROJECTS IN PENNSYLVANIA

Submitted by Chuck Cravotta

During 200 years of coal mining, Pennsylvania produced more than 25 percent of the nation's total coal output and presently ranks fourth in the nation in annual coal production by state. Coalfields are included within, or extend into, the four major river basins in Pennsylvania--the Ohio, Susquehanna, Potomac, and Delaware River Basins. Bituminous coal deposits underlie western and north-central Pennsylvania, and anthracite deposits underlie east-central and northeastern Pennsylvania. Pennsylvania's bituminous coal is used mostly for electric-power generation; anthracite is used for electric-power generation and home heating.

Acidic drainage from numerous abandoned coal mines has contaminated more than 2,400 miles of streams and associated ground waters in Pennsylvania and is the most extensive water-pollution problem affecting the four major river basins in Pennsylvania. Although abandoned underground mines cause most of the contamination, some recently mined and reclaimed surface mines have produced acidic discharges and have degraded local ground-water and surface-water resources.

Studies by the U.S. Geological Survey (USGS) have documented the extent of surface-water and ground-water degradation associated with coal mining in Pennsylvania and have evaluated the effects of mining and reclamation practices and water-treatment methods intended to reduce contamination by mines. Recent USGS studies have been supported by funds and services from the U.S. Environmental Protection Agency; the U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement; the Pennsylvania Department of Environmental Protection (formerly Department of Environmental Resources); the Philadelphia Water Department; and the Somerset County Conservation District. Coal companies and the Pennsylvania State University also participated in these studies. Updates of four current projects are presented below.

- **PA234: Allegheny-Monongahela National Water-Quality Assessment (NAWQA)**
- **PA215: The Stonycreek River and Little Conemaugh River Acid Mine Drainage Study**
- **PA237: Limestone Drains to Increase pH and Remove Dissolved Metals from an Acidic Coal-Mine Discharge in the Swatara Creek Watershed**
- **PA226: Effects of Nutrients on the**

Formation of Acidic Mine Drainage

Back to Mine Drainage Newsletter

Water Resources of California or USGS Water Resources

The URL for this page is <http://water.wr.usgs.gov/mine/sep/penn.html>.
If you have any questions or comments about this document contact:
Dale Alan Cox <dacox@usgs.gov>

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
NUMBER 3, March 1995
This newsletter is for administrative use only.
It should not be quoted or cited as a publication.

The Effects of Mining and Related Activities on the Trace Element Geochemistry of Sediments in Lake Coeur d'Alene, Idaho

by Arthur J. Horowitz[1], Kent A. Elrick[1], John A. Robbins[2], and Robert B. Cook[3]

[1] *U.S. Geological Survey Water Resources Division, Suite 130, 3039 Amwiler Road, Atlanta GA 30360*

[2] *National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, 2205 Commonwealth Blvd., Ann Arbor MI 48103*

[3] *Dept. of Geology, 210 Petrie Hall, Auburn University, Auburn, AL 36849*

Abstract

During 1989 and 1990, 12 gravity cores and 150 surface grab samples were collected in Lake Coeur d'Alene, Idaho to determine trace element concentrations, partitioning and surface and subsurface distribution patterns in the bed sediments of the lake. Substantial portions of the surface and near-surface sediments in the lake are markedly enriched in Ag, As, Cd, Hg, Pb, Sb and Zn, and somewhat enriched in Cu, Fe and Mn. Surface and subsurface distribution patterns indicate that the source of much of this enriched material is the Coeur d'Alene River. An estimated 75 million metric tons of trace-element-rich sediments have been deposited on or in the lakebed. An ash layer from the 1980 Mt. St. Helens eruption, ages estimated from ^{137}Cs activity, and the presence of 80 discernible and presumably annual layers in a core collected near the Coeur d'Alene River delta indicate that the deposition of trace- element-rich sediments began, in the Coeur d'Alene River delta some time between 1895 and 1910, dates consistent with the onset of mining and ore-processing activities that began in the area in the 188O's.

Introduction

Lake Coeur d'Alene (CDA) is a natural lake in the northern panhandle of Idaho. The main body of the lake is about 3.2 km wide by 40 km long; however, the southern part is composed of four smaller interconnected lakes that were formed in 1906 when the Post Falls Dam (10 miles downstream on the Spokane River) was completed, (Meckel Engineering *et al.*, 1983). The St. Joe and CDA Rivers annually account for 94% of the inflow to Lake CDA; major outflow from the lake occurs at the northern end through the Spokane River (Meckel Engineering *et al.*, 1983; Javorka,1991).

The South Fork of the CDA River, which flows into the CDA River, and thence into Lake CDA, drains a major part of the CDA mining district. Until 1968, most of the mining and ore-processing wastes were discharged directly into the South Fork of the CDA River. These materials were highly enriched in Ag, As, Cd, Cu, Fe, Mn, Pb, Sb and Zn (Rabe and Bauer, 1977; Bender, 1991). In 1983 the U.S. Environmental Protection Agency (EPA) established the Bunker Hill Superfund Site that encompasses 54 km2 around Kellogg and Smelterville, some 50 km upstream of Lake CDA. (e.g., Bender, 1991).

Sample Collection, Treatment, and Analytical Methods

Sample Collection

Undisturbed (stratified) surface samples were collected using a stainless steel Ekmann grab sampler in 1989 (Fig. 2). Subsamples were removed from the upper 2 cm of sediment in each grab. Twelve gravity cores were collected in 1990 using a 5 cm diameter, stainless steel 2.44 m gravity core with a clear polycarbonate liner and a non-metallic core catcher (Fig. 1).

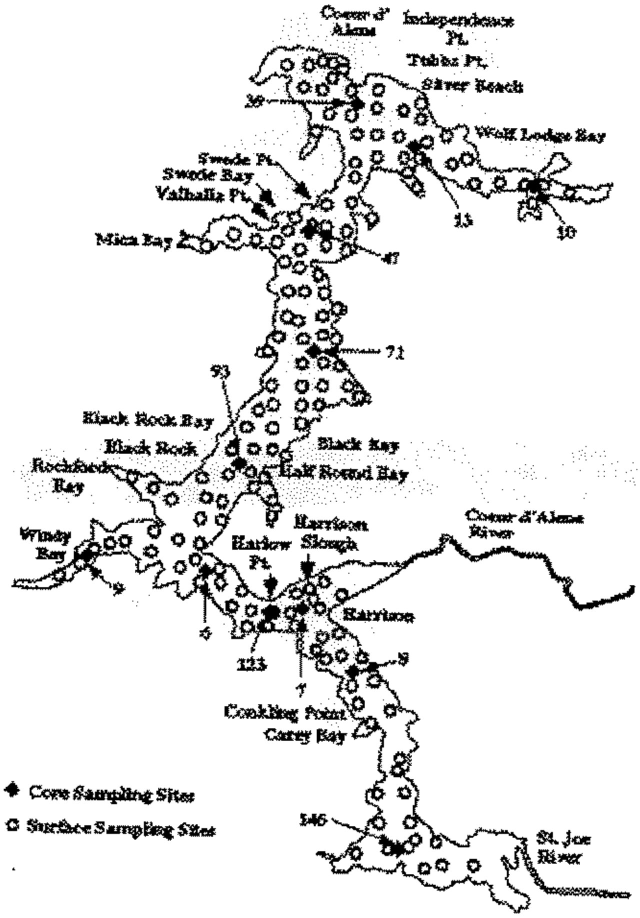


Figure 1. Map of Lake Coeur d'Alene showing sampling locations, cities and features cited in the text.

Figure 1.

Sample Analyses

All the samples were analyzed for Al, As, Cd, Cu, Fe, Mn, Pb, Sb, Ti, and Zn by inductively coupled plasma (ICP) methods following an HF/$HC10_4$ /$HN0_3$ digestion. Hg was determined by AA cold vapor, and TOC by IR spectroscopy. Selected samples were subjected to heavy-mineral separations using bromoform (2.96 g/cm^3) followed by total chemical analyses of the light and heavy fractions. Selected heavy fractions also were examined and chemically analyzed using Scanning Electron Microscopy/Energy Dispersive Analysis (SEM/EDA). Additional data on sediment-trace element partitioning were obtained using partial chemical extractions (Horowitz et al., 1993; 1995).

^{137}Cs activity was determined using a high resolution solid-state HpGe detector coupled to a multichannel analyzer. Approximately 3 days of counting time per sample were required to achieve precisions between ±7 - 20% in the vicinity of maximum activities because of the relatively small sample sizes and/or relatively low activities (Horowitz *et al.*, 1995).

Results and Discussion

Bulk Sediment Chemistry and Trace Element Distribution Patterns

The chemical data for all the samples clearly show that the upper sediment column in Lake CDA is enriched in Ag, As, Cd, Hg, Pb, Sb and Zn. The samples are less enriched in Cu, Fe and Mn relative to both unenriched fluvial sediments throughout the U.S.A. and to unenriched surface and subsurface (e.g., core 146, Fig. 1) sediments from within the lake (e.g., Horowitz 1991; Horowitz et al., 1993, 1995; Table 1). The highest trace element concentrations in Lake CDA sediments, typically by a factor of two or more, are associated with subsurface rather than surface material (Ag, Cu, Pb, Zn, Hg, As and Sb, the maximum column in Table 1); however, this pattern reverses when the surface and subsurface median concentrations are considered (with the exception of Ag and Sb, the median column in Table 1).

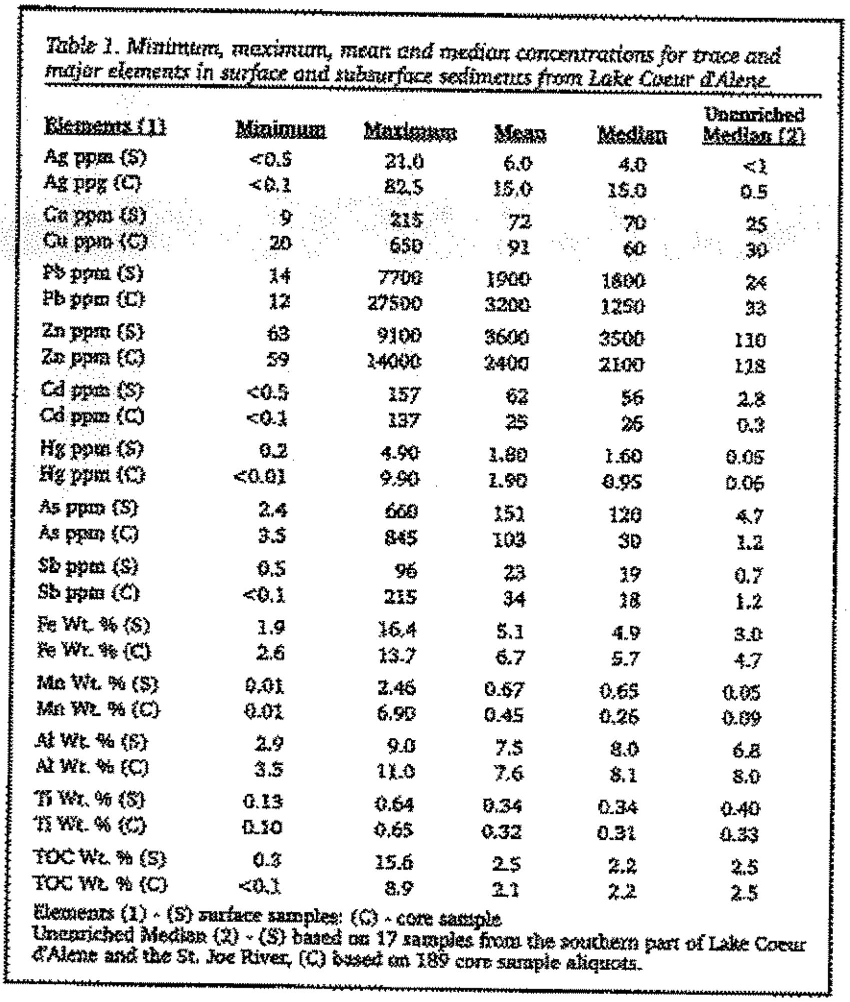


Table 1. Minimum, maximum, mean and median concentrations for trace and major elements in surface and subsurface sediments from Lake Coeur d'Alene.

Elements (1)	Minimum	Maximum	Mean	Median	Unenriched Median (2)
Ag ppm (S)	<0.5	21.0	6.0	4.0	<1
Ag ppg (C)	<0.1	82.5	15.0	15.0	0.5
Cu ppm (S)	9	215	72	70	25
Cu ppm (C)	20	650	91	60	30
Pb ppm (S)	14	7700	1900	1800	24
Pb ppm (C)	12	27500	3200	1250	33
Zn ppm (S)	63	9100	3600	3500	110
Zn ppm (C)	59	14000	2400	2100	118
Cd ppm (S)	<0.5	157	62	56	2.8
Cd ppm (C)	<0.1	137	25	26	0.3
Hg ppm (S)	0.2	4.90	1.80	1.60	0.05
Hg ppm (C)	<0.01	9.90	1.90	0.95	0.06
As ppm (S)	2.4	660	151	120	4.7
As ppm (C)	3.5	845	103	30	1.2
Sb ppm (S)	0.5	96	23	19	0.7
Sb ppm (C)	<0.1	215	34	18	1.2
Fe Wt. % (S)	1.9	16.4	5.1	4.9	3.0
Fe Wt. % (C)	2.6	13.7	6.7	5.7	4.7
Mn Wt. % (S)	0.01	2.46	0.67	0.65	0.05
Mn Wt. % (C)	0.01	6.90	0.45	0.26	0.09
Al Wt. % (S)	2.9	9.0	7.5	8.0	6.8
Al Wt. % (C)	3.5	11.0	7.6	8.1	8.0
Ti Wt. % (S)	0.13	0.64	0.34	0.34	0.40
Ti Wt. % (C)	0.10	0.65	0.32	0.31	0.33
TOC Wt. % (S)	0.3	15.6	2.5	2.2	2.5
TOC Wt. % (C)	<0.1	8.9	2.1	2.2	2.5

Elements (1) - (S) surface samples: (C) - core sample
Unenriched Median (2) - (S) based on 17 samples from the southern part of Lake Coeur d'Alene and the St. Joe River, (C) based on 189 core sample aliquots.

Table 1

The highest median concentrations for Cu, Pb, Zn, Cd, Hg and As are found in the surface sediments, whereas the highest median concentration for Ag is found in the subsurface sediments. The median concentration for sediment- associated Sb is about the same for both. The generally higher median surface sediment concentrations may be the result of post-depositional remobilization, upward diffusion, and subsequent reprecipitation caused by reducing conditions in the sediment column which may have stripped some subsurface trace elements associated with Fe oxides from the sediments.

All the enriched surface and subsurface samples were collected from the main body of Lake CDA, and all the major, and many of the minor bays north of Conkling Point and Carey Bay (near the southern end of Lake CDA, but north of the mouth of the St. Joe River, Fig. 1). Samples collected from the lake south of Carey Bay and Conkling Point and from the very back of several of the northern bays (Wolf Lodge, Rockford and Windy Bays) display trace element concentrations similar to unimpacted fluvial sediments throughout the U.S.A. (Table 1; e.g., Horowitz, 1991).

The chemical distribution patterns in Lake CDA surface sediments appear consistent with the CDA River acting as a major source for the enriched trace elements. Additionally, the patterns also appear to reflect the velocity and direction of water movement through the system (generally from south to north). These observations are in agreement with previous findings and are consistent with the enriched trace elements being transported into the lake by the CDA River. (e.g., Punk et al., 1973, 1975).

Estimated Masses of Enriched Sediments and Associated Trace Elements

Estimates of the mass of trace-element-rich sediments, as well as the mass of each enriched trace element, currently on or in the bed of Lake CDA were calculated on the basis of the chemical data from the 12 cores, and an estimated sediment bulk density of 2.0 g/cm33. These estimates indicate that there are about 75 million metric tons of trace- element-rich sediments currently blanketing about 85% of the bed of Lake CDA (Table 2). The masses of excess trace elements range from about 260 metric tons for Hg to more than 468,000 metric tons for Pb (Table 2).

