The Minewall Approach for Estimating the Geochemical Effects
of Mine Walls on Pit Lakes

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Abstract

The Minewall Approach for estimating the geochemical effects of mine walls on pit lakes was developed as a formal standardized technique for the Canadian MEND Program in the 1990's. Portions of the technique can be traced back decades to studies of underground mines in the eastern USA, showing that underground geochemical effects were well understood and predictable in the 1960's.

The primary steps in applying the Minewall Approach are as follows.

First, obtain unit-area reaction rates. These can be obtained from Minewall Stations. Alternatively, approximate rates can be estimated from well-rinsed humidity cells, based in part on the total rock-particle surface area in a cell and/or the portion attributable to certain minerals. Field rates from Stations show that physical rates of weathering can rival those of chemical weathering. As a result, fresh minerals are exposed on pit walls regularly, precluding the formation of a deep weathering "rind" that might slow rates with time. Some rates from Stations were apparently dependent on the pH of the rock surface, whereas others were dependent on factors like solid-phase levels.

Second, compile the lateral and inclined exposed surface areas by elevation in the pit, based on site-specific survey data. For closure, this can be combined with the stage curves for volume-area-elevation to simulate the rate of pit-wall submergence during flooding.

Third, estimate the fracture intensity or design the blast intensity to obtain a ratio of reactive surface area to exposed surface area, and include other rock surface like waste rock. Case studies show the average estimated ratio of reactive rock surface area to exposed (visible) mine wall varied from27:1 to 161:1. Any waste rock, ore rock, tailings, or backfill placed within a pit can add substantially to this reactive surface area. Three case studies of pits had estimated reactive surface areas of $11\text{-}240\text{x}10^6 \, m^2$, producing total acidity (based on sulphate) at a rate of approximately $2\text{-}20\text{x}10^9$ mg SO_4/wk.

Fourth, estimate the loadings that will be released on a regular or periodic basis, or retained if/until that portion of the wall is submerged. Case studies estimated that 20-35% of annual production from all reactive rock surfaces in the pits was flushed regularly or periodically, whereas 65-80% would only be released upon inundation.

1. Introduction and Historical Perspective

The prediction and monitoring of the chemistry of water draining into, through, and/or from a mine are important environmental concerns throughout the planning, operational, and closure phases. While these concerns may be considered a recent development, they actually arose many decades ago. For example, Stuart and Simpson (1961; see also Table 4.3-5 in Morin and Hutt, 1997 and 2001a) compared aqueous pHs at several underground mines in 1941 to those in 1961.

By the 1960's, the need was recognized for understanding physical and geochemical processes controlling minewater chemistry and acid rock drainage. The Ohio University became one "hot bed" for research in these areas, leading to several theses and reports. An overview of the research with some details can be found in Morth et al. (1972), which was the earliest integrated physical, chemical, and biological study of acidic drainage identified by the Minewall literature review (MEND, 1995). Although some equations in Morth et al. may be incorrect based on dimensional analysis, it became the cornerstone of the Minewall conceptual models for underground mines and contributed substantially to the conceptual models for pits (Section 2).

In addition to opposing some suspect views still held about acid generation, Morth et al. (1972) reported on field and laboratory tests involving the occasional rinsing of exposed coal. One field test involved the isolation of a face of coal in an underground mine, by cutting channels 15-30 cm deep around the selected mine walls and filling those channels with polyurethane foam to isolate the face from seeping water. This is similar to Minewall Stations (Appendix A), but Stations involve isolation only directly on the face from precipitation. This is because small channels are difficult to cut in hard rock and may cause fracturing on the face that could increase reaction rates.

The laboratory tests discussed by Morth et al. were similar to the original or "Sobek" humidity cells using excess water flushing and inundation (Section 3). These are traceable back to at least Hanna and Brant (1962).

Rates from the field mine-wall tests by Morth et al. (1972), based on rinses every 4-8 weeks, were 140-5250 mg of acidity/(m^2 of rock surface•week) or mg/m^2/wk, which are within the range from Minewall studies (Section 2.1). Laboratory rates, based on condensation leaching of reaction products on coal blocks measuring 1x2x4 inches, were less, at 21-56 mg acidity/m^2/wk, 9-16 mg sulfate/m^2/wk, and 13-51 mg iron/m^2/wk. The lower rates from the laboratory testwork may have represented the retention of some reaction products on grain surfaces due to incomplete leaching.

Based on cores into underground mine walls, Morth et al. (1972) found that sulphide oxidation was occurring at distances up to 15 m behind the exposed walls. This is consistent with visual observations at Island Copper Mine in British Columbia (MEND, 1995), during a pushback of a pit wall, that revealed fractures oxidized as far back as 10 meters from the wall. The importance of these observations is discussed in Section 2.3.

Morth et al. identified three primary mechanisms for water movement and leaching in underground mines:

1) migration of condensation carrying dissolved solids, originating from moist air in underground mines and the hygroscopic nature of concentrated acidic solutions around pyrite (labelled "diffuse leaching"),
2) unsaturated flushing of rock surfaces by trickling water ("trickle leaching"), and
3) saturated flushing of channels by inundation of the channel, temporarily halting oxidation ("inundation leaching").

With these three mechanisms, simulations were conducted on (1) the small McDaniels Mine test drift that was 12-14 m long, (2) at large-diameter holes near the McDaniels Mine known as Auger Holes 1, 3, 4, 5, and 6, and (3) on the Decker Mine with an acid output in 1964 of 76,000 kg/yr. The raw data from Morth et al. were normalized to time and reported surface area "providing water", yielding the unit-area rates for acidity production that were similar to those measured in the aforementioned field mine-wall tests.

Morth et al. (1972) concluded that hundreds of kilograms of acidity could be stored within the walls of small mines like the McDaniels (one drift of 12-14 m length). These stored reaction products can then be released slowly through time or released quickly upon flooding, which could be mistaken for ongoing acid generation. This is discussed further in Section 2.4.

2. The Minewall Technique

In order to standardize various "wall washing" procedures and to establish a field kinetic test, MEND (1995) developed the Minewall Technique to estimate in a standardized manner the geochemical effects of mine walls on water chemistry. For underground mines, the Minewall Technique followed the conceptual models of Morth et al. (1972), whereas for pits those conceptual models were adapted as discussed in Section 2.4

The Minewall Technique has four primary steps (oriented to open pits in this paper).
1) Obtain unit-area reaction rates.
2) Compile the lateral and inclined exposed surface areas by elevation in the pit.
3) Estimate the fracture intensity or design the blast intensity in order to obtain a ratio of reactive surface area to exposed surface area, and include other rock surfaces like waste rock.
4) Estimate the loadings that will be released on a regular or periodic basis, or retained if/until that portion of the wall is submerged

2.1 Unit-Area Reaction Rates

The first step in the Minewall Technique is to obtain unit-area reaction rates, such as mg of element/(m^2 of rock surface•week) [$mg/m^2/wk$]. This information can be obtained using inexpensive Minewall Stations (Appendix A). Maximum unit-area rates can also be estimated from unit-weight humidity-cell rates (Section 3), although those resulting rates are not necessarily accurate.

