

LABORATORY AND FIELD TESTING OF A  
SALT-SUPPLEMENTED CLAY CAP  
AS AN IMPERMEABLE SEAL OVER PYRITIC SLATES<sup>1</sup>

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Abstract -- During construction of a taxiway at Halifax International Airport in Nova Scotia in 1982, about 225,000 cubic metres of fractured waste pyritic slate material was disposed in a pile covering about 7 hectares on the airport property. As a result of air and water infiltration and the presence of Thiobacillus ferrooxidans, this waste rock pile has been seeping a heavy metal laden acidic effluent similar to acid mine drainage. Because sufficient quantities of a relatively impermeable clay overburden were present on site, it was decided to apply a compacted clay cap to the pile to reduce air and water infiltration. From previous experience it was known that concentrations of greater than 1% sodium chloride in the aqueous phase are inhibitory to Thiobacillus ferrooxidans. Laboratory studies confirmed that addition of a layer of highway salt beneath the clay not only inhibits the production of acid drainage, but also enhances the sealing capacity of the clay. Placement of the salt supplemented clay cap was undertaken in 1986 and 1987. Early observations indicate a reduction in the volume and an improvement in the quality of water seeping from the waste rock pile.

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#### INTRODUCTION

Halifax International Airport in Nova Scotia, Canada is located on a band of

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highly mineralized pyritic slate bedrock. As part of construction of an aircraft taxiway in 1982, a mass of this slate was blasted and excavated. About 225,000 cubic metres of waste slate material was deposited in a pile covering about 7 hectares adjacent to the taxiway. Several months after the start of construction an effluent of acid water laden with heavy metals began seeping from the waste rock pile and from the subdrains beneath the taxiway. At the direction of regulatory authorities, a system was immediately constructed to collect this acid drainage and to treat it by addition of hydrated lime. At the time, it was thought that the acid drainage would subside in several months.

When the acid seepage continued, unabated, for five years, a decision was made to place an impermeable seal over the entire pile to restrict oxygen and water penetration into the fractured pyritic slate. As sufficient quantities of a relatively impermeable clay were present adjacent to



the pile, a compacted clay cap was chosen as the seal. Because Transport Canada had little experience in the mitigation of acidic drainage, an interdepartmental committee was struck to advise on the "state-of-the-art" technology in this area. The Committee charged the Canada Centre for Mineral and Energy Technology (CANMET) to investigate the feasibility of incorporating a salt layer between the pyritic slate waste and the overlying clay cap in order to reduce acid formation through bacteriostatic activity as well as through the oxygen depletion achieved by the clay capping. This paper describes the laboratory study that tested this hypothesis, the application of the salt-supplemented clay cap in the field and early indications of the effects of the capping on acid drainage from the waste rock pile.

## MATERIALS AND METHODS

### Laboratory

Two laboratory studies were conducted to determine: (1) the effect of road salt on the production of ferric iron in a column and (2) the effectiveness of a combination salt/clay cap on the percolation rate. These studies were, in part, an outgrowth of past work on the reclamation of solonchic (sodic clay-pan) soils, where it was observed that *Thiobacilli* were unable to sustain viable populations in soils containing 4.8 meq of  $\text{Na}^+$ /100 g of soil (McCready 1982, McCready and Krouse 1982). Later studies on the adaptation of *Thiobacilli* to growth in saline waters indicated that *T. ferrooxidans* could not tolerate sodium chloride concentrations greater than 1% weight/volume. Thus, this laboratory study was conducted to test the hypothesis that the incorporation of a salt layer between the pyritic slate waste and the overlying clay cap would provide bacteriostatic activity to reduce the formation of acid in addition to the oxygen depletion effect of the clay capping.

Samples of Halifax slate and clay overburden from the Halifax Airport were provided to CANMET to carry out the laboratory study. The Halifax slate is comprised mainly of slate and metagreywacke with minor quartzite. It is rich in sulphides, with pyrite and arsenopyrite and minor amounts of pyrrhotite, sphalerite and chalcopyrite. Whole rock laboratory analyses reveal metal contents in the ranges indicated in table 1. (Lund 1987.)