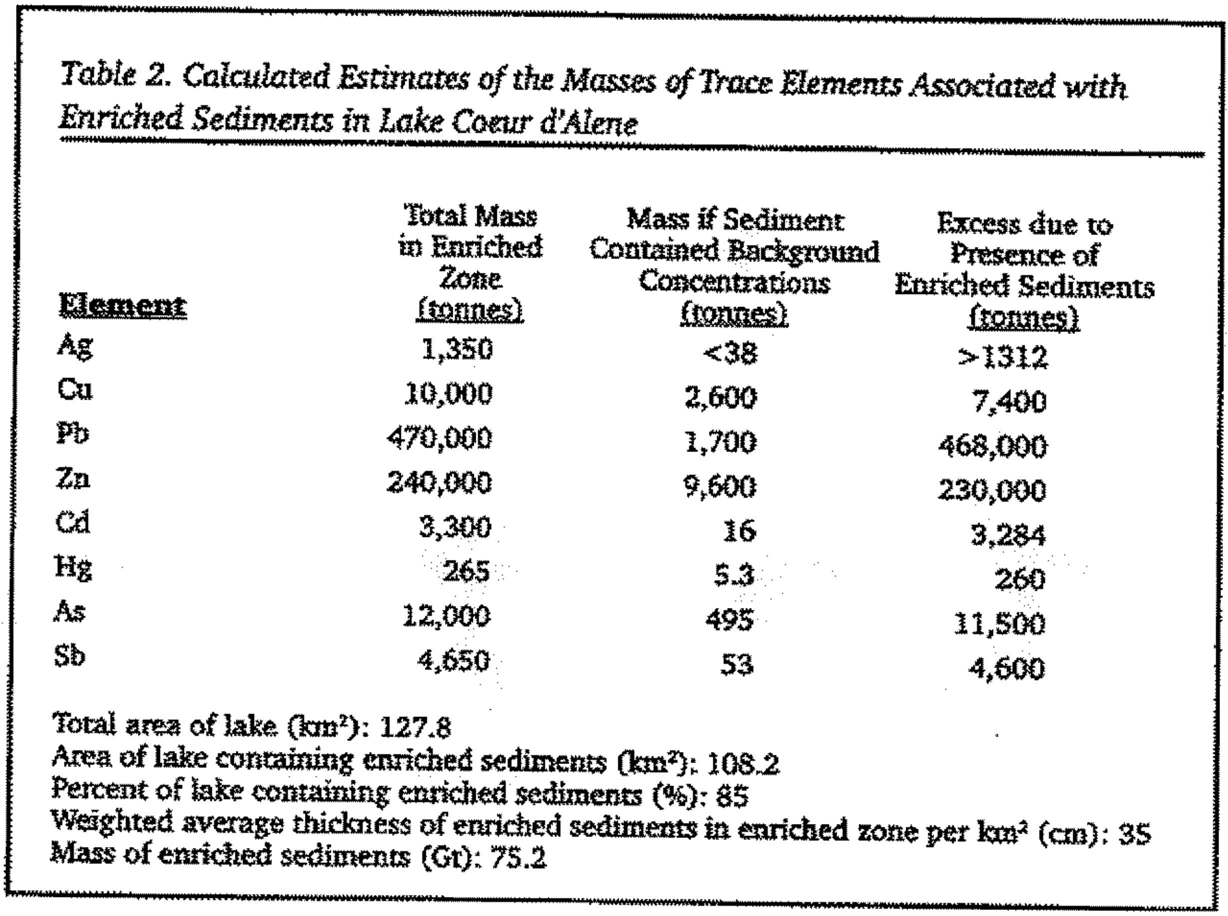


Table 2. Calculated Estimates of the Masses of Trace Elements Associated with Enriched Sediments in Lake Coeur d'Alene

Element	Total Mass in Enriched Zone (tonnes)	Mass if Sediment Contained Background Concentrations (tonnes)	Excess due to Presence of Enriched Sediments (tonnes)
Ag	1,350	<38	>1312
Cu	10,000	2,600	7,400
Pb	470,000	1,700	468,000
Zn	240,000	9,600	230,000
Cd	3,300	16	3,284
Hg	265	5.3	260
As	12,000	495	11,500
Sb	4,650	53	4,600

Total area of lake (km^2): 127.8
Area of lake containing enriched sediments (km^2): 108.2
Percent of lake containing enriched sediments (%): 85
Weighted average thickness of enriched sediments in enriched zone per km^2 (cm): 35
Mass of enriched sediments (Gt): 75.2

Table 2

Trace-Element Partitioning

The various techniques used to determine partitioning indicate that the majority of the enriched Pb, Cd, Zn, As, and Cu are associated with an operationally defined Fe oxide phase (by extraction with .25 M hydroxylamine hydrochloride in .25 M HCl heated at 50° C for 30 min.), the Ag could be associated with either Fe oxides or sulfides, whereas the Sb is predominantly associated with a refractory phase.

Trace element contributions from the heavy mineral fraction in the surface sediments are limited. Although the chemical concentrations from these fractions are elevated, their contribution to the overall chemical levels in the sediments are low because the concentration of heavy minerals also are low. The highest concentration of heavy minerals in the surface sediments (11%) is within the CDA River delta; this decreases rapidly to <1% within 2 km of the delta. Similar results were found for the majority of the core samples where major heavy mineral concentrations were limited to a few distinct bands.

The similarity in mineralogy, as well as the association of the vast majority of the enriched trace elements with an operationally defined Fe oxide phase, in both the surface and subsurface samples implies that the sources and/or concentrating mechanisms for the trace-element-rich sediments probably were the same throughout the course of their deposition in Lake CDA.

Sediment-Geochemical History of Lake CDA

Efforts to determine a geochemical history for the lake were concentrated on core 123 because of: a) the overall thickness of its trace-element-rich section (119 cm), b) the thickness and number of its readily discernible individual layers (80), c) the presence of a datable (1980) Mt. St. Helens ash layer (20.5-21.5

cm) and d) the occurrence of background trace element levels at its base (119-126 cm depth). Three separate approaches were used to estimate the age of the base of the trace-element-rich zone.

An initial age for the base of the trace-element-rich zone was made by considering the 1990 date the core was obtained, the position and age of a 1980 Mt. St. Helens ash layer, and the 9 layers between them. These factors indicate that each layer may represent annual deposition. Because there are 80 layers between the top of the core and the base of the trace-element-rich zone, deposition began around 1910.

^{137}Cs activity was determined for all the sampled layers in core 123. The data show a strong maximum at about 45 cm, and a secondary peak at 55 cm. No ^{137}Cs was detected below 60 cm, nor in the ash layer between 20.5-21.5 cm. These features are consistent with the assignment of dates of 1963-1964 for the maximum, and 1958-1959 for the secondary peak. The onset of measurable fallout and sedimentary ^{137}Cs activity occurs around 1954. The assignment of these dates [plus the dated ash layer (1980)], leads to an age-depth model which produces a predicted age of 1895 for the base of the banded (trace-element-rich) zone.

By combining (a) the date of collection for the core (1990), (b) with the date for the ash layer (1980), and (c) with the three major dates estimated from the ^{137}Cs activity, it is possible to estimate average sedimentation rates. Assuming constant deposition between the dated points, the average rates are: 2.1 cm yr^{-1} (1980-1990), 1.7 cm yr^{-1} (1965-1980), 1.3 cm yr^{-1} (1959-1965) and 1.4 cm yr^{-1} (1954-1959). The decline in sedimentation rates with increasing depth could be the result of compaction. The thickness of the undated portion of the trace-element-rich zone is 58 cm; if deposition was 1.35 cm yr^{-1}, then the undated section represents a period of 43 years and the age for the start of trace- element-rich sediment deposition is 1911.

The relative consistency of the three estimated dates (1910, 1895, and 1911) for the base of the trace-element-rich banded zone in core 123, using three somewhat different approaches, is encouraging. Certainly, the three estimated dates are consistent with the 1880-1890 period assigned for the onset of mining and ore-processing activities in the CDA mining district (e.g., Bender, 1991).

Conclusions

Substantial portions of the surface and subsurface sediments blanketing 85% of the bed of Lake CDA are enriched in Ag, As, Cd, Cu, Hg, Pb, Sb and Zn. The CDA River seems to be the source for the majority of the trace-element- rich sediments in the lake. The similarity in the locations of the trace-element-rich surface and subsurface sediments, the trace-element concentrations, and the trace-element partitioning, all suggest that the concentrating mechanisms and/or sources causing the trace-element enrichment in the lake probably have been much the same throughout the last 100-110 years. An estimated 75 million metric tons of trace-element-rich bed sediments have been deposited in Lake CDA. Most of the enriched trace elements are associated with an operationally defined Fe oxide phase. The age of the onset of trace element enrichment in the lake probably falls between 1895 and 1910. These dates are consistent with the onset of mining and ore processing in the CDA mining district, and these activities probably represent the major source for the extreme trace element enrichments in the sediments of Lake CDA.

References

Bender, S., 1991. Investigation of the chemical composition and distribution of mining wastes in Killarney Lake, Coeur d'Alene Area, northern Idaho: Unpublished M.S. Thesis, University of Idaho, Moscow: Idaho, 98 p.

Funk, W., Rabe, F. and Filby, R., 1973, *The biological impact of combined metallic and organic pollution in the Coeur d' Alene-Spokane River drainage system*, Project Completion Report OWRR B-044 WASH and B-015 IDA, Idaho Water and Energy Resources Institute, Moscow, Idaho, 202 p.

Funk, W., Rabe, F., Filby, R., Bailey G., Bennett, P., Kishor, S., Sheppard, J., Savage, N., Bauer, S., Bourg, A., Bannon, G., Edwards, G., Anderson, D., Syms, P., Rothert, J. and Seamster A., 1975, *An integrated study on the impact of metallic trace element pollution in the Coeur d' Alene-Spokane Rivers and Lake drainage system*, Office of Water Research and Technology Project Completion Report, Title II, Project C4145, Washington State University-University of Idaho, 332 p.

Horowitz, A. 1991, *A Primer on Sediment-Trace Element Chemistryi*, 2nd Ed., Lewis Publishers, Inc., Chelsea, Michigan, 136 p.

Horowitz, A., Elrick, K. and Cook, R., 1993, Effect of mining and related activities on the sediment trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. Part I: surface sediments:*Hydrological Processes*, v. 9, p. 403-423.

Horowitz, A., Elrick, K. Robbins, J. and Cook, R., 1995, Effect of mining and related activities on the sediment trace element geochemistry of Lake Coeur d'Alene, Idaho, USA. Part II: subsurface sediments: *Hydrological Processes*, v. 9, p. 35-54.

Javorka, E., 1991, *Lake water quality assessment Coeur d'Alene Lake, Benewah and Kootenai Counties, Idaho*. Coeur d'Alene Basin Interagency Group, Coeur d'Alene Tribe of Idaho: Coeur d'Alene Subagency, Plummer, Idaho, 42 p.

Meckel Engineering and Brown and Caldwell Consulting Engineers, 1983, Kootenai County lakes master plan: Meckel Engineering/Brown and Caldwell, Coeur d'Alene, Idaho, pp. 1-30-1-35, pp. 2-24-2-32.

Rabe, F and Bauer, S., 1977, Heavy metals in lakes of the Coeur d'Alene River valley:*Northwest Science*, v. 51, p. 183-197.

Water Resources of California or *USGS Water Resources*

**The URL for this page is <http://water.wr.usgs.gov/mine/lake.html>.
If you have any questions or comments about this document contact:
Dale Alan Cox <dacox@usgs.gov>
Last modified: 1230 08MAY95**

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
NUMBER 3, March 1995
This newsletter is for administrative use only.
It should not be quoted or cited as a publication.

IMPACTS OF ACID DRAINAGE ON WETLANDS IN THE SAN LUIS VALLEY, COLORADO

by Laurie S. Balistrieri
U.S. Geological Survey, Geologic Division, Branch of Geochemistry, School of Oceanography WB-10, University of Washington, Seattle, WA 98195

Introduction

Open-pit mining activities at the Summitville mine in the San Juan Mountains of southwestern Colorado have exposed pyrite and other metal (e.g., As, Cu, Zn) sulfides to air and water resulting in the production of acidic and metal-enriched drainage. This drainage flows into the Wightman Fork. The Wightman Fork and other tributaries draining mineralized areas then flow into the Alamosa River, through Terrace Reservoir, and downstream to the San Luis Valley (see map, page 4). Within the Valley, this water is used for agricultural irrigation (e.g., alfalfa and barley crops) and is a source of surface water to wetlands near and within the Alamosa National Wildlife Refuge (see overview article by Plumlee and Edelmann in this newsletter, page 4).

As part of the USGS Environmental Geoscience Studies of the Summitville mine and in cooperation with the U.S. Fish and Wildlife Service (USFWS), we examined the influence of acid drainage from natural and mine sources on the biogeochemistry of wetlands near and within the Alamosa National Wildlife Refuge in June 1993. These wetlands are seasonal hosts to migratory fowl, including the endangered whooping crane. Information about the toxic element content of these wetlands is necessary for properly managing wildlife within this area.

Our approach for assessing the influence of acid drainage on the wetlands was to identify signature elements for the drainage, evaluate the spatial extent of these signature elements within the Alamosa River system, and compare the biogeochemistry of wetlands in the San Luis Valley that receive surface water from different sources. This article focuses on a portion of the sediment geochemistry results for river-bed and wetland sediments. More details about the sediment geochemistry and information about the composition of river and wetland water and rooted aquatic wetland vegetation are discussed elsewhere (Balistrieri et al., 1995).

Signature Elements

The on-site work of Plumlee et al. (1994, 1995) at the Summitville mine indicates that drainage from the mine is significantly enriched in Al, As, Cd, Co, Cr, Cu, Fe, Li, Ni, Zn, rare earth elements (Ce, La, Nd), Th, U, V, Be, and Te. Are any of these elements enriched in the bed sediments of the Wightman Fork, the main stream draining the Summitville mine?

A comparison of the compositions of sediments collected at a site within the Wightman Fork just before it enters the Alamosa River (site B) with sediments in the Alamosa River upstream of the confluence with the Wightman Fork (site C) indicates that As, Cr, Cu, Fe, Li, and Zn are enriched in Wightman Fork sediments (Fig. 1). Of these elements, Cu and As show the greatest enrichment (13-15 times), whereas Cr, Fe, Li, and Zn are less enriched (1.3-2.0 times) in the Wightman Fork. Al, Ce, Co, Ni, Th, and V in Wightman Fork sediments show no enrichment relative to Alamosa River sediments above the confluence. Other elements identified by Plumlee et al. (1994, 1995) as being enriched in Summitville mine drainage were either not measured or below detection limits in Wightman Fork sediments.

The enrichment of certain elements (As, Cr, Cu, Fe, Li, and Zn) in Wightman Fork sediments suggests their potential use as tracers of drainage from the Summitville mine. However, these particular elements may not be definitive indicators of Summitville mining activities because acidic, metal-enriched drainage from other naturally mineralized areas enters the Alamosa River both above and below the confluence with the Wightman Fork. In this article, a subset of these signature elements--As, Cr, Cu, and Zn--are used to trace acidic, metal-enriched drainage within the Alamosa River system and within selected wetlands in the San Luis Valley.

Spatial Extent of Signature Elements Within the Alamosa River System

How far downstream are the signature elements observed in the Alamosa River system? Data indicate that 1) Alamosa River sediments downstream of the confluence with the Wightman Fork tend to be enriched in As, Cr, Cu, and Zn relative to sediments above the confluence and 2) this enrichment is observed at least 50 km downstream of the confluence (Fig. 2).

Metal Accumulation in Wetland Sediments

The wetlands within and west of the Alamosa National Wildlife Refuge are approximately 80 km downstream of the confluence of the Wightman Fork and Alamosa River. These wetlands receive surface water from either the Alamosa River, the Rio Grande River, or a mixture of Alamosa River and La Jara Creek water. Are there differences in the sediment geochemistry of wetlands receiving Alamosa River water from those that receive water from rivers, such as the Rio Grande River, that do not drain mineralized areas?

The concentration of Cu in wetland sediments receiving surface water from different sources is significantly higher in those wetlands receiving Alamosa River water (Fig. 3). These differences are also observed for Cr and Zn, but not As. Sediment metal concentrations, sedimentation rates as determined by 210Pb, and bulk sediment densities were used to determine metal accumulation rates in two wetlands--one receiving Alamosa River water and one receiving primarily Rio Grande River water. Metal accumulation rates for Cr, Cu, and Zn are two to four times larger in the wetland receiving Alamosa River water as compared to the wetland receiving Rio Grande River water, whereas accumulation rates for As are similar for the two wetlands (Fig. 4).

Conclusions

Certain metals (e.g., Cr, Cu, and Zn) derived from the weathering of mineralized areas in the southern San Juan Mountains of Colorado appear to be transported throughout the Alamosa River system and are enriched in downstream wetlands that receive surface water from the Alamosa River water.

Acknowledgments

My co-investigators in this project are Larry P. Gough and R.C. Severson of the USGS and Andrew Archuleta from the USFWS. Maria Montour assisted in collecting samples and members of the Analytical Chemistry Services Group (Betty Adrian, Paul Briggs, Jim Crock, Joe Curry, David Fey, Phil Hageman, and Clara Papp) did the analyses. Jim Crock and Kathleen Stewart provided helpful comments on an earlier draft of this article. Parts of this article were presented at the 1994 Annual Meeting of the Geological Society of America, held in Seattle, Washington, during October 1994, and also were presented at the Summitville Forum in Fort Collins, Colorado, in January 1995.

References

☐ Balistrieri, L.S., Gough, L.P., Severson, R.C., and Archuleta, A., 1995, The biogeochemistry of wetlands in the San Luis Valley: the effects of acid drainage from natural and mine sources, in, Summitville Forum Proceedings.*

☐ Plumlee, G.S., Ficklin, W.H., Smith, K.S., Montour, M., Gray, J., Hageman, P., Briggs, P.H., and Meier, A.L., 1994, Geologic and geochemical controls on the composition of acid waters draining the Summitville mine, Colorado: U.S. Geological Survey Circular 1103-A, p. 78.

☐ Plumlee, G.S., Smith, K.S., Mosier E.L., Ficklin, W.H., Montour, M. Briggs, P., and Meier, A., 1995, Geochemical processes controlling acid-drainage generation and cyanide degradation at Summitville, in, Summitville Forum Proceedings.*

☐ *Posey, H.H., Pendleton, J.A., and Van Zyl., D., eds., 1995, Summitville Forum Proceedings, Colorado Geological Survey, Special Publication 38.

Water Resources of California or *USGS Water Resources*

The URL for this page is <http://water.wr.usgs.gov/mine/luis.html>.
If you have any questions or comments about this document contact:
Dale Alan Cox <dacox@usgs.gov>
Last modified: 1230 08MAY95

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
NUMBER 4, December 1995
This newsletter is for administrative use only.
It should not be quoted or cited as a publication.

[The following paper appears in the *"Workshop Report - Mine Waste Technical Forum"*. The workshop was sponsored by the U.S. Environmental Protection Agency, and was held in Las Vegas, Nevada on July 25-27, 1994. For more information on the workshop, please contact Ken Sala, 202-260-8934]

RESPONSIBILITIES AND ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY RELATED TO MINING AND THE ENVIRONMENT

Charles N. Alpers
U.S. Geological Survey, Sacramento, California

ABSTRACT

The U.S. Geological Survey (USGS), a bureau of the U.S. Department of the Interior, is engaged in numerous investigations related to mining and its effects on the environment. The primary responsibility of the USGS with regard to mining-environment research is to provide the nation with reliable and impartial scientific information on geologic and hydrologic processes affecting mineral deposits, mined lands, and water quality.