At this time, the International Kinetic Database Version 14 (Morin and Hutt 1997 and 2001a, and www.mdag.com/ikd.html) contains average results from 37 Minewall Stations at seven minesites. A scatterplot of average pH against average sulphate-production rates (representing sulfide-oxidation rates) shows the highest rates are found mostly at the lowest pH (Figure 1). Rates below 1000 mg SO_4/m^2/wk are not correlated with pH. Sulphate production also correlates with initial solid-phase sulphide as %S (Figure 2). Leaching rates of some elements correlate well with average pH, like arsenic (Figure 3), whereas others show minor to no correlation, like copper (Figure 4). Therefore, rates are influenced by aqueous and solid-phase parameters, but not in a reliably predictable manner. This is why in-field measurements using Minewall Stations are necessary.

For Minewall Stations with suspended-solids measurements, the rate of physical weathering releasing solid rock particles can rival or exceed that of chemical leaching based on total dissolved solids (Figure 5). In all cases, physical weathering was significant at approximately 100 mg/m^2/wk and greater. It is unlikely this can be attributed to rock dust after blasting, as the Stations are well rinsed during each sampling event and then covered. Instead, chemical weathering, especially driven by sulphide oxidation, creates secondary minerals in intragrain spaces. These minerals can have a greater molar volume than the primary minerals, causing expansion of the rock and increased physical weathering (e.g., Jerz and Rimstidt, 2003 and 2004). This leads to ongoing exposure of fresh minerals and continuation of full reaction rates, precluding popular rate-decreasing processes such as shrinking-core, weathering-"rind", and mineral-occlusion models.

2.2 Exposed Surface Area by Elevation

This second step is site specific and delineates the lateral and inclined exposed surface areas of pits by elevation. The cumulative exposed surface area is one factor required for calculating total reaction products per unit time in a pit. For closure, the elevation-specific data can be combined with the stage curves for volume-area-elevation to simulate the rate of pit-wall submergence during flooding.

2.3 Fracture Intensity and Other Rock Surfaces

After geochemical reaction rates are obtained for unit surface areas (Section 2.1) and exposed surface areas in a pit have been obtained (Section 2.2), the next major step in the Minewall Technique is the amount of rock surface that is chemically reactive. A first impression might be that the total reactive surface is equal to the exposed walls of a mine. However, fractures are invariably present in mine walls naturally and by blasting and excavation (e.g., Evans, 1987; Pusch, 1989; Toran and Bradbury, 1988), and they provide additional reactive surfaces. Morth et al. (1972), for example, found reactive fracture surfaces that extended as far as 15 meters from mine walls. Also, visual observations at Island Copper Mine in British Columbia (MEND, 1995), during a pushback of a pit wall, revealed fractures oxidized as far back as 10 meters from the wall. Consequently, the fracture surfaces behind the mine walls can provide a much greater reactive surface than that suggested by the exposed walls from Section 2.2.
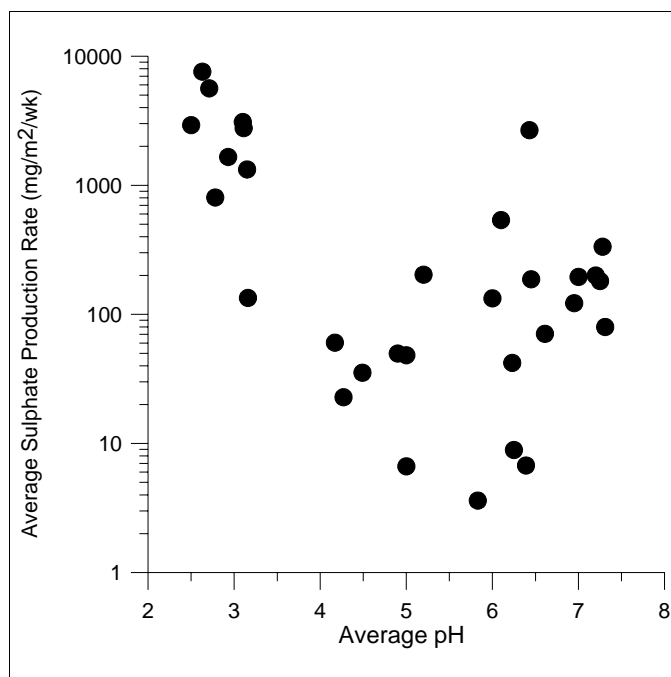
FIGURE 1. Average Sulphate Production Rate vs. Average pH for Minewall Stations in the International Kinetic Database (IKD, Version 14).
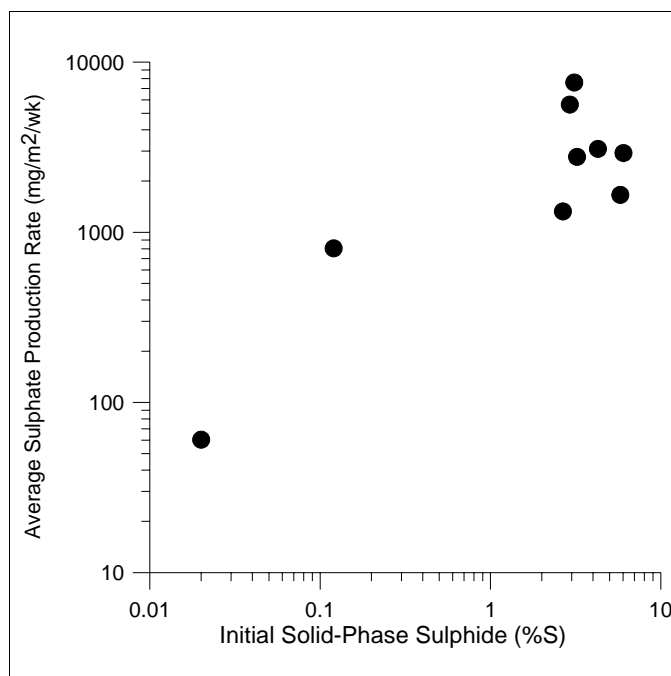

