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Thickened Sloped Tailings Disposal
- An Evaluation of Seepage and Abatement of Acid Drainage

by

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ABSTRACT

In contrast to most conventional tailings ponds, tailings disposal by the thickened, sloped, discharge system results in a gently sloping deposit of tailings without a slimes pond and without high perimeter dams, unlike most conventional disposal ponds. A program of field and laboratory studies have shown that thickening provides a homogeneous tailings mixture which exhibits moisture retention characteristics and hydraulic conductivities that aid in the abatement of acid generation. It is known that if acid generating tailings are kept saturated, acid generation is inhibited.

Numerical modelling of the seepage and moisture regimes within the tailings under long term climatic conditions illustrate that a very shallow water table develops within the deposit. Consequently, nearly saturated conditions are maintained throughout the tailings as a result of the moisture characteristics of the material. The low hydraulic conductivity and storage characteristics of the tailings also minimize the influx of climatic precipitation and consequently the discharge of contaminated pore fluid to underlying groundwater systems.

Preliminary comparisons with a conventional disposal scheme indicates that thickened tailings disposal will result in higher degrees of saturation within the tailings mass, less seepage through the tailings, and easier reclamation than the conventional disposal scheme.

1.0 INTRODUCTION

Tailings disposal by the thickened, sloped, discharge scheme has been utilized as an alternative to the conventional disposal of tailings behind high containment dams. Robinsky (1978, 1975) has suggested that thickened tailings disposal (TTD) has a number of advantages including:

(i) less initial capital investment
(ii) lower operational costs

(iii) greater placement volume for a given height of containment dyke
(iv) the elimination of the construction and maintenance of high perimeter dams
(v) the elimination of slimes ponds and decant systems
(vi) ease of reclamation

In the TTD system, tailings are thickened to levels greater than 50% solids and discharged from elevated spigot locations in order to form a cone shaped mound with a surface slope of 2 to 6 percent. After discharge, the thickened tailings flow down the tailings surface until they reach an angle of repose. In this manner, a low cone-shaped mound develops without the need for confining dams. Segregation of the deposited tailings is inhibited as a result of the thickening leaving a homogeneous, low hydraulic conductivity tailings mass. Figure 1 presents a schematic aerial view of a TTD system illustrating the proposed reclamation procedure.

The principle environmental advantages of the TDD scheme are its potential to reduce acid generation and seepage from the tailings. Thickening results in a homogeneous mass with low hydraulic conductivity and high moisture retention characteristics. Under the gently sloping depositional surface, these properties promote the development of a shallow water table and nearly saturated conditions to surface. This mitigates against acid generation and the influx of climatic precipitation, and consequently minimizes the discharge of contaminated seepage to underlying groundwater systems.

The performance of a seventeen year old TTD system is reviewed in this paper. Key characteristics of the thickened tailings such as depositional homogeneity, low hydraulic conductivity, and high moisture retention characteristics, are evaluated from field and laboratory testing. The decommissioning performance of this system is also evaluated by numerical modelling of seepage within the tailings under long-term average climatic conditions.

2.0 FIELD PERFORMANCE OF A THICKENED TAILINGS DISCHARGE SYSTEM

The TTD system at the Kidd Creek Mines near Timmins, Ontario has been in operation since 1975. Since that time, approximately 50 million tonnes of tailings have been placed. At present, the tailings are being discharged at approximately 61.5% solids onto average slopes of slightly more than 1%. The maximum depth of tailings is 13 meters. At present, the maximum difference in elevation between the tailings discharge and the perimeter of the cone is 25 meters. Preparations are underway to increase the average slope of the tailings surface to approximately 2%. Figure 2 illustrates the present thickened tailings disposal operation.

In the summer of 1990 an extensive program of field sampling and laboratory testing was undertaken in order to determine the in-situ conditions of the thickened tailings. Sampling was undertaken at four locations, up to 60 meters from the tailings discharge ramp. A piston sampler as well as a Standard Penetration Test spoon were used. Piezocone penetration tests were also undertaken at two locations and four shallow piezometers were installed within the tailings. Continuous piston sampling (up to 3 meters deep) was also undertaken up to 350 meters from the discharge ramp in order to evaluate the homogeneity of the deposit downstream from the point of discharge.