Much of this USGS work is funded directly by Congress; however, a significant portion is funded by cooperative agreements with other federal, state, and local agencies and with American Indian tribes. USGS activities involving mining and the environment include:

☐ Regional assessments: Two USGS programs conduct regional assessments. The Mineral Resource Surveys Program (MRSP) provides mineral-resource and mineral-environmental information to guide land-use, environmental, and mineral-supply decisions of other agencies, including the Bureau of Land Management and the U.S. Forest Service. The National Water Quality Assessment (NAWQA) program describes the status of and trends in the quality of the nation's surface- and ground- water resources; several NAWQA study units address the biogeochemical aspects of water quality problems related to acid mine drainage.

☐ Inventory and prioritization: Inventory and prioritization work on abandoned and inactive mine lands is facilitated by USGS databases containing comprehensive information on mineral deposits, coal deposits, water quality, and the geochemistry of rocks, soil, stream sediments, and biota.

☐ Site characterization: Numerous studies involve site characterization to determine baseline and background conditions, the environmental impacts of mineral and energy development, the sources

and effects of mining-related contamination, and the likely environmental consequences of proposed remedial actions.

☐ Monitoring and analysis: Monitoring and analysis activities include development of field and laboratory methods for conducting geochemical and geophysical surveys and for spatial and temporal watershed studies, which are essential to the evaluation of remediation success and failure.

☐ Process-oriented studies of contaminant origin, transport, and fate: These studies are conducted as part of the Toxic Substances Hydrology Program. Field sites include long-term research at several mining districts, including Globe-Miami, Arizona; Iron Mountain, California; Leadville, Silverton, and Summitville, Colorado; Couer d'Alene, Idaho; Tar Creek, Oklahoma; and Lead, South Dakota. An important aspect of USGS research is the continuing development of widely used hydrologic and geochemical models, which are needed for site characterization and for evaluation of proposed remedial actions prior to implementation.

INTRODUCTION

Metals contribute to our standard of living and our national security. Precious, industrial, and strategic metals have been extracted from uncounted mines in many parts of the United States. This legacy of mining has left metal-rich mine wastes that produce acidic drainage that affects the quality of water in many streams throughout the United States and in many other countries of the world. The effects of mine drainage, which are seen nationwide, are often severe in mountain headwater streams and can limit recreational, industrial, and municipal use of larger rivers many miles downstream from mining. More than 500,000 inactive and abandoned hard rock mines are estimated to exist in 32 states, with at least 50 billion tons of untreated, unreclaimed mining waste on private and public land. The possible cost of cleaning up environmental problems at these sites could exceed $70 billion. Scientific information that makes cleanup easier or less expensive would obviously benefit everyone.

Regulatory decisions about remediation of mining discharge must be made with the best possible information and understanding about the problems involved. In response to the need for information, the USGS, a bureau of the U.S. Department of the Interior, is engaged in numerous investigations related to mining and the environment. The primary responsibility of the USGS with regard to mining and the environment is to provide the nation with reliable and impartial scientific information on geologic and hydrologic processes affecting mineral deposits, mined lands, and water quality. These studies benefit the state and federal agencies that must make decisions about land management, the industries that are often responsible for costs, and everyone who shares concern about the environment.

The mission of the USGS is as follows:

> The U.S. Geological Survey provides the Nation with reliable and impartial information needed to describe and understand the Earth. USGS information supports decisions that will:
>
> ☐ mitigate losses resulting from natural hazards;
>
> ☐ help manage the Nation's water, energy, and mineral resources;
>
> ☐ enhance and protect the quality of the environment;
>
> and
>
> ☐ contribute to the Nation's economic and physical development,

thereby improving the safety, health, and well-being of the people.

Mining-environment issues relate closely to several themes in the USGS mission, including mineral resources, environmental quality, and economic development.

The USGS activities on mining and the environment include: 1) regional assessments, 2) inventory and prioritization, 3) site characterization, 4) monitoring and analysis, and 5) process-oriented studies of contaminant origin, transport, and fate. The purpose of this paper is to provide an overview of these activities, highlighting examples of recently completed and ongoing projects. In addition, points of contact are provided for USGS programs related to mining and the environment to facilitate communication and promote collaboration between the USGS and other organizations, including the federal, state, regional, and local agencies responsible for land management, regulation, and scientific studies.

GENERAL APPROACH: RELATIONSHIP BETWEEN THE USGS AND THE USBM

The U.S. Geological Survey (USGS) and the U.S. Bureau of Mines (USBM) work in partnership within the Department of the Interior assisting land-management and regulatory agencies to inventory, prioritize, and reduce the costs of remediating mine sites, and to minimize the environmental hazards that may result from future development of mineral resources. In September 1994, the directors of the USGS and USBM signed a memorandum of agreement (MOA) that establishes a framework for this partnership on mining and the environment. The USGS-USBM MOA defines the complementary roles of the two bureaus in a "coordinated, comprehensive approach to environmental assessment, technology development, and remedial investigations related to mineral deposits, mining and associated hazardous waste sites."

The USGS's general approach to mining-environment problems is to conduct scientific investigations designed to improve the understanding of relevant geologic, hydrologic, and chemical processes. Research and development by the USGS includes *"...basic and applied research on natural and human-induced environmental effects associated with mineral resources." In its complementary role to the USGS, the USBM "...applies scientific information from the physical, biological, and earth sciences to develop and demonstrate engineering solutions to...prevent and control contaminants... around mineral production sites and to remediate mineral- and metal-contaminated hazardous waste sites."*

Some research areas that the USGS is currently emphasizing are: 1) field and laboratory studies on element mobility within mineral deposits and the surrounding environment, 2) new methods to define background and baseline conditions, 3) conceptual environmental models of mineral deposits and element distribution in various climatic settings, and 4) quantitative models of contaminant transport in surface and ground waters.

REGIONAL ASSESSMENTS

USGS conduct two national programs that address mining-environment issues on a regional scale: the Mineral Resource Surveys Program (MRSP) and the National Water-Quality Assessment (NAWQA) program.

Mineral Resource Surveys Program

The MRSP is concerned with gathering and disseminating mineral-resource and mineral-environmental information for land-use, environmental and mineral-supply decisions. Principal cooperation is with federal land management agencies, including the Bureau of Land Management (BLM), the National Park

Service (NPS), and the U.S. Forest Service (USFS). MRSP activities are conducted under four issue-related subprograms:

- ☐ Assessments are a high priority in the western region of the country, where most of the federal lands and non-coal mine sites are located. About one-third of the nation, 740 million acres, is federal land. Federal land management agencies are required by law to consider mineral resource values that may be present on federal lands when they develop land management plans, sell or exchange federal lands, and evaluate wilderness potential. Integrated mineral-resource and mineral-environmental assessments provide information on known mineral resources, determine the potential for new mineral deposits, and evaluate present and predicted effects resulting from mineral-resource development.
- ☐ Mitigation studies determine geochemical baselines and backgrounds (pre-mining conditions), document human-induced processes that result in environmental problems, and suggest methods for mitigation or remediation. USGS scientists work cooperatively or in partnership with biologists, botanists, soil scientists, hydrologists, and other researchers at state and federal agencies. For example, the U.S. Environmental Protection Agency (EPA), the Office of Surface Mining, and the State of Colorado requested that the USGS provide information on the geologic framework and environmental geology of the Summitville Mine for use in preparing environmental modeling and predictive studies related to remediation efforts. These studies benefit the nation by reducing the cost of remediation and minimizing future contamination.
- ☐ Resource investigations, often performed in cooperation with industry or international agencies, provide innovative data and interpretations to government and industry concerning unconventional mineral deposits and new frontiers of mineral-resource potential. This information can be used to formulate mineral-resource policies for maintaining reliable, cost-effective supplies of mineral materials, to improve assessment capabilities, and to assist industry in the discovery and development of new mineral resources.
- ☐ Mineral-related information acquired by the USGS over more than 100 years is available in paper and electronic forms, including maps, reports, databases, geographic information systems (GIS), models, interpretations, and assessments. Much of the information is contained in two databases: the Mineral Resources Data System (MRDS) and the National Geochemical Database (NGDB). These databases are described in more detail in the "Inventory and Prioritization" section of this paper.

National Water-Quality Assessment Program

The purpose of the NAWQA program is to demonstrate the status and trends in quality of the nation's surface and ground waters. NAWQA began as a pilot program in the late 1980s and was implemented as a national program during fiscal year (FY) 1991 with 20 study units, each consisting of a large watershed. An additional 15 study units began their assessments during FY 1994, and 15 to 20 additional study units are scheduled to begin in FY 1997. When fully implemented, the NAWQA program will have assessed the long-term trends in water quality affecting about 60 to 70 percent of the nation's surface- and ground-water resources.

Of the 35 active NAWQA study units, several involve areas with severe mine drainage impacts. For example, the Sacramento Valley NAWQA study unit in northern California includes surface waters affected by acidic metal-rich drainage from Iron Mountain Mine, an EPA Superfund site. Studies of metal transport in the Sacramento River using natural tracers such as lead isotopes will determine the relative metal contributions from mining, agriculture, and urban sources. Another NAWQA study unit with mining impacts is the Rio Grande Valley in Colorado, New Mexico, and Texas, where metal transport and bioaccumulation in mosses has been studied.

INVENTORY AND PRIORITIZATION

Numerous federal, state, and local agencies are concerned with conducting inventories of inactive and abandoned mine sites, and with prioritization of these sites for remediation. The USGS maintains several databases that can be very useful resources for inventory and prioritization activities.

MRDS contains more than 110,000 records of mineralized sites or areas. Each record pertains to a location, which usually represents a single deposit or mine. Data for each record is stored in approximately 200 data fields, which include information on location; geology; descriptions of mine workings; history of exploration, development, and production; reserves and resources; and references. Records are available for about 150 mineral commodities, from abrasives to zinc. Complete records or selected fields can be sorted, indexed, and viewed, downloaded to files compatible with a GIS, or printed. Plots of site locations can be made at standard scales or customized to suit the user's needs. Data from MRDS have been used as a starting point for a number of inventories of abandoned and inactive mine lands, including work by the State of Montana, the BLM, and the USFS.

NGDB is another source that can be used to develop inventories of abandoned and inactive mine lands, as well as to determine baseline and background concentrations of various natural materials. The NGDB consists of more than 2 million records from samples of stream sediments, soils, rocks, waters, panned concentrates, drill cores, and vegetation. The data were collected during geochemical surveys conducted by the USGS and other federal agencies, such as the Department of Energy's extensive National Uranium Resource Evaluation, Hydrogeochemical and Stream Sediment Reconnaissance (NURE HSSR). Two other databases that are part of the NGDB are the Rock Analysis Storage System (RASS) and PLUTO, which contain geochemical data for rock, soil, sediment, and plants. Samples from which data in the NGDB were generated are held in archival storage and are available for further analysis.

The USGS databases related to mining and the environment are available in paper and electronic forms, which are increasingly interactive. The NURE HSSR data from stream sediments and soils cover a large proportion of the conterminous United States at a scale of one sample per square mile. The portion of the NGDB containing the NURE HSSR data for the western United States has been published as USGS Publication DDS-1, using CD-ROM technology. USGS has recently begun to publish state-by-state summaries of available data related to mining sites. A series of USGS Open-File Reports (OFRs) contain data for a given state from MRDS, NGDB, and the MILS/MAS database on mining sites developed by the U.S. Bureau of Mines; these data are compiled as compressed files on a single floppy diskette. Data reports have been completed for the States of Colorado (OFR 94-579), Idaho (OFR 95-644), Montana (OFR 95-229), and New Mexico (OFR 95-528). Other western states, including Arizona and California, will be completed during federal FY 1995 and FY 1996.

Evaluation of water-quality data can be a useful step in prioritizing mine sites for remediation, in terms of recognizing the magnitude of environmental impacts on stream reaches. USGS water- quality databases provide an accessible resource to support this type of evaluation. Water-quality data collected by USGS are stored in the QWDATA program, which is accessible and searchable on line. QWDATA is part of the National Water Information System (NWIS 1), which also includes other databases with comprehensive information on ground-water and surface-water measurements conducted by the USGS. On a regular basis, the water-quality data in QWDATA are uploaded into WATSTORE, a centralized system that interfaces with EPA's STORET database. A major upgrade of NWIS 1 to NWIS 2 is under way. NWIS 2 will replace WATSTORE and NWIS 1 in FY 1996 or FY 1997 with a relational and discipline-integrated database containing basic data storage and processing capabilities as well as an index of data and sources.

Assessments of Abandoned Mine Lands in Colorado

The BLM and the USFS are currently charged with identifying and prioritizing for remediation tens of thousands of abandoned mine sites in Colorado. The USGS, in cooperation with the State of Colorado's Geological Survey and the BLM, has developed a geology-based regional screening process that was used to identify and rank Colorado mining districts according to their likely mine drainage hazards. This screening process allows land management agencies to focus their remedial efforts rapidly on mining districts with the greatest potential for environmental problems, thereby avoiding costly, detailed field assessments of all mining districts.

The BLM, USFS, and other federal agencies are proposing that EPA use this geology-based regional screening approach to help assign and assess stormwater permits for multiple abandoned mine sites on public lands. The mining industry can also use this geology-based screening approach to improve prediction, planning, and mitigation of the environmental consequences of mineral-resource development.

SITE CHARACTERIZATION

The USGS conducts numerous detailed studies of individual mine sites to determine: 1) geochemical backgrounds (natural concentrations of elements in natural materials that exclude human influence) and baselines (elemental concentrations that may include human influence, measured at a specific time), 2) environmental impacts of mineral and energy development, 3) sources and effects of mining-related contamination, and 4) likely consequences of proposed remedial alternatives.

Three examples follow of USGS site characterization studies in areas affected by mining. At Summitville, Colorado, the USGS has integrated studies from several disciplines to characterize the mine site as well as the surrounding environment. At the Penn Mine in California, the USGS has performed detailed characterization of the hydrogeology and geochemistry of a fractured-rock aquifer contaminated by acid mine drainage. At Iron Mountain, California, the USGS sampled and analyzed water and solids from underground mine workings and from a downstream reservoir receiving the acidic drainage. At all three of these sites, the USGS studies have provided important data and information that will improve the effectiveness of regulatory and remedial actions.

Summitville, Colorado

Open-pit gold mining at Summitville, Colorado, led to increased acid drainage and leaks of cyanide-bearing processing solutions into the Wightman Fork of the Alamosa River. These environmental problems are of concern because of the extensive downstream use of Alamosa River water for livestock, agricultural irrigation, and wildlife habitat. USGS studies have provided unbiased geoscience information on the Summitville Mine and its downstream environmental effects (1). These studies included acid drainage and cyanide geochemistry on site, effects on the Alamosa River and Terrace Reservoir, and effects on soils, agriculture, and wetlands downstream in the San Luis Valley. This information is being used by: 1) EPA to help improve site remediation; 2) the State of Colorado, land management agencies, and the mining industry to help understand and prevent similar environmental problems at other mines; and 3) downstream water users such as farmers, water conservancy districts, and the Alamosa National Wildlife Refuge (managed by the U.S. Fish and Wildlife Service) to evaluate the potential impacts of Summitville on agriculture and wildlife ecosystems.

Studies of 1993 alfalfa and barley crops showed that metal concentrations in crops irrigated with water affected by acid mine drainage from Summitville were far below toxic levels and were well within concentration ranges measured in alfalfa and barley crops elsewhere in the United States. In fact, local farmers felt that increased copper levels measured in the alfalfa crops have actually increased the value of the alfalfa because copper is an essential nutrient for cattle.

Penn Mine, California

In cooperation with the State of California and a regional water district, the USGS conducted a study of ground-water flow and metal transport in an area contaminated by acid drainage from sulfide mine wastes and from underground workings at the Penn Mine, which produced copper, zinc, lead, and gold from massive sulfide deposits in the Sierra Nevada foothills. Borehole geophysical techniques, including acoustic televiewer and heat-pulse flowmeter, were used to determine the location and orientation of hydraulically active fracture zones in a structurally complex metamorphic rock terrain.

Inflatable packers were installed in boreholes to separate rock types and to isolate fracture zones for geochemical sampling, water-level measurements, and hydraulic testing. Naturally occurring stable isotopes of hydrogen and oxygen in water were used as tracers to determine the origin of ground water in a contaminated plume flowing from an unlined impoundment to a fresh water reservoir. Several hundred feet upgradient, USGS drilled into underground mine workings and determined the relative proportion of contamination seeping from the underground workings and from surficial waste-rock piles using naturally occurring chemical tracers. Results of the USGS investigations are being used by the responsible parties in planning cost-effective remediation efforts for the site.

Iron Mountain, California

Acid mine drainage from Iron Mountain is among the most metal-rich ever detected and represents a serious environmental threat to the Sacramento River in northern California. The inactive mines in the Iron Mountain area yielded several million tons of massive sulfide ore from which copper, zinc, gold, silver, and pyrite (for sulfuric acid) were produced. Several million tons of ore remain in the ground, however, exposed to air and percolating ground water. The volcanic host rocks have little capacity to neutralize acid, creating an extreme degree of sulfuric acid production and metal mobility.

USGS has worked with EPA and other federal and state agencies since the mid-1980s to determine effective remediation strategies as part of EPA's Superfund project. This work has included underground sampling of mine waters (including documentation of highly unusual negative pH values) and mineralogic study of secondary sulfate salts that accumulated in the underground mine workings. Geochemical modeling of mine plugging scenarios shows that salt dissolution would contribute significant quantities of acid and ferric iron to the mine water, leading to continued sulfide oxidation and unacceptable risks. Mass-balance analysis determined separate drainage contributions from two adjacent mines, one of which could not be plugged. This analysis encouraged the construction of a lime neutralization plant, which has reduced loadings of copper, zinc, and cadmium by about 80 percent.

