TECHNOLOGY OVERVIEW

BACKFILLING AND SUBAQUEOUS DISPOSAL

August 2010

Prepared by
The Interstate Technology & Regulatory Council
Mining Waste Team

Permission is granted to refer to or quote from this publication with the customary acknowledgment of the source. The suggested citation for this document is as follows:

ITRC (Interstate Technology & Regulatory Council). 2010. *Backfilling and Subaqueous Disposal*. Washington, D.C.: Interstate Technology & Regulatory Council, Mining Waste Team. www.itrcweb.org.

TABLE OF CONTENTS

LIST OF TABLES

BACKFILLING AND SUBAQUEOUS DISPOSAL

1. INTRODUCTION

Backfilling and subaqueous disposal technologies can be effective treatment alternatives for remediation of solid mining wastes and mining-influenced water (MIW). In its most basic form subaqueous disposal involves removal of surface material and placing it underground and under water, thus eliminating direct contact exposures. It is typically applied to sulfide-containing solid mine wastes to reduce oxidation of the wastes, thus limiting acid generation and metals release. It has also been used to dispose of non-acid-generating solid mine wastes through backfilling. Solid mine wastes have been disposed of into deep submarine environments, natural lakes, pit lakes, subsidence features, underground mines, and surface mines with mixed results in terms of environmental impacts. Site-specific conditions dictate the applicability of subaqueous disposal options. In the broadest sense subaqueous disposal also includes injection of MIW and process waters into geologic formations below the depth of fresh groundwater, but this has not been widely practiced.

The concept of subaqueous disposal evolved out of the abandonment of underground mines. Under anaerobic conditions such as those found in most subdrainage systems, pyritic rock produces less MIW at slower rates than under exposed or aerobic conditions (Demchak, Skousen, and McDonald 2004; Evangelou 1995; Fennemore, Neller, and Davis 1998). MIW from subdrainage systems was observed to slowly stabilize, becoming moderate in pH and low in metals. Although this process may take years or even decades, it tends to reduce the amount and longevity of constituents of concern in MIW from subdrainage underground mines. The chemical processes at work in subdrainage systems to isolate pyritic rock from oxygen were incorporated into subaqueous disposal systems designed for both in-mine disposal and disposal in surface ponds and lakes. Disposal of certain materials into underground mines may reduce the formation of MIW from the unmined sulfide rock as well as remediate the existing MIW. More recent developments include the use of biological mechanisms to quickly establish and maintain anaerobic conditions in subaqueous conditions.

Recent advances in the manipulation of aquifers to promote bioremediation has led to the use of various organic substrate additives to establish and maintain anaerobic conditions suitable to long-term subaqueous disposal in lakes, pits, or flooded mines (Totsche1 and Fyson n.d.). This process can be combined with chemical treatment where various alkaline materials are added to raise pH and produce alkalinity and are similar to the processes observed in biochemical reactors used in constructed treatment wetlands. The basic process uses a carbon source to promote metabolism that sequentially chemically reduces oxygen, nitrate, metals, and sulfate and establishes highly anaerobic conditions. As the sulfate is chemically reduced to sulfide, it combines with the metals to produce highly insoluble metal sulfides, essentially reversing the process that produces MIW. This highly anaerobic condition is maintained by heterotrophic bacteria until the substrate is depleted. The heterotrophic bacteria are thought to prevent oxygen from reaching autotrophic bacteria most commonly associated with the release of acid from pyritic rock by either coating them, thereby preventing oxygen from reaching the autotrophic bacteria directly, or by consuming oxygen before it can reach the autotrophic bacteria (Marchand and Thompson 1999).

The resultant biomass also produces bicarbonates that neutralize acidity according to the following formula:

$$2CH_3CHOHCOO^- + 3SO_4^{2-} + 2H^+ = 6HCO^{3-} + 3H_2S$$

New research suggests that the addition of a carbon substrate may change the microbial ecology to favor the formation of a microbial biomass that forms a film on pyritic rock that prevents oxidation (Song et al. 2008). Research is being conducted (Robinson-Lora and Brennan 2009) on complex substrates that combine both chemically active components and biological components to chemically buffer systems and biologically establish and maintain anaerobic conditions. One such substrate is being tested at the National Tunnel Site in Black Hawk, Colorado and the Standard Mine Site in Crested Butte, Colorado (see case studies Central City/Clear Creek Superfund Site—National Tunnel Discharge and Standard Mine Site at Crested Butte).