A summary of the grain size analysis of four samples of the clay overburden is found in table 2.

A hydrometer analysis on sample 4 revealed that 34% of the weight of the sample is clay size particles (0.005 mm grain size or smaller). This overburden is described by the Unified Soil Classification System (U.S.C.S.) as Silty, Sandy Clay and Sandy, Silty Clay. (CL). Its permeability is  $4 \times 10^{-7}$  cm/sec.

Table 1 -- Metals found in Halifax slates.

Element	Percentage	ppm
Aluminum	9-13	
Iron	3-6	
Manganese	0.01-0.04	
Cobalt		10-80
Nickel		40-270
Lead		10-48
Arsenic		4-19
Copper		18-46
Zinc		70-210

Table 2 -- Clay overburden - percent passing standard sieves (by weight).

Sample	19 mm	9.5 mm	4.75 mm	425 micro-meter	75 micro-meter
1	100	100	97	87	63
2	100	99	96	82	53
3	100	100	99	86	60
4	100	99	98	87	65

### Effect of road salt on ferric iron production

For the first laboratory study four columns (6 cm in diameter and 50 cm in length) were loaded with one kg of Halifax slate and overburden as shown in Fig. 1. In two of the four columns, 5 grams (less than 10 mm thickness) of road salt (NaCl) was placed on the surface of the slate. One salt-supplemented column and one unsupplemented slate column were inoculated with 500 mL of a 96-hour culture *T. ferrooxidans* grown on the low phosphate medium (McCready et al. 1986). The other salt-supplemented column and the remaining unsupplemented column were trickle leached with distilled water. The distilled water and the *T. ferrooxidans* cultures were circulated through the columns using a Gilson Minipuls-2 peristaltic pump at a flow rate of 300 mL/h. Samples of the recirculating solutions were collected periodically from the two columns for pH determinations and ferric iron analyses. The total volume of solution for each column was kept constant at 500 mL by the periodic addition of distilled water.

### Effect of a salt and clay capping

In the second laboratory study, which assessed the effect of a salt (NaCl) and clay cap, two additional columns were prepared as shown in fig. 2. The test column had a layer of road salt placed between the pyritic slate sample and the clay layer

which was tightly compacted in both columns. Two hundred and fifty mL of distilled water was added to each column to assess the percolation rate through the clay.

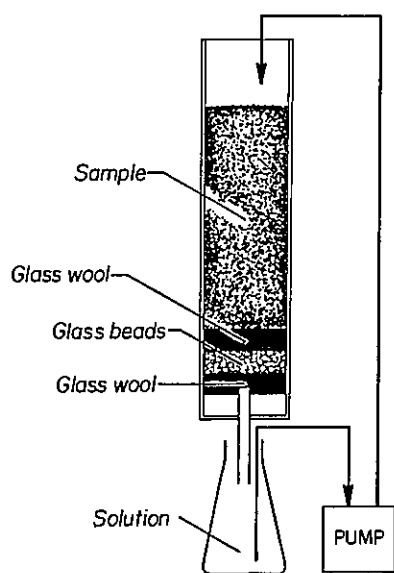


Figure 1. -- Column design for testing the effect of 1.5% NaCl in solution.

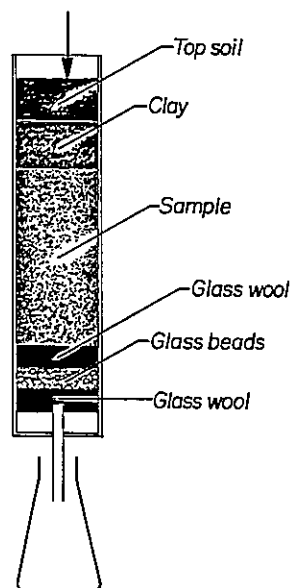


Figure 2. -- Column design for testing clay-capping.

