APPENDIX B

ACID MINE DRAINAGE

(This page intentionally left blank)

Appendix B
Acid Mine Drainage

Table of Contents

(This Page Intentionally Blank)

Appendix B
Acid Mine Drainage

B.1 Introduction

Acid mine drainage (AMD), also called acid rock drainage (ARD), is a natural occurrence resulting from the exposure of sulfur and iron bearing materials to erosion and weather. Percolation of water through these materials results in a discharge with low pH and high metals concentration. Although AMD is naturally occurring, mining activities may greatly accelerate its production. AMD production is accelerated since mining exposes new iron and sulfide surfaces (e.g, underground mine walls, open pit walls, and overburden and mine waste piles) to oxygen. As such, AMD is one of the primary environmental threats at mining sites.

To efficiently remediate mining sites, project managers must understand the formation of AMD and those factors that influence its quality and quantity, such as the interaction of sulfide minerals, air, water, and micro-organisms. This section has been added to introduce the project manager to these issues.

B.2 Description

AMD results from the oxidation of sulfide minerals inherent in some ore bodies and the surrounding rocks. Iron sulfide minerals, especially pyrite (FeS_2) and also pyrrhotine (FeS) contribute the most to formation of AMD. Oxygen (from air or dissolved oxygen) and water (as vapor or liquid) which contact the sulfide minerals directly cause chemical oxidation reactions which result in the production of sulfuric acid. The primary reactions associated with pyrite are described below.[1]

Pyrite is initially oxidized by atmospheric oxygen producing sulfuric acid and ferrous iron (Fe^{2+}) according to the following reaction:

$$FeS_2 + 7/2\ O_2 + H_2O > Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (1)$$

$$Fe^{2+} + 1/4\ O_2 + H^+ > Fe^{3+} + ½\ H_2O \quad (2)$$

The ferrous iron may be further oxidized by oxygen releasing more acid into the environment and precipitating ferric hydroxide.

$$Fe^{2+} + 1/4\ O_2 + 5/2\ H_2O > Fe(OH)_3 + 2H^+ \quad (3)$$

As acid production increases and the pH drops (to less than 4), oxidation of pyrite by ferric iron (Fe^{3+}) becomes the main mechanism for acid production.

$$FeS_2 + 14Fe^{3+} + 8H_2O > 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

---

1 Singer, P.C. and W. Strumm. 1970. Acid Mine Drainage: the rate-determining step, Science 167:1121-1123.

This reaction is catalyzed by the presence of Thiobacillus ferrooxidans. This bacterium accelerates the oxidation of ferrous iron into ferric iron (reaction 2) by a factor of 106:1. The sulfuric acid produced in the above reactions increases the solubility of other sulfide minerals in the solid surfaces. Ferric iron in acidic solution can oxidize metal sulfides per the following reaction:

$$MS + 2Fe3+ > M2+ + S + 2Fe2+ \quad (5)$$

where MS = metal sulfide (galena PbS, sphalerite, ZnS, etc.)

Metals commonly solubilized from sulfides in AMD include aluminum, copper, lead, manganese, nickel, and zinc. Metals in the form of carbonates, oxides, and silicates may also be mobilized, often aided by biological catalysts. AMD may also leach uranium, thorium, and radium from mine wastes and tailings associated with uranium mining operations. The most common metal in AMD is iron in the form of soluble ferrous ions, ferrous hydroxide (Fe(OH)2), ferrous sulfate, and ferric sulfate, as well as suspended insoluble ferric hydroxide precipitate. The iron hydroxides give AMD a red to orange color.[2]

The rates of the reactions associated with AMD have important implications, as they influence the quality (pH and metals content) and quantity of AMD produced. The rate of AMD formation depends on several factors, including the presence of microorganisms, the type of the sulfide and non-sulfide minerals present, particle size of the minerals, pH, temperature, and the amount of oxygen present.

The presence of iron-oxidizing microorganisms as catalysts affects the rate of AMD forming reactions. These bacteria are indigenous to many environments including sulfide ore bodies. As discussed above, the iron oxidizing autotrophic bacteria, T. ferrooxidans, greatly increases the oxidation of ferrous to ferric iron, which causes reaction 4 to quickly proceed. Reaction 4 produces 16 equivalents of hydrogen ions further lowering pH and causing more ferric iron to be oxidized. At low pH levels (pH 2 to 4) these bacteria thrive and multiply, further increasing reaction rates. Sulfide-oxidizing bacteria, such as T. thiooxidans may also increase AMD formation, although to what extent is less well-known.

Mineral sulfides vary in their reactivity. This is due to the physical and chemical characteristics of the various sulfide minerals. For example some metal sulfides (i.e., copper, lead, and zinc) have a tendency to form low solubility minerals which encapsulate them and prevent further oxidation. The crystal structure of the sulfide minerals is an important factor for two reasons: (1) certain crystalline structures are more stable and resist weathering (oxidation); and (2) due to the increased surface area, smaller crystals react faster.[3]

The rate of AMD formation depends upon the particle size and surface area of rocks containing the sulfide minerals. Smaller particles have increased surface area that can contact the

---

[2] duMond, Mike, "New Mexico Mine Drainage Treatment," State of New Mexico Energy, Minerals and Natural Resources Department, Albuquerque, New Mexico, 1987.

[3] Steffen, Robertson, and Kirsten Inc., Acid Rock Drainage Draft Technical Guide, Volume 2 - Summary Guide, December 1989.

weathering agents. Therefore, rock tailings (very fine particles) will weather faster than large boulders. Rates of weathering and production of AMD are dramatically increased in processed materials (e.g, crushed tailings from mineral processing or leaching), due to the increased amount of surface area.

The rate of AMD formation is also dependent on pH and temperature. The chemical reaction rate is higher at low pH because the solubility of the metals increases and biological oxidation peaks at a pH of about 3.5. Therefore, it is generally true that as more sulfuric acid is released and the pH decreases, more leaching occurs. Both the chemical and biological reaction rates also increase with increased temperature. This is because of increased solubility of metal species and increased biological activity at higher temperatures.

It is apparent from the above discussion that the production of AMD is complicated. Due to the many factors that influence AMD, the short-term and long-term quality and quantity produced may be difficult to characterize or predict. Section A.4.2 of this document discusses methods for characterizing the production of AMD from waste solids (sources) associated with mining processes.

B.3 Environmental Effects

As discussed above, AMD introduces sulfuric acid and heavy metals into the environment. The environment can naturally assimilate some AMD through dilution, biological activity, and neutralization, although its capacity to treat AMD may be limited. When this treatment capacity is exceeded, drainage and surface water flowing out of mining areas can be very acidic and contain elevated concentrations of metals. The metal-laden acidic drainage and surface water can lead to ground water contamination.

The ability of the receiving environment to assimilate AMD will depend on site specific conditions such as drainage patterns and dilution, biological activity, and neutralizing capacity of the ore, waste material, tailings, and/or surrounding soils. Drainage patterns and dilution depend largely on the climate and topography of a site. Naturally occurring biological activity can attenuate the metals concentration by adsorption and precipitation of some metal species such as sulfates.

Neutralization is the consumption of acidity in which hydrogen ions are consumed according to the following reactions:

$$CaCO3 + H+ > Ca2+ + HCO3- \quad (6)$$
$$HCO3- + H+ > H2O + CO2 \quad (7)$$

The neutralization capacity of a soil depends largely on the presence of naturally occurring, acid consuming minerals. The most common mineral is calcite (CaCO3), a major constituent of limestone, and dolomite (CaMg(CO3)2). Other neutralizing minerals include other carbonates of iron and magnesium and aluminum and iron hydroxides. As neutralization occurs, metals precipitate because of decreased solubility at higher pH.

The impact of AMD can increase over time if the neutralizing capacities of the soil are depleted. This may occur if the neutralizing minerals have a tendency to form crusts of precipitated salts or gypsum which inhibits further reaction, or if the neutralizing minerals are depleted through numerous reactions with AMD. The impact of AMD can also change if the rates of AMD formation change due to the alteration of site conditions. For these reasons, there is often a time lag after mining activities begin until AMD is detected. The times can range from 1 to 10 or more years; AMD may not be detected until after surface reclamation occurs. Acid generation, once it begins, is difficult to control, often accelerates, and can persist for centuries.

AMD may be compounded by other problems caused by mining activities. Chemicals or petroleum products used in equipment and vehicle maintenance can pollute mining sites. Heap leaching technologies utilize cyanide to extract gold, and the failure of liners can introduce cyanide into the environment. In addition, mining often leads to higher erosion rates and increased dissolved salts, sediment loads, and turbidity of run-off. Radionuclides can also be leached out of the rock. All of these contaminants, as well as the heavy metals mentioned earlier can enter the surface water and the ground water. These contaminants, in addition to the acidic run-off, must all be considered when treating AMD.

If site conditions are conducive to AMD formation and the capacity to assimilate AMD has been exceeded, environmental impacts can be quite severe. Impacts depend on the nature (strength and volume) of the AMD and the proximity of aquatic resources. Impacts can include lowering of water quality, alteration of aquatic and terrestrial ecosystems, potential destruction of aquatic habitats, and, if the site is near human residences, contamination of drinking water supplies. Impacts are far reaching, are of concern to regulatory decisionmakers, and must be addressed during cleanup actions.

B.4 Contacts and References

Appendix B of this Manual is an annotated bibliography of passive acid mine drainage treatment technologies. EPA regional and other Federal Land Management Agency contacts with expertise in acid mine drainage prediction, analysis, and remediation, can be found in Appendix L. The remainder of this document is an annotated bibliography of acid mine drainage references.

B.5 AMD Annotated Bibliography

Ackman, Terry E. and R.L.P. Kleinmann. “In-Line Aeration and Treatment of Acid Mine Drainage,” Avondale, MD, U.S. Dept. of the Interior, Bureau of Mines, 1984.
Reference not available.

Ackman, Terry E. “Sludge Disposal from Acid Mine Drainage Treatment,” Avondale, MD, U.S. Dept. of the Interior, Bureau of Mines, 1982.
Reference not available.

Aljoe, W.W. and J.W. Hawkins, 1991. “Hydrologic Characterization and In-Situ Neutralization of Acidic Mine Pools in Abandoned Underground Coal Mines,” in Proceedings Second International Conference on the Abatement of Acidic Drainage, September 16-18, 1991, Montreal, Canada, Volume 1, pp.69-90.
Reference not available.

Alpers, Charles N. and Blowes, David W., 1994. *Environmental Geochemistry of Sulfide Oxidation,* ACS Symposium Series 550, American Chemical Society, Washington, D.C.
Contains several papers on acid mine drainage. Reference not available.

