TECHNOLOGIES TO REDUCE ENVIRONMENTAL LIABILITY OF MINE WASTES

D.G. Feasby

Manager, MEND Secretariat
CANMET
555 Booth Street
Ottawa, Ontario
KlA 0G1
Telephone: (613) 992-8736
Facsimile: (613) 947-5284

G. A. Tremblay

Coordinator, Prevention and Control
MEND Secretariat, CANMET
555 Booth Street
Ottawa, Ontario
KlA 0G1
Telephone: (613) 992-0968
Facsimile: (613) 947-5284

Keywords: acidic drainage, liability, environment, tailings, waste rock, sulphide oxidation

Abstract

Acidic drainage is the largest single environmental problem facing the world's metal mining industry today. Technologies to prevent, or substantially reduce, acidic drainage from occurring in waste rock piles and tailings sites, and on the walls of open pits and exposed mine workings, need to be improved and demonstrated. These new technologies will substantially reduce the long term care and maintenance needs at operating and at closed mine waste sites.

The Mine Environment Neutral Drainage (MEND) program continues to develop knowledge and technology that will reduce the concerns and the actual environmental problems caused by acid mine drainage. However, it is not probable that a 100 % solution to the problem will be found, but rather a substantial reduction will be achieved in the negative impact on the environment and on economic activity by the mining industry.

Research and development on acid mine drainage sponsored by MEND has produced some important and successful technology improvements including:

- Improved predictive techniques for tailings and waste rock;
- Design procedures and innovative dry covers for tailings (e.g. fine tailings for covers) and waste rock;
- Confirmation of water covers and subaqueous disposal as the best technique to prevent acidic drainage;
- New, and potentially more economical waste disposal technologies (e.g. sulphide separation);

The mineral processor is playing an important role in the prevention of acid generation from sulphide-containing mine wastes. In addition to sulphide separation, the addition of alkalinity, and the engineering of tailings characteristics on discharge are playing important roles in the design of waste management areas that produce little acidity. For example, the use of fine, moisture-containing tailings holds considerable promise in the production of affordable dry covers. Gravity techniques, such as cycloning or sedimentation sizing, long used to prepare backfill are important techniques that can produce the fine fractions needed for a "dry" cover.

Water covers is the most technique for disposal of acid-generating wastes. In order to get a complete water cover, the mill operator must match tailings densities with that required by the underwater disposal system.

*Manager, MEND Secretariat, CANMET

** Coordinator, Prevention and Control, MEND Secretariat, CANMET

Table of Contents

1.0 What is Acid Mine Drainage?

Acid generation is a natural process that is essentially oxidation of sulphides, particularly pyrite and pyrrhotite. On exposure to oxygen and water these sulphides produce oxidation products - sulphuric acid and metal sulphates and hydroxides, and surface waters become acidic if sufficient acid-neutralizing minerals such as calcite or dolomite are not present. The acidic water from metal mines frequently carries with it elevated concentrations of heavy metals such as zinc, copper and nickel and high levels of dissolved sulphates of aluminum iron and magnesium. Severe acid mine drainage (AMD) can contain over 100 g/l dissolved salts.

Naturally occurring bacteria, thiobacillus ferrooxidans, play a very significant role in the acidification process accelerating the oxidation process by 2 to 3 orders of magnitude. Therefore the fixation of carbon is also an important process in AMD production. Rain-fall and snow-melt flush the toxic solutions from the waste sites into the downstream environment. If acidic drainage is left uncollected and untreated, the drainage will contaminate groundwater and local water courses, damaging the health of plants, wildlife, and fish.

At active mine sites (and at many inactive mine sites), mining companies operate comprehensive systems to collect and treat effluents and seepage from all sources. These facilities, when well operated and maintained, are sufficient to prevent downstream environmental impact. However, acid generation may persist for hundreds of years following mine closure; mine waste from metal mining in Europe 500 years ago are still producing acidic drainage ($pH < 3$). The operation of treatment plants for many decades or even hundreds of years is clearly not desirable. In addition, the conventional and most economical treatment technology using lime, produces sludges that can contain a very low percentage by weight of solids. In some severe cases, in a few decades, the volume of sludge will exceed the volume of tailings or waste rock producing the acidic drainage, and there will simply be no place to put the sludges.