## Field

Field testing of the salt-supplemented clay cap was carried out on the pyritic slate waste rock pile at Halifax International Airport, which, being constructed on a slope, ranged in depth from about 2 m to 10 m. The waste slate was surrounded on three sides by clay berms and was covered by a loose clay layer varying in thickness from 100 mm to 500 mm. The top of the pile, although generally flat, had several depressions allowing water to pond. Side slopes varied from 2.5:1 to 4:1, which had led to significant erosion of the clay slope cover. The acid drainage collection pond is located at the base of the slope on the west side of the pile (fig. 3).

The field work described here resulted from a contract awarded in October 1986 to construct surface drainage intercept channels at the base of the north, east and south sides of the waste rock pile; reshape the top surface of the pile to provide a uniform gradient of 1.5%; supply highway coarse salt over the entire surface of the pile (including side slopes) at the rate of  $11.5 \text{ kg/m}^2$ ; place a compacted clay cover 750 mm thick over the entire area; supply and place 150 mm topsoil over this; place sod on the side slopes and areas of higher water flow on top; and hydraulically seed the remainder of the site. Fig. 4 is a typical section through the finished work.

Work commenced immediately and by December 1986, when work stopped due to winter conditions, the top of the pile had been regraded, the coarse salt had been applied, and a 375-mm thick compacted clay layer had been installed over the entire top surface. The surface water intercept channels were constructed in March 1987. Due to the low permeability and resulting high water retention of the salt-supplemented clay layer, work was unable to start again until July 1987. The final 375-mm compacted clay layer was completed by early September, and the 150 mm of topsoil was placed by the end of September. Sodding was completed by October 15, 1986, but the hydraulic seeding remains to be done.

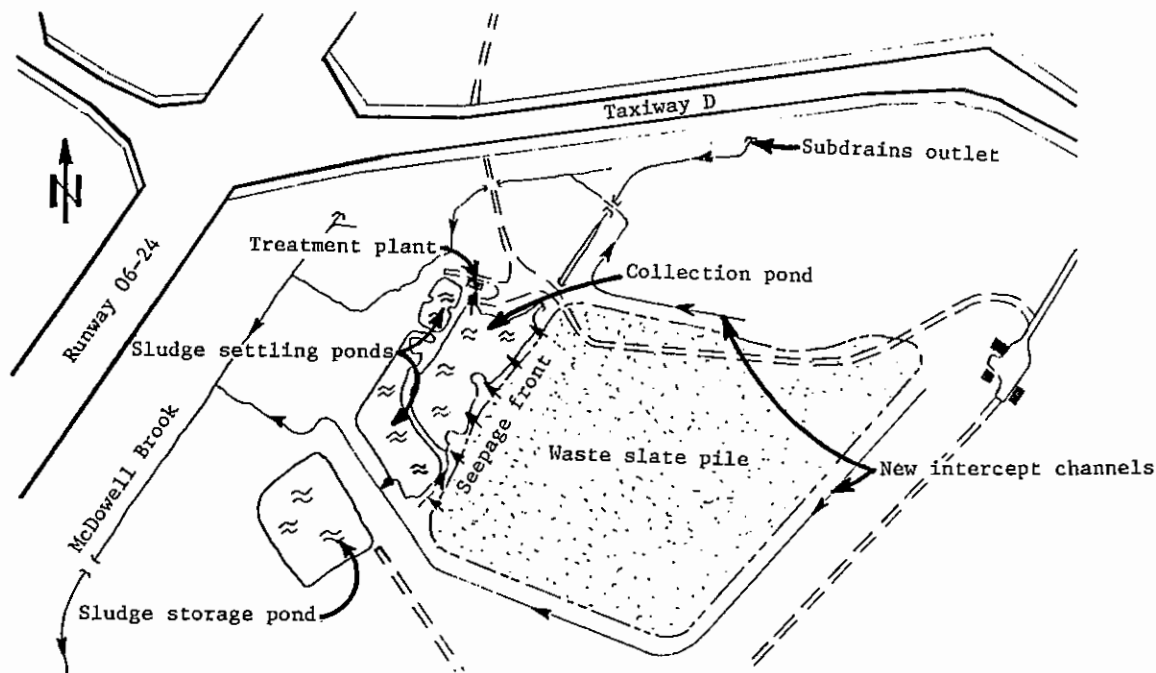


Figure 3. -- Site plan.