Altringer 1991. Altringer, P.B., Lien, R.H., Gardner, K.R., Biological and Chemical Selenium Removal from Precious Metals Solutions, proceedings of the Symposium on Environmental Management for the 1990s, Denver, Colorado, February 25-28, 1991.
Reference not available.

Balistrieri, Laurie S., 1995. Impacts of acid drainage on wetlands in the San Luis Valley, Colorado, *in USGS Mine Drainage Newsletter,* No. 3, March, 1995, http://water.wr.usgs.gov/mine/mar/luis.html.
Describes metal accumulation in sediments of a natural wetland receiving AMD from the Summitville gold mine. The wetland, located in the Alamosa River system, exhibits increased levels of Cu, Cr, and Zn.

Batal, Wafa, Laudon, Leslie S., Wildeman, Thomas R., and Mohdnoordin, Noorhanita, 1988. Bacteriological tests from the constructed wetland of the Big Five Tunnel, Idaho Springs, Colorado, *in Proceedings of the U.S. EPA’s Forum on Remediation of CERCLA Mining Waste Sites, April 25, 1989, Ward, Colorado,* p. 134-148.
Describes variations in the types and amounts of bacteria found in three different substrate materials in constructed wetland test cells following two months of AMD flow through the cells.

Bhole, A.G., 1994. Acid mine drainage and its treatment, *in Proceedings of the International Symposium on the Impact of Mining on the Environment, Problems and Solutions,* A.A. Balkema, Rotterdam, p. 131-142.
Reference not available.

Bikerman, Jacob Joseph, et al. “Treatment of Acid Mine Drainage” prepared by Horizons Inc. for Federal Water Quality Administration, Dept. of the Interior. Washington: for sale by the Superintendent of Documents, U.S. Government Printing Office, 1970.
Reference not available.

Bituminous Coal Research, Inc. “Studies on Limestone Treatment of Acid Mine Drainage; Optimization and Development of Improve Chemical Techniques for the Treatment of Coal Mine Drainage.” Washington: Federal Water Pollution Control Administration; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1970.

Reference not available.

Blowes, D.W., et al. “Treatment of Mine Drainage Using In Situ Reactive Walls,” in Proceedings of the Sudbury '95 Conference, Mining and the Environment. May 28-June 1, 1995, Sudbury, Ontario. Vol 3, pp. 979-987, 1995.

Reference not available.

Blowes, D.W., Ptacek, C.J., Waybrant, K.R., and Bain, J.G., 1995. In situ treatment of mine drainage using porous reactive walls, *Proceedings of the BIOMINET Eleventh Annual Meeting, January, 1995,* Ottawa, Ontario, pp. 119-128.

Describes a system for treating acidified waters that contaminate shallow ground water by installing screens of organic carbon in an excavated portion of the aquifer. Various carbon sources were tested down-gradient from mine tailings at Sudbury, ON. The reactive walls induce bacterially mediated sulfate reduction and subsequent metal sulfide precipitation. Pilot studies show Fe and SO4 concentrations decreased dramatically while pH and alkalinity increased.

Blowes, D.W., et al. 1994. In situ treatment of mine drainage water using porous reactive walls. In: The “New Economy” Green Needs and Opportunities, Environment and Energy Conference of Ontario, November 15 & 16, 1994, Toronto, Ontario. (Manuscript distributed on diskette.)

Boling, S.D. and Kobylinski, E.A., 1992. Treatment of metal-contaminated acidic mine drainage, *in 47th Purdue Industrial Waste Conference Proceedings,* Lewis Publishers, Chelsea, MI, p. 669-676.

Reference not available.

Bolis, Judith L., 1992. *Bench-scale Analysis of Anaerobic Wetlands Treatment of Acid Mine Drainage,* Unpubl. M.S. thesis, Colorado School of Mines, Golden, CO, 116 pp.

Experimental tests of high-alkalinity organic substrates to evaluate anaerobic treatment of AMD from the Big Five Tunnel, National Tunnel and Quartz Hill Tunnel in Clear Creek, CO. Results showed that removal of Cu, Zn, Fe, and Mn exceeded 99 percent and that treatment raised pH from 2.5-5.6 to greater than 7.0. Experimental results were used to calculate loadings and can be used in the design of pilot-scale or full-scale wetlands.

Borek S. L., T. E. Ackman, G. P. Watzlaf, R. W. Hammack, J. P. Lipscomb, 1991, "The Long-Term Evaluation of Mine Seals Constructed in Randolph County, W.V. in 1967," in Proceedings Twelfth Annual West Virginia Surface Mine Drainage Task Force Symposium, April 3-4, 1991, Morgantown, West Virginia.

Reference not available.

Boult, S., Collins, D.N., White, K.N., and Curtis, C.D., 1994. Metal transport in a stream polluted by acid mine drainage -- The Afon Goch, Anglesey, UK, *Environmental Pollution,* v. 84, p. 279-284.

Studies the natural precipitation of metal complexes in a stream contaminated by acid drainage (pH=2.3) from metal mines caused by the inflow of neutral tributary waters. Discusses implications for the management and remediation of polluted stream systems.

Bowders, J. and E. Chiado, 1990, " Engineering Evaluation of Waste Phosphatic Clay for Producing Low Permeability Barriers," in Proceedings 1990 Mining and Reclamation Conference and Exhibition, Volume 1, 11-18pp, West Virginia University.

Reference not available.

Brady, K. B., M. Smith, R. Beam and C. Cravotta III, 1990, "Effectiveness of Addition of Alkaline Materials at Surface Coal Mines in Preventing and Abating Acid Mine Drainage: Part 2 Mine Site Case Studies," in Proceedings of the 1990 Mining and Reclamation Conference and Exhibition, Volume 1, 227-242pp, West Virginia University.

Reference not available.

Brady K.B., J.R. Shaulis and V.W. Sekma, 1988, "A Study of Mine Drainage Quality and Prediction Using Overburden Analysis and Paleoenvironmental Reconstructions, Fayette County, Pennsylvania," in Conference Proceedings, Mine Drainage and Surface Mine Reclamation, U.S. Bureau of Mines Information Circular 9183, 33-44pp.

Reference not available.

Brodie, G., et al. “Passive Anoxic Limestone Drains to Increase Effectiveness of Wetlands Acid Drainage Treatment Systems,” Proceedings: 12th Annual NAAMLP Conference, Returning Mined Land to Beneficial Use, Breckinridge, Colorado, September 16-20, 1990.

Reference not available.

Brodie, G.A., 1993. Staged, aerobic constructed wetlands to treat acid drainage: Case history of Fabius impoundment 1 and overview of the Tennessee Valley Authority’s program, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 157-165.

Reviews the success of 12 wetland systems operated by TVA and discusses the quality of effluent from impoundment 1, which has been in operation since 1985.

Brodie, G.A., Britt, C.R., Tomaszewski, T.M., and Taylor, H.N., 1993. Anoxic limestone drains to enhance performance of aerobic acid drainage wetlands: Experiences of the Tennessee Valley Authority, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 129-138.

Reviews the effectiveness of anoxic limestone drains in increasing alkalinity to prevent pH decreases due to Fe hydrolysis.

Brodie, Gregory A., Hammer, Donald A., and Tomljanovich, David A., 1989. Treatment of acid drainage with a constructed wetland at the Tennessee Valley Authority 950 Coal Mine, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Ann Arbor, MI, p. 201-209.

Reviews the design, construction, and success of a constructed wetland to treat acidic drainage from impoundment 3 at the 950 coal mine in AL.

Brodie, Gregory A., Hammer, Donald A., and Tomljanovich, David A., 1988. An evaluation of substrate types in constructed wetlands acid drainage treatment systems, *in* U.S. Bureau of Mines, *Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183, p. 389-398.

Experimentally investigated the effectiveness of 5 substrate types (natural wetland, acidic wetland, clay, mine spoil, and river pea gravel) in mitigating acidic drainage from the Fabius coal mine (AL). Study showed that substrate type is less important than the plant-soil-microbe complex that developed in each cell.

Brookhaven National Laboratory, Dept. of Applied Science. "Treatment of Acid Mine Drainage by Ozone Oxidation." Washington: EPA Water Quality Office; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1970.
Reference not available.

Brooks 1992. Reclamation of the Timberline Heap Leach: Tooele County, Utah, USDI Bureau of Land Management, Technical Note #386, by Steven J. Brooks, 1992.
Reference not available.

Burnett, MacKenzie and Skousen, Jeffrey G., 1995. Injection of limestone into underground mines for AMD control, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 357-362.
Describes a project in which a coal mine portal was sealed and backfilled with limestone. Initially, the seal reduced water flow, increased pH of the remaining effluent, and created net alkaline effluent with reduced Fe and Al concentrations. Subsequent high flows changed flow paths so that water no longer contacts the limestone and escapes untreated.

Cambridge, M., 1995. Use of passive systems for the treatment and remediation of mine outflows and seepages, *Minerals Industry International,* No. 1024, p. 35-42.
A review of the potential uses of the passive systems available and of their effectiveness in preventing long-term environmental damage. Cites case studies of the treatment systems used at the Wheal Jane and Consolidated copper-tin mines (Cornwall, England). Includes a discussion of general principles that may affect the long-term development of acidity.

Camp, Dresser & McKee, Inc., 1991. *Clear Creek Phase II Feasibility Study Report,* prepared for the Colorado Department of Health, Hazardous Materials and Waste Management Division, Denver, CO, vol. 1, p. 3-77 to 3-179.
Contains sections on passive treatment and combined passive and active systems for treating metal-laden AMD from precious metal mines in the Clear Creek drainage of Colorado. Passive treatment technologies include cascade aeration to promote precipitation of iron compounds and wetland treatment in aerobic and anaerobic environments to reduce metal and sulfur contents. Passive treatment designs are discussed for the Argo Tunnel, Big Five Tunnel, National Tunnel, Burleigh Tunnel, Rockford Tunnel, Gregory Incline, Quartz Hill Tunnel, and McClelland Tunnel. Discusses designs that incorporate disposal of precipitated metals in accordance with RCRA guidelines and for *in situ* fixation of precipitated metals. Active treatment includes chemical precipitation of metals. Considers treatment of surface and ground waters.

Caruccio F. T. and G. Gediel, 1989, "Water Management Strategies in Abating Acid Mine Drainage - Is Water Diversion Really Beneficial?," in Proceedings 1989 Multinational Conference on Mine Planning and Design, University of Kentucky, Lexington, Kentucky.
Reference not available.