Acidic drainage is not only caused by mining activity. Civil works can expose reactive sulphides; at an eastern Canadian airport, remedial measures are necessary to treat acidic drainage from a pyritic shale excavated for runways. In the past, acid-generating rock has been used for the construction of roads and railways; "acid highway and acid railway drainage".

Prospectors have known for a very long time that the tell-tail red streams caused by acidic drainage is a sign of massive sulphides - eg the Red Dog lead-zinc deposit in Alaska.

Types of mines where typically acid-generation may occur are:

Complex sulphide and base metal
Uranium (Elliot Lake)
Coal (Eastern)
Gold (infrequent)

2.0 Estimation of Current Liability Caused by AMD

2.1 Inventory of Acid-generating Mine Wastes in Canada

CANMET and MEND (Mine Environment Neutral Drainage program) have recently conducted surveys of mine wastes in Canada. The results of these 1994 surveys are summarized in Tables 1 and 2.

Table 1

Estimates of Mine All Wastes In Canada

	Tailings		Waste Rock
	Million Tonnes	Hectares	Million Tonnes
Newfoundland & Labrador	608	4,030	604
Nova Scotia	19	190	47
New Brunswick	78	614	27
Québec	1,884	8,405	2,704
Ontario	1,677	11,882	128
Manitoba	209	2,400	102
Saskatchewan	391	2,103	54
British Columbia	1,732	10,571	2,571
Territories	213	1,243	27
Canada	6,811	41,438	6,264

2.2 Acid-generating Mine Wastes

Table 2 contains estimates of acid-producing and potentially acid-producing mine tailings and waste rock. The estimates include wastes at mine sites that have been fully rehabilitated or at sites where the wastes have been deposited under water cover. Where estimates of either tonnes or hectares were not available, it is assumed that there are 150,000 tonnes of tailings per hectare and 400,000 tonnes of waste rock per hectare.

Table 2

Estimates of Acid-producing and Potentially Acid-producing Mine Wastes In Canada

	Tailings		Waste Rock
	Million Tonnes	Hectares	Million Tonnes
Newfoundland & Labrador	29.5	170	0.5
Nova Scotia	11.3	90	35.9
New Brunswick	76.5	564	25.7
Québec	254	2390	70.0
Ontario	984	6481	80.1
Manitoba	200	1780	68.8
Saskatchewan	66.4	273	19.9
British Columbia	192	571	421.0
Territories	64	243	17.0
Canada	1,877.7	12,562	738.9

2.3 AMD Liabilities

Using cost evaluation spreadsheets developed by Noranda Technology Centre (NTC 1992) and Steffen, Robertson and Kirsten (SRK 1994) reclamation and maintenance costs were developed for the following options for acid-generating mine wastes:

Tailings Option	Method	Assumptions
1.	Collect acidic seepage and treat indefinitely	100 or more years of water treatment
2.	Water cover	10 years of water treatment, perpetual embankment maintenance
3.	Establish complex dry cover	50 years of water treatment

Waste Rock		Assumptions
1.	Collect and treat seepage	100 or more years of water treatment
2.	Move to pit, add alkalinity and cover with soil	5 years of water treatment
3.	Recontour slopes, add complex earth cover	100 years of water treatment

The above options are shown schematically in Appendix A. Every operating and inactive mine waste site is different and a combination of the above options or other options may be determined to be the most environmentally and economically attractive. Also, as we shall discuss below, several mining companies are evaluating what can be done to minimize sulphide oxidation by additions or modifications in the milling process.

The discount rate selected for calculation of net present value (NPV) of future costs is 3 % for all options examined, and an annual cost maintaining a presence or "being there" of $120,000 is assumed for each 100 hectares of tailings and each 25 million tonnes of waste rock site. Water treatment is assumed to be by conventional low density sludge lime treatment technology.

A summary of the estimated existing liabilities for acid-producing mine wastes is shown in Table 3. Wastes with acid-production potential that have been completely disposed of underwater in natural lakes and in oceans do not represent any present or future liability and are excluded from these estimates. However, exposed beaches are often present at many "subaqueous" disposal sites, and acid-generating materials have sometimes been used to construct embankments and roadways. This practice leads to surface contamination, and these sites are included in the estimates.