FIGURE 2. Average Sulphate Production Rate vs. Initial Solid-Phase Sulphide for Minewall Stations in the International Kinetic Database (IKD, Version 14).
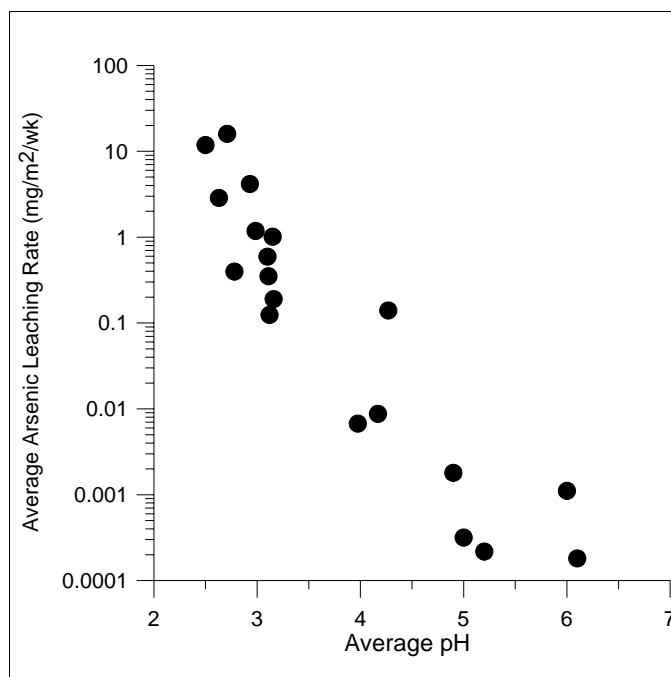
FIGURE 3. Average Arsenic Leaching Rate vs. Average pH for Minewall Stations in the International Kinetic Database (IKD, Version 14).
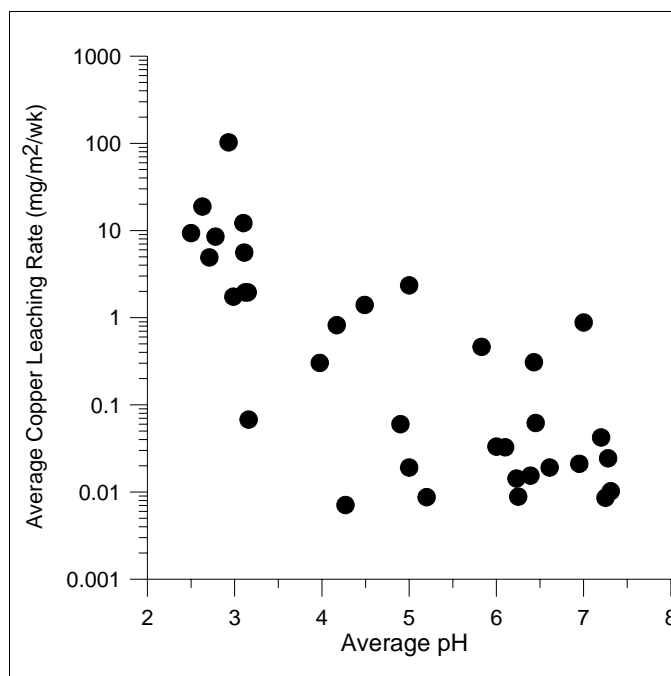

FIGURE 4. Average Copper Leaching Rate vs. Average pH for Minewall Stations in the International Kinetic Database (IKD, Version 14).
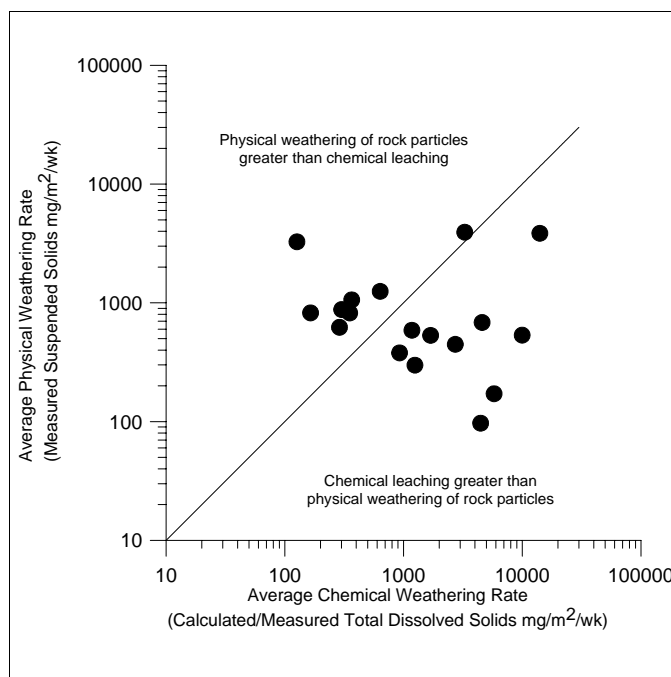
FIGURE 5. Average Physical Weathering Rate vs. Average Chemical Weathering Rate for Minewall Stations in the International Kinetic Database (IKD, Version 14).
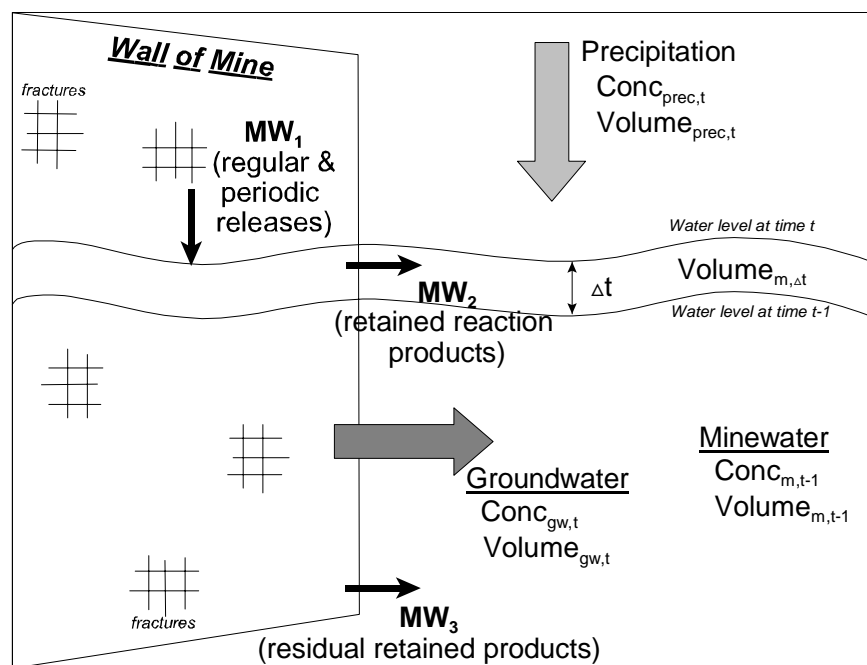

FIGURE 6.   Minewall Conceptual Model for a Pit Wall Undergoing Inundation.