Catalytic, Inc. "Neutradesulfating Treatment Process for Acid Mine Drainage," prepared for the U.S. Environmental Protection Agency; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1971.
Reference not available.

Chapman, B.M, Jones, D.R., and Jung, R.F., 1983. Processes controlling metal ion attenuation in acid mine drainage streams, *Geochimica et Cosmochimica Acta,* v. 47, p. 1957-1973.

Presents detailed analyses of two acid mine drainage streams in Australia to determine the dominant processes that control heavy metal transport and attenuation under conditions of chronic high-level pollution. Streams receive AMD input from sulfide-rich base and precious metals deposits. Results show that natural processes cause precipitation of metal hydroxides that lower Fe, Cu, and Al in stream waters as pH rises due to the inflow of higher pH tributary waters. Concentrations of Cd, Zn, and Mn apparently diminished only by dilution. Presents a graphical method to delineate the point along a stream channel where chemical removal mechanisms become effective for each element.

Cliff, John, Sterner, Pat, Skousen, Jeff, and Sexstone, Alan, 1995. Treatment of acid mine drainage with a combined wetland/anoxic limestone drain: A comparison of laboratory versus field results, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 311-330.

Compares results from the Douglas Highwall project (WV) and greenhouse experiments conducted at West Virginia University, both of which utilized similar designs. Found that slight differences in influent flow rate and the hydraulic conductivity of organic substrates used in anoxic limestone drains greatly affected the ability of the system to reduce and remove Fe, increase Eh, and neutralize acid.

Cohen, R.H., 1996. The technology and operation of passive mine drainage treatment systems, *in Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites,* U.S. Environmental Protection Agency Seminar Publication No. EPA/625/R-95/007, p. 18-29.

Reference not available.

Colorado Department of Public Health and Environment, Wetlands-based treatment, http://www.gnet.org/gnet/tech/techdb/site/demongng/colodepa.htm.

Describes the technology in use and status of studies at metal mines in Colorado.

Concurrent Technologies Corporation, “Recovering Metal Values from Acid Mine Drainage: Market and Technology Analyses,” Summary Report to Southern Alleghenies Conservancy, March 29, 1996.

Reference not available.

Dames and Moore, 1981, "Outcrop Barrier Design Guidelines For Appalachian Coal Mines," prepared for the U.S. Bureau of Mines, Contract J0395069, Bureau of Mines Open File Report 134-81.

Reference not available.

Dames and Moore, 1981, “Outcrop Barrier Design Guidelines For Appalachian Coal Mines,” prepared for the U.S. Bureau of Mines, Contract J0395069, Bureau of Mines Open File Report 134-81.

Reference not available.

Davison, J., 1993. Successful acid mine drainage and heavy metal site bioremediation, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 167-178.

Discusses the Lambda Bio-Carb Process (patent pending) for *in situ* bioremediation. The process uses site-indigenous cultures in microecological balance to construct a self-sustaining system that self-adjusts to variations in influent composition.

Desborough, George A., 1992. *Ion exchange capture of copper, lead, and zinc in acid-rock drainages of Colorado using natural clinoptilolite--Preliminary field studies,* U.S. Geological Survey Open-File Report 92-614, 16 pp.

Study evaluated efficiency of clinoptilolite-rich rock in reducing heavy metal concentrations in 9 stream sites contaminated by acid mine drainage (pH=2-5) in central CO. Fe and As deposited as fine particles on zeolite surface, whereas Cu, Pb, and Zn were ion exchangeable using ammonium chloride solution. Dominant factors influencing ion exchange rates were dissolved metal concentration, water flow rate, zeolite fragment size, and water temperature.

Dietz, Jonathan M., Watts, Robert G, and Stidinger, Dennis M., 1994., Evaluation of acidic mine drainage treatment in constructed wetlands systems, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 71-79.

Conducted and evaluated field tests of 6 constructed wetland treatment systems for a 2 year period. Tests monitored acid and metals removal from stream sites receiving AMD in central PA.

Donlan, Ron, "Constructed Wetlands for the Treatment of Acid Mine Drainage," Water Pollution Control Association of Pennsylvania, March-April 1989.

Reference not available.

Donovan, Joseph J. and Ziemkiewicz, Paul F., 1994. Early weathering of pyritic coal spoil piles interstratified with chemical amendments, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 119-128.

Monitored acidity from eleven 400-ton constructed piles in WV during 1982. Piles had 1) no treatment, 2) layered base amendments (limestone, lime, rock phosphate), and 3) sodium lauryl phosphate amendment. Acid conditions ensued for all nontreated piles and amended piles with NP/MPA <1. Acid conditions developed in some amended piles with NP/MPA up to 2.3. Layered amendments were judged to be less effective than piles in which basic materials were evenly dispersed.

Doyle 1990. *Mining and Mineral Processing Wastes,* proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, California, May 30-June 1, 1990, Society for Mining, Metallurgy, and Exploration, Inc., Doyle, F.M., editor, 1990.

Reference not available.

DuMond, Mike, 1988. New Mexico mine drainage treatment, *in Proceedings of the U.S. EPA's Forum on Remediation of CERCLA Mining Waste Sites, April 25, 1989, Ward, Colorado,* p. 65-94.

Describes a variety of techniques presently being used to treat AMD at coal, metal, and uranium mines in New Mexico. Both active and passive treatment techniques are discussed.

Durkin, T.V. and Hermann, J.G., 1996. Focusing on the problem of mining wastes: An introduction to acid mine drainage, *in Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites,* U.S. Environmental Protection Agency Seminar Publication No. EPA/625/R-95/007, p. 1-3.

Reference not available.

Eger, Paul and Lapakko, Kim, 1989. Use of wetlands to remove nickel and copper from mine drainage, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 780-787.

Describes the use of natural wetlands to treat drainage from taconite mines in MN contaminated with Ni, Cu, Co, and Zn. Also discusses the siting and design of test cells within existing wetlands.

Eger, P. and Lapakko, K., 1988. Nickel and copper removal from mine drainage by a natural wetland, *Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183, p. 301-309.

Reports results of a study of metal removal from neutral drainage (pH=7.2) generated from an open-pit taconite mine in MN. The natural white cedar peatland removed significant amounts of nickel and copper, most taken up by the peat.

Ellison, R.D. & Hutchison, I.P.G., Mine Waste Management: A Resource for Mining Industry Professionals, Regulators and Consulting Engineers, Lewis Publishing, INC.,Chelsea, MI, 1992, pgs.127-184.

Reference not available.

Emerick, J.C., Huskie, W.W., and Cooper, D.J., 1988. Treatment of discharge from a high elevation metal mine in the Colorado Rockies using an existing wetland, *in Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183, p. 345-351.

Reports inconclusive results of a study in which acidic mine drainage (pH=3.6) was diverted into a natural wetland. Study found that significant accumulations of metals existed in the wetland prior to the introduction of mine drainage and that the low hydraulic conductivity of the peat precluded significant flow of mine drainage through wetland sediments. Study did confirm that the plant species present had a high tolerance to metals and low pH and could be used in constructed wetlands throughout the region.

Emerick, John C., Wildeman, Thomas R., Cohen, Ronald R., and Klusman, Ronald W., 1994. Constructed wetland treatment of acid mine discharge at Idaho Springs, Colorado, *in* K.C. Stewart and R.C. Severson, eds., *Guidebook on the Geology, History, and Surface-Water Contamination and Remediation in the Area from Denver to Idaho Springs, Colorado,* U.S. Geological Survey Circular 1097, p. 49-55.

Investigates factors influencing the effectiveness of wetlands constructed to treat acid mine drainage from the Big Five Tunnel over a three year period. Discusses biochemical processes that lead to effective treatment. Results show that Cu and Zn are effectively removed, Fe less effectively removed, and pH buffered to 5.5 or higher for the long term. Concludes that treatment systems incorporating forced vertical flow are more effective than those relying on lateral flow and that low flow rates permit more metal removal than high flow rates.

Environmental Research and Applications, Inc. “Concentrated Mine Drainage Disposal Into Sewage Treatment Systems; the Disposal of Acid Brines from Acid Mine Drainage in Municipal Wastewater Treatment.” Washington: EPA Research and Monitoring, 1971.

Reference not available.

Erickson, B.M., Briggs, P.H., and Peacock, T.R., 1996. Metal concentrations in sedges in a wetland receiving acid mine drainage from St. Kevin Gulch, Leadville, Colorado, *in* Morganwalp, David W. and Aronson, David A., eds., *U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Colorado Springs, CO, September 20-24, 1993,* U.S. Geological Survey Water Resources Investigation Report 94-4015, p. 797-804.

Characterizes the concentrations of Cd, Cu, Fe, Pb, Mn, and Zn in apparently healthy sedges from a natural wetland receiving AMD. Finds that baseline concentrations are elevated above the geometric mean for noncontaminated areas and that Cd, Pb, and Zn locally exceed recommended dietary levels for cattle.

Erickson, B.M., Briggs, P.H., and Peacock, T.R., 1994. Metal composition of sedges collected on the wetland receiving acid mine drainage from St. Kevin Gulch, Leadville, Colorado, *U.S.G.S. Research on Mineral Resources - 1994,* U.S. Geological Survey Circular 1103-A, p. 33-34.

Characterizes the content of Cd, Cu, Fe, Pb, Mn, and Zn in sedges from a wetland receiving acid mine drainage, in order to determine background values and the amount of material removed from AMD influent.

Erickson, L.J., and J.H. Deniseger, 1987. "Impact Assessment of Acid Drainage from an Abandoned Copper Mine on Mt. Washington", in an unpublished report of the British Columbia Ministry of Environment and Parks, Waste Management Program, Nanaimo.

Reference not available.

Evangelou, V., U. Sainju and E. Portig, 1991, "Some Considerations When Applying Limestone/Rock Phosphate Materials on to Acid Pyritic Spoils," in Proceedings Twelfth Annual West Virginia Surface Mine Drainage Task Force Symposium , April 3-4, 1991, Morgantown, West Virginia.

Reference not available.

Faulkner, Ben B. and Skousen, Jeff G., 1995. Treatment of acid mine drainage by passive treatment systems, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 267-274.

Reviews the effectiveness of wetlands and anoxic limestone drains in treating AMD from coal mines in WV. Studied sites include the Keister, S. Kelly, Pierce, and Z&F wetlands and the Greendale, Kodiak, Lillybrook, Preston, Lobo Capital, and Benham anoxic limestone drains. Finds that limestone in wetland substrates does not appear to improve metal removal efficiency, that hay added to anoxic limestone drains diminishes the ability of limestone to neutralize acidity, and that maintaining water flow through the drain is critical to the drain’s success.