USGS has also studied the geochemistry and aquatic toxicity of metal-rich sediment and pore water in Keswick Reservoir, which receives the acid drainage from Iron Mountain in the Sacramento River system. USGS is cooperating with EPA and other federal and state agencies to develop a remediation strategy for these contaminated sediments that is cost-effective and environmentally sound.

MONITORING AND ANALYSIS

Monitoring activities are essential in evaluating the extent of contamination as well as the degree of remedial success and failure. The USGS continues to be recognized nationally and internationally as a leader in the development of field methods, sampling protocols, and analytical procedures that result in high-quality, reliable, and reproducible data on chemical and physical properties of geologic materials.

The USGS conducts a wide variety of systematic monitoring activities that provide useful data and information regarding mined lands. Spatial and temporal studies of watersheds include long-term records of stream flow and associated water-quality data, including geochemistry and suspended-sediment loading. Long-term and spatially comprehensive data records enable calibration of robust models of surface- and ground-water hydrology and contaminant transport. (The development of such models is described briefly in the next section.) Geophysical data, including extensive remote sensing files, are archived by the USGS and are available to the public.

PROCESS-ORIENTED STUDIES OF CONTAMINANT ORIGIN, TRANSPORT, AND FATE

A distinct strength of the USGS as a scientific organization is its ability to conduct long-term research on geologic and hydrologic processes at sites where the geologic and hydrologic frameworks are well known. The USGS began the Toxic Substances Hydrology (Toxics) Program in 1982 to study, in an interdisciplinary manner, the fate and effects of toxic substances in the environment. The objectives of the Toxics Program are to provide earth-science information that can be used to help prevent or mitigate contamination of the nation's ground- and surface-water resources, and to develop methods of sampling, analysis, and data interpretation for use in water-quality assessments, site investigation, and remediation.

Several field sites affected by mining have been sites of long-term USGS research as part of the Toxics Program, including Pinal Creek (Globe-Miami mining district), Arizona; the Upper Arkansas River (Leadville mining district), Colorado; Tar Creek (Picher mining area), Oklahoma and Kansas; and the Whitewood Creek-Belle Fourche River system (Lead and Deadwood mining areas), South Dakota. (See (2) for a bibliography of publications and brief descriptions of study areas.) The Toxics Project also provided some of the funding for USGS studies at Iron Mountain, California; Summitville, Colorado; and Coeur d'Alene, Idaho.

An important aspect of USGS research is the continuing development of widely used hydrologic and geochemical models based on fundamental principles. In certain situations, and with careful attention to assumptions and uncertainties, such models can be used in a predictive mode to estimate the consequences of remedial actions and to demonstrate the need for filling critical data gaps to reduce the uncertainty of costly remediation decisions.

A summary of USGS research in the upper Arkansas River area is presented as an example of the multidisciplinary nature of studies in the Toxics Program.

Upper Arkansas River, Colorado

Heavy metals from years of mining in the Leadville, Colorado, area enter into the Arkansas River as a result of acid mine drainage and runoff from numerous piles of waste rock and tailings. The metals and the acidic conditions exert a toxic effect on aquatic life. This site represents a classic acidic mine drainage setting where aluminum, cadmium, copper, iron, lead, manganese, and zinc are present in high concentrations. Headwater streams typically are changed by acid, metal-rich inflows over short distances. The pattern of metal concentration downstream from the inflows is a result of the interplay of streamflow and chemical processes; both dilution and metal precipitation can cause decreased metal concentrations downstream.

The USGS has studied diverse hydrologic settings in mountain streams using tracer injections to quantify discharge and metal loads in the streams. This has provided information to prepare computer simulations of the transport and chemical reactions in the streams, allowing characterization of specific sites efficiently with noninvasive techniques. Two unique aspects of the USGS studies have been the ability to draw upon many diverse sites and synthesize the findings and to study the chemical reactions of metals in the context of stream transport. This watershed approach to understanding the impact of mine drainage can be more readily applied to management decisions.

The USGS research in the upper Arkansas River area has been at the forefront of understanding several important processes that influence the fate of metal contamination in mountain streams and rivers: 1) cycling of metals by iron photoreduction, 2) effects of photosynthesis on metals, and 3) importance of colloids in the transport of metals downstream from mining.

ACKNOWLEDGMENTS

The material in this paper is based on USGS fact sheets and briefing sheets prepared by staff scientists in the Office of Mineral Resources and the Office of Water Quality. Copies of pertinent fact sheets and briefing sheets can be obtained by contacting the chiefs of these offices (see below). Other information was provided by Briant Kimball, Sherman Marsh, William R. Miller, Geoff Plumlee, G. Robert Robinson, and Marc Sylvester. Constructive reviews of the manuscript by D. Kirk Nordstrom, David W. Morganwalp, and Sherman Marsh are greatly appreciated.

ADDITIONAL INFORMATION

For more information, contact:

Chief, Office of Mineral Resources
U.S. Geological Survey
913 National Center
Reston, VA 22092
Tel: (703) 648-6100
Fax: (703) 648-6057
e-mail: whwhite@usgs.gov

Project Chief, Mineral Resources Data System
U.S. Geological Survey
913 National Center
Reston, VA 22092
Tel: (703) 648-6198
Tel: (703) 648-6198

Chief, Office of Water Quality
U.S. Geological Survey
412 National Center
Reston, VA 22092
Tel: (703) 648-6861
Fax: (703) 648-5295
e-mail: drickert@usgs.gov

Chief, National Water Quality Assessment Program
U.S. Geological Survey
413 National Center
Reston, VA 22092
Tel: (703) 648-6868
Fax: (703) 648-5722
e-mail: tlmiller@usgs.gov

Leader, USGS Mine Drainage Interest Group
U.S. Geological Survey
2800 Cottage Way, Room, W-2233
Sacramento, CA 95825
Tel: (916) 979-2615, ext. 356
Fax: (916) 979-2668
e-mail: cnalpers@usgs.gov

USGS Home Pages on the World Wide Web

The World Wide Web (WWW) system allows rapid access to text, graphics, video, and sound. Special software (a "web browser") is needed to access the USGS home pages. The Uniform Resource Locators (URL's) for several USGS home pages with information pertinent to mining and the environment are listed below.

USGS home page
http://www.usgs.gov/

USGS Mineral Resource Surveys Program
http://minerals.er.usgs.gov/

USGS Water Resources Information
http://h2o.usgs.gov/index.html

USGS NAWQA Program
http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html

USGS Mine Drainage Interest Group http://water.wr.usgs.gov/mine/home.html

REFERENCES

1. King, T.V.V., ed. 1995. Environmental considerations of active and abandoned mine lands lessons from Summitville, Colorado. U.S. Geological Survey Bulletin 2220.

2. Morganwalp, D.W., compiler. 1994. Bibliography of publications from the Toxic Substances Hydrology Program, U.S. Geological Survey. U.S. Geological Survey Open-File Report 94-91.

For additional information see also:

Plumlee, G.S., S.M. Smith, M.I. Toth, and S.P. Marsh. 1993. Integrated mineral-resource and mineral-environmental assessments of public lands Applications for land management and resource planning. U.S. Geological Survey Open-File Report 93-571.

USGS Mine Drainage Newsletter

U.S. Department of the Interior - U.S. Geological Survey
This newsletter is for administrative use only.
It should not be quoted or cited as a publication.

On-line Discussion Groups

An exciting capability of the Internet is the advent of Mailservers to facilitate on-line discussions via electronic mail.

Recently, two such mailservers have started, which are of potential interest to USGS MDIG members.

1) The "ENVIROMINE" technical and issues mailservers, maintained by Robertson Info-Data, Inc., to facilitate discussions on environmental aspects of mining, and

2) the "Cleanstream" listserver, maintained by the Office of Surface Mining, to provide a forum for communicating activities relate to the Appalachian Clean Streams Intitiative.

Following are announcements provided by the sponsors of these two mailservers The ENVIROMINE announcement also contains some information on the World Wide Web home page (see Other Links of Interest). Thanks to Elliott Spiker for providing the information on Cleanstream, which also has a related WWW home page (see Other Links of Interest).

Please Note: The Enviromine discussion group has been split into two groups: ENVIROMINE_TECHNICAL and ENVIROMINE_ISSUES

ENVIROMINE_TECHNICAL MAILING LIST

(Mine/Environmental Discussion Group)

Robertson GeoConsultants Inc offers a MAILING LIST Discussion Group on mining-related environmental technology and management. Certain members of the Western Governor's Association Mine Waste Task Force and several consulting firms, mining industry, and federal government representatives have agreed to assist as mentors in providing technical input and to help solicit participation from a wider Internet audience. Discussions are encouraged in the following areas:

- ☐ Reclamation
- ☐ Pollution prevention
- ☐ Operating/engineering design
- ☐ Waste management practices and requirements
- ☐ Case histories (active operations and abandoned mines)
- ☐ Acid rock drainage (prediction, control, and mitigation)
- ☐ Environmental monitoring

Anyone interested in the technical aspects of environmental effects and controls at mining operations will find this Internet service particularly valuable. The ENVIROMINE_TECHNICAL discussion group represents an opportunity to keep abreast of the latest breaking developments in the area of environmental technology and management at mine sites. If you are an industry representative, regulator, policy maker, technology developer, technology user, consultant, or a member of an environmental group, academia, or the general public interested in mining, you will want to participate in the ENVIROMINE_TECHNICAL discussion group.

To subscribe to the ENVIROMINE_TECHNICAL MAILING LIST, please send an e-mail to:

listproc@info-mine.com

with the following message in the text:

subscribe enviromine_technical your name

Once subscribed you will automatically receive all messages posted on the ENVIROMINE_TECHNICAL MAILING LIST. If you wish to post a message, article, or question to the enviromine_technical audience send an e-mail to:

enviromine_technical@info-mine.com

with your message in the main body of the e-mail.

To unsubscribe from the ENVIROMINE_TECHNICAL MAILING LIST, send an e-mail to listproc@info-mine.com with the following message in the text: unsubscribe enviromine_technical

The following people have agreed to serve as mentors to participate on a regular basis and to catalyze interactive discussions: Charles N. Alpers, Ph.D. (Research Chemist, U.S. Geological Survey, Water Resources Division, Sacramento, CA), Charles H. Bucknam, MS Analytical Chemistry (Newmont Metallurgical Services, Salt Lake City, UT), Tom Durkin, CPG (South Dakota Minerals and Mining Program, Pierre, SD), Geoffrey S. Elliott (Principal NEPA Strategist & Editor-In-Chief, AmbioCom Strategies, Inc., Grand Lake, CO), Tom Farrell, CPS (Env.) (Principal Environmental Scientist, Woodward-Clyde, Sydney, Australia), Rick Humphries, R.G. (California Resource Control Board in Sacramento, CA), Robert Kleinmann, Ph.D (Research Supervisor, U.S. Dept. of Energy - Pittsburgh Research Center), Rebecca A. Miller (Montana Dept. of Environmental Quality, Helena, MT), Andy Robertson, Ph.D., P.E. (Robertson GeoConsultants Inc. in Vancouver, B.C.), Andre Sobolewski, Ph.D. (Microbial Technologies, Vancouver, BC), Leonard Walde, MBA, P. E. (President, Sigma Energy Engineering, Inc., Orinda, CA), Peter Wampler (Oregon Department of Geology and Mineral Industries, Mined Land Reclamation Program), and Peter Woods Ph.D. (Sr. Environmental Scientist: ERA Ranger Mine, Jabiru NT, Australia).

Dr. Christoph Wels (Robertson GeoConsultants Inc.) is administrator of the enviromine_technical mailing list. If you would like to serve as an additional helper by providing initial discussion items, please send a separate e-mail message to him at wels@info-mine.com

---

"ENVIROMINE_ISSUES" MAILING LIST

(Mine/Environmental Discussion Group)

Robertson GeoConsultants Inc. offers a MAILING LIST Discussion Group on mining-related environmental issues which are non-technical (i.e., qualitative impacts, socio-economic, cultural, political or regulatory). Certain members of the Western Governor's Association Mine Waste Task Force and several consulting firms, mining industry, and federal government representatives have agreed to assist as mentors in providing input and to help solicit participation from a wider Internet audience. Discussions are encouraged in the following areas:

- ☐ Laws, regulations and permit requirements.
- ☐ Identification and evaluation of environmental effects and issues.
- ☐ Permit and project review processes.
- ☐ Public involvement and relations.
- ☐ Cultural and land-use issues.

Anyone interested in the evaluation and regulation of environmental effects of mining operations and public interaction will find this Internet service particularly valuable. The ENVIROMINE_ISSUES discussion group represents an opportunity to keep abreast of the latest breaking developments in the area of environmental effects and issues at mine sites. If you are an industry representative, regulator, policy maker, consultant, or a member of an environmental group, academia, or the general public interested in mining, you will want to participate in the ENVIROMINE_ISSUES discussion group.

To subscribe to the ENVIROMINE_ISSUES MAILING LIST, please send an e-mail message to:

listproc@info-mine.com

In the body of the message, type:

subscribe enviromine_issues your name

Once subscribed, you will receive automatically all messages posted to the ENVIROMINE_ISSUES MAILING LIST. If you wish to post a message, article, etc. yourself to the enviromine audience, send an e-mail to enviromine_issues@info-mine.com with your message in the main body of the e-mail. To unsubscribe from the ENVIROMINE_ISSUES MAILING LIST, send an e-mail to listproc@info-mine.com with the following message in the text: unsubscribe enviromine_issues

The group of mentors listed in the enviromine_technical mailing list have agreed to participate on a regular basis and catalyze interactive discussions. Glenn Robertson (Robertson GeoConsultants Inc.) is the administrator for the enviromine_issues mailing list (glennr@info-mine.com)

OSM's Cleanstream Listserver

To subscribe to the cleanstream listserver, simply send email to

Majordomo@m5.osmre.gov

and put the following single line in the message:

subscribe cleanstream

(You can leave the Subject line blank.)

In response, you may get a short questionnaire.

To unsubscribe, send email with the following line:

unsubscribe cleanstream

Here is some information about the cleanstream listserver:

>>>> info cleanstream
[Last updated on: Tue Jan 31 10:08:08 EST 1995]

The "Cleanstream" list is a forum for communicating activities related to the Appalachian Clean Streams Initiative (ACSI). OSM has staff working on ACSI in the Washington and Pittsburgh regional offices; in each Field Office in Appalachia; and in TIPS Denver office. These staff will need to inform each other about contacts made with congressional staff, citizens, community organizations, watershed associations, state agencies, EPA, etc.

There will also be explanations of ACSI goals; discussions about funding of acid mine drainage remediation projects; project descriptions and status reports; explanations of AMD clean-up technology; citizens' guides; project selection guidelines; ACSI geographic information system (GIS) planning and design information/instructions; file transfers; reports of field data collection activities; discussion of ACSI policy and procedures; notices of upcoming ACSI meetings and technology transfer events; media and public relations opportunities; and general ACSI coordination messages. Eventually the list server will be available to other state and Federal agencies and anyone interested in ACSI.

The descriptors should be:

- funding of ACSI acid mine drainage remediation projects
- ACSI project descriptions and status reports
- explanations of AMD clean-up technology
- citizens' guides to ACSI
- ACSI project selection guidelines
- ACSI geographic information system (GIS) planning and design information/instructions
- file transfers
- reports of ACSI field data collection activities
- discussion of ACSI policy and procedures
- notices of upcoming ACSI meetings and technology transfer events
- media and public relations opportunities
- ACSI coordination messages

The list administrator is Mary Ann Miovas of the ESC office. She can be reached at mmiovas@osmre.gov or 412-937-2883.

>>>> help
This is Brent Chapman's "Majordomo" mailing list manager, version 1.93.

In the description below items contained in [ ]'s are optional. When providing the item, do not include the [ ]'s around it.