As a numerical example, a pit wall that has (1) spacings for vertical and horizontal fractures of 1 meter and (2) oxidation occurring to 10 meters behind the wall will have 41 m^2 of reactive surface for each m^2 of exposed wall. For three Minewall case studies of pits (MEND, 1995), the average estimated ratio varied from 27:1 to 161:1, yielding total reactive surface areas of $11-240x10^6$ m^2. When multiplied by their unit-area sulphate rates (as indicators of total acid generation), these pits were generating approximately $2-20x10^9$ mg SO_4/wk.

Any waste rock, ore rock, tailings, or backfill placed in the pit can add to this reactive surface area. For example, the Island Copper Pit contained $11.5x10^6$ t of waste rock at the end of mining, and its estimated rock-surface area rivalled that of the pit walls (MEND, 1995).

2.4 Estimate the loadings that will be released regularly or retained if/until that portion of the wall is submerged

Morth et al. (1972) defined three types of reaction-product removal, involving diffuse leaching, trickle leaching, and inundation leaching (Section 1). These three processes can be adapted to open pit mines: the flushing of rock surfaces "regularly", "periodically" such as by a storm or snow melt, and "not until flooded" which is usually relevant only after closure (Figure 6).

Mathematically, concentrations in mine waters can be estimated during operation and closure using Equation1 and 2, respectively. These equations are explained further in Morin and Hutt (2001b). During active drainage or pumping during operation, the equation for each concentration in the drained or pumped minewater is relatively simple:

$$Conc_m = \{[Flow_1*Conc_1] + [Flow_2*Conc_2] + \, ... \, + MW_1\} / \{Flow_1+Flow_2+...\} \qquad [1]$$

where $Conc_m$ = concentration in pumped/drained minewater (mg/L);

$Flow_x$ = positive (inflow) or negative (outflow) flowrate such as precipitation or groundwater (L/wk)

$Conc_x$ = concentration associated with $Flow_x$ (mg/L)

MW_1 = loading (mg/wk) from regular and periodic flushing of mine walls

Equation 1 assumes all input $Flow_x$, $Conc_x$, and MW_x are constant, but can easily be adjusted to consider weekly variations in input (see Equation 2). Equation 1 also assumes concentrations are not significantly affected by geochemical processes (see factor Evol in Equation 2). A negative value for $Conc_m$ in Equation 1 means there is a net loss of water from the mine, which occurs in some circumstances.

After mining when active pumping or draining ceases, concentrations in the water filling the mine can reflect additional effects like the ongoing accumulation of mine water and the additional contributions from chemical retention in the mine walls (Figure 6). The general equation for concentrations in minewater during closure is:

$$Conc_{m,t} = \{[Conc_{m,t-1}*Volume_{m,t-1}] + [Flow_{1,t-1}*Conc_{1,t-1}] + [Flow_{2,t-1}*Conc_{2,t-1}] + \, ...$$
$$+ MW_{1,t-1} + MW_{2,t-1} + MW_{3,t-1}\}*Evol_{m,t} / Volume_{m,t} \qquad [2]$$

and $\text{Volume}_{m,t} = \text{Volume}_{m,t-1} + \text{Flow}_{1,t-1} + \text{Flow}_{2,t-1} + ...$ [3]

where $\text{Conc}_{m,t}$ = Closure concentration (mg/L) in ponded minewater at current week, t
$\text{Conc}_{m,t-1}$ = Closure concentration (mg/L) in ponded minewater at previous week, t-1
$\text{Volume}_{m,t}$ = volume of ponded mine water at current week (L)
$\text{Volume}_{m,t-1}$ = volume of ponded mine water from previous week (L)
$\text{MW}_{1,t-1}$ = loading (mg/wk) from regular and periodic flushing of mine walls
$\text{MW}_{2,t-1}$ = loading (mg/wk) from recently submerged mine walls
$\text{MW}_{3,t-1}$ = any residual ongoing loading (mg/wk) from previously submerged mine walls
$\text{Evol}_{m,t}$ = factor representing evolution of minewater chemistry between times t-1 and t; each element can have a different value derived from secondary-mineral solubility, sorption, etc.

When there is no accumulation of water in the mine (Volume = 0) and no significant evolution over the time period ($\text{Evol}_{m,t}$ = 1.0), Equation 2 reduces to Equation 1.

Three case studies of open pits modelled with Minewall, calibrated to pre-existing monitoring data, indicated regular and periodic flushing ($\text{MW}_{1,t-1}$, Equation 2) was 20-35% of annual production from all reactive rock surfaces in the pits. Inundation ($\text{MW}_{2,t-1}$) was 65-80%, and residual leaching ($\text{MW}_{3,t-1}$) was zero (MEND, 1995).

3. Extrapolation of Unit-Weight Humidity-Cell Rates to Unit-Area Rates

In the International Kinetic Database Version 14 (Morin and Hutt 1997 and 2001a, and www.mdag.com/ikd.html), there are several minesites that have rates for both humidity cells as unit-weight mg/kg/wk and for Minewall Stations as unit-area mg/m^2/wk. Because Minewall Stations undergo heavy rinsing, comparisons can be made only to cells that have undergone excess rinsing or inundation ("Sobek" procedure, see Section 1) for consistency.

Although identical samples were not tested in both the cells and the stations in the IKD, general comparisons using ranges (highs-lows) can be made to estimate the conversion factors needed to calculate unit-area station rates from unit-weight cell rates. Mathematically, this factor takes the form of:

Calculated Surface Area (CSA in m^2/kg, shown on the y-axis of several figures below) =
Cell rate (mg/kg/wk) / Station rate (mg/m^2/wk) [4]

This calculated area represents a correction factor, nominally the grain-surface area, needed to obtain the cell rate from the station rate, but the calculated area may not coincide with the grain-surface area for the cell. This leads to an important question: can the CSA be estimated in advance when Minewall Stations are not available, based on data solely from humidity cells? A review of available information in the IKD can answer this.

The calculated surface area from Equation 4 can be compared with the grain-surface area (or "geometric" surface area in m^2/kg) in the corresponding humidity cell. The geometric surface area is derived from the cell sample's grain size analysis (Morin and Hutt, 1997 and 2001a, and Grain 3.0 at www.mdag.com/grain30.html), determined from:

Geometric Surface Area of a Humidity Cell Sample (GSA in m^2/kg) =

$$(\sum_{i=1}^{n}(s_i * c_i) + s_f)/wt \qquad\qquad [5]$$

where   n = number of sieves used in the grain-size analysis

s_i = the surface area (m^2/particle) for one particle, based on simplified geometry (sphere or cube), using the sieve aperture (in m) halfway between i and i-1

c_i = the number of particles retained on sieve i, requiring specific gravity of grains

s_f = cumulative surface of the grains passing through the finest sieve (m^2), requiring an assumed average grain size

wt = weight of the whole sample (kg)

A free-of-charge spreadsheet for calculating geometric surface areas can be found at www.mdag.com/grain30.html.