Faulkner, Ben B. and Skousen, Jeff G., 1993. Monitoring of passive treatment systems: An update, *in Proceedings Fourteenth Annual West Virginia Surface Mine Drainage Task Force Symposium,* Morgantown, West Virginia, April 27-28, 1993.

Reports updated monitoring results on the Keister, S. Kelly, Pierce, and Z&F wetlands and the Benham, Lobo Capital, Kodiak, Lillybrook, and Preston anoxic limestone drains, all of which are associated with eastern coal mines.

Faulkner, B. (ed.), 1991, "Handbook for Use of Ammonia in Treating Mine Waters," West Virginia Mining and Reclamation Association, Charleston, West Virginia.

Reference not available.

Filipek, Lorraine H., 1986. Organic-metal interaction in a stream contaminated by acid mine drainage, *in* Donald Carlisle, Wade L. Berry, Isaac R. Kaplan, and John R. Watterson (eds)., *Mineral Exploration: Biological Systems and Organic Matter, Rubey Volume V,* Prentice-Hall, Englewood Cliffs, NJ, p. 206.

Abstract reporting results of a study to examine the effect of pH on the metal scavenging ability of algae. Concludes that cationic species are less effectively scavanged at low pH, whereas anionic metal species (e.g., As) are completely removed from solution within a short distance from the source.

Frostman, T.M., 1993. A peat/wetland treatment approach to acidic mine drainage abatement, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 197-200.

Reviews the design and operation of a peat/wetland system that could be installed to treat AMD from an iron mine in MN (pH of 5-6, low metal content).

Fyson, Andrew, Kalin, Margarete, and Adrian, Les, W., 1994. Arsenic and nickel removal by wetland sediments, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 109-118.

Laboratory experiments to test the capacity of muskeg sediments to treat mildly acidic (pH=4), metal-bearing drainage. Alfalfa, potato waste and hydroseed mulch used to simulate muskeg sediments. Experiments show this treatment can be effective in removing metals and raising pH, especially if reducing conditions can be maintained.

Ganse, Margaret A., 1993. *Geotechnical Design of a Four-stage Constructed Wetland for the Remediation of Acid Mine Drainage,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO, 133 pp.

Develops guidelines for creating effective conceptual designs that utilize knowledge of wetland chemistry, hydraulic capacity, and structural integrity of treatment components. Applies guidelines to the redesign of the passive treatment system from the Marshall No. 5 coal mine near Boulder, CO. System components include an anoxic limestone drain to add alkalinity, a settling basin to promote aeration of the AMD, a wetland with aerobic and anaerobic function to raise pH, and a polishing cell for final aerobic treatment. Preliminary results show pH increasing from 4.5 to 6.4 and alkalinity increasing from 8 mg/l to 79 mg/l.

Garbutt, K., Kittle, D.L., and McGraw, J.B., 1994. The tolerance of wetland plant species to acid mine drainage: A method of selecting plant species for use in constructed wetlands receiving mine drainage, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 2, p. 413.

Study exposed five common wetland species to AMD with a range of pH values to test individual species tolerance. Recommended species are suggested for various pH levels.

Girts, M.A. and Kleinmann, R.L.P., 1986. Constructed wetlands for treatment of mine water, *in American Institute of Mining Engineers Fall Meeting, St. Louis, MO.*

Reference not available.

Gormely, L., Higgs, T.W., Kistritz, R.U., and Sobolewski, A., 1990. Assessment of wetlands for gold mill effluent treatment, report prepared for the Mine Pollution Control Branch of Saskatchewan Environment and Public Safety, Saskatoon, SK, Canada, 63 pp.

Reference not available.

Gross, M.A., Formica, S.J., Gandy, L.C., and Hestir, J., 1993. A comparison of local waste materials for sulfate-reducing wetlands substrate, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 179-185.
Investigates the suitability of locally derived organic materials for their use in sulfate-reducing constructed wetlands at a clay mine in AR and presents the results of lab tests.

Groupe de Recherche en Geologie de L'ingenieur, 1992. *Acid Mine Drainage Generation from a Waste Rock Dump and Evaluation of Dry Covers using Natural Materials: La Mine Doyon Case Study, Quebec,* Final Report to Service de la Technologie Miniere Centre de Recherches Minerales, 22 pp.
Objectives were to characterize the problem of AMD generation in the south mine dump of the La Mine Doyon and to study the feasibility of using natural materials to construct dry covers to control air and water circulation in the dump.

Guertin, deForest, Emerick, J.C., and Howard, E.A., 1985. Passive mine drainage treatment systems: a theoretical assessment and experimental evaluation, Colorado Mined Land Reclamation Division, Unpubl. Manuscript, 71 pp.
Describes utility of passive AMD systems with application to the Marshall No. 5 coal mine.

Hammer, D.A., ed., 1989. *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Ann Arbor, MI.
Contains numerous papers on passive treatment systems at metal mines and coal mines, most of which are annotated herein.

Healey, P.M. and Robertson, A.M., 1989. A case history of an acid generation abatement program for an abandoned copper mine, *in* Vancouver Geotechnical Society, *Geotechnical Aspects of Tailings Disposal and Acid Mine Drainage,* May 26, 1989.
Describes rationale for the implementation of an AMD abatement program at an open-pit copper mine and aspects of the design. The method selected to control AMD consisted of a low permeability till cover over waste material to reduce oxygen and water infiltration to sulfide-bearing materials, collection and diversion ditches and a limestone-lined channel.

Hedin, Robert S., Hammack, Richard, and Hyman, David, 1989. Potential importance of sulfate reduction processes in wetlands constructed to treat mine drainage, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 508-514.
Discusses the processes by which sulfides are formed and destroyed in wetlands and the importance of maintaining a sulfide-forming (reducing) environment. Presents characteristics of an ideal treatment system and discusses it operation.

Hedin, R.S. and Nairn, R.W., 1993. Contaminant removal capabilities of wetlands constructed to treat coal mine drainage, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 187-195.
Reports measurements of contaminant removal at 11 constructed wetlands in western PA. Concludes that contaminant removal occurs in a manner consistent with well-known chemical and biological processes.

Hedin, R.S. and Nairn, R.W., 1990. Sizing and performance of constructed wetlands: Case studies, *in Proceedings of the 1990 Mining and Reclamation Conference and Exhibition,* Charleston, WV, vol. 2, p. 385-392.
Reference not available.

Hedin, Robert S., Nairn, Robert W., and Kleinmann, Robert L.P., 1994. *Passive Treatment of Coal Mine Drainage,* U. S. Bureau of Mines, Information Circular 9389, 35 pp.
Reviews the construction and operation of passive treatment systems, including chemical and biological processes, contaminant removal, and system design and sizing. Considers three types of passive technologies: aerobic wetlands, organic substrate wetlands, and anoxic limestone drains. Presents a model for design and sizing of passive treatment systems.

Hedin, Robert S. and Watzlaf, George R., 1994. The effects of anoxic limestone drains on mine water chemistry, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 185-194.
Studied construction and water quality characteristics of 21 anoxic limestone drains in Appalachia to identify and evaluate factors responsible for the variable performance of these systems. Large changes in acidity were primarily associated with retention of ferric iron and aluminum. Presents a technique to determine drain size.

Hedin, Robert S. and Robert W. Nairn. "Designing and Sizing Passive Mine Drainage Treatment Systems," 13th Annual West Virginia Surface Mine Drainage Task Force Symposium, April 8-9, 1992.
Reference not available.

Hedin, R.S., et al., "Constructing Wetlands to Treat Acid Mine Drainage," Course Notes, 13th Annual West Virginia Surface Mine Drainage Task Force Symposium, April 8-9, 1992.
Reference not available.

Hedin, R.S., "Passive Anoxic Limestone Drains: A Preliminary Summary," 1990.
Reference not available.

Hedin, R.S. and R.W. Nairn, "Sizing and Performance of Constructed Wetland: Case Studies," Mine and Reclamation Conference and Exhibition, Charleston, WV, April 23-26, 1990.
Reference not available.

Hedin, R.S., "Treatment of Coal Mine Drainage with Constructed Wetlands," Wetlands, Ecology and Conservation: Emphasis in Pennsylvania, Pennsylvania Academy of Science, 1989. (Chapter 28)
Reference not available.

Heil, Michael T. and Kerins, Jr., Francis J., 1988. The Tracy wetlands: A case study of two passive mine drainage treatment systems in Montana, *in* U.S. Bureau of Mines, *Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183, p. 352-358.
Reports results for two constructed wetlands receiving acidic (pH=2.7) coal mine drainage. Low system retention times and minimal contact time between the peat and mine drainage precluded effective treatment by these wetlands.

Hellier, William W., Giovannitti, Ernest F., and Slack, Peter T., 1994. Best professional judgment analysis for constructed wetlands as a best available technology for the treatment of post-mining groundwater seeps, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 60-69.

Results of an analysis of 73 constructed wetlands to assess removal of acidity, Fe and Mn from surface coal mines. Develops sizing guidelines and costs to treat seeps for 25 years with and without anoxic limestone drain pretreatment.

Henrot, Jacqueline, Wieder, R. Kelman, Heston, Katherine P., and Nardi, Marianne P., 1989. Wetland treatment of coal mine drainage: Controlled studies of iron retention in model wetland systems, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 793-800.

Results of a pilot lab study to evaluate the effects of Fe concentration in influent waters on Fe retention in wetlands. Concludes that the formation of iron oxides is key control on iron retention and the effective lifetime of a constructed wetland.

Holm, J. David and Bishop, Michael B., 1985. Passive mine drainage treatment, *in* Randol International, Ltd., *Water Management and Treatment for Mining and Metallurgical Operations,* vol. 3, p. 1593-1602.

Describes natural processes that can be used to passively treat acidic mine drainage. Includes a description of wetlands constructed to treat AMD from the Delaware Mine, a silver mine in the Peru Creek, CO drainage and the Schuster Mine and Marshall No. 5 Mine, both of which are coal mines.

Holm, J.D. and Elmore, T., 1986. Passive mine drainage treatment using artificial and natural wetlands, *in Proceedings of the High Altitude Revegetation Workshop,* no. 7, p. 41-48.

Reference not available.

Holm, Bishop, and Tempo, 1985. Incomplete reference included in Randol International, Ltd., *Water Management and Treatment for Mining and Metallurgical Operations,* vol. 3, p. 1651-1670.

Briefly describes passive treatment systems in use at the Marshall No. 5 Coal Mine (CO), U.S. Bureau of Mines Bruceton Research Station, AMAX Buick lead and zinc mill (MO), New Lead Belt region (MO), and the Pierrepont (NY) lead-zinc mine.