Table 3

Estimates of Acid-Producing Mine Waste Liability in Canada
($ Billions)

Option	Up-Front Costs	Maintenance Costs		Total Costs
		Annual	Net Present Value	
Tailings - 1 Pump & treat	0.10	0.045	1.42	1.52
Tailings -2 Water cover	1.08	0.052	0.45	1.53
Tailings -3 Dry Cover	2.07	0.044	1.10	3.18
Waste Rock -1 Pump and treat	0.02	0.012	0.38	0.40
Waste Rock -2 Return to pit	2.04	0.007	0.03	2.07
Waste Rock -3 Dry Cover	0.37	0.009	0.28	0.65
Least costly technology: Collect and treat water - $1.92 billion				
Most costly technology: Dry soil covers for tailings and return rock to pit - $5.25 billion				

Geocon (1994) has estimated the Canadian liability to be $2.2 billion to $3.6 billion, with an "average estimate" to be $3.6 billion. Irregardless, the estimated liabilities are very high, and beyond the affordability of the industry and the public.

Geocon (1994) has estimated the Canadian liability to be $2.2 billion to $3.6 billion, with an "average estimate" to be $3.6 billion. Irregardless, the estimated liabilities are very high, and beyond the affordability of the industry and the public.

3.0 Methods to Reduce AMD Liability

Twenty years ago, acid generation from mine tailings and waste rock was not widely recognized as a significant environmental issue for the mining industry. The general approach to mine waste rehabilitation was essentially contouring for stability and erosion control, and the establishing a stable vegetation cover. Mine waste management and reclamation in Canada has evolved over the past 20 years from revegetation to more proactive strategies. The most productive strategy is prevention; once acid generation starts, it is almost impossible to stop.

Since 1989, the mining industry, the federal government and 5 provinces have voluntarily combined resources under the MEND program to develop technology that will significantly and permanently reduce this enormous liability.

3.1 Waste Rock

3.1.1 Existing Waste Rock Piles

Old rock piles represent the most stubborn AMD problems. Because of heat of sulphide oxidation internal temperatures can exceed 70^{0}C and this generates a "chimney effect" that keeps the oxygen being supplied by thermal drafts. Many mill operators have gazed out the window on cold winter's mornings and saw steam jets rising from rock piles that the miners have built. Also, some rock piles started generating acid after several years of dormancy.

Research and field experience with waste rock piles and heap leach operations has shown that the best method for slowing down the acid generation process is to restrict the supply of oxygen and water. This can be done by compacting the surface or applying a soil cover. Equity Silver reported (Feasby et al 1994) that applying a clay cover reduced the long term (net present value) cost of liability for a 77 million tonne rock pile by over $20 million.

3.1.2 Newly-excavated Rock

Mine operators are much more aware of methods to prevent acid generation from newly excavated waste rock, including low-grade stockpiles. Most operators are checking the acid-generating potential of waste rock as it is being produced, and many mill metallurgical laboratories are now routinely doing acid-base accounting and humidity-cell tests. The techniques being used to prevent AMD generation in new piles are:

- Blending and segregation, or layering;
- Compaction;
- Alkalinity addition (generally short term effective); and
- Underwater disposal.

3.2 Existing Tailings Areas

Old tailings areas also represent a challenge for mine owners. Old tailings areas that have "gone acid" contain considerable amounts of stored oxidation products and contamination potential. Various kinds of dry and wet covers can be considered in addition to the "do nothing" option - collect water and treat indefinitely. The options, including new developments, are summarized in Table 4.

Table 4
Options for Oxidized Tailings Sites

OPTION	Cost	Comments
Collect and Treat	Medium	Indefinite
Water Cover	Medium	Not applicable at most sites
Elevated Water Table	Variable	May need active maintenance
Simple soil cover	Low	Need to treat water indefinitely
Multi-zone earth covers	High	May provide only "walk-away"
Organic	Low	May need replenishing

3.3 New Tailings Areas

The most effective method for preventing acid generation in unoxidized tailings is the use of water covers. Although pond water contains a small amount of dissolved oxygen, the rate of oxidation is so slow that residual alkalinity in the tailings from either the natural mineral matrix or from the mineral processing is enough to prevent acid generation for a very long time. In the meantime, natural sedimentation processes will generate a reductive layer over submerged tailings. From extensive studies conducted by MEND on lakes where tailings have been disposed in the past, it has been conclusively shown that the tailings are geochemically stable and the transfer of metals is from the water column into the sediments.