It understands the following commands:

```
subscribe "list" ["address"]
        Subscribe yourself (or "address"> if specified) to the named
.

 unsubscribe "list" ["address"]
        Unsubscribe yourself (or "address" if specified) from the named
.

    get "list" "filename"
        Get a file related to "list".

    index "list"
        Return an index of files you can "get" for "list".

    which ["address"]
        Find out which lists you (or "address" if specified) are on.

    who "list"
        Find out who is on the named "list".

    info "list"
Retrieve the general introductory information for the named
"list".

lists
Show the lists served by this Majordomo server.

help
Retrieve this message.

end
Stop processing commands (useful if your mailer adds a signature).

Commands should be sent in the body of an email message to
"majordomo@m5.osmre.gov".

Commands in the "Subject:" line NOT processed.

If you have any questions or problems, please contact
"majordomo-owner@m5.osmre.gov".
```

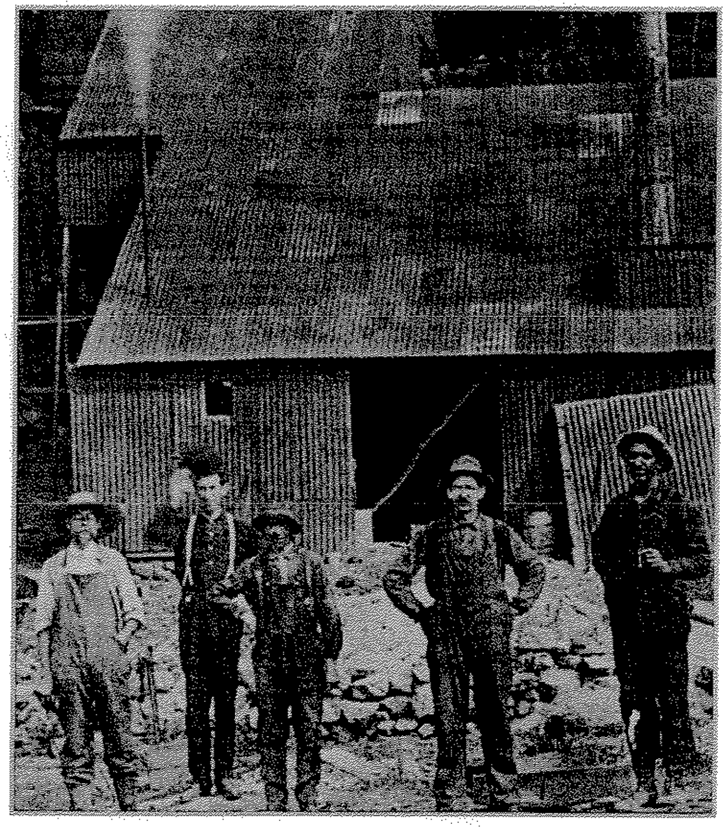
Back to Mine Drainage Newsletter

Water Resources of California* or *USGS Water Resources

The URL for this page is <http://water.wr.usgs.gov/mine/sep/online.html>.
If you have any questions or comments about this document contact:
Dale Alan Cox <dacox@usgs.gov>

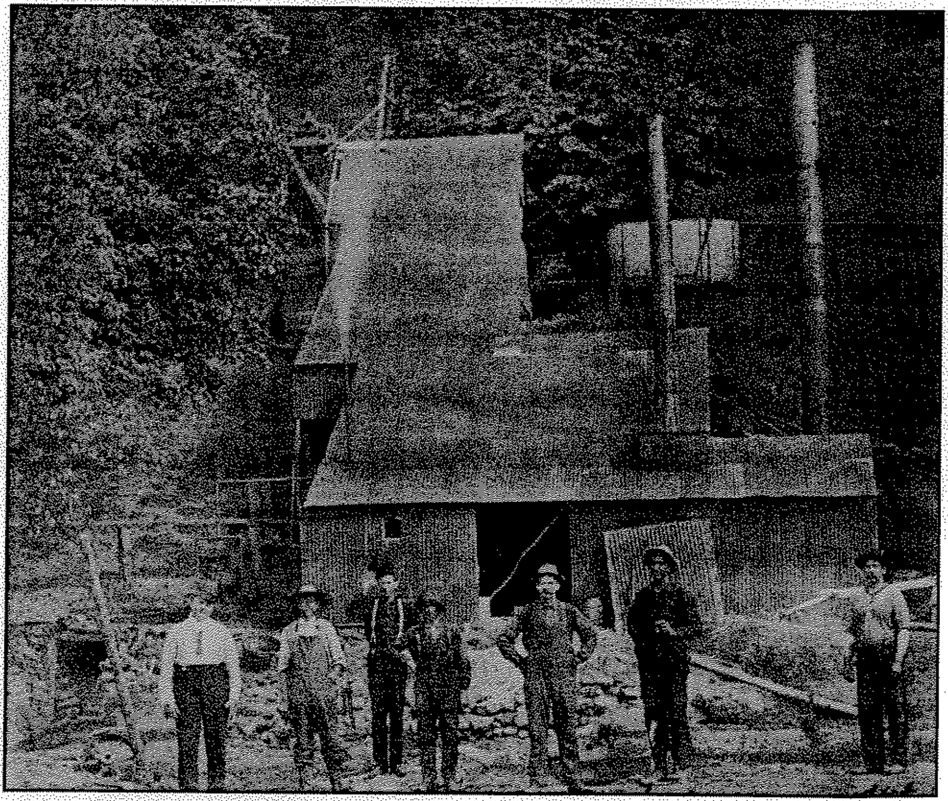
Mining A Wisconsin Tradition

Mining A Wisconsin Tradition



Modern Mining Builds On A Wisconsin Tradition

- *The first major influx of settlers to Wisconsin consisted of lead prospectors and miners. In 1836, when the Wisconsin Territory was formed, 5,000 of its 11,000 settlers lived in the southwestern lead region.*
- *During its history, Wisconsin has been a major producer of lead, zinc and iron. As late as 1968, it was among the nation's top ten zinc producers.*
- *In 1971, the Wisconsin Legislature passed a bill designating galena – lead sulfide – as the official state mineral.*
- *To this day, more than 10,000 Wisconsin residents are employed in mining-related jobs.*



Early miners, circa 1900, stand outside a small zinc mine near New Diggings, Wisconsin. At this mine, ore was removed by tunneling into the hillside. This operation included a mill that produced zinc concentrates, which were shipped off-site for smelting.

When we think of mining states, we often look west to Nevada, Wyoming and Colorado, or north to Alaska, or east to the Appalachians. But Wisconsin itself has been and remains an important mining state. Driving through the scenic hill country in the state's southwest corner, it is hard to imagine the area as one of the most productive metallic mining regions in the United States. But it was. From small lead mines carved out of hillsides in the 1800s, to large underground zinc mines that operated into the 1970s, Wisconsin contributed greatly to the nation's metal supplies.

Metallic mining in Wisconsin began well before 1700, when Native Americans mined lead in the southwest region. It continued almost without interruption into the 1980s, with lead, zinc and copper production in the southwest, and with iron ore production around Florence, Hurley, Iron Ridge, Baraboo and Black River Falls.

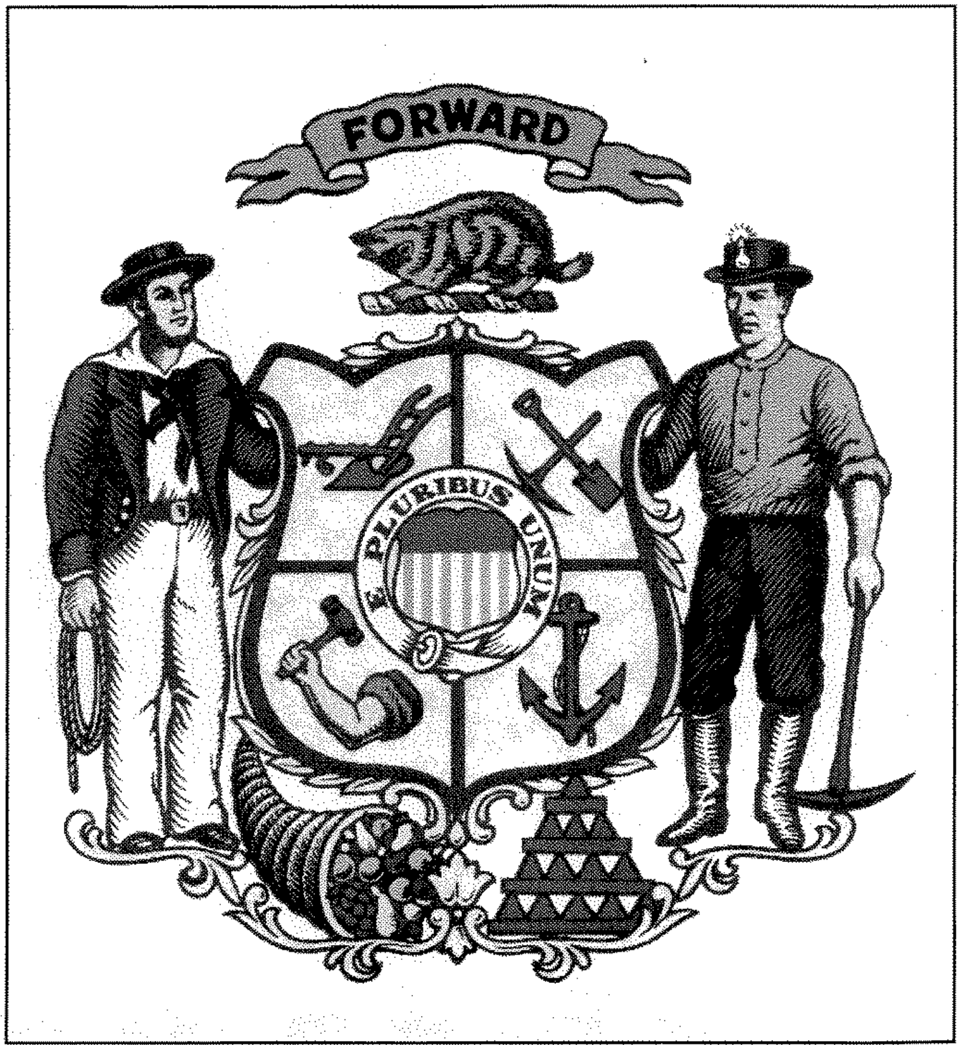
Today, mining is back in the state's economic picture. The open pit Flambeau copper/gold mine in Rusk County is nearing the end of its productive life, and reclamation has begun. Crandon Mining Company is now seeking permits for an underground zinc/copper mine in Forest County. Meanwhile, other mining companies are actively exploring for ore deposits elsewhere in the state.

Far from representing a "new" industry, these projects continue a long-standing tradition – one that has contributed greatly to the state's character and prosperity.

*W*isconsin's *M*ining *H*istory:

A SNAPSHOT

One look at Wisconsin's territorial and state seals shows how important mining was to early settlement and economics. But European settlers were not the first miners in the region. Historic records show that Native Americans mined lead ore as early as 1658-59 (and probably long before that) within what is now called the Upper Mississippi Zinc-Lead District. This district covers some 4,000 square miles, most of it in southwest Wisconsin, but including parts of northeast Iowa and northwest Illinois. Over the years, thousands of small lead mines, about 400 zinc mines and several small copper and iron mines were operated within the district. All told, these mines produced some 69 million tons of zinc ore and more than 1 million tons of lead metal. In addition to the lead and zinc mines, Wisconsin was home to several of the nation's most significant iron mines, which operated until as recently as 1983.



The Wisconsin State Seal shows a miner, mining implements, stack of pig lead and the badger, a symbol of early lead miners who burrowed into hillsides. The state seal also appears on the state flag.

LEAD MINING

French explorers and resident Native Americans mined lead on a small scale in the Upper Mississippi district throughout the 18th Century. The first lead smelter in what became Wisconsin was built in 1816 at Gratiot, in what is now LaFayette County.

The first major lead strikes in Wisconsin were near New Diggings, Hazel Green (then called Hardscrabble) and Shullsburg in 1825. More large finds were made around Benton, White Oak Springs and Willow Springs in 1826. William S. Hamilton, son of the famous Federalist and the first U.S. Secretary of the Treasury, Alexander Hamilton, found a large lead deposit neat Wiota in 1827. Extensive mining around Platteville began in 1828.

With these and other discoveries, annual lead production grew from 440,000 pounds in 1825 to 13 million pounds in 1829. By that time, 4,253 miners were digging for lead in Wisconsin, and 52 smelters were operating. These early miners gave Wisconsin its nickname, the Badger State. Too busy digging for the "gray gold" to build houses, some miners moved into abandoned mines or, like badgers, lived in burrows in hillsides.

From 1830-71, the Upper Mississippi district was by far the most important lead-producing area in the United States. The metal was used mainly for pewter, weights, printers' type, shot, pipe, roofing and paint.

The lead region furnished many leaders in territorial government and in the attainment of statehood. For six of the twelve territorial years, the region provided the delegate to Congress. It provided the territorial governor for eight years, as well as the state's first governor, Nelson Dewey.

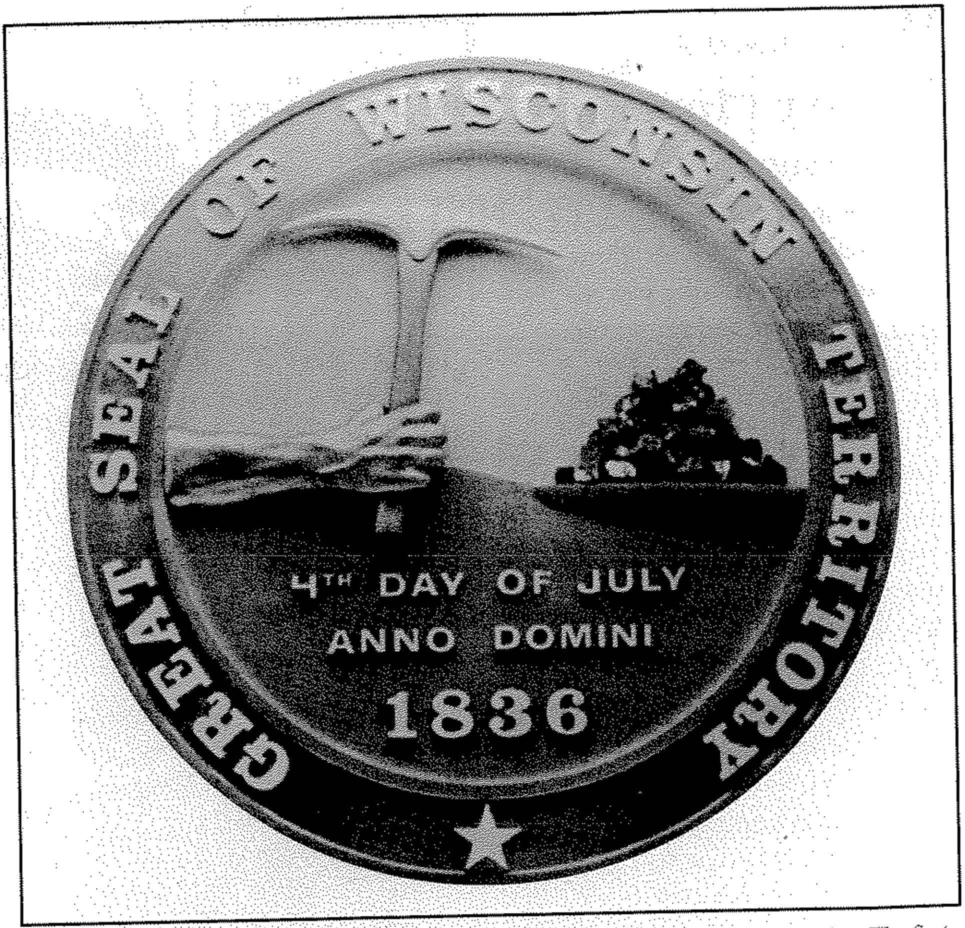
In 1871, the University of Wisconsin created a Department of Mining and Metallurgy. In 1908, the Legislature established The Wisconsin Mining Trade School at Platteville. In 1939, it became The Wisconsin Institute of Technology, and in 1959 it merged with The Wisconsin State College-Platteville, forerunner of what is now The University of Wisconsin-Platteville.

ZINC MINING

Lead mining began to decline in 1848 and, by the late 1800s, zinc had taken over as the primary ore in the district. Lead remained important, however, and the district also produced some copper and iron ore. By 1911, Wisconsin ranked third among zinc-producing states. Production rose steadily, peaking in 1917, when the district produced 64,000 tons of zinc metal. At the onset of World War I, more than 5,000 miners were at work in the district.

Zinc mining was most heavily concentrated in the Shullsburg/Benton area, but the Platteville, Dodgeville and Mineral Point areas also saw major activity. The Mineral Point Zinc Company operated a major zinc oxide processing plant from the late 1800s to 1931. Other important zinc-producing areas were Hazel Green, Cuba City, Linden, Highland and Mifflin.

Zinc production declined sharply during the Great Depression in the 1930s, but rose again during World War II. During the war years, 30 to 40 mines were operating in the Upper Mississippi district. Between 1948 and 1968, Wisconsin remained among the nation's ten largest zinc producers. Most of the zinc was used in galvanizing and for the manufacture of brass and other alloys, batteries, and for zinc oxide, used in making paint, rubber and pharmaceuticals.



The Wisconsin Territorial Seal demonstrates the importance of mining to the region. The first major influx of settlers to what became Wisconsin consisted of lead prospectors and miners. This photograph shows a replica of the Territorial Seal on display at the Mining Museum in Platteville.

IRON MINING

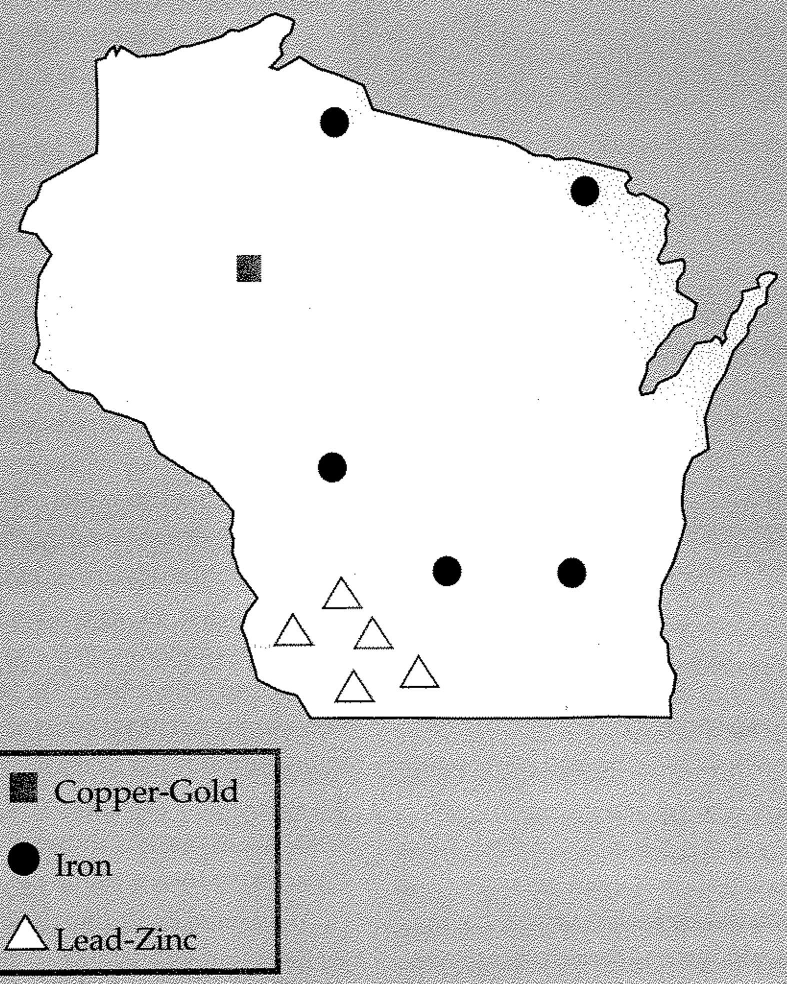
Besides lead and zinc, Wisconsin contained all or parts of six iron ranges in scattered locations. These deposits were mined from the mid-1800s through the early 1980s. The last of Wisconsin's iron mines was the open-pit Jackson County mine, operated from 1969-83 by Jackson County Iron Company, a wholly owned subsidiary of Inland Steel. Its on-site taconite plant had capacity to produce 750,000 tons per year. The Jackson County mine site has been fully reclaimed and is now the 3,200-acre Wazee Lake Recreation Area. Its centerpiece is the reflooded mine pit, now called Wazee Lake. This deep, clear, 146-acre lake is a popular fishing place and a major attraction for scuba divers. Other Wisconsin iron ranges were:

Iron Ridge/Neda. The Iron Ridge open pit and underground mine in Dodge County produced 436,000 tons of ore from 1849-92 and from 1896-1914. The nearby Mayville mine produced 2.1 million tons of ore from 1892-1928. Mayville was also the site of a large iron smelting works.