Tests were performed on samples obtained from the field program. The tests included: consolidation tests, hydraulic conductivity tests, grain size analyses, and the measurement of index properties and slaking behavior. Only a few of these results will be reported in this paper due to space limitations.

Homogeneity of Deposition

One of the most important elements of the TTD operation is that the discharged tailings are deposited as a homogeneous mass. If segregation occurs it will lead to variations in moisture retention and hydraulic conductivity as well as variations in the depositional slope. Figure 3 presents grain size curves of samples obtained 45 meters from the discharge point over depths of .45 to 12.5 meters. It is evident that little segregation of the thickened tailings mass has occurred even at such close proximity to the point of discharge.

The homogeneity of the deposit with depth is reflected in the data shown in Table 1. This table lists some test results from a typical boring. The Standard Penetration test results are given together with the percent solids, water content and dry density over 12 meters of tailings, deposited approximately 45 meters from the discharge ramp.

Table 1 - Standard Penetration and laboratory test results from a boring 60 m from discharge ramp.

Depth (m)	Recovery (m)	SPT Blow Count	Solids (%)	Water Content (%)	Dry Density (T/m^3)
0.0-.48	0.38	2	79.3	26.1	1.704
0.75-1.20	0.30	5	80.6	24.1	1.765
1.5-2.0	0.38	1	79.2	26.2	1.702
2.25-2.75	0.46	0	78.5	27.3	1.669
3.0-3.5	0.51	2	81.7	22.4	1.820
3.75-4.25	0.46	0	81.9	22.1	1.830
4.5-5.0	0.40	2	80.7	23.9	1.770
5.25-5.75	0.43	4	78.7	27.1	1.675
6.0-6.5	0.40	2	79.5	25.9	1.711
6.25-7.25	0.46	4	81.9	22.2	1.827
7.6-8.0	0.33	4	79.0	26.6	1.690
8.4-8.8	0.40	5	79.8	25.3	1.727
9.1-9.6	0.35	3	80.8	23.9	1.773
9.9-10.3	0.40	2	79.3	26.2	1.702
10.6-11.1	0.35	5	82.4	21.3	1.856
11.4-11.9	0.33	3	80.9	23.7	1.778
12.2-12.6	0.38	8	84.8	18.0	1.979
Average:	-	-	80.5	24.2	1.764