3.4 Balancing of Net Mineral Value with Closure Costs

Mine operators are now making decisions on deposits to be mined based not only on their mineral value, but on their net value after waste disposal costs are deducted. This means that high iron sulphide, low metal-containing deposits have lower value. Also considered in the mining decision is the full costs of development rock, should it be considered a potential acid producer.

4.0 Mineral Processing and AMD

4.1 Waste Rock

The mill operator has traditionally had little to do with waste rock. One operator, Cominco has operated a sink and float plant for many years on run-of-mine feed and has been able to effectively separate silicates from sulphide-containing rocks. This technology may be applied again in the future for AMD prevention purposes if economics permit.

The addition of alkaline compounds (e.g. lime, limestone) to prevent acid formation in the short term prior to final disposal may be the only option available for some sites. At the Stratmat site in New Brunswick, acid generating waste rock was placed in a dump bedded with layers of limestone to prevent and control AMD. The laboratory results (Sheremata et al 1991) showed that acid generation should be controlled for approximately three years based on the dosage used. At close-out the waste rock would be moved and placed in the flooded mined-out pit for long term disposal.

Blending of acid generating and acid consuming materials is an acid rock drainage prevention strategy being used in B.C. Several existing and proposed sites are using this technique also referred to as layering. In such cases it is important for the operator to have sufficient information about the materials and sufficient neutralizing capability to ensure that blending can be carried out safely.

4.2 Tailings

4.2.2 Separation of Iron Sulphides

Separation of sulphides has been considered for many years as a measure to prevent AMD in stacked tailings. With the advent of new high capacity flotation cells and process control, pyrite and pyrrhotite can now be efficiently removed. The object of this removal, in addition to lowering S02 emissions from smelters, is to provide a low sulphide or sulphide-free tailings surface. The questions that the operator must answer are:

- To what level must the sulphides be removed?
- Is froth flotation the only practical method? (MEND says yes)
- What is to be done with the sulphide-rich fraction?
- How can an even spread of tailings be ensured year round?

Current knowledge on the degree of sulphide removal suggests that as a first estimate that an excess of alkalinity to acid potential is required but the exact level of sulphide removal for the long term depends on several factors, and each site needs to be assessed on a case-by-case basis. Sulphide removal is seen to be one the most promising technologies for large areas of stacked tailings. If the sulphides could be separated from the non-sulphides, this would open up several disposal options. Since the sulphide portion would be a volume of material that would settle to high densities, separate under water disposal in a lined containment, regarded as the most efficient method of disposal for sulphide-rich concentrates, could become realistic. Of course, mineral processors know that sulphides cannot be effectively separated from some high sulphide ores such as found in the Bathurst camp.

4.2.3 Tailings Rheology Engineering

4.2.3.1 Thickened Tailings Discharge (TTD)

For many years, Kidd Creek has operated a thickened tailings discharge (TTD) system near Timmins. The company and MEND have examined this system as a method of reducing AMD concerns and have determined that in addition to the elimination of slime ponds as per the original design, the tailings are predicted to maintain a high water table upon closure which will effectively prevent AMD. It is possible that the final closure design may include a cover immediately above the minimum level predicted for the water table. If the fluctuating phreatic surface can be kept above the sulphides, this will provide a good, economical abandonment strategy option for Kidd and for the remainder of the mining industry.

4.2.3.2 Chemical Addition

Kidd Creek has also determined that a small amount of lime (0.05 - 0.08%) added to tailings after thickener discharge improves the performance of the thickened discharge system, reducing even further size segregation and improving moisture retention capacity. This lime increases the efficiency of the deposition system by increasing the viscosity and densities of the tailings. Limestone has been used in the uranium industry to neutralize leaching acids and have also been used to neutralize surface acidity at many tailings areas in preparation for revegetation. It is expected that the use of limestone on sulphide tailings will increase.