Menominee Range. A small part of this important Upper Michigan range extends into Wisconsin. The Florence County mines produced about 7 million tons of ore through 1955.

Gogebic/Penokee Range. The Wisconsin part of this historic 53-mile-long iron range stretches west from Hurley to Pence. It includes the Montreal mine, the world's deepest underground iron mine, which yielded 44 million tons of exceptional quality ore from 1886-1962. This district supplied U.S. and Canadian steel

Wisconsin's Historic Metallic Mining Districts



waste near Mineral Point. Over time, leachate from these wastes made its way into Brewery Creek, a small, spring-fed stream that flows into the Mineral Point branch of the Pecatonica River. The leachate colored the stream bright orange, acidified the water for several miles downstream, and depleted fish life. In a clean-up completed in 1993 under DNR supervision, the waste was moved to a new site for containment, the stream was rerouted, and the area was graded and seeded with native grasses and plants. Water quality in the creek has improved markedly and fish populations have rebounded, although the recovery is not yet complete.

Skinner Roaster, New Diggings. In the early 1900s, processing by the Wisconsin Zinc Company at The Champion Mine near New Diggings left a roaster waste pile in a neighboring wetland. Leachate from the waste pile washed into a small tributary to the Fever River during localized flooding in spring 1993. The roaster waste will soon be removed as part of a DNR supervised cleanup project that started in fall 1996.

Environmental Problems in Modern Perspective

Mining has changed drastically since even the most recent of Wisconsin's lead and zinc mines closed down. The few incidents listed above, and other small-scale problems that may exist elsewhere, resulted from practices that today would be against the law.

Old mines and mills in Wisconsin used low technology and operated when there were few environmental regulations. Waste rock and tailings from these mines were simply placed in piles exposed to the elements. Water pumped out of mine workings was discharged onto the ground or into streams without treatment. Few mines were formally reclaimed.

Problems caused by these practices in Wisconsin and elsewhere led to the comprehensive mining regulations that exist today. New mines cannot open without reclamation plans that ensure long-term environmental safety. Mine water cannot be discharged unless it meets strict quality standards that protect even the most sensitive aquatic life. Groundwater regulations protect drinking water quality. Mine tailings must be placed in engineered facilities that protect ground and surface waters. These facilities must be designed for the specific characteristics of the site and of the tailings material.

By the 1920s and 1930s, mines began installing powered equipment, such as this electric locomotive used to move ore from the working face of the mine to the bottom of the shaft. From there, the ore was hoisted to the surface for milling. This locomotive operated at the Crawford mine near Hazel Green.

If those standards had been in place when Wisconsin's lead-zinc region was active, the handful of past environmental problems would have been even fewer. But, as it stands, given the number and pervasiveness of the mines in southwestern Wisconsin, the industry left behind a remarkably clean legacy.

The Mining Industry in Wisconsin Today

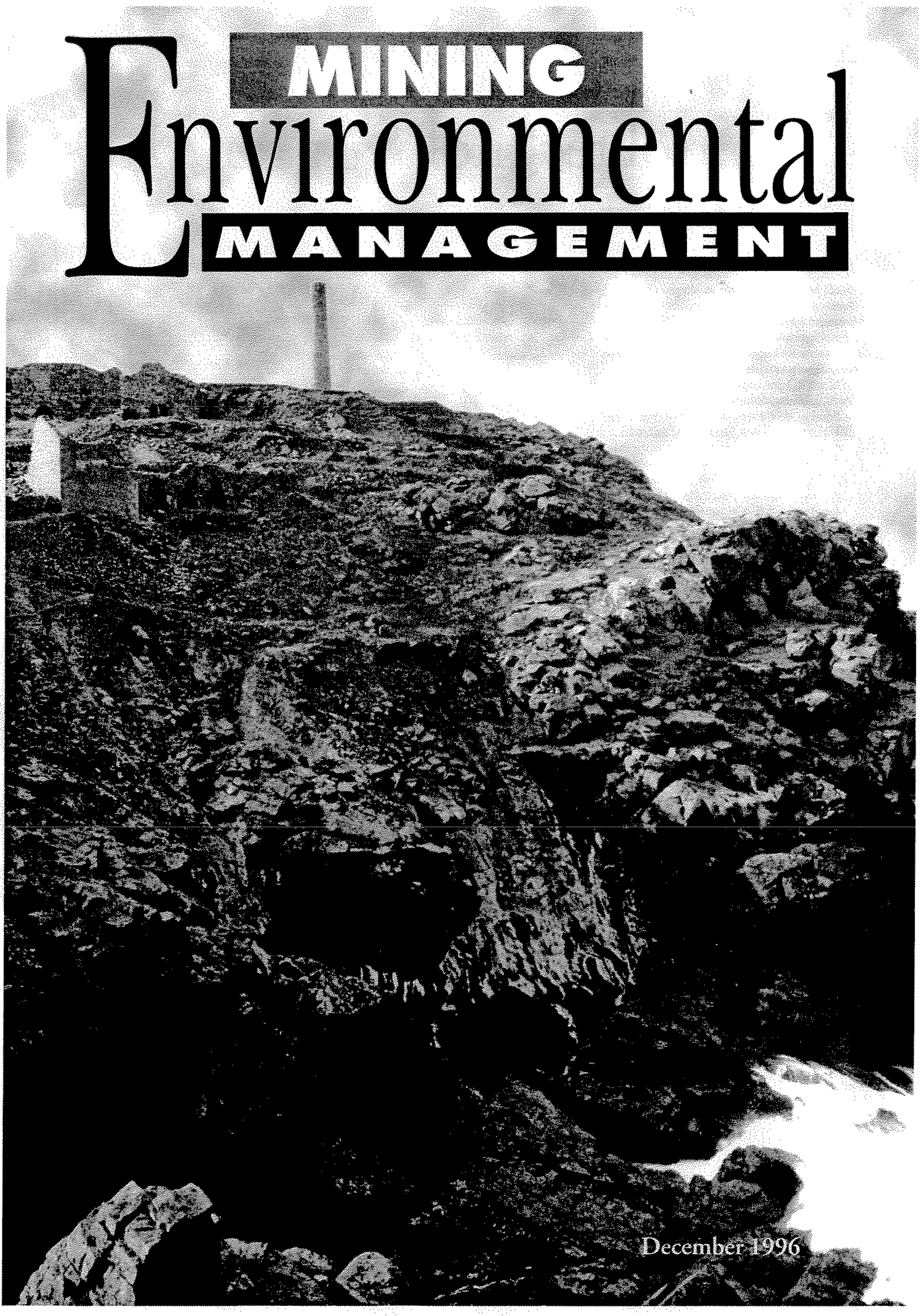
Mining remains important to Wisconsin's economy, with or without the Flambeau mine and the proposed Crandon project. Since it opened in 1993, the Flambeau operation has employed an average of 60 people in well-paid positions. The Crandon mine, if permitted, will employ some 400 during an estimated 28 years of production.

Meanwhile, other Wisconsin companies supply equipment and services to the mining industry in North America and worldwide. These include Falk, Harnischfeger, Nordberg, Rexnord and Bucyrus International in Milwaukee, Applied Power in Butler, Young Radiator in Racine, Telsmith in Mequon, Svedala Industries in Waukesha, Intetractor America Corp. in Elkhorn, Enginaire in Janesville, and Ansul, Inc. in Marinette. The Wisconsin Mining Association estimates that 10,000 state residents hold mining-related jobs.

Mining has been, and remains, a part of Wisconsin's culture, character and economy. Modern mining, with state-of-the-art technology under strict environmental regulations, can return this essential industry to prominence in our state, providing family-wage jobs while protecting the natural resources state residents hold dear.

*** Historic photos unless otherwise noted courtesy of Benton (Wis.) Museum.*

MINING Environmental MANAGEMENT



December 1996

Control technologies for ARD

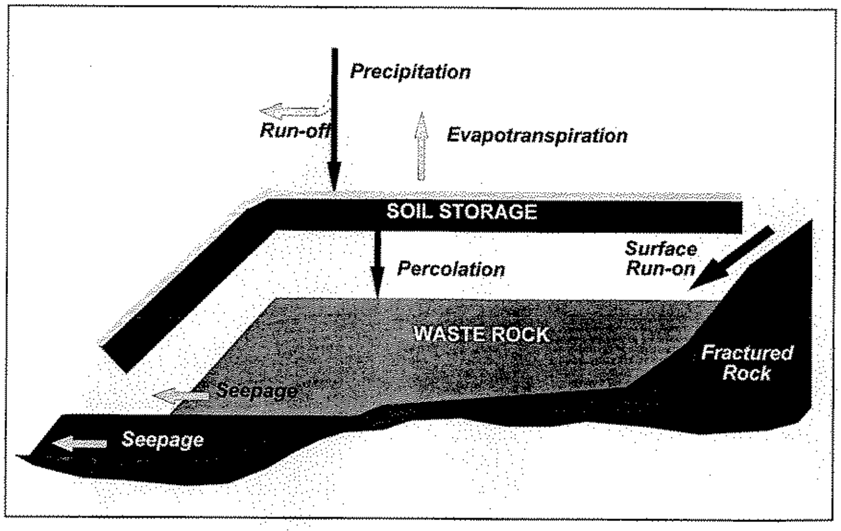


Figure 1. Conceptual water balance of a mine waste rock pile.

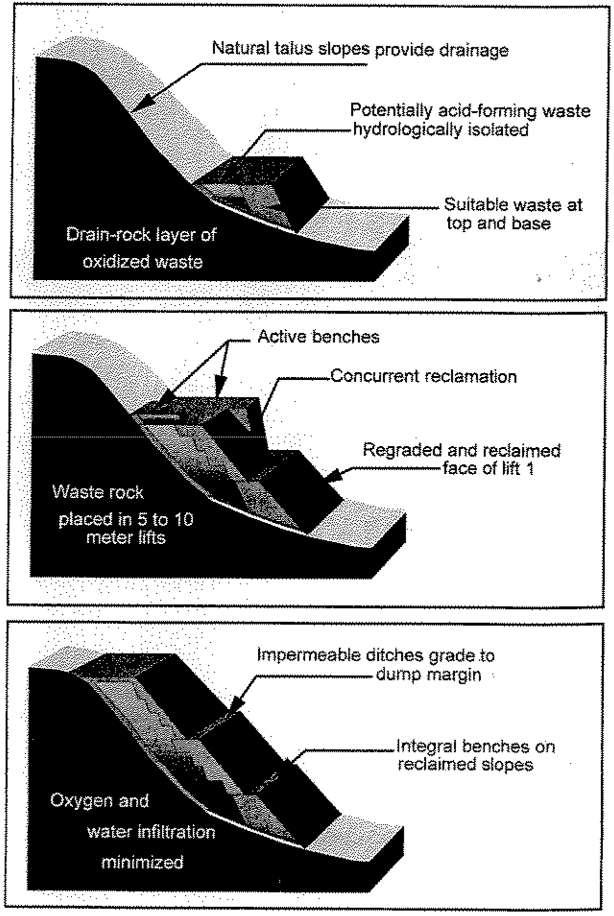


Figure 2. Waste rock piles built in lifts have less potential for air and water movement.

Acid rock drainage (ARD) is one of the most significant environmental challenges facing the mining industry today. ARD is produced by the exposure of rock, rich in pyrite and other sulphide minerals, to oxygen and water. It causes a number of serious water quality impacts due to its typically low pH and unacceptable concentrations of metals. While ARD can form naturally, it occurs at a number of mining operations throughout the world. When ARD develops at a mine, its control can be difficult and costly.

Mining operations can increase the rate of ARD generation compared to the natural environment because rock is moved from its original place in the earth and crushed, ground, or otherwise treated in ways that increase the exposure of pyrite to oxygen and water. Sulphide-enriched waste rock can have significant ARD potential and is usually stored on the surface, where it is subjected to abundant oxygen, weathering, and leaching. Sulphide-rich tailings are generally slower to produce ARD than waste rock because they are finer-grained (hence less permeable) and are typically stored in near-saturated conditions. Historically, many tailings have been deposited or stored in ponds along valley bottoms, where they are subject to active erosion by streams and high precipitation events.

Three broad categories of ARD control measures exist: source control, migration control and treatment. Source control refers to measures that can be employed to prevent acid generation before it develops. Migration control restricts the amount of water moving through potentially acid generating mining waste, thereby preventing the movement of acid. Collection and treatment of ARD is the control option of last resort because it is typically the most expensive and may be required for many years after mining has ceased.

One of the best means of eliminating the risk of ARD at new mine sites is through the engineering design of the mine and facilities. Geochemical characterisation is important in determining if there is a potential ARD risk. It is necessary to know which rock types pose a concern, what their potential volumes are, where and how they can be stored and if their storage poses a short- or long-term threat to surface- or groundwater quality. The mine facilities can then be designed and constructed to eliminate or significantly reduce the potential for ARD.

CONTROL TECHNIQUES

Control techniques are much less costly than the collection or treatment of ARD. Reliable testing techniques have been developed in recent years, allowing ARD risk to be predicted before it occurs. As the potential impact of ARD has been recognised, mines have increasingly employed up-front ARD testing and prediction. A mining company will have many more ARD control options if measures are taken before mining begins. When the risk of ARD is confirmed, facilities that store potentially acid generating rock material can be situated, designed, operated and reclaimed in a manner that prevents or controls ARD.

Mine operators need to plan ahead to use source control measures. Depending on the climate and the nature of the waste, these measures may include segregation and/or encapsulation of potentially acid generating mining wastes, their disposal under water where they

Reprinted from Mining Environmental Management, December 1996.

will not be in contact with oxygen, the addition of limestone to neutralise the acid at source and the removal of sulphides from the tailings during mineral processing followed by special placement of these sulphides. Covers, caps and seals can be used to isolate or encapsulate sulphide-bearing waste and limit the access of either water or oxygen, or both, to these materials. Excluding oxygen from waste materials is very effective as a means of preventing sulphide oxidation, but may be more difficult than excluding water. Capping materials that have a low coefficient of oxygen diffusion include water, amended and compacted soils and geofabrics or membranes.

If there is no seepage or movement of acid out of a waste storage facility, there can be no ARD even when pyrite oxidises and forms acid *in-situ*. Thus, migration control measures seek to minimise the amount of water entering the facility and contacting the rock. To do this effectively requires an understanding of the water balance of the site. The methods used in managing the water balance are aimed at reducing infiltration into mined materials, surface-water control and diversion, and groundwater interception (Figure 1).

Proper siting of the facility, diversion of surface water, regrading of slopes and use of engineered covers are the most commonly used tools for preventing ARD migration. In humid climates, with more than 50 cm of rainfall, an effective cover usually employs a low permeability layer such as clay or a synthetic geomembrane. In drier climates, a soil layer on which vegetation is established can be just as effective in preventing water movement as more costly and complex covers.

If possible, it is best to choose sites for waste rock disposal that are high and dry, because waste rock piles need to be protected from surface-water run-on and groundwater seepage prior to, during and after, closure. Valley bottoms and tributary stream channels should be avoided to minimise surface run-on and the need for long-term, high maintenance diversion systems. Likewise, low-lying wet areas and hillsides, with numerous seeps and springs, should also be avoided to minimise groundwater inflow or seepage. Waste rock piles built with multiple 5 to 10 m lifts are a better design for minimising ARD than single-lift dumps (Figure 2).

Tailings impoundments are often sited in valley bottoms or low areas for various engineering reasons. Large volumes of tailings can be contained in natural topographic 'bowls' with minimum embankment construction. However, in these areas, long-term stream diversions and liner systems are likely to be necessary to protect the dams and materials from erosion and from infiltration by oxidising surface- and groundwaters, even if sub-aqueous tailings closure plans are being considered.

An understanding of the site water balance is critical to the control of surface water and the diversion of flows away from waste rock and tailings facilities. Diversions are used to prevent the flow of otherwise clean water across materials with the potential to form ARD and release trace metals. Diversion ditches may be lined to prevent infiltration into the underlying materials and may be armoured to minimise erosion.

Collection and treatment of ARD is the control option of last resort

Diversions are also used to concentrate or collect water from the waste rock or tailings storage sites so that it can be monitored, and stored and treated, if necessary. To avoid standing water on the storage site, the top is typically sloped slightly into the hillside, where a lined diversion ditch collects and channels run-off away. This type of diversion system helps to minimise the amount of water that needs to be treated, should treatment become necessary. During reclamation, the side of the site is regraded to at least a slope of two units in the horizontal to one unit in the vertical (2H:1V). This regrading allows for placement of soil, if necessary, and reduces the potential for erosion (Case Study No.1).

Groundwater migration is usually controlled using some type of interceptor structure. Grout curtains and slurry walls are both effective constructed diversions. Also, diversion ditches can be used to intercept and divert groundwater flow. Occasionally, the natural setting contains geologically and hydrologically favourable containment structures. Elsewhere, the slow movement of groundwater through natural materials can be used to attenuate low levels of metal concentrations.