2. APPLICABILITY

Backfilling and subaqueous disposal technology is applicable to the following situations:

- solid mining waste or MIW
- can treat high volumes of material
- remote or rural areas
- can treat most contaminants of concern
- can be used solo or in conjunction with other technologies

The most common applications of backfilling and subaqueous disposal involve placing solid mining waste under a water cover to restrict its exposure to atmospheric oxygen and thus limit the formation of acid rock drainage. However, solid mining wastes that are not acid generating have been used for backfilling material and disposed of subaqueously to remove the direct contact exposure pathway. During active mining, subaqueous disposal is usually implemented using a slurry to dispose of the large volume of solid mining wastes generated, typically in excess of 95% of the ore produced. This material usually is placed into a tailings pond, but in a few cases where the mine was located near the shore, the solid mine wastes have been disposed in the deep submarine environment in a process known as submarine tailings disposal. Although no ecological impacts have been demonstrated (specifically to the fishing industry), the effectiveness and permanence of submarine tailings disposal is questionable due to line breaks, upwelling, convection currents, and strong density currents leading to transport of the fine tailings to the near surface aerobic environment where direct contact of contaminant with aquatic organisms is possible.

A classic example of this effect is the Island Copper Mine of north Vancouver Island, where around 400 million cubic yards of mine tailings were discharged through an outfall at 50 m depth into the adjacent fiord. After mining was completed in the 1990s, about 1 million metric tons of waste rock was placed back in the pit (which was the lowest land elevation in the world at the time), and a canal was constructed to connect the fiord with the open pit, thus rapidly flooding the pit with sea water to inhibit the formation of an acidic pit lake (Gusek and Figueroa 2009; Moore, Pelletier, and Horne n.d.; http://archives.library.uvic.ca/featured_collections/esa/fonds_island_copper_mines/default.html. Many other examples exist around the world, particularly in the southwest Pacific. The reason for consideration of submarine tailings disposal is related to the large land requirements, drastic failures of tailings dams, and the resultant cost in terms of loss of human life and environmental impacts.

3. ADVANTAGES

Backfilling and subaqueous disposal systems have the following advantages:

- permanent
- reduces the risk of exposure through direct contact
- easily implemented
- limited long-term monitoring with institutional controls
- flexible applications

The main advantage of subaqueous disposal is that it removes contaminants from the surface and reduces the risk of exposures through direct contact. It also reduces the potential for contaminant generation and release from oxidation of sulfide bearing wastes. Active mining sites have the option of using a water cover over a tailings pond or a lake or, if located near the sea, submarine disposal of tailings. At abandoned sites subaqueous disposal may be into water-filled underground mines or surface pits. Subaqueous disposal for the most part is permanent in the sense that the contaminants are removed from direct contact exposures at the surface and that little additional work is required to maintain or monitor the remedy.

The disposal options are typically easily implemented through simple excavation and disposal methods or transport of a mine waste slurry to the disposal site by gravity flow. In some cases the wastes are transported to the disposal site via a conveyor (as at Copper Basin site). Upon placement of the waste, little monitoring is necessary and institutional controls (see Administrative and Engineering Controls Technology Overview) may limit the use of the land to protect the remedy. Land use restrictions may be limited to nonresidential. Temporary periodic monitoring may be required to show that the MIW surrounding the disposed solid mine waste does not contaminate a source of drinking water (as at the Tar Creek chat washing pilot test site).

There are added benefits which may result from subaqueous disposal of mining wastes besides the elimination of a source of generation of MIW from oxidation of sulfide bearing wastes:

- removing the contaminant exposure pathway
- restoration of land to beneficial use
- reducing the impacts of MIW, by chemical precipitation in water-filled underground mines (or open pit) through pH or redox adjustments when chemical or biochemical amendments are added
- reduction of subsidence potential of underground mines and mine shafts

4. LIMITATIONS

- high cost
- regulatory limitations
- location of suitable disposal structures
- environmental concerns

The cost for subaqueous disposal is high relative to treatment options and capping due to the large volume of waste material that must be excavated, transported, and disposed. The waste from mining operations typically is greater than 95% of the material mined, totaling many millions of tons of rock. Consequently, the total cost for disposal is very high even though the unit costs may be quite reasonable through economy of scale.