4.3 Use of Tailings in Covers

In most of the covers projects currently underway in Canada and abroad, dry covers are usually constructed from natural fine grain soils (e.g. till, silt or clay) are maintained at a high degree of saturation to minimize the diffusion of oxygen through the cover. Because low permeability soils may not be readily available, alternate materials having somewhat similar physical properties may be substituted. MEND commissioned a study to evaluate potential materials and the use of non-reactive tailings was identified as one of the most promising materials that could be used in layered cover systems (SENES 1994).

Barbour (1990) and Aubertin et al (1994) have shown that both desulphurized tailings and fine moisture-retaining tailings have technical and economic potential in cover design placed over potentially acid-generating tailings. The concept is shown below in Figure 1.

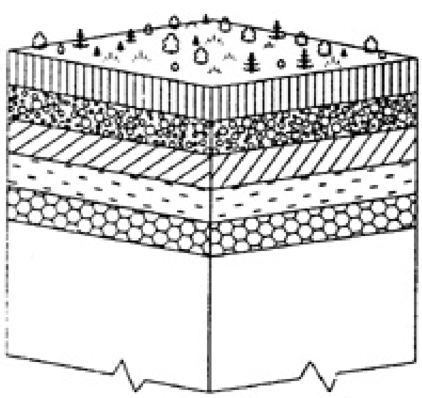


Figure 1
Typical section of a dry cover (Aubertin et al 1991)

Laboratory results have shown that a degree of saturation of over 90 % has been obtained for fine desulphurized tailings. In porous media this produces a layer that has about the same effective diffusion coefficient as that of water (Aachib et al 1994). An in situ testing program to validate the laboratory findings is currently underway.

Size separation will be the most important element for mineral processors. It has been shown that the sulphide fractions tends to be concentrated in the finest size fractions of the tailings (Cominco 1994). Based on this, gravity techniques may be incapable of separating the sulphides sufficiently to remove the acid generating capability of the tailings. Direct flotation was found to be the best method but quality control will be extremely important.

5.0 Other AMD Prevention Techniques Available to Mill Operator

5.1 Alkalinity addition

The addition of alkalinity materials (e.g. lime, limestone) to fresh acid generating mining wastes is a technique that could be used to control acid generation in the short term. The stoichiometric requirements of lime are calculated using agriculture formulas. As much as 2 times the required amount is placed since only 50% of the lime surface may be available for reaction or distribution is incomplete. The remainder is coated. This option has limitations because of costs, and difficulty in obtaining distribution and is probably restricted to low sulphide content tailings.

5.2 Oxidation of Sulphides

Another possible option available to mill operators is to force oxidation of the sulphides and produce acid in a controlled environment. As an example, roasting or autoclaving might be given additional consideration where some gold is present in the sulphides. However, oxidation of pyrite or pyrrhotite concentrates without metal recovery to produce acid is not currently economic and is not expected to be for a long time.

5.3 Sizing and gravity separation

One area that has generated considerable interest is the use of tailings as cover materials. In isolated circumstances where the gradation of the tailings permits, it may be possible to obtain adequate separation using gravity techniques to allow the construction of a dry cover using the generated coarse and fine fractions.

Disposal options and the feasibility of using artificial methods to raise the phreatic surface above the reactive tailings are being evaluated technically and economically as a method of reducing acid production. Placement of fine non-reactive materials on coarser acid generating tailings will result in a raised water table by capillary action. As noted above in Section 4.2.3. 1, if the fluctuating phreatic surface can be kept above the sulphides, this will provide a good, economical abandonment strategy option for many mines. Falconbridge have covered high pyrrhotite tailings with low sulphur, low permeability tailings slimes to decrease the oxygen and water movement through the tailings. The slimes cover has raised the phreatic surface such that most of the high sulphide portion is saturated and presently in the unoxidized state. After five years of abandonment the tailings was not acidic.