DRY COVERS AND LINERS

Dry covers and liners of soil or geofabric are used to restrict the entry of water or oxygen into rock or tailings materials. They can be effective in preventing rainfall infiltration, particularly when combined with a vegetative cap. However, if clay or other low-permeability soil is used, it must be kept saturated with water to limit oxygen penetration and prevent cracking. To be effective, dry covers need to be used in conjunction with a surface water run-on control plan.

Geofabrics such as polyvinyl chloride (PVC) and high density polyethylene (HDPE) are currently used for both top and bottom liners for mining wastes and tailings. Because of their very low permeability, they are excellent at excluding both air and water if properly installed. This requires caution to prevent punctures and careful preparation of bedding and upper surface protection layers. Most geofabrics have not been in use long enough to be able to predict accurately how long they will last. However, they are expected to last for at least 100 years if properly installed and protected from differential settlement, puncturing, root penetration and weathering.

Covers or top liners are typically protected with thick multiple layers of material designed to provide lateral drainage, liner protection and a substrate for revegetation. Bottom liners are frequently constructed with a compacted clay bedding layer that effectively duplicates the low-porosity and permeability of the geofabric, thereby duplicating protection. They may or may not have an under-drain system and are typically covered with a layer of protective material prior to the placement of wastes or tailings.

In semi-arid climates, simple single-layer soil covers can be a remarkably effective means of controlling percolation of water into mining waste. A satisfactory thickness of soil material and an appropriately regraded slope that will induce some run-off, resist erosion and retain water is an ideal dry cover. Establishment of a dynamic vegetative community will maximise the evapo-transpiration of water, thus decreasing potential infiltration. Studies have shown that percolation rates can be reduced to 1-2% of total rainfall, in zones with less than 50 cm of rainfall. The efficiency of revegetated soil covers can be increased by placing a layer of coarse rock beneath the cover, which forms a capillary break, further minimising any percolation.

Multi-layer covers, often used in higher rainfall areas, employ various layers for specific purposes. The layers may include, from top to bottom: a revegetated soil layer to retain moisture; a coarse layer to provide lateral drainage of infiltrating water; a compacted, low-permeability clay layer to prevent infiltration; and a prepared, compacted base layer with added neutralising material to facilitate cap construction and minimise reaction of water in the waste with the clay layer.

SUB-AQUEOUS DEPOSITION

Sub-aqueous or wet covers appear to be the most promising means of controlling the generation of acid, especially in higher rainfall areas. Oxygen has a very low solubility and a diffusion rate through water almost four orders of magnitude less than in air. Therefore, placing potentially acid generating materials beneath a cover of water or in water-saturated material reduces the rate of oxidation to such a slow rate that ARD does not occur.

Sub-aqueous deposition of tailings or waste rock can encompass many forms, including back-filling of mine pits and allowing the pit to flood, placement in man-made lakes or impoundments, or placement in flooded underground workings.

Disposal in lakes and marine environments, although effective in controlling acid production, may increase turbidity and cause the release of metals into the water. Back-filling requires double handling of materials; frequently not all of the material mined will fit back into the mine openings. Sub-aqueous deposition in man-made impoundments is probably the most common application of this technology.

SEPARATION AND BLENDING

Sulphide-bearing waste and tailings materials should be examined for their acid-producing characteristics, trace element contents and mobility, prior to mining. Once potentially problematic materials have been delineated, the potentially acid generating waste or tailings can be segregated for storage. These 'reactive wastes' should be placed where they are isolated hydrologically or where they are not in contact with oxygen. Isolation from water is typically accomplished in waste rock piles by placing the potentially acid generating waste above an under-drain layer of coarse unreactive rock. The potentially acid generating waste is then covered with compacted clay or low-permeability unreactive waste rock (Figure 2).

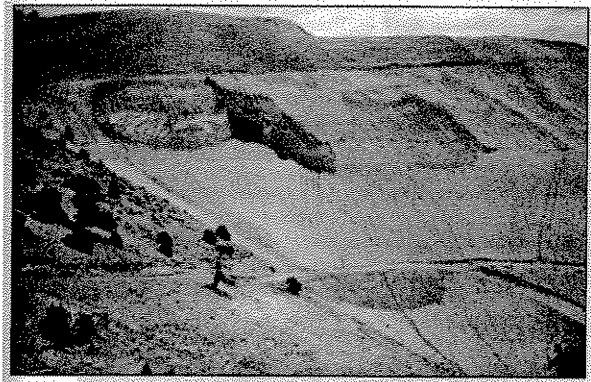
If materials can be segregated and separated based on their acid generation potential, then the blending of potentially acid generating rock with local or off-site neutralising materials may also mitigate ARD risk. The neutralising products most frequently used are limestone ($CaCO_3$), lime (CaO), hydrated lime ($Ca(OH)_2$), soda ash (Na_2CO_3) and caustic soda ($NaOH$). Adding neutralising minerals is a very effective means of controlling acid-drainage from waste or tailings materials and is also used extensively to amend acidic soils prior to revegetation.

Research has shown that alkaline materials must be intimately blended with sulphide waste, not merely layered. Also, the amount of limestone required for long-term neutralisation may be greater than that necessary to equally balance the acid generation potential, as indicated by static acid-base accounting tests. Typically, the final ratio of acid neutralising potential to acid generating potential in the amended material is between 1.25 and 3, depending on the relative rates of dissolution of the neutralising and acid generating materials (Case Study No.2).

Blending neutralising materials with potentially acid generating waste does not stop pyrite oxidation. Rather it neutralises the acid produced at the source. If no steps are taken to minimise water infiltration into the blended waste, through an appropriate cover or revegetation, then a neutral drainage may develop with unacceptably high total dissolved solids and sulphate content. Some metals, especially zinc and cadmium, may also be soluble at neutral pH. Thus, blending of potentially acid generating waste must usually be combined with migration control measures.

BACTERICIDES

Bactericides made of surfactant chemicals have been added to potentially acid generating materials to temporarily suppress the growth of acidophilic bacteria, particularly *Thiobaccillus ferrooxidans*, which can accelerate the rate of sulphide oxidation. This technique is only effective after acid production has begun,



Left: Initial reclamation involved regrading to a 2V:1H slope with diversion ditches every 200 vertical feet.

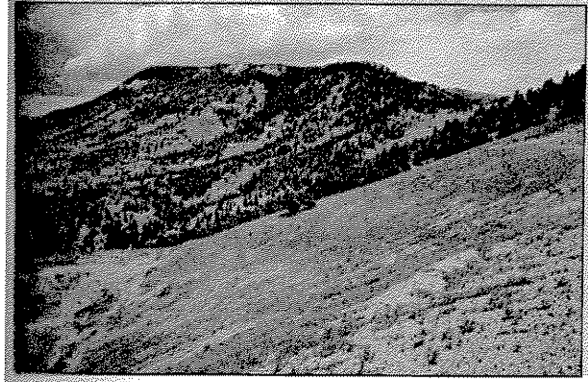
Right: The dozer is creating basins to minimise sheet run-off during the earliest stage of revegetation.

Case Study No.1: Golden Sunlight mine

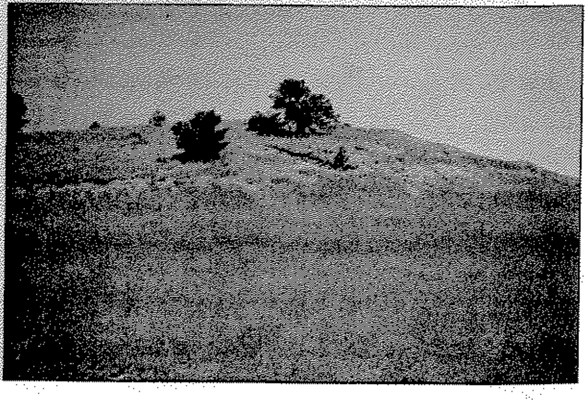
The Golden Sunlight mine (Placer Dome) is a large precious metal complex in Whitehall, Montana U.S., where waste rock contains an abundance of unoxidised, sulphide-rich material. The climate is semi-arid temperate and sulphide oxidation has led to heating of the rock mass and evolution of steam from the dump surface, but acid rock drainage has not occurred. Regulatory agencies have expressed concern that water movement through reclaimed dumps could cause ARD to migrate from the facilities. A waste rock reclamation hydrology study was conducted by Schafer and Associates in response to these concerns.

The focus of the West Dump study has been to evaluate the effectiveness of various reclamation strategies, including surface water diversion, slope regrading (3H:1V vs. 2H:1V), soil covers and revegetation, in promoting slope stability and preventing acid seepage by limiting infiltration into the dump. Evaluation of the reclamation demonstration programme is accomplished through the use of neutron probe equipment to measure water content in the waste rock, thermistors to measure temperature, gas ports to measure oxygen and carbon dioxide concentrations and lysimeters for collection of water quality samples. Erosion monitoring troughs have also been constructed on waste dump slopes to compare sediment yield and runoff volumes on sites with varying styles and degrees of reclamation.

Results from the first five years of study indicate that the concurrent use of surface water diversions, grade control (2H:1V), cap construction using oxide cap covered with soil, and revegetation is successful in virtually eliminating infiltration under average precipitation conditions of 340 mm/y. Reclaimed sites stay significantly drier and exhibit far less pyrite oxidation than unreclaimed control sites. Erosion is minimal, and revegetation is successful, indicating that the 2H:1V slopes are stable. These results indicate that the waste rock reclamation programme will prevent the migration of significant ARD from the waste rock facilities at Golden Sunlight.



Left: Revegetation after one year.



Right: Revegetation after two years. The line just beneath the trees is the uppermost diversion ditch separating reclaimed waste rock below from the natural slope and vegetation above.

Reprinted from Mining Environmental Management, December 1996.

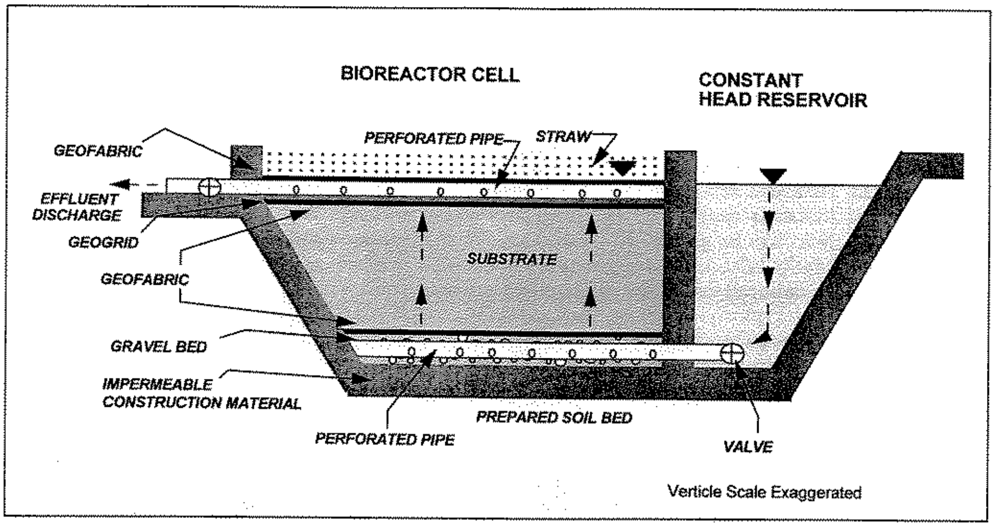


Figure 3. Schematic of a typical upflow anaerobic bioreactor. The arrows show the flow.

because bacterially catalysed oxidation only becomes important when the pH of the system is less than 3.5.

Bactericides only work well for limited periods of time, unless a time-release formulation is applied. They do, however, work more effectively when combined with the addition of neutralising material and natural organic fertilisers which stimulate the growth of vegetation and benign microbes.

COLLECTION AND TREATMENT

Many mines, especially in humid or tropical climates, produce excess water that needs to be discharged into the environment. Some of these discharges may require a water treatment system to achieve regulatory standards prior to release.

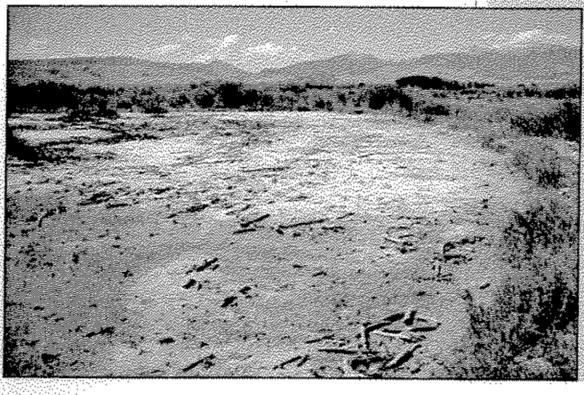
Water treatment systems are commonly used to treat both process and decant water from tailings ponds, and also can be used to treat contaminated water from ARD. However, traditional active water treatment can be capital and labour intensive and may need to continue for many years after mine closure. Treatment of ARD using passive (or low-maintenance) treatment options such as constructed wetlands or bioreactors, lagoons and anoxic limestone drains has recently offered hope of reducing costs. Traditional active water treatment methods for ARD use lime, caustic soda, or soda ash. The most common method is the use of lime to increase the pH and precipitate metals as hydroxides and some of the sulphate as gypsum. To bring metal levels down to permitted levels, a second-stage treatment at a different pH or by sulphide precipitation may also be required. Collection systems may be a series of ditches and holding or collection ponds for surface flows. Trenches, pump-back wells and cut-off walls are used when necessary to collect or bring groundwater to the surface for treatment. Active treatment methods are quite effective in controlling ARD and related mine drainage problems. However, they typically require continuous operation, a constant power supply, back-up systems or contingencies for excess water storage, and a means of disposing of large volumes of sometimes hazardous sludges.

Wetlands have been used to improve water quality in settings where acidic drainage has already developed. Two main types of constructed wetland or passive bioreactor approaches are currently in use to treat mine drainage. They are surface-flow aerobic wetlands and subsurface-flow anaerobic bioreactors. (The term 'bioreactor' is used with anaerobic systems because they typically function better without vegetation and are often covered.) The chemistry of the water to be treated and the final water quality determine which type of treatment, or series of treatments, is appropriate. Drainages of constant, low flow rates are most amenable to passive treatment. The climate can also affect treatment efficiency because the geochemical and microbial reactions decrease substantially in cold weather.

Case Study No.2: Historic tailings

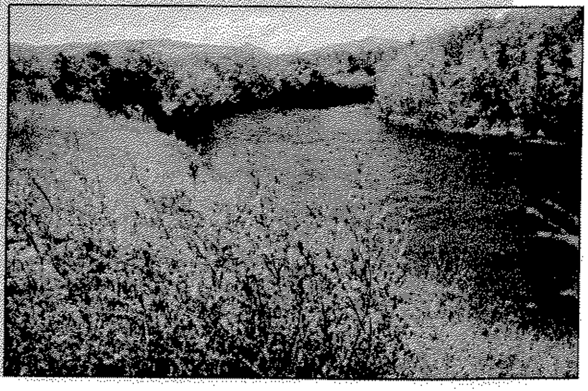
Nineteenth and early twentieth-century mining and smelting in and near Butte, Montana U.S., placed millions of tonnes of metal-laden, acid-producing mine tailings and waste rock along 130 km of the Clark Fork River and its tributaries. As late as 1989, rains washed toxic levels of soluble metals into the river from the tailings, resulting in fish kills. Traditional contaminant removal was impractical and cost-prohibitive due to the size of the site, the tonnage of contaminated materials and habitat sensitivity. The climate of the area is semi-arid temperate, with an annual precipitation of about 400 mm. Therefore, it was decided to try a simple amendment addition to treat the tailings in-place.

Schafer and Associates developed and tested alternative amendment methods to restore the stream corridor to beneficial use without disruption. Lime and limestone were added to the tailings in an amount about 25% greater than that needed to neutralise the acidity, so that a slightly alkaline soil was formed. The amended tailings were deep-tilled to a depth of about one metre. They were then seeded to restore wildlife habitat, minimise infiltration into the tailings, and retard stream bank erosion. The amendments and revegetation have reduced soil acidity and made metals insoluble, improving water quality and encouraging the growth of vegetation. Additional damaged riparian areas are presently being revegetated to improve forage and habitat for livestock and wildlife.



Left: Historic tailings deposited along the Clark Fork River.

Right: Amended and revegetated tailings after about three years.



Reprinted from Mining Environmental Management, December 1996.

Aerobic Wetlands: The dominant processes treating mine drainage in aerobic wetlands are oxidation of iron (II) to iron (III) by aeration spillways, precipitation of iron (III) hydroxides, and settling of the hydroxides in ponds. Vegetation is typically used within the system because it helps trap suspended matter and provides additional oxygen. Aerobic wetland treatment works best on coal mine drainages with low concentrations of other metals because these generally require a pH above 9 to precipitate as oxides or hydroxides. Aerobic treatment requires sufficient alkalinity in the water to keep the pH from falling as a result of the hydrolysis of iron:

$$Fe^{3+} + 3\,H_2O \longrightarrow Fe(OH)_3 + 3\,H^+$$

Anoxic Limestone Drains: An anoxic limestone drain can sometimes be installed before a wetland to add alkalinity and raise pH. These provide 'up-front' alkalinity, and are usually used to help remediate poor water quality in situations where acidic drainage has already developed. The alkalinity is provided by caches of limestone buried in the hillside or waste facility immediately up-gradient of the point where an acidic seepage surfaces.

Dissolution of limestone can be effective in reducing acidity by buffering and neutralising the pH of downstream waters only under very specific conditions. The seepage water must be 'anoxic', containing no dissolved oxygen which may oxidise iron (II) in the drainage to iron (III). No measurable iron (III) or aluminium can be present in the initial drainage because either of these species will precipitate on the limestone and coat, or 'armour', the limestone, making it unreactive. Anoxic limestone drains are most effective when used in conjunction with settling ponds and wetland treatment systems.