## RESULTS AND DISCUSSION

### Laboratory

#### Effect of road salt on ferric iron production

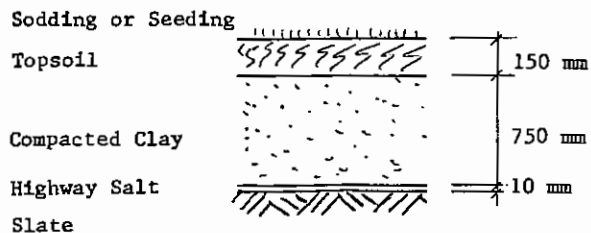


Figure 4. -- Typical section through finished work.

When the cultures of *T. ferrooxidans* were recirculated through the pyritic slate columns the soluble ferric iron content of the solution decreased due to adsorption of the iron to the clays in the slate/overburden mixture. After one month, the soluble ferric iron concentration of the leachate increased in the non salted column due to microbial activity (fig. 5). This was confirmed by microscopic examination of the leachate; after 50 days the leachate contained about  $10^6$  organisms/mL.

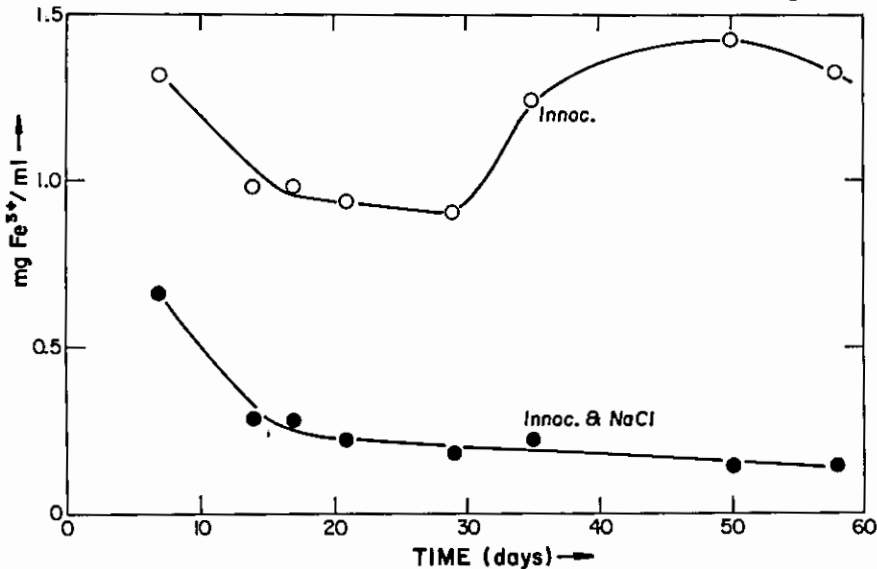


Figure 5. -- Fe<sup>3+</sup> in test column effluents.

In contrast, in the salt-treated columns, the soluble ferric iron content decreased over the first 20 days and remained at a minimal concentration until the experiment was terminated. No active bacterial cells were observed during microscopic examination of the leachate.

In the two columns leached with distilled water there was very little iron release and no *T. ferrooxidans* could be detected in the leachate. Extensive physical breakdown of clay components of the overburden was observed in the salt-supplemented column. The continuous recycle of the saline solution most likely resulted in the stripping of calcium ions from the clays and the sodium ion replaced the calcium in the cation exchange sites. This resulted in the formation of clay fines which plugged the column after 35 days. Repeated back-flushing of the column finally resulted in clearing of the clay fines and the experiment was continued to the 58th day.

#### Effect of a salt and clay capping

After compacting the clay and soil layers on the two columns, 250 mL of distilled water was placed on the top of the columns. None of this water penetrated through the clay layer in either column. After two weeks the added water had evaporated and the soil and clay layers were allowed to dry out.