6.0 The Future

While no 100% solution has yet been found in solving the problem of acidic drainage, considerable progress has been made in developing new techniques that can be widely used, and will help Canada maintain a viable metal mining industry. Prediction and waste disposal techniques will continue to be refined. Further emphasis must be placed on the prevention, rather than containment of acidic waters or treatment of AMD. The use of effective disposal techniques is more cost-effective than solving the problem once AMD has started. Mill operators must have a thorough understanding of the nature of all materials exposed during the mining cycle and will frequently need to pay as much attention to tailings characteristics and disposal as with metal recovery. Regulatory bodies across Canada require that new mines have approved closure plans before mining can proceed. The public and the investors want guarantees with respect to long term liabilities.

The MEND program is providing a solid credible basis for technology implementation. The knowledge gained will remove the environmental concerns about the development of new mines; acidic drainage can be prevented!

7.0 References

Aachib, M., Aubertin, M., Chapuis, R.P., "Column Tests Investigation of Milling Wastes Properties used to Build Cover Systems". Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, Pennsylvania, April 24 - 29, 1994, Vol. 2, pp 128 - 137.

Aubertin, M., Chapuis, R.P., "Consideration hydro-geotechnique pour 1'entreposage der residus miniers dans le nord-ouest du Quebec". Second International Conference on the Abatement of Acidic Drainage, Montreal, Quebec, September 16 - 18, 1991, Vol. 3, pp 1 - 22.

Aubertin, M., Chapuis, R.P., Aachid, M., Ricard, J.F., Tremblay, L., Bussiere, B., "Cover Technology for Acidic Drainage: Hydrogeological Properties of Milling wastes Used as Capillary Barrier". First International Conference on Environmental Geotechnics, Edmonton 1994.

Barbour, S.L., "Reduction of Acid Generation in Mine Tailings Through the Use of Moisture-retaining Cover Layers as Oxygen Barriers: A Discussion". Canadian Geotechnical Journal, Vol. 27, pp 398 - 401, 1990.

Cominco Engineering Services Limited, "Separation of Sulphides from Mill Tailings - Phase I (MEND)". MEND Project 2.45. 1 a, June 1994.

Feasby, G., Jones, R.K., "Report of Results of a Workshop on Mine Reclamation, Toronto, Ontario, March 10 - 11, 1994". August 1994.

Geocon, "Economic Evaluation of Acid Mine Drainage Technology". MEND Project 5.8. 1, July 1994.

Noranda Technology Centre Internal Report, "Comparative Costs of decommissioning Technologies", November 1992.

SENES Consultants Limited, "Evaluation of Alternate Dry Covers for the Inhibition of Acid Mine Drainage from Tailings", MEND Project 2.20. 1, March 1994.

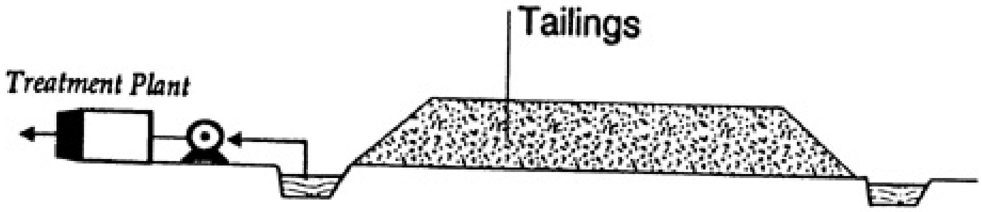
Sheremata, T.W., Yanful, E.K., St-Arnaud, L.C., and Payant, S.C., "Flooding and Lime

Addition for the Control of Acidic Drainage from Mine Waste Rock: A Comparative Laboratory Study". First Canadian Conference on Environmental Geotechnics, Montreal, Quebec, May 14 -16, 1991, pp. 417 - 423.

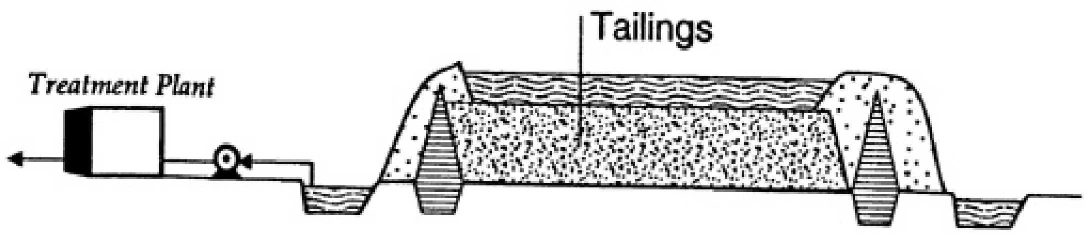
Steffen, Robertson and Kirsten, "Reclamation Cost Estimating Model". Report prepared for Department of Indian Affairs and Northern Development (DIAND). January 1994.