Subaqueous disposal of mining wastes may be prohibited due to regulatory concerns. Underground injection control (UIC) regulations may apply for solid mining waste slurry and MIW injection requiring lengthy permitting process or prohibition of the process altogether. Some options such as submarine disposal may be prohibited due to potential environmental impacts. Due to the large volume of waste materials usually dealt with at abandoned mine sites, there may not be a convenient location for disposal. For example, the underground mines from which the ore was produced may be a great distance from the location of the mine waste, necessitating excessive transport, which may not be feasible. In addition, gaining access to the underground network of voids may be a limiting factor for disposal.

Depending on the disposal option, there are several environmental concerns:

- potential impact on benthic community, aquatic plants and animals
- modification of the food web and sediment structure from potential contaminant releases due to remedy disruption or failure
- potential negative impact of natural biological activity on waste stability and bioturbation

There are recent indications that injection of coal slurries into mine backfill wells may have contributed to contamination of nearby underground sources of drinking water (USDWs) (see Tar Creek Case Study).

5. PERFORMANCE

Subaqueous disposal is generally a variation of the sealing activities for underground mines researched in the 1920s by the U.S. Bureau of Mines. The concept follows the idea that using water as a barrier to maintain low oxygen levels is more economical than other measures to isolate reactive rock. Early models from the British Coal Corporation resulted in a rule of thumb that held that iron concentrations would decrease by 50% for each exchange in pore volume. A Works Progress Administration program in the early 1930s showed that sealing mines could reduce the acid loading to the Ohio River by over 25%. Studies since that time suggested that a significant reduction can be seen in contaminant levels over a period of decades in subdrainage systems. More recent results from well-designed systems suggest that significant reduction in acidity and metals can be realized in as little as three years (Demchak, Skousen, and McDonald

2004). A purposely designed subaqueous system can be expected to exhibit similar performance, especially if combined with chemical or biological systems to increase the kinetics of the surface reactions.

Backfilled and subaqueous disposal sites are successfully performing since the direct contact exposure pathways and acid generating potential of the wastes have been reduced or eliminated. These appear to be functioning as intended for as many years. The results of subaqueous disposal are mixed in terms of environmental impacts when considering disposal into surface waters (submarine or lakes). This process is an emerging technology, and short-term impacts to the benthic and aquatic communities need to be assessed on a site-by-site basis (discussed in an ITRC Contaminated Sediments Team document planned for 2011).

At old abandoned sites, solid mining wastes are usually excavated and transported to the disposal site by dumping, slurry, or conveyor placement. This process is exemplified where 500,000 cubic yards of solid mine waste was disposed using a conveyor into a collapsed underground mine at the Copper Mine site in Tennessee (Copper Basin Mining Case Study). At the Brewer Gold Mine of South Carolina, waste rock and tailings were placed into three water-filled open pits, which were then capped and revegetated (http://www.epa.gov/region4/superfund/sites/npl/southcarolina/brewgldmisc.html).

At the Tar Creek site in northeast Oklahoma, about 75,000 cubic yards of lead and zinc containing mining waste (locally known as chat) was excavated, transported, and dumped at the edge of a water-filled subsidence feature, then pushed into the collapse (McNeeley-Green Reclamation Case Study). Afterwards a three-foot clay cap was placed over the filled subsidence, and a monitor well was installed. This process resulted in about 50 acres of land being reclaimed for agriculture use and elimination of the direct contact exposure pathway for the lead, zinc, and cadmium contaminants. After the solid waste disposal, the water showed an initial increase in concentrations, particularly zinc and total dissolved solids, that declined slowly over time. A similar subaqueous disposal operation has taken place in at the Waco site in southwestern Missouri, which has led to consideration of subaqueous disposal as part of the remedy for lead and zinc mine wastes at superfund sites in Missouri and southeast Kansas (Hinrichs, Doolan, and Wienecke n.d.).

At a pilot test site at Tar Creek, about 10,000 cubic yards of fine tailings was excavated, transported, and slurried, prior to being injected (gravity flow) into the abandoned, water-filled underground mine workings (Tar Creek Superfund Case Study). Another pilot test currently being conducted at the Tar Creek site involves the subaqueous disposal of fines from a chat washing operation. The process water slurry containing about 5%–10% solids is typically routed to a series of settling ponds to remove the fines; then the water is pumped back to the wash plant for reuse in a closed-loop, total-retention system. For the pilot test, mine water is pumped to the washing screens, and the fines slurry is piped to wells that extend to the underground mine workings for disposal by gravity flow. This is essentially a closed system with the fines being deposited in the water filled mine voids, the water supply wells being located far away from the injection wells. Monitoring wells have been installed, and the effects on the water quality of the already degraded mine water by this operation is being monitored.