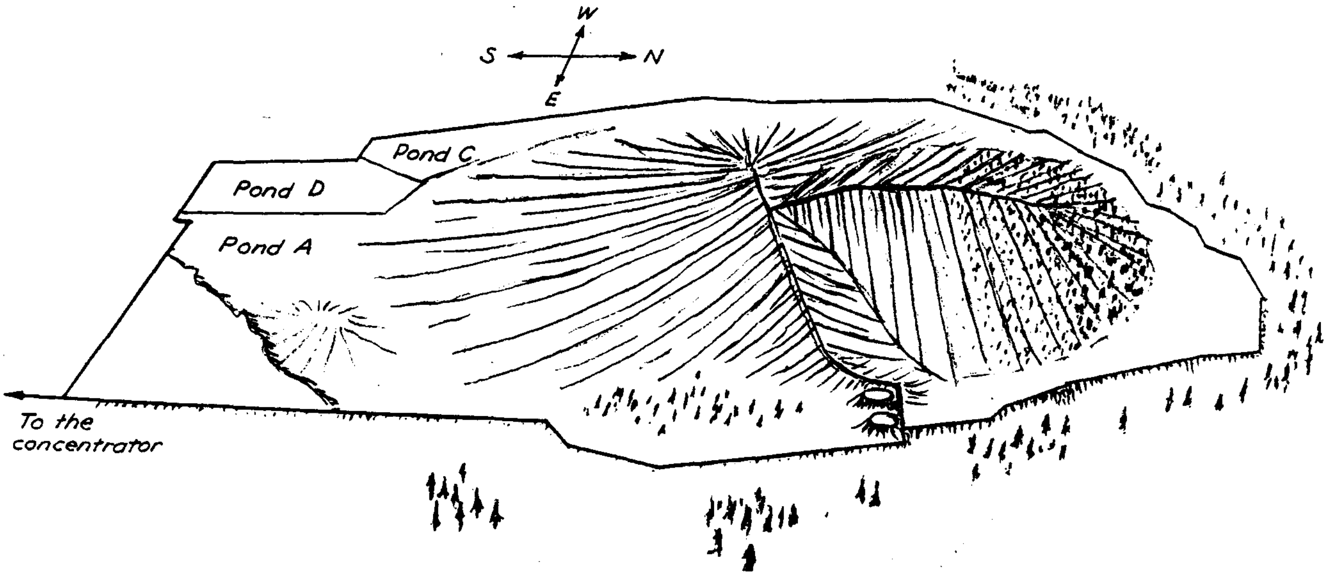


Figure 1 View of thickened tailings disposal system and proposed progressive reclamation scheme.

Figure 2 View of thickened tailings disposal operations. Note the spread of tailings into sheet flow.

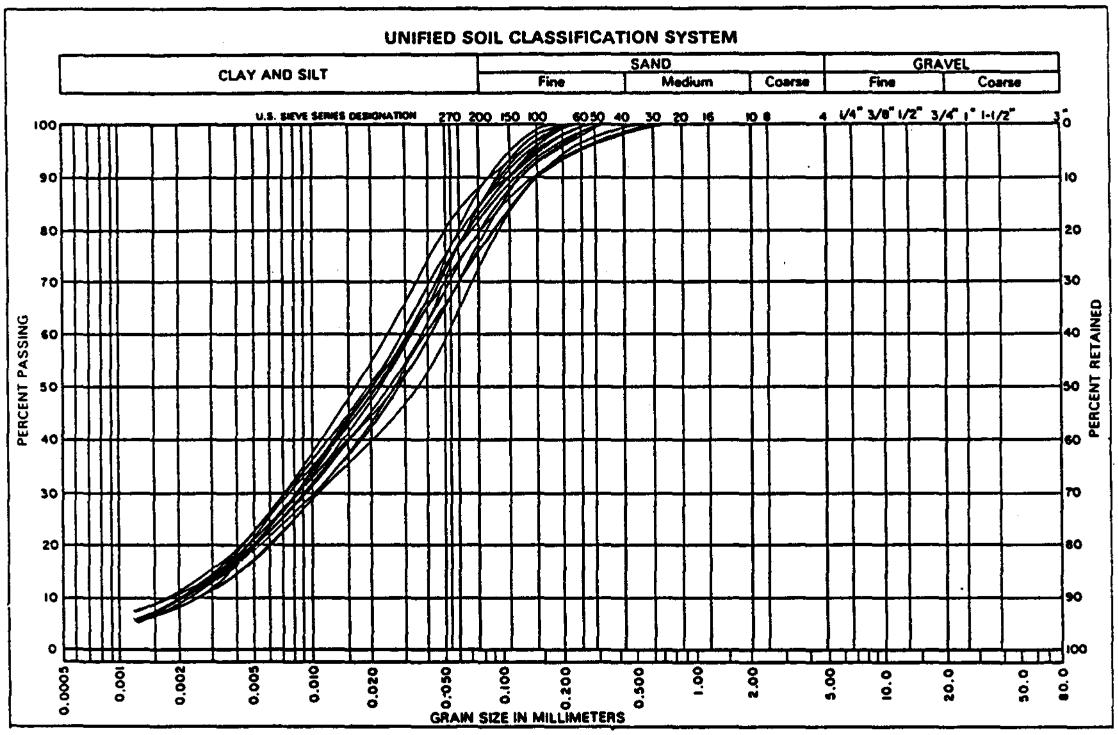


Figure 3 Grain size curves for samples obtained 45 m from discharge and taken from 0.45 to 12.5 m depths.