Appendix A

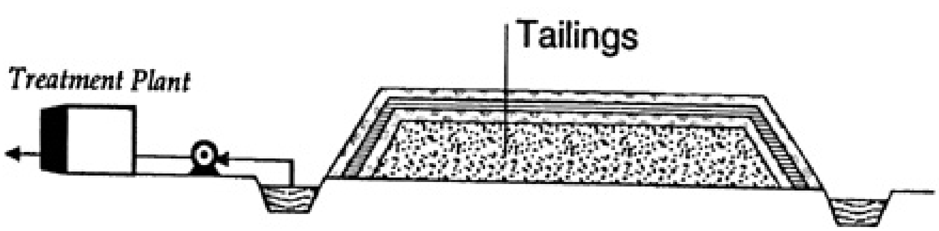
Schematic Representation of Options to Control Acid Mine Drainage



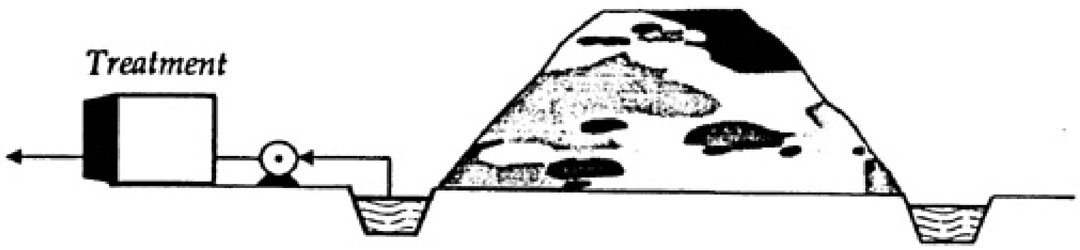
Tailings Base Case 1
Collect and Treat



Tailings Case 2
1m Water Cover, Collect and Treat

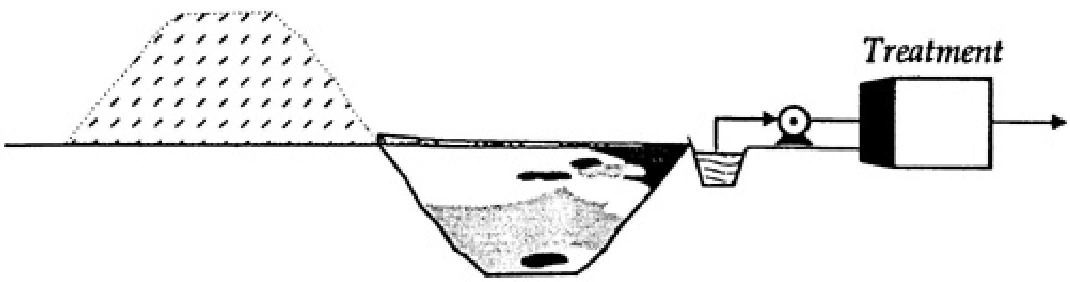


Tailings Case 3
3 Layer Earth Cover , Collect and Treat



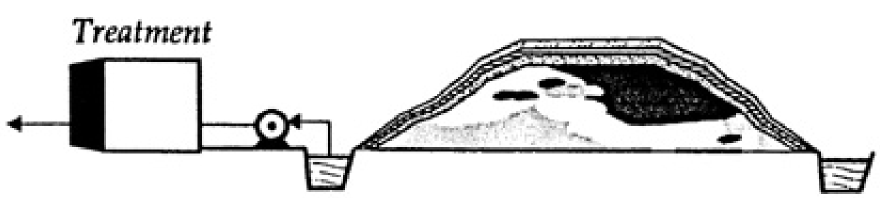
Rock Pile Base Case

Collect and Treat



Rock Pile Case 2

Move to Pit, add Limestone, Lime and Cover



Rock Pile Case 3

Recontour to a 3:1 Slope Complex Cover, Collect and Treat