Land reclamation projects commonly use backfilling of mining wastes to close surface coal mines, followed by grading and revegetation (Hume and Cottonwood Creek case studies). Numerous coal mines have been hydraulically backfilled with coal mine waste and or cementacious material (including fly ash) for subsidence control (Dodd 2000). Applications using cemented mine waste backfill may lead to less contaminated groundwater through reduced oxidization of sulfides (Levens and Boldt 1996). However, there is recent evidence showing potential contamination of underground sources of drinking water (USDWs) caused from injections of coal slurries and fly ash through mine backfill wells in West Virginia, Maryland, Illinois, Indiana, and Kentucky (Murray 2009). Murray (2009) reviewed case studies in West Virginia where 1.4 billion gallons of coal slurry was injected into mines at the Sprouse Creek site (Mingo County) and several hundred million gallons of coal slurry was injected into mines near Laurel Creek site in Boone County. The slurry liquids contained Sb, As, Pb, Ba, Cd, and Cr greater than maximum contaminant levels (MCLs) and Al, Fe, Mn, Zn, and Cu grater than safe drinking water standards. Fifteen private wells were sampled in Mingo County and showed MCLs were exceeded 13 times for seven metals and secondary standards were exceeded 36 times for five metals. West Virginia Department of Environmental Protection has issued an indefinite moratorium on new permits for slurry injection wells.

At the abandoned Valzinco lead, zinc, and copper mine in Virginia (Valzinco Case Study), a bactericide and lime were added to the mine waste prior to underground disposal, capping, and revegetation with native grasses to eliminate acid-producing microbes and neutralize acid generation. Another related application of backfilling involves in-place treatment of mine waste with lime (Copper Basin Site Case Study), followed by grading and revegetation. The solid mining wastes are buried underground and underwater to limit atmospheric oxygen contact and the generation of acid mine water and to restore the land surface to reduce environmental impacts. At the Flambeau Mine site in Wisconsin (http://dnr.wi.gov/topic/mines/flambeau.html), high-sulfur waste rock was blended with limestone and placed in 3-foot lifts back into the open pit, followed by placement of the low-sulfur waste rock, weathered bedrock, sandstone, and glacial till to neutralize any acid formation upon refilling of the pit. Topsoil was added graded and revegetated. About 50,000 yd^3 of gunite-treated, high-sulfur waste rock was placed subaqueously into the neutralized water-filled pit at the Barite Hill Mine site in South Carolina (Harrington et al. 2008). The remaining 200,000 yd^3 of waste rock located within the pit but above the water level was graded and capped (http://www.epa.gov/region4/superfund/sites/npl/southcarolina/bhilngldflsc.html). At the Bark Camp site in Pennsylvania (Bark Camp Case Study), dredged sediment was disposed subaqueously, and the mine voids were to be closed with fly ash cementacious grout. This final grouting has not been accomplished at this writing.

Subaqueous disposal, in its broadest sense, also refers to disposal of MIW or mining process waters into subsurface geologic formations. However, in most cases the mine process waters are disposed along with the solid mine waste into the tailings pond. At the Copper Basin site (Copper Basin Case Study), lime-treated MIW is disposed into an open pit that is acting as a settling basin for lime sludge. This is also the case at the Berkley Pit in Butte Montana, where sludge from lime treatment of MIW is disposed into the pit (Zick et al. 2004 and www.mbmg.mtech.edu/env/env-berkeley.html).

6. COSTS

The costs for subaqueous disposal depend on the type of material being deposited, at what point in the process the disposition is being conducted, and the design of the disposal option. Subaqueous disposal is usually associated with solids such as waste rock or sediments but can also include impacted water. The improper disposal of waste solids has been an historic concern, which has led to many of the environmental issues associated with mining; therefore, proper design is imperative.

It is very important at which point the technology process is implemented related to the mining operation. If a subaqueous system can be integrated into the production process, costs can be reduced. If the subaqueous system is to be implemented as a remedial action, costs for removal, placement, and revegetation need to be included.