Holm, J.D., 1983. Passive mine drainage treatment: Selected case studies, *in* Medine A. and Anderson, M., eds., *Proceedings, 1983 National Conference on Environmental Engineering,* American Society of Civil Engineers.

Provides descriptions of case studies of wetlands constructed to treat AMD from non-coal mines in Colorado. Reference not available.

Holm, J. David, and Guertin, deForest, 1985. Theoretical assessment and design considerations for passive mine drainage treatment systems, *in* Randol International, Ltd., *Water Management and Treatment for Mining and Metallurgical Operations,* vol. 3, p. 1603-1650.

Briefly describes passive treatment mechanisms including pH modulation, cation exchange, sorption and coprecipitation, complexing, biological extraction, and dilution. Discusses the design of passive treatment systems and evaluation of appropriate sites for their installation.

Howard, Edward A., Emerick, John C., and Wildeman, Thomas R., 1989. Design and construction of a research site for passive mine drainage treatment in Idaho Springs, Colorado, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 761-764.

Describes the design and construction of a wetland in a high mountain climate to treat AMD from the Big Five Tunnel. Provides information on liner types, drain spacing and size, organic substrate materials, and vegetation.

Howard, Edward A., Emerick, John C., and Wildeman, Thomas R., 1988. The design, construction and initial operation of a research site for passive mine drainage treatment in Idaho Springs, CO, *in Proceedings of the U.S. EPA's Forum on Remediation of CERCLA Mining Waste Sites, April 25, 1989, Ward, Colorado,* p. 122-133.

Describes the design and construction of an artificial wetland to treat AMD from the Big Five Tunnel precious metal mine. Included are sections that discuss the preparation of plants and substrate materials and procedures for sample collection.

Howard, Edward A., Hestmark, Martin C., and Margulies, Todd D., 1989. Determining feasibility of using forest products or on-site materials in the treatment of acid mine drainage in Colorado, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 774-779.

Characterizes the cation exchange capacities and metal removal efficiencies of humus and forest litter from ponderosa pine, lodgepole pine, spruce-fir, and aspen forests. Concludes that ponderosa and aspen litters have the highest ion exchange capacities but that aspen and spruce-fir materials were the most efficient at removing metals from AMD. These materials are suitable for passive treatment systems.

Huskie, William W., 1987. Pennsylvania mine drainage diversion study: Site survey and water quality assessment, *in* Emerick, John C., Cooper, David J., Huskie, William W., and Lewis, W. Stephen, eds., *Documentation and Analysis of the Effects of Diverted Mine Water on a Wetland Ecosystem, and Construction of a Computerized Data Base on Acid Mine Drainage in Colorado,* Final Report to the Mined Land Reclamation Division, Department of Natural Resources, Colorado, p. 13-50.

Evaluated the effects of rerouting AMD from a base and precious metals mine into a wetland ecosystem. Results showed that only Fe was significantly removed, with little effect on Al, Mn, or Zn levels. Surface water quality below the wetland was not improved significantly. The natural wetland was found to have a significant metal content prior to diversion that may have precluded additional metal uptake during the experiment.

Huskie, William W., 1987. *The Pennsylvania Mine Diversion Drainage Study: Evaluation of an Existing High Mountain Wetland for Passive Treatment of Metal-Laden Acid Mine Drainage in Colorado,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO.

Reference not available.

Hutchison, Ian P.G., Leonard, Sr., Michael L., and Cameron, David P., 1995. Remedial alternatives identification and evaluation, *in* Posey, Harry H., Pendleton, James A., and Van Zyl, Dirk, eds., *Proceedings: Summitville Forum '95,* Colorado Geological Society Special Publication 38, p. 109-120. This paper describes how treatment strategies (active and passive) are being developed for the Summitville (CO) Mine. It provides a brief summary of the AMD issues at Summitville Mine, identifies the types of remedial technologies and process operations that could be applied at the site, discusses the basis for evaluating alternative remedial measures, and describes selected remedial measures and their implementation.

Hyman, D.M. and G.R. Watzlaf, “Mine Drainage Characterization for the Successful Design and Evaluation of Passive Treatment Systems,” presented at the 17th Annual National Association of Abandoned Mine Lands Conference. Undated.

Reference not available.

Inventory Guiding Principles Group, 1996. *Guiding Principles for Inventorying Inactive and Abandoned Hardrock Mining Sites*, The Inventory Guiding Principles Group, Western Governor’s Association and U.S. Bureau of Mines.

Reference not available.

Jones, D.R. and Chapman, B.M., 1995. Wetlands to treat AMD - Facts and fallacies, *in* Grundon, N.J. and Bell, L.C., eds., *Proceedings of the Second Annual Mine Drainage Workshop,* Queensland, Australia, p. 127-145.

Reference not available.

Kelly, Martyn, 1988, Mining and the Freshwater Environment, Elsevier Science Publishing Co., London, pgs. 16-42

Reference not available.

Kepler, D.A., 1988. Overview of the role of algae in the treatment of acid mine drainage, *in* U.S. Bureau of Mines, *Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183, p. 286-290.

Reports preliminary results from a wetland system constructed to treat coal mine drainage in PA (pH=5.0), which show that algae effectively bioaccumulate metals including Mn and Fe.

Kepler, Douglas A. and McCleary, Eric C., 1994. Successive alkalinity-producing systems (SAPS) for the treatment of acid mine drainage, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 195-204.

Study focuses on the ability to create effective anoxic limestone dissolution treatment components for AMD abatement in open atmospheres. Studies 3 SAPS in PA that utilize wetlands with mixed substrates of organic compost and limestone gravel. This wetland configuration promotes anoxic conditions, generates alkalinity in excess of acidity regardless of acidity concentrations, produces quasi-neutral water and decreases treatment area requirements.

Kim, A., B. Heisey, R. L. P. Kleinmann and M. Duel, 1982, "Acid Mine Drainage: Control and Abatement Research," U.S. Bureau of Mines Information Circular 8905.

Reference not available.

Kimball, Briant A., 1996. Past and present research on metal transport in St. Kevin Gulch, Colorado, *in* Morganwalp, David W. and Aronson, David A., eds., *U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Colorado Springs, CO, September 20-24, 1993,* U.S. Geological Survey Water Resources Investigation Report 94-4015, p. 753-758.

Describes the chemical reactions that affect metal transport in AMD in surface waters of the St. Kevin Gulch drainage near Leadville, CO in the context of hydrologic setting. Results can be used to design effective remediation measures.

Kleinmann, Robert L.P., 1985. Treatment of acid mine waters by wetlands, *in* U.S. Bureau of Mines, *Control of Acid Mine Drainage: Proceedings of a Technology Transfer Seminar,* U.S. Bureau of Mines Information Circular 9027, p. 48-52.

Discusses general aspects of passive AMD treatment and provides an update on pilot-scale and full-scale field evaluations being conducted by the Bureau of Mines.

Kleinmann, R.L.P. and Hedin, R.S., 1993. Treat minewater using passive methods, *Pollution Engineering,* vol. 25, no. 13, p. 20-22.

Reference not available.

Kleinmann R.L.P., D.A. Crerar and R.R. Pacelli, 1981, "Biogeochemistry of Acid Mine Drainage and a Method to Control Acid Formation," Mining Engineering, March 1981.

Reference not available.

Kleinmann, R.L.P. and R. Hedin, "Biological Treatment of Mine Water: an Update", in Chalkley, M.E., B.R. Conrad, V.I. Lakshmanan, and K.G. Wheeland, 1989, Tailings and Effluent Management, Pergamon Press, New York, pgs 173-179.

Reference not available.

Klepper, R.P., R.C.Emmett, and J.S. Slottee, "Equipment Selection For Tailings and Effluent Management", in Chalkley, M.E., B.R. Conrad, V.I. Lakshmanan, and K.G. Wheeland, 1989, Tailings and Effluent Management, Pergamon Press, New York, pgs. 207-214.

Reference not available.

Klusman, R.W. and Machemer, S.D., 1991. Natural processes of acidity reduction and metal removal from acid mine drainage, *in* Peters, D.C., ed., *Geology in the Coal Resource Utilization,* Tech Books, Fairfax, VA, p. 513-540.

Reference not available.

Knight Piesold, Ltd., 1996. Wheal Jane minewater project: The development of a treatment strategy for the acid mine drainage, *in Minerals, Metals, and Mining,* Institution of Mining and Metallurgy.

Reference not available.

Kolbash, Ronald L. and Romanoski, Thomas L., 1989. Windsor Coal Company wetland: An overview, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 788-792.

Describes the design, construction, and effectiveness of a wetland treatment system at a coal mine in WV.

Kuyucak, N. and St-Germain, P., 1994. Possible options for *in situ* treatment of acid mine seepages, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06B-94, vol. 2, p. 311-318.

Presents results of bench-scale evaluation tests of passive treatment of base metal acid mine drainage seepages. Assessed methods including: 1) anoxic lime drains (limestone kept under anoxic conditions); 2) limestone-organic mixture utilizing sulfate-reducing bacteria; 3) biosorbency in which metals are taken up by wood waste, and 4) a biotrench that utilizes different nutrients than the limestone-organic mixture. Concludes that a combination of 1 and 2 above is best for treating AMD.

Kwong, Y.T.J., 1992. Generation, attenuation, and abatement of acidic drainages in an abandoned minesite on Vancouver, Island, Canada, *in* Singhal, Raj K., Mehrotra, Anil K., Fytas, Kostas, and Collins, Jean-Luc, eds., *Environmental Issues and Management of Waste in Energy and Mineral Production,* A.A. Balkema, Rotterdam, p. 757-762.

Discusses the potential utility of passive wetlands treatment of AMD from the abandoned Mount Washington porphyry copper mine. Describes successes and failures of reclamation activities conducted to date.

Ladwig, K., P. Erickson and R. Kleinmann, 1985, Alkaline Injection: An Overview of Recent Work," in Control of Acid Mine Drainage, Proceedings of a Technology Transfer Seminar, U.S. Bureau of Mines Information Circular 9027.

Reference not available.

Ladwig, K., P. Erickson and R. Kleinmann, 1985, Alkaline Injection: An Overview of Recent Work," in Control of Acid Mine Drainage, Proceedings of a Technology Transfer Seminar, U.S. Bureau of Mines Information Circular 9027.

Reference not available.

LaRosa, et al., Black, Sivalls, and Bryson, Inc. "Evaluation of a New Acid Mine Drainage Treatment Process," prepared for the U.S. Environmental Protection Agency; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1971.

Reference not available.