Once the GSA for a cell sample has been determined, the GSA for specific minerals, like sulphide or zinc-bearing minerals, can be estimated. For example, if there is 0.15%S sulphide in a sample with a GSA of 10 m^2/kg, then there would be 0.015 m^2 of sulphide surface/kg of whole sample (10 * 0.15%/100). This is based on the critical assumption that sulphide (or other mineral) grains have the same distribution as the sample as a whole, which has been assumed by many researchers examining mineral reaction rates (e.g., Biglari et al., 2003). In reality, the sulphide grains could be coarser than the sample as a whole, or finer.

Sulphate production rate is the surrogate for sulphide oxidation rate when leachable solid-phase sulphate is minimal. Each cell from the IKD has a sulphate production rate in mg/kg/wk (Figure 7). This cell rate can then be divided mathematically by the range of Minewall rates in mg/m^2/wk to obtain a range of CSA values as defined by Equation 4. The range for each cell appears as a vertical line in Figure 8. This shows that there is no significant correlation of CSA (y-axis) with a sample's GSA from Equation 5.

When a sample's GSA is multiplied by its sulphide content to obtain a sulphide-mineral GSA (x-axis of Figure 9), a general correlation is seen, suggesting sulphide-mineral area exerts an influence on oxidation rate. Except for samples from one minesite, the general correlation shows that an approximate maximum rate of sulphate production in mg/m^2/wk can be calculated from the cell rate using the equation:

Approximate Maximum Estimated Minewall Rate (mg/m^2/wk) =   [6]
  Cell Sulphate Rate (mg/kg/wk)) /[GSA of Sample (m^2/kg) * (%S sulphide/100)) * 100:1]

The factor of 100:1 is derived from the upper dashed line in Figure 9. However, it is important to note that many ranges span about one order of magnitude or more, so Equation 6 can produce an approximate maximum that could be a factor-of-ten or more too high. Furthermore, for one minesite, the approximate maximum would be around 1:1 rather than 100:1, so Equation 6 would lead to an overestimation of at least a factor of 100. Therefore, the conversion of cell rates to unit-area rates cannot be done reliably with only cell data.

One interpretation of Figure 9 is that sulphide grains tend to have more grain surface area per kg than the sample as a whole, and thus are finer than the sample as a whole. Based on the dependence of grain surface area on the square and cube of the radius, a hundredfold greater (100:1) CSA (y-axis) than sulphide GSA (x-axis) as seen in Figure 9 would be equivalent to sulphide grains having roughly one-hundredth the radius of the sample's grains as a whole. Such a tendency of sulphide minerals towards finer grain sizes in crushed samples has been reported (e.g., Price, 1997).

A similar correlation of acidity production to the sulphide surface area exists (Figure 10), although there are fewer datapoints (fewer vertical range bars than in Figure 9). Nevertheless, Equation 6 can also be used to calculate approximate maximum unit-area acidity production rates. Acidity can be affected by independent neutralization reactions that could distort correlations with sulphide minerals, so the observed general correlation despite this distortion is notable.

Valid alkalinity production rates can be calculated only from cells with effluent pH above 4.5, yielding only four cells from the IKD. These few data ranges suggest a general correlation with the geometric surface area of neutralizing minerals based on NP (Figure 11). Maximum alkalinity-production rates could be approximated using Equation 6, but with the factor of 100:1 reduced to 10:1.

For copper leaching, the correlation of CSA was weak with the geometric areas of copper minerals (Figure 12) and of sulphide minerals. However, the correlation was better when compared to the geometric surface area of the whole sample (Figure 13), but insufficient to derive an equation similar to Equation 6 for approximate maximum rates. A similar observation can be made for zinc leaching (Figure 14).