The design of the subaqueous system also substantially impacts costs. Consideration must be given to the disposal location, future use, and suitability to maintain containment of the wastes. System designs can be as simple as direct subaqueous deposition of material into a mine, pit, or lake that rely on isolating the material from oxygen to systems that include chemical and/or biological amendments to establish and maintain specific conditions to prevent the migration of contaminants or limit their impacts on the environment. Subaqueous disposal costs can also significantly vary depending on the future planned use of the disposal area. The costs associated with disposal of material into a lake can be significantly less than the deposition of material into a mine on or near property that may be reopened. Although subaqueous disposal is a relatively passive approach after the placement of material, costs for monitoring, inspections, and possible structure maintenance should be considered when establishing a total project cost.

The McNeely Green Reclamation Project at the Tar Creek site cost \$6,734 per acre or \$4.38 per yd^3 to excavate, transport, and dispose (subaqueously) 84,000 yd^3 of chat into a water-filled collapse feature, which was then capped. The site was graded and revegetated. Land reclamation at the Hume Mine and Cottonwood Creek sites cost \$2,500 per acre to backfill, grade, and revegetate coal mine waste rock in Missouri. Operations and maintenance costs are associated with monitoring and maintaining the vegetative cover.

7. REGULATORY CONSIDERATIONS

From a simplistic viewpoint, the concept of subaqueous disposal essentially reverses the mining process; mining removes material from the subsurface and exposes it to air, and subaqueous disposal places material into a subsurface environment that is isolated from air. The major differences are that subaqueous disposal is generally in areas that are more prone to impacting human health and the environment and the replaced material is usually mineralogically modified. Therefore, the replacement of material must be conducted in accordance with local, state, and federal requirements. Consideration must also be given to any regulatory impacts of transporting material.

Subaqueous disposal of mining wastes may be prohibited due to regulatory concerns. UIC regulations may apply for MIW injection requiring lengthy permitting process and solid mine waste slurry injected into mines through wells. Some options such as submarine disposal may be prohibited due to potential environmental impacts.

8. STAKEHOLDER CONSIDERATIONS

Since subaqueous disposal can occur in a highly visible existing or constructed surface water body, stakeholder participation can be more contentious than for many technologies. Since the design of a subaqueous disposal cell can take on many forms, future use of a surface water body containing a subaqueous cell needs to be controlled in accord with the original design. Subaqueous disposal can also represent a long-term solution that will require long-term stakeholder input.

At the McNeely Green site the stakeholder concerns were twofold:

- potential for additional contamination of the existing contaminated groundwater
- potential for recollapse of the reclaimed area

Groundwater monitoring is conducted to address the first concern, and the area will be used for only nonresidential (agricultural) purposes through land use restrictions (deed restrictions and land owner agreements) to address the second concern.

Concerns were also lodged about the potential for subaqueous disposal of fines from the chat washing operations at the Tar Creek site to contaminate the underlying source of drinking water, the Roubidoux aquifer. The pilot project is closely monitored, and a groundwater computer model will be used to evaluate this potential.

At the Copper Basin site coordination with the regulatory agencies, stakeholders, and responsible parties resulted in a good working environment with smooth implementation of the remedies. The Flambeau Mine site was controversial, and an administrative judge had to resolve the problems through issuance of mining permits.

9. LESSONS LEARNED

Although subaqueous disposal has been historically a default option for many sites, the complex chemical interactions involved are just now being sufficiently understood to allow successful systems to be designed and constructed as long-term remedies. Recent developments in biological and combined chemical/biological treatment of MIW and isolation of pyritic material are still being proven but promise to make subaqueous disposal a highly economical remedy for many sites.