Logsdon, Mark and Mudder, Terry, 1995. Geochemistry of spent ore and water treatment issues *in* Posey, Harry H., Pendleton, James A., and Van Zyl, Dirk, eds., *Proceedings: Summitville Forum '95,* Colorado Geological Society Special Publication 38, p. 99-108.

Describes the design and operation of the cyanide heap leach pad at the Summitville precious metals mine, a program for decommissioning the leach pad, and a geochemical evaluation of potential environmental impacts from the pad. Includes brief sections on active and passive treatment of acid drainage from the leach pad. Passive treatment alternatives under consideration include wetlands, engineered anoxic systems, and direct land application; does not include information on design and feasibility of passive systems.

Madel, Robin E., 1992. *Treatment of Acid Mine Drainage in Sulfate Reducing Bioreactors: Effect of Hydraulic Residence Time and Metals Loading Rates,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO.

Study investigated the ability of sulfate-reducing bacteria to treat AMD at lower residence times by using multiple stage systems in parallel and series. The test results determined using samples of AMD from the Eagle Mine have implications for the design of passive treatment systems.

Meek A., 1991, "Assessment of Acid Preventative Techniques at the Island Creek Mining Co. Tenmile Site," in Proceedings Twelfth Annual West Virginia Surface Mine Drainage Task Force Symposium , April 3-4, 1991, Morgantown, West Virginia.

Reference not available.

MEND, "Economic Evaluation of Acid Mine Drainage Technologies," MEND Report 5.8.1, January 1995.

Reference not available.

MEND, "Acid Mine Drainage - Status of Chemical Treatment and Sludge Management Practices," MEND Report 3.32.1, June 1994.

Reference not available.

MEND, 1993. *Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment,* MEND Report 3.11.1, Natural Resources Canada.
Reference not available.

MEND, "Study on Metals Recovery/Recycling from Acid Mine Drainage," MEND Project 3.21.1(a), July 1991.
Reference not available.

MEND, 1991. *Study of Metals Recovery/Recycling from Acid Mine Drainage,* MEND Report 3.21.1(a), Natural Resources Canada.
Reference not available.

MEND, 1990. *Assessment of Existing Natural Wetlands Affected by Low pH, Metal Contaminated Seepages (Acid Mine Drainage),* MEND Report 3.12.1a, Natural Resources Canada.
Reference not available.

MEND, MEND Reports Available, Mine Environment Neutral Drainage Program http://www.NRCan.gc.ca/mets/mend/report-t.htm
Listing of reports available for purchase.

Mills, Chris, An Introduction to Acid Rock Drainage. http://www.enviromine.com/ard/Eduardpage/ARD.htm
Brief description of the chemistry of acid mine drainage generation and neutralization and the kinetics of the chemical reactions. Includes links to pages concerning the role of micro-organisms in AMD.

Morin, Kevin A., 1990. *Acid Drainage from Mine Walls: The Main Zone Pit at Equity Silver Mines,* British Columbia Acid Mine Drainage Task Force, 109 pp.
Provides an overview of the generation and migration of acid mine drainage at open-pit mines, with emphasis on the Equity silver mine in British Columbia. Presents a predictive model for acid drainage from pit walls that could be used to design treatment systems.

Mueller, R.F., Sinkbeil, D.E., Pantano, J., Drury, W., Diebold, F., Chatham, W., Jonas, J., Pawluk, D., and Figueira, J., 1996. Treatment of metal contaminated groundwater in passive systems: A demonstration study, *in Proceedings of the 1996 National Meeting of the American Society for Surface Mining and Reclamation, Knoxville, TN, May 19-25, 1996,* p. 590-598.
Reference not available.

Noller, B.N., Woods, P.H., and Ross, B.J., 1994. Case studies of wetland filtration of mine waste water in constructed and naturally occurring systems in northern Australia, *Water Science and Technology*, vol. 29, p. 257-266.
Reference not available.

Norecol Environmental Consultants, 1989. Wetland treatment, *in* British Columbia Acid Mine Drainage Task Force, *Draft Acid Rock Drainage Technical Guide, Volume 1* ,p. 8-47 to 8-52.
Provides a general overview of wetlands treatment of AMD, including a discussion of the advantages and disadvantages of wetland treatment systems.

Novotny, Vladimir and Olem, Harvey, 1994. *Water Quality: Prevention, Identification and Management of Diffuse Pollution,* Van Nostrand, New York, 1054 pp.

Contains sections that review the retention of sulfur in wetland environments, the types of constructed wetlands, design considerations and parameters for constructed wetlands, constituent loadings in wetlands, and metals and toxic chemicals in wetland environments.

Parisi, Dan, Horneman, Jeffrey, and Rastogi, Vijay, 1994. Use of bactericides to control acid mine drainage from surface operations, *International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06B-94, vol. 2, p. 319-325.

Describes three applications of bacterial inhibitors: 1) surface coal mine with highly pyritic shale overburden in central PA, 2) refuse disposal area in central PA, 3) silver mine in Idaho where waste rock is used as pit backfill. All studies were successful field tests indicating that bacterial inhibitors control acid generation and achieve long-term control through controlled release systems.

Paschke, Suzanne S. and Harrison, Wendy J., 1995. Metal transport between an alluvial aquifer and a natural wetland impacted by acid mine drainage, Tennessee Park, Leadville, Colorado, *in Tailings and Mine Waste '95,* A.A. Balkema, Rotterdam, p. 43-54.

Describes the effects of percolating AMD carried in a surface stream (St. Kevin Gulch) on regional ground water quality. Discusses the fate of AMD generated from metal mining in ground water where both oxidizing and reducing conditions are present.

Pfahl, J.C., 1996. Innovative approaches to addressing environmental problems for the upper Blackfoot mining complex: Voluntary remedial actions, *in Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites,* U.S. Environmental Protection Agency Seminar Publication No. EPA/625/R-95/007, p. 75-80.

Reference not available.

Phillips, Peter, Bender, Judith, Simms, Rachael, Rodriguez-Eaton, Susana, and Britt, Cynthia, 1994. Manganese and iron removal from coal mine drainage by use of a green algae-microbial mat consortium, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 99-108.

Results of a field test of three constructed wetlands using native blue-green algae and limestone or pea gravel substrates at the Fabius Coal Mine, AL. AMD was pre-treated in an oxidation pond prior to flow into the wetland. Study evaluated feasibility of microbial mat treatment and assessed mat performance under environmental conditions (seasonal variation, day-night conditions, etc.).

Plumlee, G., Smith, K.S., Erdman, J., Flohr, M., Mosier, E., and Montour, M., 1994. Geologic and geochemical controls on metal mobility from the Summitville mine and its downstream environmental effects, *in Abstracts with Programs,* Geological Society of America Annual Meeting, vol. 26, p. A-434 to A-435.

Abstract describes the geochemisty of metal-rich AMD generated from the Summitville gold mine (CO) and its downstream distribution in the Alamosa River system.

Posey, Harry H., Pendleton, James A., and Van Zyl, Dirk, 1995. *Proceedings: Summitville Forum '95,* Colorado Geological Survey Special Publication 38, 375 pp.

Contains numerous articles that describe the geochemistry of AMD from the Summitville gold mine and its downstream effects on the Alamosa River, Terrace Reservoir, and natural wetlands.

Powers, Thomas J. "Use of Sulfate Reducing Bacteria in Acid Mine Drainage Treatment." U.S. EPA Risk Reduction Engineering Laboratory. Undated.

Reference not available.

Ptacek, C.J., Inorganic Contaminants in Groundwater and Acid Mine Drainage. http://gwrp.cciw.ca/gwrp/studies/ptacek/ptacek.html

Describes the mechanisms controlling the transport of metals in tailings impoundments and underlying aquifers. Contains a reference to *In-situ remediation of metal contaminated groundwater*, which describes the use of porous reactive walls to passively treat metals contaminated groundwater. Lists numerous AMD abstracts published by the author.

Renton, J., A. H. Stiller and T. E. Rymer, 1988, "The Use of Phosphate Materials as Ameliorants for Acid Mine Drainage," in Conference Proceedings Mine Drainage and Surface Mine Reclamation, U.S. Bureau of Mines Information Circular 9183, 67-75pp.

Reference not available.

Renton, J., A.H. Stiller, and T.E. Rymer, 1988, "The Use of Phosphate Materials as Ameliorants for Acid Mine Drainage," in Conference Proceeding Mine Drainage and Surface Mine Reclamation, U.S. Bureau of Mines Information Circular 9183, pp. 67-75.

Reference not available.

Rex Chainbelt, Inc. Technical Center. "Treatment of Acid Mine Drainage by Reverse Osmosis," prepared for the Commonwealth of Pennsylvania, Dept. of Mines and Mineral Industries and the Federal Water Quality Administration, U.S. Dept. of the Interior; Washington: for sale by the Superintendent of Documents, U.S. Government Printing Office, 1970.

Reference not available.

Robertson, A.M., Blowes, D.W., and Medine, A.J., 1992. *Prediction, Prevention, and Control of Acid Mine Drainage in the West,* Workshop, Breckenridge, CO.

Notes, references, papers and presentations from a workshop on AMD.

Robertson, Emily, 1990. *Monitoring Acid Mine Drainage,* British Columbia Acid Mine Drainage Task Force, 72 pp.

Examines current monitoring methods at mines with AMD, reviews statistics as they are applied to water quality data and emphasizes the importance of flow data, uses a set of data collected daily to elucidate the range of fluctuations that naturally occur, and presents general guidelines for monitoring untreated water and the receiving environment.

Rowley, Michael V., Warkentin, Douglas D., Yan, Vita T., and Piroshco, Beverly M., 1994. The biosulfide process: Integrated biological/chemical acid mine drainage treatment - results of laboratory piloting, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06A-94, vol. 1, p. 205-213.

Biosulfide treatment separates chemical precipitation of sulfides from biological conversion of sulfate to sulfide to produce saleable products. Objective of study was to operate and evaluate a continuous, integrated system that depended solely on microbially generated products for treatment of strongly acid water (pH=2.45). Process was demonstrated to be effective, reliable, and easy to operate through more than 1 year of operation.

Russell, Charles W., 1994. Acid rock drainage associated with large storm events at the Zortman and Landusky mines, Phillips County, Montana, *in Abstracts with Programs, Geological Society of America,* vol. 26, no. 7, p. A-34.

Describes use of a reclamation cover to control acid-generating reactions, prevent flushing of reaction products, and establish lower oxidation states to allow implementation of effective passive treatment systems.