Shallow Water Table / Low Hydraulic Conductivity / High Moisture Retention Characteristics

The results of field and laboratory hydraulic conductivity tests performed on the tailings are shown in Table 2. It is evident from this data that a fairly consistent value of permeability has been measured in all of the tests. The most conservative of the values obtained was used in the numerical modelling presented later in this paper (i.e., 1.0 x 10^{-7} m/s). Monitoring of the piezometers over the summer months demonstrated that the water table was quite shallow (i.e. generally less than 2.5 meters). This was also confirmed by negative pore-pressure readings measured in the piezocone penetration tests. The piezometers also indicated that the location of the water table was quite responsive to precipitation and evaporation events, suggesting that the tailings above the water table are near saturation. In every case in which undisturbed samples were obtained, the near surface samples were always saturated, even when the water table was at a depth of 2 to 3 meters.

Figures 4 and 5 illustrate the insitu moisture retention characteristics of the thickened tailings. In spite of the development of shrinkage cracks up to 0.5 meters in depth the tailings surface will still liquify if disturbed. This demonstrates how the surface materials remain near saturation even after drying.

Table 2 - Summary of field and laboratory measurements of hydraulic conductivity.

Test Method	Hydraulic Conductivity (m/s) of the Tailings at the depth indicated*				
	0-2m	At 3m	At 10m	At 18m	At 25m
A	-	$4.8X10^{-8}$	$4.2x10^{-8}$	$3.3x10^{-8}$	$3.1x10^{-8}$
B	$1.1x10^{-7}$	-	-	-	-
C	Mean value for 8 measurements at depths of 2.3 m to 8.9 m = $1.71x10^{-7}$ m/s.				

*(Samples have been consolidated to stress levels equivalent to the depths shown)
A. Laboratory Tests
B. Laboratory Column Tests.
C. Field Piezocone Penetration Tests.

Laboratory Determination of Moisture Characteristic Curves

Confirmation of the high moisture retention characteristics of the tailings was obtained by direct testing using a Tempe[1] cell pressure plate apparatus. Three samples of tailings were prepared from a slurry of approximately 70% solids content. Samples 1A and 1B were consolidated to 7.7 kPa and 58.8 kPa respectively, prior to being transferred to the Tempe cell. This was carried out in order to simulate the effects of densification at different depths within the tailings pile. Sample 1C was placed directly into the Tempe cell as a slurry.

Following the Tempe Cell test, smaller portions of each sample (1 to 5 gm) were also used to determine the moisture characteristic of the specimen under extreme suctions. This was done by placing a portion of each sample into a osmotic desiccator. The relative humidity conditions within the desiccator are controlled by the selection of varying strengths and compositions of salt solutions.

Figure 6 illustrates the results of the Tempe cell and osmotic desiccator tests. It is evident that over the maximum range of the Tempe cells (i.e. 100 kPa suction), little drainage took place from the tailings. In fact, the decrease in volumetric water content over this range is likely due more to a reduction in the total soil volume under increasing negative pore pressures rather than due to drainage. Although further testing is still required, it appears that the tailings would remain near saturation even at a suction of 100 kPa (i.e. approximately 10 meter of negative pressure head).