10. CASE STUDIES

Table 10-1 Case studies using backfilling and subaqueous disposal

Hume Mine, Bates County, Missouri
Cottonwood Creek Mine, Bates County, Missouri

Valzinco Mine, Virginia
Copper Basin, Tennessee
Tar Creek Superfund Site, Oklahoma
McNeely Green Reclamation, Oklahoma
Bark Camp, Pennsylvania
Central City/Clear Creek Superfund Site National Tunnel Discharge, Colorado
Standard Mine Site Crested Butte, Colorado www.epa.gov/superfund/sites/npl/nar1740.htm
Brewers Mine Site, South Carolina www.epa.gov/superfund/sites/npl/nar1725.htm http://www.epa.gov/region4/superfund/sites/npl/southcarolina/brewgldmisc.html
Island Copper Mine, Vancouver Island, BC, Canada www.mindat.org/loc-12057.html http://archives.library.uvic.ca/featured_collections/esa/fonds_island_copper_mines/default.html
Flambeau Mine, Wisconsin http://dnr.wi.gov/topic/mines/flambeau.html
Barite Hills Mine, South Carolina http://www.epa.gov/region4/superfund/sites/npl/southcarolina/bhilngldflsc.html www.youtube.com/watch?v=44RlG_uIEQU
Berkeley Pit, Butte, Montana http://www.pitwatch.org/index.html http://www.mbmg.mtech.edu/env/env-berkeley.html https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0800416 http://www.epa.gov/superfund/programs/aml/tech/news/mwtpgilt.htm

11. REFERENCES

Demchak, J., J. Skousen, and L. M. McDonald. 2004. "Surface Water Quality, Longevity of Acid Discharges from Underground Mines Located above the Regional Water Table," *Journal of Environ*mental *Quality* **33**: 656–68.

Dodd, W. E. 2000. "Fly Ash Use in Pressurized Grout Remote Backfilling of Abandoned Underground Mines in North Dakota," presented at Interstate Technical Group on Abandoned Underground Mines, 3rd Biennial Workshop, April 25–27, Kansas City, MO. www.fhwa.dot.gov/engineering/geotech/hazards/mine/workshops/kdot/kansas04.cfm.

Evangelou, V. P. 1995. *Pyrite Oxidation and Its Control*. Boca Raton, FL: CRC Press.

Fennemore, G. G., C. N. Neller, A. Davis. 1998. "Modeling Pyrite Oxidation in Arid Environments," *Environmental Science and Technol*ogy **32**: 2680–87.

Gusek, J. J., and L. A. Figueroa, eds. 2009. *Mitigation of Metal Mining Influenced Water*. Littleton, CO: Society for Mining, Metallurgy, and Exploration.

Harrington, J., M. Gobla, L. Francendese, and E. Bates. 2008. "Low Cost Treatment of a Highly Contaminated Pit Lake Using Innovative Technology, Barite Hill Mine, McCormick, SC." www.epaosc.org/sites/2768/files/low%20cost%20trmnt%20of%20barite%20hill%20mine%20pit%20lake%209-26-08%20final%20draft.pdf.

Hinrichs, D., M. Doolan, and C. Wienecke. *Demonstration of Subaqueous Disposal of Mill Waste.*

Levens, R. L., A. D., and C. M. K. Boldt. 1996. *Environmental Impacts of Cemented Mine Waste Backfill*. Report of Investigation RI9599. U.S. Department of Interior, Bureau of Mines. http://www.itrcweb.org/miningwaste-guidance/References/cdc_9518DS1.pdf.

Marchand, E., and D. Thompson. 1999. *Biological Control of Acid Mine Drainage.* EPA Grant Number U914934. University of Colorado at Boulder.

Murray, A. J. 2009. *Evaluation of the Potential for Ground Water Contamination from Mine Backfill Wells*. Draft Report Summary.

Robinson-Lora, M. A., and R. A. Brennan. 2009. *Efficient Metal Removal and Neutralization of Acid Mine Drainage by Crab-Shell Chitin under Batch and Continuous-Flow Conditions.* University Park, PA: The Pennsylvania State University Department of Civil and Environmental Engineering.

Song J., P. H. Fallgren, J. M. Morris, and J. S. Cooper. 2008. "Source Treatment of Acid Mine Drainage at a Backfilled Coal Mine Using Remote Sensing and Biogeochemistry," *Water, Air, and Soil Pollution* **188**: 205–12.

Totschel, O., and A. Fyson. n.d. *Neutralizing Extremely Acidic Mining Lakes by Chemical and Microbial Treatment—Mesocosm Studies.*

Zick, R. L., D. A. Velegol, M. W. Hess, and M. Foote. 2004. "Butte Mine Flooding Water Treatment Facility: Implementation of Major Component of Selected Remedy for Historic Contamination at Berkeley Pit Site," presented at the 21st American Society of Mining and Reclamation Meeting, April 18–22, Morgantown, WV. http://www.itrcweb.org/miningwaste-guidance/References/2079-ZickPA.pdf