Schultze, Larry E., Zamzow, Monica J., and Bremner, Paul R., 1994. AMD cleanup using natural zeolites, *in International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06B-94, vol. 2, p. 341-347.

Experiments using 3 samples of clinoptilolite with varying Na content and an AMD sample from the Rio Tinto copper mine in northeastern Nevada. Zeolites had differing cation exchange capacities but all were able to remove metals to drinking water standards. Zeolites could be regenerated using NaCl solution.

SCRIP Acid Mine Drainage Remediation Project, Passive Treatment Technologies, http://ctcnet.net/scrip/passive.htm

Contains an online bibliography of papers related to acid mine drainage remediation and a discussion of passive treatment technologies including oxidizing and reducing wetlands.

Sellstone, Christopher M., 1990. *Sequential Extraction of Fe, Mn, Zn, and Cu from Wetland Substrate Receiving Acid Mine Drainage,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO, 88 pp.

The study attempts to determine the geochemical phases into which Fe, Mn, Cu, and Zn are partitioned in a pilot-scale constructed wetland receiving AMD from the Big Five Tunnel in Idaho Springs, CO by using a geochemical technique known as sequential extraction.

Sencindiver, J.C. and Bhumbla, D.K., 1988. Effects of cattails (Typha) on metal removal from mine drainage, *in Mine Drainage and Surface Mine Reclamation,* U.S. Bureau of Mines Information Circular 9183, p. 359-368.

Reference not available.

Shelp, Gene, Chesworth, Ward, Spiers, Graeme, and Liu, Liangxue, 1994. A demonstration of the feasibility of treating acid mine drainage by an in situ electrochemical method, *International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06B-94, vol. 2, p. 348-355.

Experimentally proved technical feasibility of electrochemical treatment using a block of massive sulfide-graphite rock as cathode, scrap iron as anode, and AMD from an open-pit iron mine in Canada as the electrolyte. Electrolyte pH was raised to a maintained level of 5.5, reduction-oxidation potential was decreased, and iron sulfate precipitate removed Al, Ca, and Mg from solution.

Sherlock, E.J., Lawrence, R.W., and Poulin, R., 1995. On the neutralization of acid rock drainage by carbonate and silicate minerals, *Environmental Geology,* vol. 25, p. 43-54.

Provides a detailed discussion of the dissolution and neutralizing capacity of carbonate and silicate minerals related to equilibrium conditions, dissolution mechanism, and kinetics. Illustrates that differences in reaction mechanisms and kinetics have important implications for the prediction, control, and remediation of AMD.

Silver, Marvin, 1989. Biology and chemistry of generation, prevention, and abatement of acid mine drainage, *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Chelsea, MI, p. 753-760.

Reviews the processes that lead to the formation of acid from sulfide and sulfate minerals, mechanisms by which acid generation can be prevented, and options for abating AMD.

Singer, P.C. and W. Stumm, 1970, "Acid Mine Drainage: The Rate Determining Step," Science 167;pps 1121-1123.

Reference not available.

Siwik, R., S. Payant, and K. Wheeland, "Control of Acid Generation from Reactive Waste Rock with the Use of Chemicals", in Chalkley, M.E., B.R. Conrad, V.I. Lakshmanan, and K.G. Wheeland, 1989, Tailings and Effluent Management, Pergamon Press, New York, pgs. 181-193.

Reference not available.

Skousen, J.G., et al., 1990, "Acid Mine Drainage Treatment Systems: Chemicals and Costs," in Green Lands, Vol. 20, No. 4, pp. 31-37, Fall 1990, West Virginia Mining and Reclamation Association, Charleston, West Virginia.

Reference not available.

Skousen, J. G., J. C. Sencindiver and R. M. Smith, 1987, "A Review of procedures For Surface Mining and Reclamation in Areas with Acid-producing Materials," in cooperation with The West Virginia Surface Mine drainage Task Force, the West Virginia University Energy and Water Research Center and the West Virginia Mining and Reclamation Association, 39pp, West Virginia University Energy and Water Research Center.

Reference not available.

Skousen, Jeffrey, and Paul Ziemkiwicz, ed. "Acid Mine Drainage: Control & Treatment," National Mine Land Reclamation Center. Undated.

(available from the National Mine Land Reclamation Center for $15: (304) 293-2867 ext. 444)

Reference not available.

Skousen, Jeff, 1995. Anoxic limestone drains for acid mine drainage treatment, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 261-266.

A general review of the operation and effectiveness of anoxic limestone drains in the treatment of AMD. Includes steps for building an anoxic limestone drain and discusses important parameters in design and sizing.

Skousen, Jeff G., 1995. Douglas abandoned mine project: Description of an innovative acid mine drainage treatment system, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 299-310.

Reviews the historical development of passive treatment strategies including wetlands, anoxic limestone drains, and alkalinity producing systems. Describes the design and construction of a two-phase treatment system employed at the Douglas Highwall mine (WV) that uses two trenches with varying ratios of organic material and limestone. Preliminary results show that the system raises pH by 3 log units, increases alkalinity from 0 to 200 mg/l, and effectively removes dissolved Al, Fe, and Mn from acidified waters.

Skousen, Jeff, Faulkner, Ben, and Sterner, Pat, 1995. Passive treatment systems and improvement of water quality, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 331-344.

Reviews the function of different passive treatment technologies including aerobic and anaerobic wetlands, anoxic limestone drains, alkalinity producing systems, open limestone channels, limestone ponds, and reverse alkalinity producing systems and the processes by which they improve water quality. Discusses the effectiveness of backfilling and revegetating surface mines in reducing acid loads and improving water quality.

Skousen, J., Sexstone, K., Garbutt, K., and Sencindiver, J., 1995. Wetlands for treating acid mine drainage, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 249-260.

A general overview passive wetlands treatment, including important wetlands processes, alkalinity generation and anoxic limestone drains, design and sizing parameters, and plant selection for optimum wetlands effectiveness.

Skousen, J., Sexstone, K., Garbutt, K., and Sencindiver, J., 1994. Acid mine drainage treatment with wetlands and anoxic limestone drains, *in* Kent, D.M., ed., *Applied Wetlands Science and Technology,* Lewis Publishers, Boca Raton, p. 263-281.

Reference not available.

Skousen, Jeffrey and Ziemkiewicz, Paul, 1995. *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, 362 pp.

Contains 10 papers that deal with aspects of the design, treatment, and effectiveness of passive treatment systems, most dealing with coal mine AMD, in addition to multiple papers on active treatment systems and AMD prevention.

Smith, K.S., 1991. *Factors Influencing Metal Sorption onto Iron-rich Sediment in Acid-Mine Drainage,* Unpubl. Ph. D. Dissertation, Colorado School of Mines, Golden, CO.

Reference not available.

Smith, Kathleen S., Plumlee, Geoffrey S., and Ficklin, Walter H., 1994. *Predicting Water Contamination from Metal Mines and Mining Wastes,* U.S. Geological Survey Open-File Report 94-264.

Notes from a workshop presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage in Pittsburgh, PA.

Smith, Teri R., Wilson, Timothy P., and Ineman, Fredrick N., 1991. The relationship of iron bacteria geochemistry to trace metal distribution in an acid mine drainage system, NE Ohio, *Geological Society of America Abstracts with Programs,* v. 23, no. 3, p. 61.

Investigates the relationship between iron bacteria type, abundance, stream environment, and water/sediment chemistry in acid drainage from a coal strip mine. Concludes that bacteria exert significant control over the precipitation of Fe-Mn oxyhydroxides, which affect the distribution of trace metals in effluent.

Sobolewski, A., 1996. Metal species indicate the potential of constructed wetlands for long-term treatment of mine drainage, *Journal of Ecological Engineering,* vol. 6, p. 259-271.

Reference not available.

Sobolewski, A., 1995. Development of a wetland treatment system at United Keno Hill Mines, Elsa, Yukon Territory, *Proceedings of the Twentieth Annual British Columbia Mine Reclamation Symposium,* Kamloops, British Columbia, p. 64-73.
Reference not available.

Sobolewski, Andre, Wetlands for Treatment of Mine Drainage. http://www.enviromine.com/wetlands/Welcome.htm
Contains links to numerous internet sources on acid mine drainage including constructed wetlands at base and precious metals mines (/wetlands/metal.htm) and examples of natural and constructed wetlands that are remediating AMD. Also includes a link to a web page that briefly describes the UK effort to remediate acid mine drainage from Cornish tin mines (http://www.intr.net/esw/494/uk.htm).

Staub, Margaret W., 1994. *Passive Mine Drainage Treatment in a Bioreactor: The Significance of Flow, Area, and Residence Time,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO.
Demonstrated the effectiveness of microbiological treatment on acidic mine drainage water with high metals concentration. Experiments used pilot scale bioreactors constructed underground at the Eagle Mine Superfund site in Colorado. The systems removed 95 to 100 percent of the metals.

Steffen, Robertson, and Kirsten, Inc., 1989. *Draft Acid Rock Drainage Technical Guide, Volumes 1 & 2,* prepared for the British Columbia Acid Mine Drainage Task Force, BiTech Publishers, Richmond, British Columbia.
Reference not available.

Stilwell, C.T., 1995. Stream restoration and mine waste management along the upper Clark Fork River, *in Tailings and Mine Waste '95,* A.A. Balkema, Rotterdam, p. 105-107.
Describes an attempt to attenuate AMD from metal mines in a riparian corridor in Montana. AMD is generated from tailings that were eroded and fluvially redeposited during flood events. One design uses *in situ* lime treatment, in which lime is admixed with tailings, then recontoured and vegetated.

Tarutis, W.J., Jr., Unz, R.F., and Brooks, R.P., 1992. Behavior of sedimentary Fe and Mn in a natural wetland receiving acidic mine drainage, Pennsylvania, U.S.A., *Applied Geochemistry,* vol. 7, p. 77-85.
Reference not available.

Taufen, Paul M., 1995. *A Geochemical Study of Groundwaters and Stream Waters at Two Mineralized Sites in the Noranda District, Quebec - Application to Mineral Prospecting, Mine Development, and Environmental Remediation,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO.
Study examines the controls on metal mobility and transport in subsurface and stream waters. A conceptual hydrogeochemical model for the production of AMD is provided for the base-metal-sulfide deposits at the abandoned Waite and Amulet mines.

Taylor, H.N., Choate, K.D., and Brodie, G.A., 1993. Storm event effects on constructed wetlands discharges, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 139-145.
Examines the effects of storm water drainage through two constructed wetlands by evaluating effluent water quality (total Fe, total Mn, TSS, pH).