The clay layer in the column without salt cracked vertically and on rewetting with 250 mL of water, the water penetrated through the clay layer and the column within 4 hours; the clay seal has not resealed to date. In contrast, the clay and salt seal in the other column cracked horizontally on drying. When 250 mL of water was reintroduced it took 12 hours for the water to penetrate through the clay and column. An addition of a second 250-mL aliquot of water, the clay resealed itself and no additional water percolation through the column has been observed to date.

The water which passed through these two columns initially was analyzed for iron content and pH. These values are presented in table 3.

Table 3 -- pH and ferric iron concentration of the initial effluent and after 250 mL of effluent had passed through the clay sealed columns.

Seal	Effluent	pH	Fe <sup>+3</sup> ppm
Clay alone	First 5 mL	2.47	292
	After 250 mL	2.60	82
Clay + NaCl	First 5 mL	2.41	98
	After 250 mL	2.51	34

As stated above, the clay-capped column without salt has not resealed to date. After drying and cracking, with subsequent resettling of the clay, water percolation was observed to be 55 mL/day. After four months, the percolation rate has declined to 22 mL/day, and there has been 0.75 increase in the effluent pH over this period (fig. 6). In contrast, the column with salt added sealed completely after drying and the subsequent addition of 500 mL of water; to date no further effluent has been collected. Removal of an interstitial water sample indicated that the water had a pH of 2.98 with a very low iron content (48 ppm).

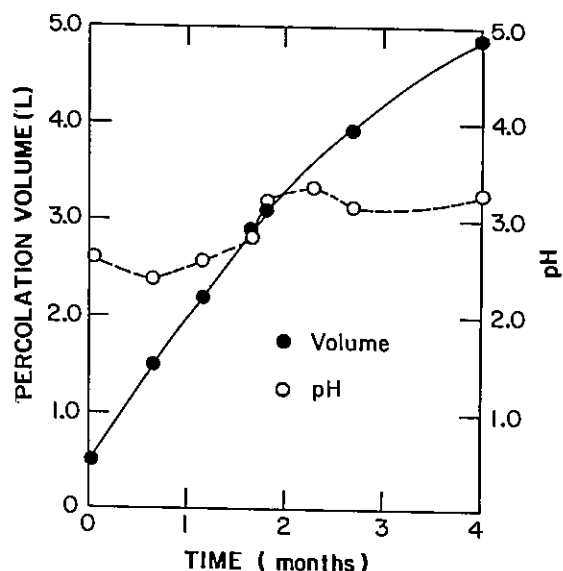


Figure 6. -- Volume and pH of the effluent from the clay-capped column without the salt layer

#### Field

As indicated in figure 3, all seepage from the waste rock pile and from the pavement subdrains beneath Taxiway D is collected jointly in the treatment plant collection pond west of the waste rock pile. The taxiway subdrain flows are directed to this pond by a single channel. Because flows from the waste rock pile enter the collection pond along a seepage front, there are no specific quality nor quantity data available for this seepage. The quantity of seepage from the waste rock pile must therefore be calculated by subtracting the known taxiway subdrain flow volume from the known volume pumped through the treatment plant, while adjusting for changes in the level of the collection pond (fig. 7). The quality of the water at the plant intake represents a combination of the quality of water from the subdrains and from the waste rock pile.

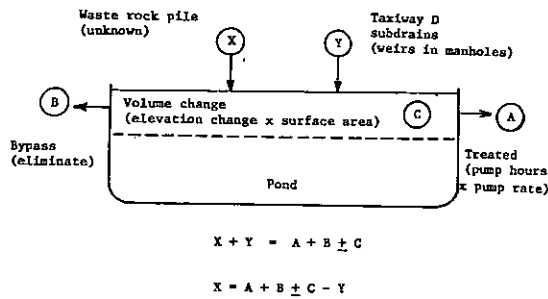


Figure 7. -- Method of calculating seepage volume.