In summary, unit-weight rates from well-rinsed humidity cells can theoretically be converted to unit-area rates using the geometric surface area of the sample. However, actual comparisons at a few sites with both cell and Minewall rates show the theoretical conversion is not correct or reliable. Approximate maximum unit-area rates for sulphate, acidity, and alkalinity can be calculated using the geometric surface area of the respective minerals multiplied by some factor (e.g., 100:1), but this can overestimate actual rates by at least an order of magnitude. Such a relatively simple conversion for maximum rates could not be derived for the leaching of copper and zinc.
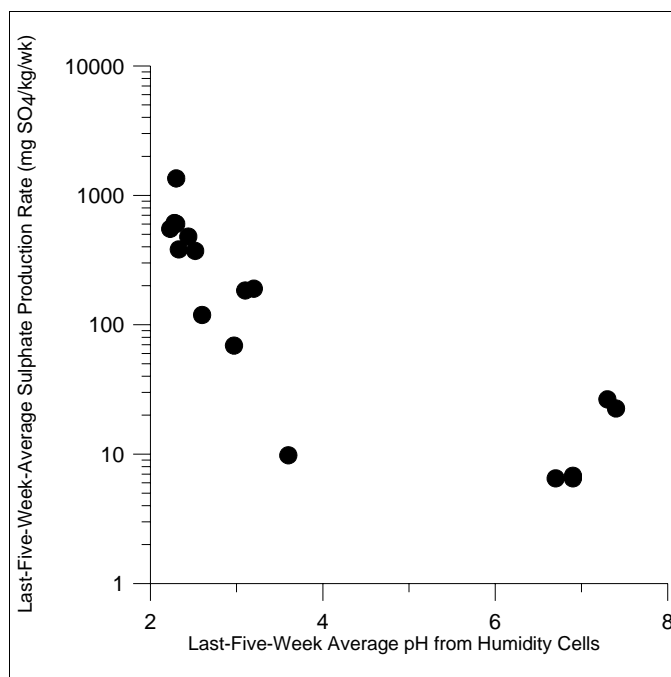
FIGURE 7. Average Sulphate-Production Rate vs. Average Effluent pH from Cells at Minesites with Minewall Stations.
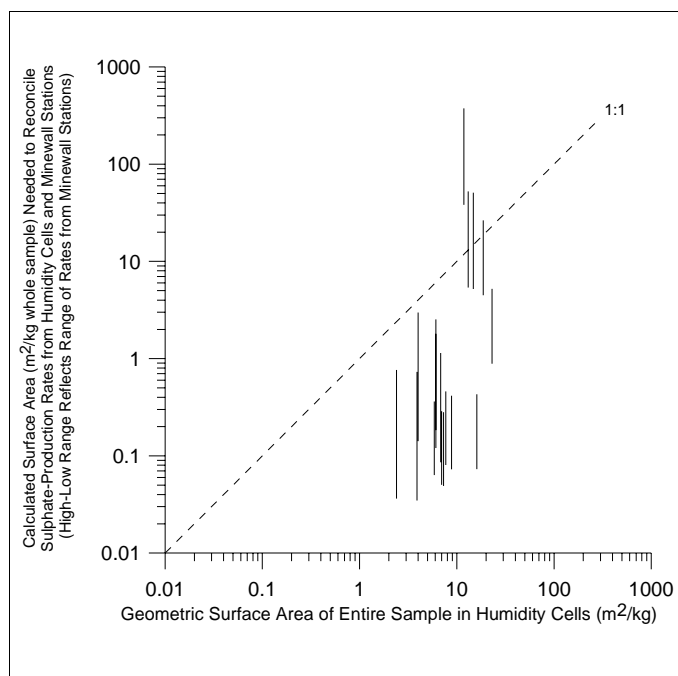
FIGURE 8. Calculated Surface Area to Reconcile Cell and Minewall Rates of Sulphate Production vs. Geometric Surface Area of Entire Sample.
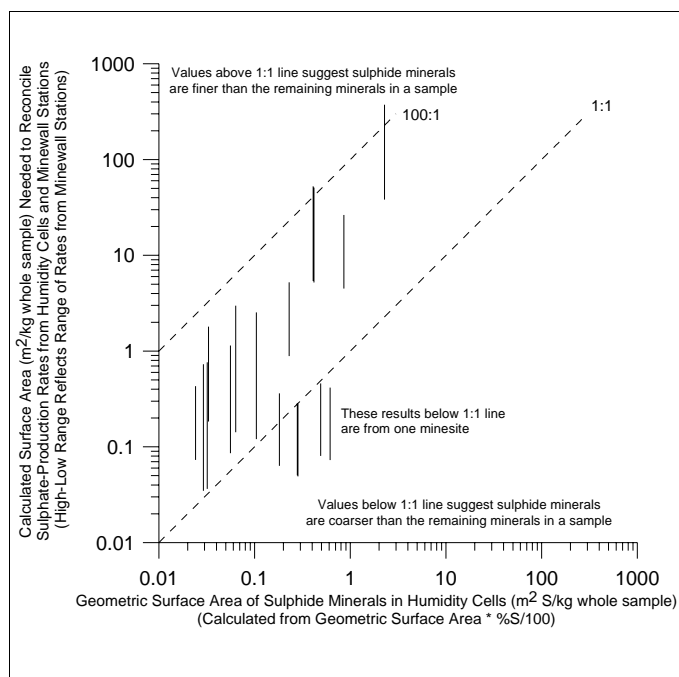
FIGURE 9. Calculated Surface Area to Reconcile Cell and Minewall Rates of Sulphate Production vs. Geometric Surface Area of Sulphide Minerals.
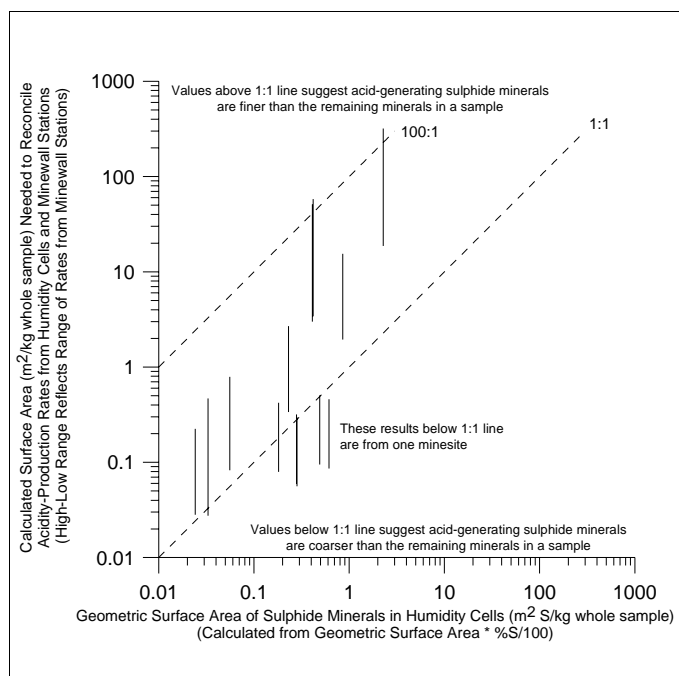

FIGURE 10.   Calculated Surface Area to Reconcile Cell and Minewall Rates of Acidity Production vs. Geometric Surface Area of Sulphide Minerals.
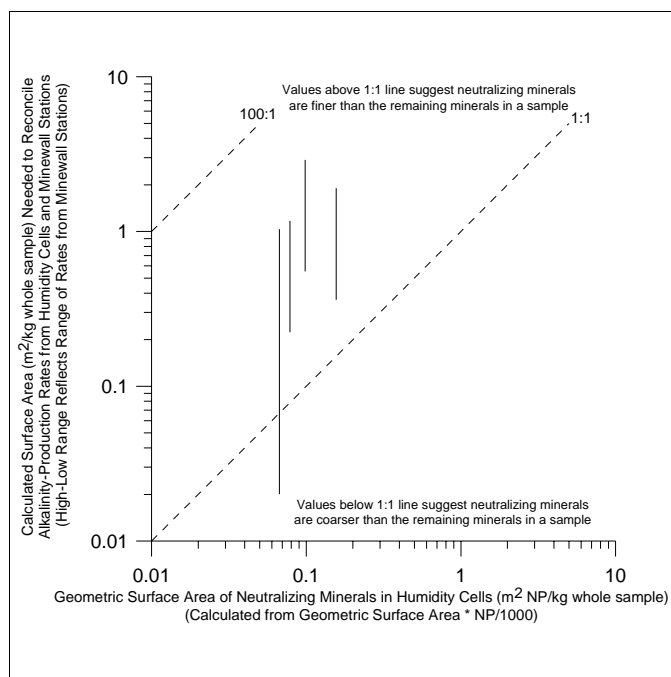
FIGURE 11.   Calculated Surface Area to Reconcile Cell and Minewall Rates of Alkalinity Production vs. Geometric Surface Area of Neutralizing Minerals.
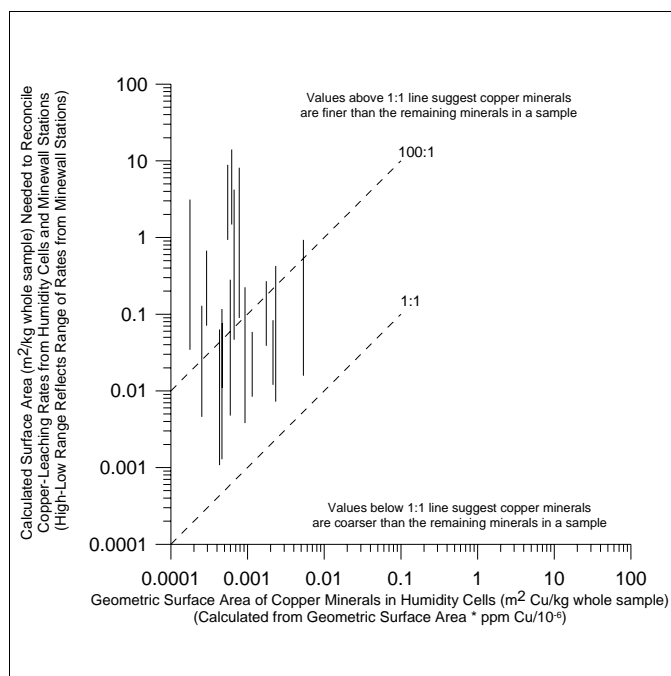