Tetcher, J.J., T.T. Phipps, and J.G. Skousen, "Cost Analysis for Treating Acid Mine Drainage from Coal Mines in the U.S.," in Proceedings Second International Conference on the Abatement of Acidic Drainage, September 16-18, 1991, Montreal , Canada, Volume 1, pp. 561-574.

Reference not available.

Titchenell, Troy and Skousen, Jeff, 1995. Acid mine drainage treatment in Greens Run by an anoxic limestone drain, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 345-356.

Describes the use of anoxic limestone drains to treat three point sources of AMD from coal mines in WV. Preliminary water quality analyses indicate that the drain is increasing pH, adding alkalinity, and removing Fe and Al.

Turner, D. and D. McCoy, "Anoxic Alkaline Drain Treatment System, a Low Cost Acid Mine Drainage Treatment Alternative," National Symposium on Mining, University of Kentucky, Lexington, Kentucky, May 14-18, 1990. pp. 73-75.

Reference not available.

Tyco Laboratories. "Silicate Treatment for Acid Mine Drainage Prevention; Silicate and Alumina/Silica Gel Treatment of Coal Refuse for the Prevention of Acid Mine Drainage." Washington: EPA Water Quality Office; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1971.

Reference not available.

UN/DTCD, 1991. Environmental aspects of non-ferrous mining, *in Mining and the Environment — The Berlin Guidelines,* Mining Journal Books, p. 25-52.

Reference not available.

U.S. Bureau of Mines, 1988. *Mine Drainage and Surface Mine Reclamation, Volume I: Mine Water and Mine Waste,* U.S. Bureau of Mines Information Circular 9183.

Proceedings of a Conference held in Pittsburgh, PA, April 19-21, 1988. Contains sections on biological mine water treatment (6 papers), wetland systems for mine water treatment: case studies (5 papers), and wetland systems for mine water treatment: process and design (5 papers).

U.S. Bureau of Mines, 1994. *International land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication SP 06A-D-94, 4 volumes.

Proceedings of the conference.

U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, "Managing Hydrologic Information: A Resource for Development of Probable Hydrologic Consequences (PHC) and Cumulative Hydrologic Impact Assessments (CHIA)," January 31, 1997.

Reference not available.

U.S. Environmental Protection Agency, 1996. *Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites,* U.S. Environmental Protection Agency Seminar Publication No. EPA/625/R-95/007.

Reference not available.

U.S. Geological Survey, The Summitville Mine and its Downstream Effects: An On-line Update of Open File Report 95-23. http://helios.cr.usgs.gov/summit.web/summit.htm

An update of a previous open-file report on the environmental effects of the Summitville gold mine. Provides recent information on the impact of AMD on the Alamosa River system and wetlands in the San Luis Valley.

U.S. Geological Survey, USGS Mine Drainage Newsletter, Technical Forum, U.S. Geological Survey, http://water.wr.usgs.gov/mine/archive/forum.html

Newsletter with short technical articles pertaining to various aspects of acid mine drainage.

Updegraff, D.M., Reynolds, J.S., Smith, R.L., and Wildeman, T.R., 1992. Bioremediation of acid mine drainage by a consortium of anaerobic bacteria in a constructed wetland, *Abstracts of Papers, Part 1,* American Chemical Society, 203rd National Meeting, San Francisco, CA, April, 1992, Abstract GEOC 174.

Discusses the operation of a wetland constructed in Idaho Springs, CO to treat acid mine drainage with low pH and high concentrations of heavy metals.

Vile, Melanie A. and Weider, R. Kelman, 1993. Alkalinity generation by Fe(III) reduction versus sulfate reduction in wetlands constructed for acid mine drainage treatment. *Water, Air and Soil Pollution,* vol. 69, p. 425-441.

Study conducted to determine the extent to which ferric iron reduction occurs and the extent to which sulfate reduction versus ferric iron reduction contributes to alkalinity generation in 5 wetlands constructed with different organic substrates. Studies conducted over 18 to 22 month period in KY, using AMD from coal mines. Initial results showed that treatment was effective. However, monitoring revealed a general pattern of diminished ability to reduce concentrations of H+, soluble Fe, and SO4 during winter months, with failure to reestablish effective treatment after the second winter. Successful long-term treatment depends on the continued ability for biological alkalinity generation to balance influent acid load.

Walton, Kenneth C. and Johnson, D. Barrie, 1992. Microbiological and chemical characteristics of an acidic stream draining a disused copper mine, *Environmental Pollution,* vol. 76, p. 169-175.

Examines downstream changes in pH, metals concentrations, and iron oxidizing bacteria in AMD as a result of natural processes. Describes the relationships between stream chemistry and microbiology.

Walton-Day, Katherine, 1996. Iron and zinc budgets in surface water for a natural wetland affected by acidic mine drainage, St. Kevin Gulch, Lake County, Colorado, *in* Morganwalp, David W. and Aronson, David A., eds., *U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Colorado Springs, CO, September 20-24, 1993,* U.S. Geological Survey Water Resources Investigation Report 94-4015, p. 759-764.

Studies the attenuation of iron and zinc from AMD (pH=3.5-4.5) by natural processes in a wetland. Study shows that approximately 75 percent of total iron is removed by precipitation of iron hydroxides from influent but that zinc is not removed.

Weider, R. Kelman, 1994. Diel changes in iron (III)/iron (II) in effluent from constructed acid mine drainage treatment wetlands. *Journal of Environmental Quality,* vol. 23, p. 730-738.

Study documents dramatic shifts in Fe+3/Fe+2 abundances in effluent from constructed wetlands that correlates to time of day (high Fe+3 prior to sunset; high Fe+2 prior to sunrise). Discusses implications for sampling protocols for assessing Fe retention and release. Study used coal mine AMD in KY.

West Virginia University, Acid Mine Drainage Treatment, http://www.wvu.edu/~research/techbriefs/acidminetechbrief.html.

An introduction to treatment of acid mine drainage for the novice. Site is maintained by Dr. Jeff Skousen.

Western Governor's Association, 1996. *Final Report of Abandoned Mine Waste Working Group,* prepared for the Federal Advisory Committee to develop on-site innovative technologies (DOIT), Western Governor's Association, Denver, CO.

Reference not available.

Wetzel, R.G., "Constructed Wetlands: Scientific Foundations are Critical", in Moshiri, Gerald A., 1993, Constructed Wetlands for Water Quality Improvement, Lewis Publishers, Ann Arbor, pgs. 3-7.

Reference not available.

Whitesall, Louis B., et al. Continental Oil Company, Research and Development Dept. "Microbiological Treatment of Acid Mine Drainage Waters," prepared for the U.S. Environmental Protection Agency. Washington: EPA Reseach and Monitoring; for sale by the Superintendent of Documents, U.S. Government Printing Office, 1971.

Reference not available.

Wildeman, Thomas R., Filipek, Lorraine H., and Gusek, James, 1994. Proof-of-principle studies for passive treatment of acid rock drainage and mill tailing solutions from a gold operation in Nevada, *International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage,* U.S. Bureau of Mines Special Publication, SP 06B-94, vol. 2, p.387-394.

Samples of arsenic- and selenium-bearing AMD (pH=2.5) was treated by precipitating iron hydroxide to remove As, then passively treated in an anaerobic cell using a manure substrate to remove heavy metals, As and Se to Federal drinking water standards. Additional metals were removed in a passive aerobic polishing cell.

Wildeman, Thomas R. and Laudon, Leslie, S., 1989. Use of wetlands for treatment of environmental problems in mining: Non-coal-mining applications, , *in* Hammer, Donald A., ed., *Constructed Wetlands for Wastewater Treatment,* Lewis Publishers, Ann Arbor, MI, p. 221-231.

Reviews the chemistry of metal mine drainage, cites differences between metal mine and coal mine drainage, analyzes the geochemistry of metals removal in wetlands, and briefly summarizes the results of studies at the Big Five Tunnel (CO), Red Lake (ON), Sudbury (ON), Danka Mine (MN), and Sand Coulee (MT).

Wildeman, Thomas R. and Laudon, Leslie, S., 1988. The use of wetlands for treatment of environmental problems in mining: Non-coal mining applications, *in Proceedings of the U.S. EPA's Forum on Remediation of CERCLA Mining Waste Sites, April 25, 1989, Ward, Colorado,* p. 42-62.

Provides brief descriptions of the wetlands treatment systems presently in use at six base and precious metals mines in the U.S. and a detailed case history of the pilot treatment project at the Big Five Tunnel in Idaho Springs, CO.

Willow, Mark A., 1995. *pH and Dissolved Oxygen as Factors Controlling Treatment Efficiencies in Wet Substrate, Bio-Reactors Dominated by Sulfate-Reducing Bacteria,* Unpubl. M.S. Thesis, Colorado School of Mines, Golden, CO.

Experiments were conducted to determine if pH and dissolved oxygen of influent wastewaters limited the removal of heavy metals from AMD. Results showed that dissolved oxygen was not a limiting factor but that reduced pH did lower sulfate reduction.

Witthar, S.R., 1993. Wetland water treatment systems, *in* Moshiri, Gerald A., ed., *Constructed Wetlands for Water Quality Improvement,* Lewis Publishers, Boca Raton, p. 147-155.

Describes wetland design criteria used to construct treatment system wetlands, including physical requirements and wetland flora.

Ziemkiewicz, Paul, Skousen, Jeff, and Lovett, Ray, 1995. Open limestone channels for treating acid mine drainage: A new look at an old idea, *in* Skousen, Jeffrey and Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 275-280.

Reviews the effectiveness and practical application of open channels armored with limestone for treating AMD from coal mines. Studied sites include the Brownton, Dola, Florence, Webster, and Airport channels, all located in western PA.

Ziemkiewicz, P.F., Skousen, J.G., Brant, D.L., Sterner, P.L., and Lovett, R.J., 1995. Acid mine drainage treatment with armored limestone in open limestone channels, *in* Skousen, Jeffrey and

Ziemkiewicz, Paul, eds., *Acid Mine Drainage: Control & Treatment, 2nd edition,* National Mine Land Reclamation Center, p. 281-298.

Reports the results of field and laboratory studies conducted to assess the extent to which the neutralizing capability of limestone clasts diminishes as a consequence of armoring by metal precipitates. Found that armoring reduced neutralizing capabilities by 5 to 50 percent.

Ziemkiewicz, P.J. Renton and T. Rymer, 1991, "Prediction and Control of Acid Mine Drainage: Effect of Rock Type and Amendment," in Proceedings Twelfth Annual West Virginia Surface Mine Drainage Task Force Symposium, April 3-4, 1991, Morgantown, West Virginia.

Reference not available.

(This page intentionally left blank)