Figures 8, 9, and 10 plot the concentrations of acidity, iron, and aluminum in seep water at the outlet of the Taxiway D subdrains and at the inlet to the treatment plant, beginning 10 months prior to start of improvements and continuing to present.

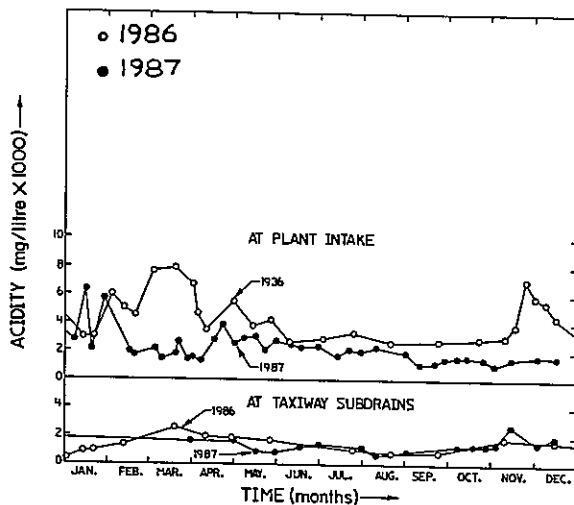


Figure 8. -- Concentration of acidity in seep water.

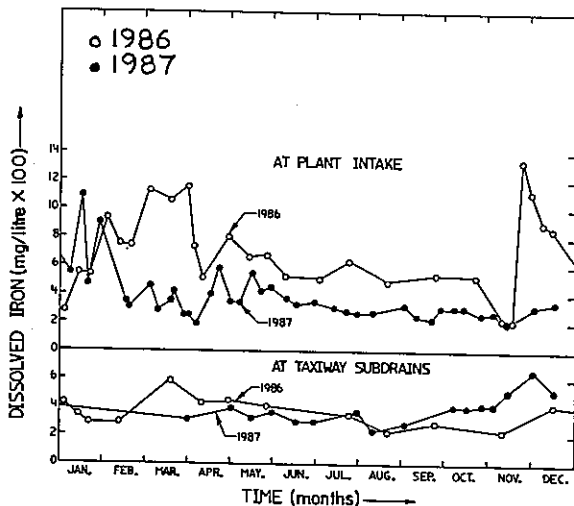


Figure 9. -- Concentration of iron in seep water.

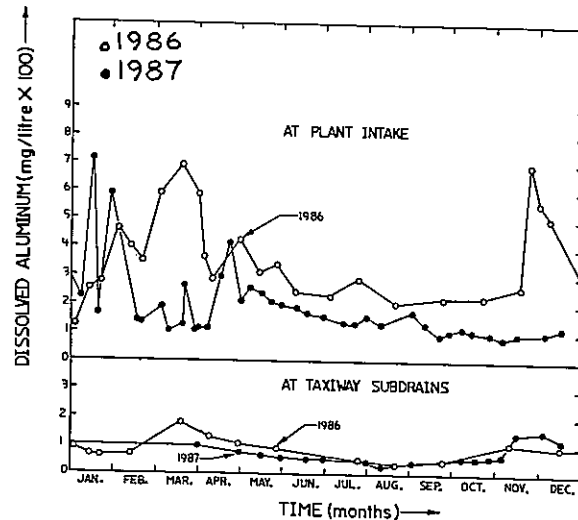


Figure 10. -- Concentration of aluminum in seep water.

All three parameters exhibit the same trend. During initial reshaping of the waste rock pile in November, 1986, a large rainfall on areas of freshly exposed pyritic slate caused concentrations of acidity, iron, and aluminum at the plant intake to jump to levels as high as or higher than previously recorded at this station. These increased concentrations did not diminish to pre-construction levels until mid-February of 1987, about three months later. With the salt layer and half the thickness of the clay cap in place, the 1987 spring runoff resulted in much lower concentrations of the three parameters at the plant intake than for the previous year. Since that time all parameters at this station have been at concentrations 6% to 35% lower than the same period of the previous year. Because the concentrations of these parameters have at the same time remained relatively constant at the outlet of the taxiway subdrains, the improvement in the quality of water seeping from the waste rock pile has been even more pronounced.