FIGURE 12.   Calculated Surface Area to Reconcile Cell and Minewall Rates of Copper Leaching vs. Geometric Surface Area of Copper Minerals.
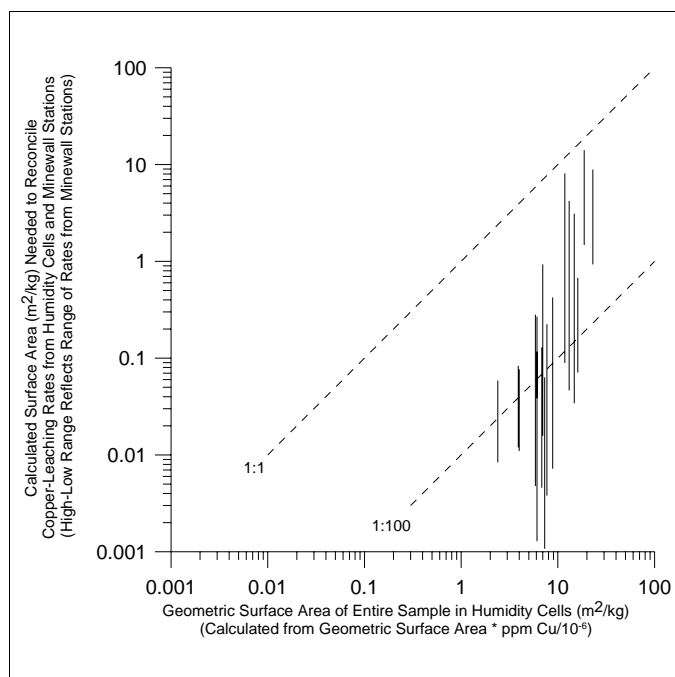
FIGURE 13.   Calculated Surface Area to Reconcile Cell and Minewall Rates of Copper Leaching vs. Geometric Surface Area of Entire Sample.
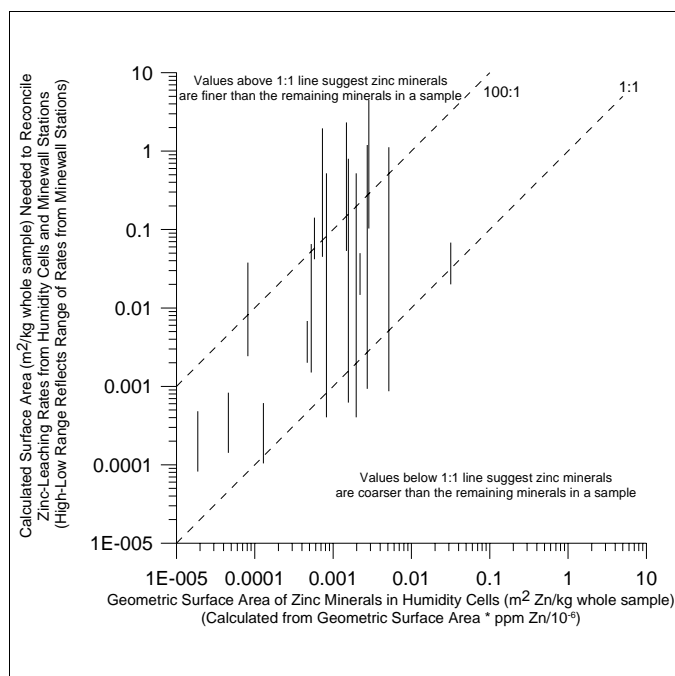

FIGURE 14.   Calculated Surface Area to Reconcile Cell and Minewall Rates of Zinc Leaching vs. Geometric Surface Area of Zinc Minerals.

4. Conclusion

This paper has summarized the standardized Minewall Technique for estimating the geochemical effects of mine walls on pit lakes. This Technique is based on studies and modelling of underground mines in the 1960's, which was adapted to open pits. The four primary steps are:

1) Obtain unit-area reaction rates. These can be obtained from Minewall Stations (Appendix A) or approximate maximum rates can be estimated from appropriate humidity cells (Section 3). Physical rates of weathering can rival those of chemical weathering so that fresh minerals are exposed regularly. Some rates are apparently dependent on the pH of the rock surface, whereas others are dependent on others like solid-phase levels.

2) Compile the lateral and inclined exposed surface areas by elevation in the pit, based on site-specific survey data.

3) Estimate the fracture intensity or design the blast intensity in order to obtain a ratio of reactive surface area to exposed surface area, and include other rock surface like waste rock. Case studies show the average estimated ratio of reactive rock surface area to exposed (visible) mine wall varied from 27:1 to 161:1. Any waste rock, ore rock, tailings, or backfill placed in the pit can add substantially to this reactive surface area. Three case studies of pits had estimated reactive surface areas of $11\text{-}240 \times 10^6$ m^2, producing total acidity (based on sulphate) at a rate of approximately $2\text{-}20 \times 10^9$ mg SO$_4$/wk.

4) Estimate the loadings that will be released on a regular or periodic basis, or retained if/until that portion of the wall is submerged. Case studies estimated that 20-35% of annual production from all reactive rock surfaces in the pits was flushed regularly or periodically, whereas 65-80% would only be released upon inundation.

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Appendix A: Installation and Operation of Minewall Stations

       The following is taken from Appendix D of Morin and Hutt (1997), based on information in MEND (1995).