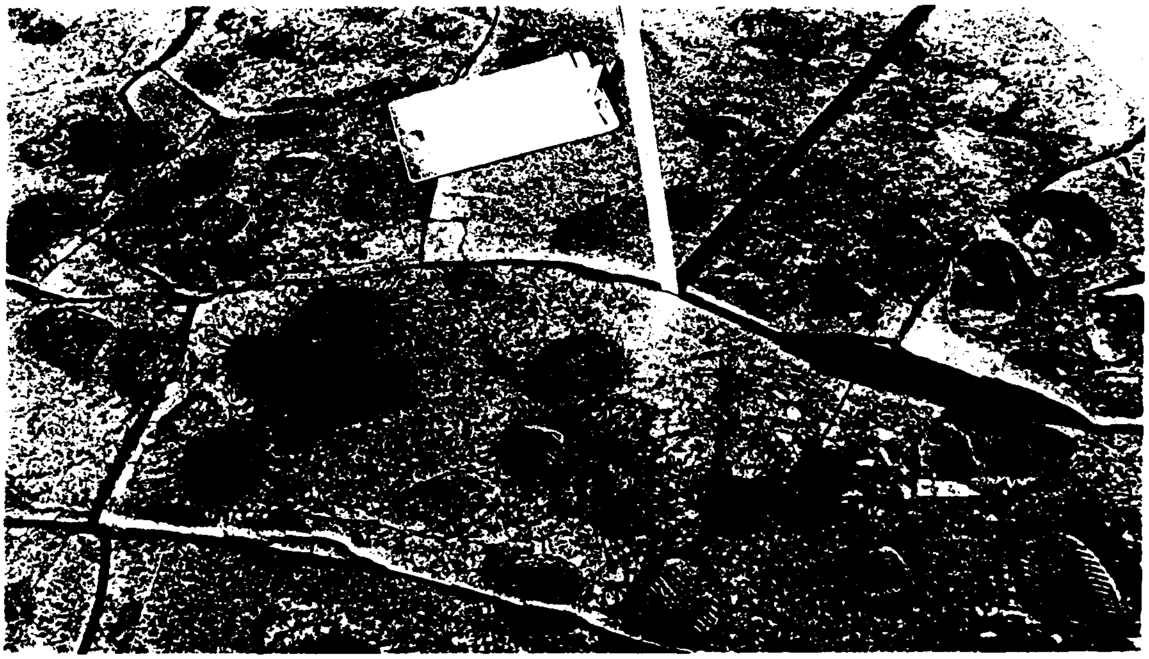


Figure 4 Persistent deep cracks within active tailings disposal area.