Because of variations in amounts of precipitation among seasons and from year to year, the discharge volume/unit of rainfall during the same time period was used to determine the impact of the salt supplemented clay cap on the volumes of water seeping from the waste rock pile. The total volume of seep water was calculated per Figure 6 and then divided by the total rainfall during the same time period to yield the unit discharge volume. Figure 11 shows this unit discharge for specific rainfall events for which all necessary data are available, beginning in August 1986 (when an hour meter was first installed on the pump at the treatment plant) and

continuing to present. Figure 11 also illustrates the monthly average unit discharge volumes from the waste rock pile over the same time span.

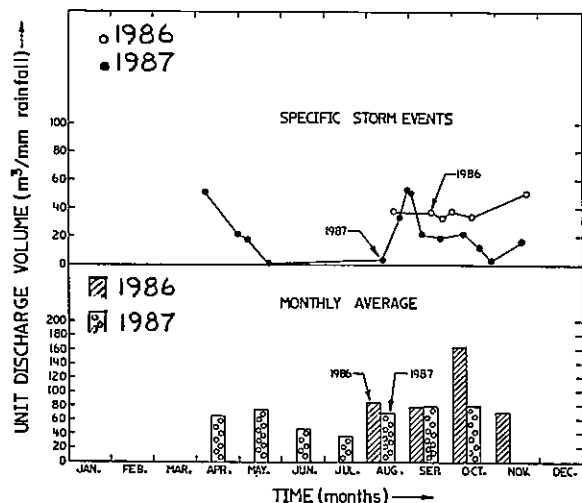


Figure 11. -- Waste rock pile unit discharge quantities.

Prior to start of construction of the cap, the unit discharge volumes over a 24-hour period for five specific rainfall events for which data are available lay consistently between 33 and 40 m<sup>3</sup> of discharge/mm of rainfall. The storm during November 1986, on the freshly regraded waste rock pile resulted in a unit discharge volume from the pile of over 50 m<sup>3</sup>/mm.

Because of winter conditions, no more data are available until the end of April 1987, at which time the salt layer and half the thickness of the clay cap had been installed. Unit discharge volumes for four specific storms varied from about 20 m<sup>3</sup>/mm at this time to near zero in mid-August (when the clay cap was nearly completed). During three storms during late August and early September, after one of the driest summers on record, the unit discharge volume rose inexplicably to 35 and then to over 50 m<sup>3</sup>/mm. In six storms since this, the yield dropped to about 20 m<sup>3</sup>/mm or less.

The monthly average unit discharge volumes have trended downward from a high of 160 in October 1986 (just prior to start of improvements) to less than 40 in July of 1987. Again, August of 1987 has an unexplainably higher yield, although it is still lower than August of 1986. This yield held approximately constant through September and October, 1987.

#### Conclusions

In the laboratory study, preliminary work confirmed that road salt inhibited the production of ferric iron. In further work, the addition of a salt layer between

the pyritic slate and the clay cap resulted in a higher water retention time by the clay cap as indicated by the longer time required for drying and cracking of the clay layer. On drying, the clay cap cracked horizontally, rather than vertically, thereby preventing oxygen penetration to the underlying slate. On rewetting, the salt induced swelling of the clay results in the reformation of an impermeable seal more quickly than in the absence of salt. In addition, if the clay should rupture, any water percolation would result in the leaching of soluble salt into the slate, thereby inhibiting any Thiobacilli within the water-penetrated slate.

The salt-supplemented clay cover installed in the field on the waste rock disposal site has caused an initial decrease in levels of acidity and dissolved iron and aluminum in the water seeping from the pile and a gradual decrease in the volume of seepage from the pile. After one winter with only one half of the thickness of the clay in place, the effectiveness of the cap has not diminished. Monitoring is being continued to determine the long term effectiveness of this sealing method.

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