Equipment (for each station):
❶   3 m of 90°-bent, flexible plastic bathtub edging
❷   2 tubes of pure silicon bathroom sealant (must be pure silicon)
❸   1 sheet of clear plastic 1 m by 1 m
❹   8 black metal clasps often used for holding unbound reports
❺   1 L of distilled water in a squeeze bottle which allows the direction and pressure of water
             to be controlled

Installation Procedure (see Figure A-1):
❶ Select a relatively flat surface of rock, preferably with no surface fractures, measuring no more
       than 1 m by 1 m.
❷ Mark the intended perimeter of the station on the surface with a pencil, with three, four, or five
       limbs of plastic edging.
❸ The lowest, or bottom, limb must slope downwards from horizontal so that all water caught on
       it will drain in one direction for collection and later analysis.
❹ Cut the plastic edging to the length required for each limb.
❺ Install each limb by using pure silicon sealant as glue.
❻ Ensure silicon sealant fills all open spaces between the edging and the rock surface so that no
       water can pass underneath.
❼ Ensure each limb overlaps so that no large gaps exist at any junction; seal any smaller gaps with
       silicon.
❽ Ensure the upper limb(s) will divert wall runoff around the sides of the station so that the water
       will not flow over the isolated area.
❾ With 1 L of distilled water, wash the entire isolated surface within the edging, rinsing out any
       loose rock/dust and ensuring all water is caught by the edging and directed to the bottom
       limb where the water can then be caught in a bottle.
❿ Cut the clear plastic sheet to extend 2 cm over each limb, then loosely attach the plastic sheet with
       the metal clasps, ensuring the plastic sheet does not touch the rock surface but prevents all
       precipitation or runoff from reaching the isolated rock surface.

Regular Sampling:
❶ Carefully remove the plastic sheet and place it somewhere clean and dry.
❷ Inspect the station for loose edging and broken seals against the rock; repair any problems after
       sampling (below), but avoid losing rinse water through any broken seals.
❸ Record a note if there is any condensation and if any water may have condensed and trickled out
       of the station between sampling events.
❹ Place a calibrated collection bottle at the downstream (outflow) end of the lower limb (trough)
       to catch all subsequent rinse water.

❺ With a calibrated squeeze bottle, spray at least 200 mL onto the isolated rock surface to rinse the entire area thoroughly; use as little water as possible; it is important to catch all rinse water in the collection bottle; record the volume of water sprayed on the rock.

❻ Record the amount of water recovered in the collection bottle.

❼ Analyze the water in the collection bottle like any other water sample, including pH, acidity, alkalinity, sulfate, dissolved metals, and total metals as desired.

❽ As a quality-assurance procedure for one round of sampling, also filter a similar volume of the distilled water through a 0.45 µm filter, then analyze like all other water samples

PLAN VIEW

A

ISOLATED ROCK SURFACE

RINSE
WATER

A'

CROSS-SECTION A-A'
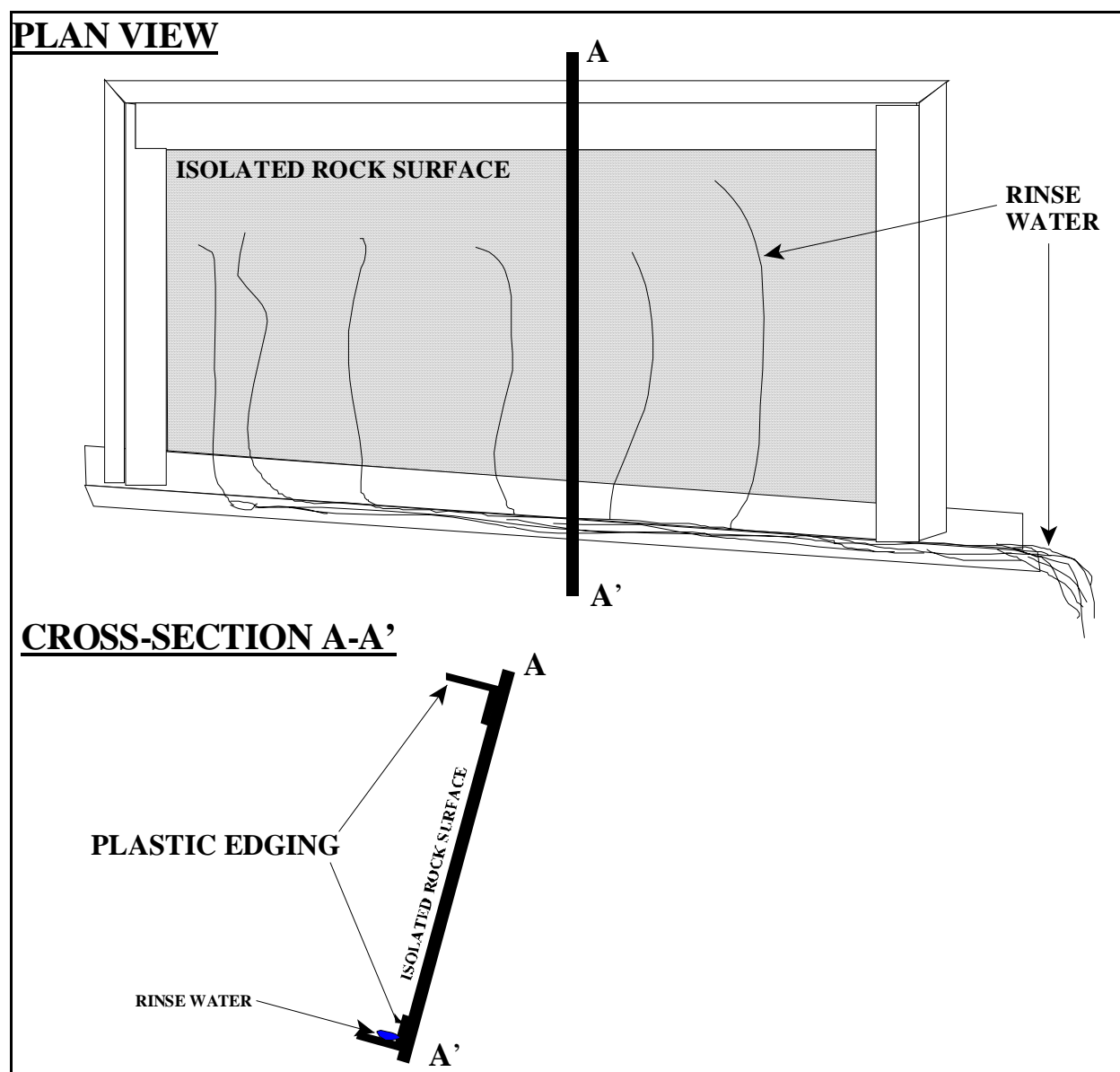
A

PLASTIC EDGING

ISOLATED ROCK SURFACE

RINSE WATER

A'

FIGURE A-1. Example of a MINEWALL Station (Plan View and Cross-Section).