Manganese Wetlands: Treatment of manganese requires a special type of aerobic wetland that is highly oxidising and contains populations of micro-organisms that help catalyse the precipitation reaction. Without catalysis, manganese requires a pH greater than 9 to precipitate. Manganese wetlands are usually shallow rock wetlands, colonised with green algae and cyanobacteria, to locally raise pH and redox potential (Eh). They are usually preceded by an aeration spillway to ensure the water is highly oxidised.

Anaerobic Bioreactors: Metal sulphides are much less soluble than their corresponding hydroxides and will precipitate at acid to neutral pH. Therefore, a recent emphasis has been placed on methods to remove metals from ARD as sulphides. Anaerobic bioreactors use bacterial reduction of sulphate and iron to accomplish metal sulphide precipitation.

The reduction reactions occur only in the subsurface of the bioreactor because the bacteria cannot tolerate the presence of oxygen. Therefore, uniform rates and even distribution of flow through the bioreactor substrate are critical to effective treatment. The ideal flow is vertical, either 'downflow' or 'upflow'. Figure 3 shows a typical upflow cell.

An exciting new approach to anaerobic ARD treatment is co-treatment with sewage and recovery of potentially economic metal sulphides. This treats two water quality problems at once and combines the advantage of metal sulphide precipitation and recovery with the advantage of a constant source of 'fresh' organic matter.

Many environmental issues that the public associates with mining are based on inaccurate perceptions stemming from mining practices used early in the century, and which are no longer in use today. Some environmental problems, however, remain challenges even today. One of these issues is ARD. In the last decade, the mining industry has demonstrated that ARD can be prevented through proper mine planning, design, implementation, and monitoring.

By Dr Lorraine Filipek[1], Mr Allan Kirk[2] and Dr William Schafer[1]

[1] *Principals, Schafer and Associates, 143 Union Blvd, Suite 900, Lakewood, Colorado 80228-1229, U.S. Tel: (+1 303) 989 6966. Fax: 989 9033. E-mail: schafer@qadas.com*
[2] *President, Brimstone Mining Co.*

This article is based on Section 5 of a white paper entitled "A Review of Acid Mine Drainage: Chemical Evolution, Prediction, and Control" by Allan Kirk, which was submitted to the State of Wisconsin (USA), Department of Natural Resources, in 1995 while Allan was with Schafer and Associates.

The Mining Journal Ltd, 60 Worship Street, London EC2A 2HD, UK.
Tel: (+44 171) 216 6076. Fax: 216 6050.
E-Mail: mjournal@easynet.co.uk

Executive Summary

A Survey of Modern Mining Principles and Practice At Mines Throughout North America

A number of mining success stories are compelling evidence that metallic mineral mining can supply the materials we need and protect the environment we value

---

A Precambrian volcanogenic massive sulfide mineral belt in Northern Wisconsin has attracted the attention of mining and mineral exploration companies for over 25 years. Two commercially viable deposits have been discovered: the Flambeau deposit in Ladysmith and the Crandon deposit in Crandon.

The Flambeau Mine, an open-pit copper mine, began operations in 1993.[1] It has a spotless environmental record, and final reclamation is set to begin in 1997. Currently, Crandon Mining Company (CMC) is in the permitting process to build, operate and reclaim the Crandon zinc and copper deposit.

Despite the success of the Flambeau project and Wisconsin's comprehensive regulatory structure,[2] mining opponents in Wisconsin have continued to insist that mining is inherently incompatible with environmental protection. In 1995–97, those charges have taken the form of proposed legislation which challenges the mining industry to prove sulfide mining can be done in an environmentally safe and responsible manner.[3] This debate is not unique to Wisconsin. Across North America, mining industry detractors rely on outmoded images of mining to bolster their claims that no mining is safe.

In support of its planning and permitting process and its position that the hard rock mining industry has, can and will continue to operate mines that use proven technology and sound science to comply with comprehensive state and federal laws, CMC commissioned a study to determine the extent and degree of environmental awareness and sensitivity in mining and processing operations and to locate examples of environmentally responsible operations in a sulfide ore environment.

CMC retained the services of two highly respected and experienced mining environmental experts to conduct the survey, Jeffrey Todd and Debra Struhsacker.[4] In addition to identifying mining operations that meet the arbitrary criteria contained in AB 758, introduced in 1996, their survey focused on substantiative documentation and real measurements of how well the mining industry is performing and can perform.

The survey was initiated in the fall of 1995. Hundreds of potential sites were screened to determine which were operating within or had historically operated within a sulfide ore zone. Over the course of several months, more than 150 telephone discussions with the companies, regulatory agencies and industry and environmental organizations were initiated to narrow the field of study. More than two dozen active and closed mines were identified for possible site visits, and 14 visits were conducted in the fall of 1996.

Modern Mining Success Stories: Six Exemplary Mines

- The Henderson Mine and Mill
  Empire, Colorado
- The McLaughlin Mine
  Lower Lake, California
- The Cannon Mine
  Wenatchee, Washington
- The Viburnum Mine No. 27
  Viburnum, Missouri
- The Stillwater Mine
  Nye, Montana
- The Flambeau Mine
  Ladysmith, Wisconsin

The survey reveals four key points:

- There are mines in Southwest Wisconsin that meet both criteria contained in AB 758.
- In addition, several active operations answered part of the challenge set for in AB 758, namely "that a mining operation has operated in a sulfide ore body in the United States and Canada for at least 10 years without polluting groundwater or surface water from acid drainage at the tailings site or at the mine site or from release of heavy metals."
- The bill sets arbitrary standards without scientific or technical basis and thus eliminates many exemplary mines from consideration, including many that use state-of-the-art technology and environmental controls but simply have been closed and reclaimed for less than the 10-year criterion. Mines examined as part of this study include those that have been successfully reclaimed within the last 10 years.
- A more meaningful yardstick for measuring the success of a mining operation must include the following criteria: the existing regulatory framework and the level of enforcement of those laws; the application of sound science and proven technology in all aspects of the mine's design and operations; the attention to reclamation, ongoing monitoring and closure inherent in modern mining; and the commitment of the mine operator to meet, or surpass existing environmental expectations as well as community and public expectations.

The Todd and Struhsacker survey evaluated environmental practices at modern mines and identified active, reclaimed, closed and partially closed mines that employ sound proactive and contemporary environmental management practices. In this manner, the survey focuses on identifying environmentally responsible mines that have been developed under the current regulatory framework and that have used modern pollution prevention and environmental protection technology. Metallic mining under the modern, stringent, environmentally sensitive regulatory climate at the state and federal levels is a completely different enterprise than 100 year ago…or even 20 years ago.

In short, the survey identified mines that meet a higher standard than AB 758 or subsequent bills demand.

Findings of Fact

Today's mines are highly regulated and make extensive use of pollution prevention technology. It is inappropriate to use environmental problems at antiquated mine sites to predict what will happen in the future at modern mines.

Environmentally responsible operations are evident at every active mine site explored by this survey.

There are examples of currently active sulfide mines that have been in operation for more than 10 years and have not caused surface or groundwater pollution.

There are several successfully closed and reclaimed mines that operated for at least 10 years

There are a number of old lead-zinc sulfide mines in southwestern Wisconsin that operated for more than 10 years, were either closed or mined out more than 10 years ago and have caused no known surface or groundwater pollution problems.

A more meaningful measure of compliance with all applicable environmental protection standards would evaluate operating and closed sites that are subject to rigorous and regular monitoring, reporting, and inspection requirements.

For a complete copy of the report, published by the Society for Mining, Metallurgy, and Exploration, Inc. (SME), please contact the Executive Director,
Wisconsin Mining Association, P.O. Box 352,
Madison, Wisconsin 53701-0352.

Footnotes:

1. For a complete record of the Flambeau Permitting Process, see Decision, Findings of Fact, Conclusions of Law and Permits, State of Wisconsin, Division of Hearings and Appeals.

2. Wisconsin's mining laws are discussed in detail in The Wisconsin Geological and Natural History Survey (WGNHS) of the University of Wisconsin-Extension Special Report 13, Wisconsin's Metallic Mining Regulations.

3. Several versions of the mining ban bill have been introduced: 1995–96, AB 758; 1997, AB 70 and SB 3.

4. Mr. Todd has degrees in wildlife ecology and more than 23 years' experience in environmental and regulatory affairs. Ms. Struhsacker is a geologist with over 20 years of experience in the mining industry, 11 of which have dealt with environmental and regulatory issues.

Regulatory Time Line

Comprehensive Regulations Define Modern Mining

Date	Commencement of Mining Activities	Enactment of Environmental Laws or Regulations Affecting Mining
1825	Upper Mississippi Valley lead mining (Southwestern Wisconsin and adjacent Iowa and Illinois)	
1849	California—gold mining	
1858	Colorado—precious metals mining	
1859	Nevada—Comstock Lode silver and gold mining	
1862	Montana—gold mining	
1863	Utah—copper mining	
late 1860s	Upper Mississippi Valley zinc mining (Southwestern Wisconsin and adjacent Iowa and Illinois)	
1875	South Dakota—Black Hills gold mining	
1877	Colorado—base metal mining, and Arizona—copper mining	
1882	Montana—copper mining	
1917	Colorado—molybdenum mining	
1965	Nevada—Carlin-type gold mining started	
1966		National Historic Preservation Act
1967		Air Quality Act
1969		National Environmental Policy Act (NEPA)
1970		Occupational Safety and Health Act (OSHA), Clean Air Act, and CA Environmental Quality Act (CEQA)
1971		MT Metal Mine Reclamation Act and MT Environmental Policy Act (MEPA)
1972		Federal Water Pollution Control Act/Clean Water Act
1973		Endangered Species Act
1974	Mining begins at Henderson Mine, CO	Safe Drinking Water Act (SDWA) and U.S. Forest Service Mining Regulations
1975		CA Surface Mined Land Reclamation Act (SMARA)
1976		Federal Land Policy and Management Act (FLPMA), Resource Conservation and Recovery Act (RCRA), Clean Water Act Amendments, and CO Mined Land Reclamation Act
1977		Mine Safety and Health Act (MSHA), Surface Mining Control and Reclamation Act (SMCRA), WI Metallic Mining Reclamation Act, and ID Surface Mining Act
1979		Archeological Resources Protection Act
1980	Mining begins at Jerritt Canyon, NV	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund
1981	Viburnum Mine No. 27 becomes drinking water source for Viburnum, MO	U.S. Bureau of Land Management Mining Regulations
1982		SD Mined Land Reclamation Act, WI Metallic Mineral Mining (Ch. NR 132) and Regulation of Metallic Mining Waste (Ch. NR 182)
1984		Hazardous and Solid Waste Amendments, CA Chapter 15 Discharges of Waste to Land, Article 7, Mine Waste Management
1985	Mining begins at Cannon Mine, WA, McLaughlin Mine, CA, and Sleeper Mine, NV	
1986	Mining begins at Goldstrike Mine, NV and Montana Tunnels, MT	Superfund Amendments and Reauthorization Act, and Emergency Planning and Community Right-to-Know Act
1987	Mining begins at Stillwater Mine, MT	UT Mined Land Reclamation Act (amended)
1988		ID Code §39-118A (statutory provision requiring permits for processing ore by cyanidation)
1989		NV Mined Land Reclamation Act and MT Admin. R. §§26.4.160 to .168, and NV Water Pollution Control Law
1990		Clean Air Act Amendments and CO Mined Land Reclamation Act Amendments
1993	Mining begins at Flambeau Mine, WI	

Over 140 years of mining before these laws and regulations were passed

Davis Creek Reservoir at the McLaughlin Mine in Lower Lake, California. Built as a freshwater reservoir for the mine, it is now an ecological research site for University of California at Davis.

Modern Mining:

Science, Technology and Comprehensive Regulations Make it Possible

Crandon Mining Company Announces Environmentally Responsible Mining Survey Results

Take a Look for Yourself at Modern Mines Across America

Ongoing environmental monitoring at the Flambeau Mine in Ladysmith, Wisconsin

Crandon Mining Company has conducted a year-long intensive survey of modern mining industry environmental practices. This survey included over 150 interviews with mining industry representatives and state and federal regulatory authorities with jurisdiction over mining in the U.S. and Canada, and visits to 14 sulfide mining operations in California, Washington, Montana, Colorado, Nevada, Missouri, New York, and Wisconsin. The survey was conducted by independent environmental consultants who are experts in evaluating environmental issues associated with mining.

What did those experts find? Environmentally responsible sulfide mining is occurring all across the country. Many of the mine sites researched during the survey are located in scenic, high altitude mountainous areas that receive severe winter weather and provide valuable habitat for terrestrial and aquatic wildlife. The many environmentally sensitive settings prove that similar sulfide mining can be done in an environmentally responsible manner in Wisconsin-especially in light of Wisconsin's stringent mining regulations. These regulations require state-of-the-art engineering design, pollution prevention technology, monitoring, and financial guarantees to ensure that Wisconsin mines are built, operated, and reclaimed to the highest environmental standards.

A few examples of environmentally responsible sulfide mines include the following:

The Henderson Mine and Mill

This molybdenum sulfide mine and mill have maintained a spotless environmental compliance record since 1976 when mining and milling operations commenced. Located less than a two-hour drive west of Denver, Colorado, at an elevation of 10,346 feet in the spectacular mountain scenery of the Colorado Front Range; the areas immediately around the mine and mill serve as Denver's back yard and receive intensive year-round recreational use. Denver residents regularly use areas adjacent to the mine and mill sites for fishing, camping, picnicking, hunting, hiking, skiing and snowmobiling. Treated wastewater from the operation supports a thriving population of Boreal toads, a species that the U.S. Fish and Wildlife Service is considering listing as threatened and endangered. Streams downstream from both the mine and mill facilities are excellent brown and brook trout fisheries. Both the mine and the mill are located in Denver's watershed, and two reservoirs associated with the nearby reclaimed Urad Mine are used as municipal reservoirs for the city of Golden, Colorado.

The Viburnum Mine No. 27

Developed in geology similar to that found in southwestern Wisconsin's lead-zinc mining district, the water from this lead-zinc-copper sulfide mine, which operated from 1960 to 1978, is so clean it has served as the primary domestic water source for the town of Viburnum, Missouri, since 1981.

The McLaughlin Mine

Straddling three counties about 70 miles north of San Francisco in the rugged mountainous terrain of California's Coast Range, this gold mine is acknowledged by regulators, environmentalists, and the mining industry to be a model of effective environmental practice. Proactive mine planning and permitting processes, pollution prevention features, and reclamation and habitat management programs are just some of the mine's successful environmental efforts that have been adapted for use at other mine sites. Comprehensive environmental monitoring of the McLaughlin Mine confirms the ecological effectiveness of these practices. This monitoring demonstrates that

The tailings management area at the active Henderson Mill near Parshall, Colorado

since its development in 1985, the mine has operated without environmental harm, and has not only protected but actually enhanced the quality of both on-site and downstream habitats and improved downstream water quality. Using ecology-based habitat management planning, resource values of the surrounding landscape that were disturbed by historic mining are in the process of being restored and enhanced. Ultimately the entire mine site and attached buffer lands of thousands of acres will become a wildlife preserve and an environmental studies field research station for the University of California.

The Stillwater Mine

Located in southern Montana in the magnificent Beartooth Mountains on the northern edge of the Absaroka-Beartooth Wilderness, about 30 miles north of Yellowstone National Park, this platinum-palladium sulfide mine is an excellent example of environmentally responsible mining in an extremely beautiful and sensitive environment. Operating since 1987, the Stillwater Mine has maintained a clean environmental record. The only domestic source of these strategic minerals, the Stillwater operation includes an off-site smelter in Columbus, Montana, with state-of-the-art pollution control equipment. This underground mine is recognized by regulators, environmental groups, and industry experts for its excellent concurrent reclamation activities, wildlife enhancement projects, community support programs, and responsive environmental management. In addition to its scenic attributes, the area around the mine is also recognized for its recreational opportunities-the mine is adjacent to the Stillwater River, a Montana Blue Ribbon Trout Fishery.

The Cannon Mine

Located at the intersection of South Miller and Circle Streets, this gold mine was developed in 1985, one block south of the Wenatchee, Washington, city limits. This agricultural community of approximately 40,000, known as "the apple capital of the world," is about 150 miles east of Seattle. With residents, parks, churches, schools, hospitals, and an equestrian center as its neighbors, the Cannon Mine is a model of environmentally responsible mining in an established urban environment. The mine, which operated for nine years, is now in the final stages of reclamation, and nearly all traces of this once bustling underground mining and milling project are gone. All of the millsite buildings have been removed, the area regraded, and replanted; the mine portal has been plugged; and the tailings management area has been reclaimed and planted with natural grasses. The local school district has converted the mine buildings into offices and an equipment maintenance facility. As quoted in a July 2, 1996, article entitled "A Promise Kept-Mine Tailing Cleaned Up" in the *Wenatchee World*, a local official states that the mine has done a good job living up to its promises—"The scale of the (reclamation) work is just amazing. It's been a good project."

The Flambeau Mine

Located in northern Wisconsin's Rusk County, practically within the city limits of Ladysmith and immediately adjacent to the Flambeau River, this copper mine has complied with all applicable environmental regulations since opening in 1993. Stormwater runoff from sulfide waste material and the operating open pit, along with groundwater infiltration into the pit, are treated in a state-of-the-art water treatment facility that produces mine discharge water which has proven safe at 100 percent concentration (i.e., without dilution) for the most sensitive aquatic life and meets state drinking water safety standards. Examinations of fish, crayfish, macro-invertebrates, and dragonfly; sediment sampling; and habitat characterization both above and below the mine discharge point prove the mine water has not adversely affected river life. Upon completion of mining in 1997, the open pit will be backfilled and the site will be recontoured and revegetated to pre-mining conditions. City officials credit the mine with creating an economic miracle for the local community of 4,000 people. Tax revenue from the mine has stimulated an economic development boom in Rusk County where the unemployment rate has fallen from 15.3% just prior to the mine opening to 4.0% in October 1996. The Flambeau Mine is one of Rusk County's top tourist attractions, with over 30,000 people per year visiting the mine's information center.