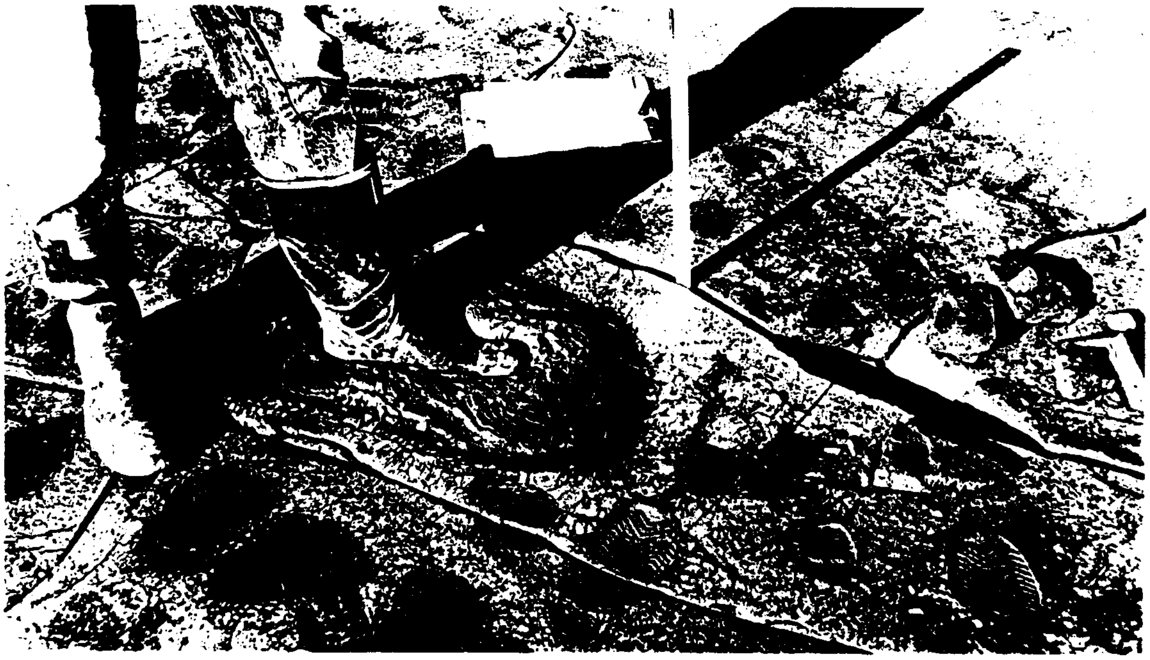
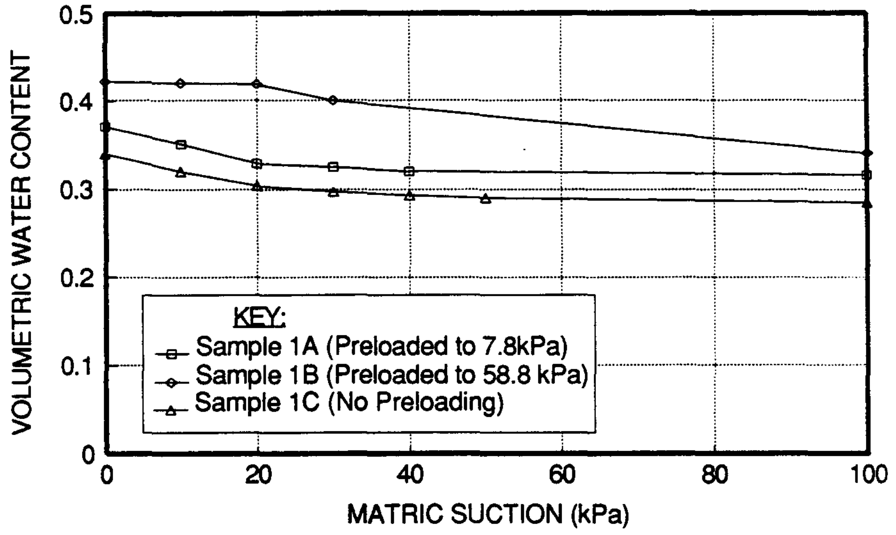
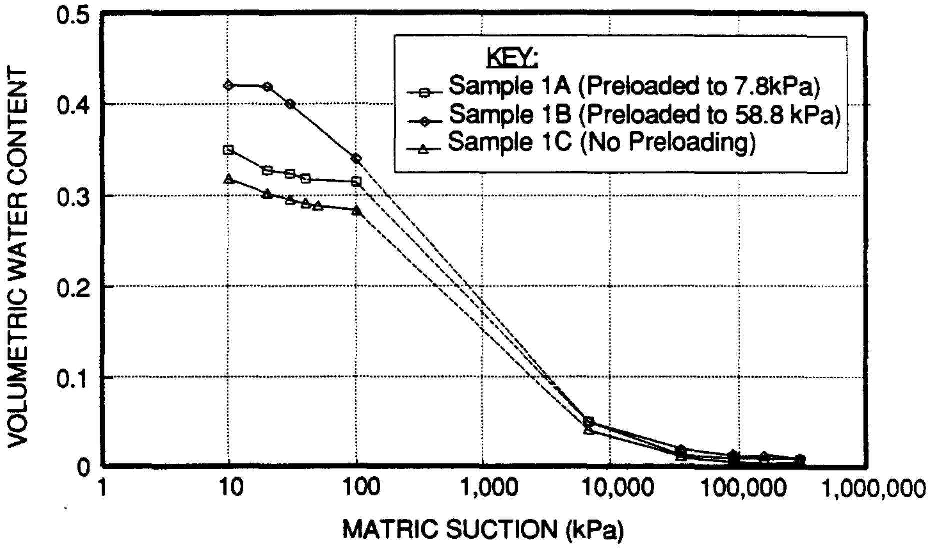


Figure 5 "Liquefaction" potential of apparently dry surface tailings after disturbance (The depth of the crack shown was approximately 0.46 m)



a)



b)

Figure 6 **Volumetric water content versus suction curves for remolded samples of tailings over:**
a) 0 to 100 kPa range of suction
b)1 to 1,000,000 kPa range of suction.

3.0 MODELLING OF SEEPAGE UNDER LONG TERM CLIMATIC CONDITIONS

Typical cross-sections for a Conventional Tailings Disposal (CTD) system and a TTD system were used to evaluate the seepage from these systems under long term climatic conditions. Cross-sections of these two systems are presented in Figure 7. Axysymmetric modelling was used for both the CTD and TTD models. A two-dimensional vertical plane model of seepage for the TTD system was also performed. All the modelling was performed using a commercial finite element saturated / unsaturated seepage model called PC-SEEP (GEO-SLOPE 1990).

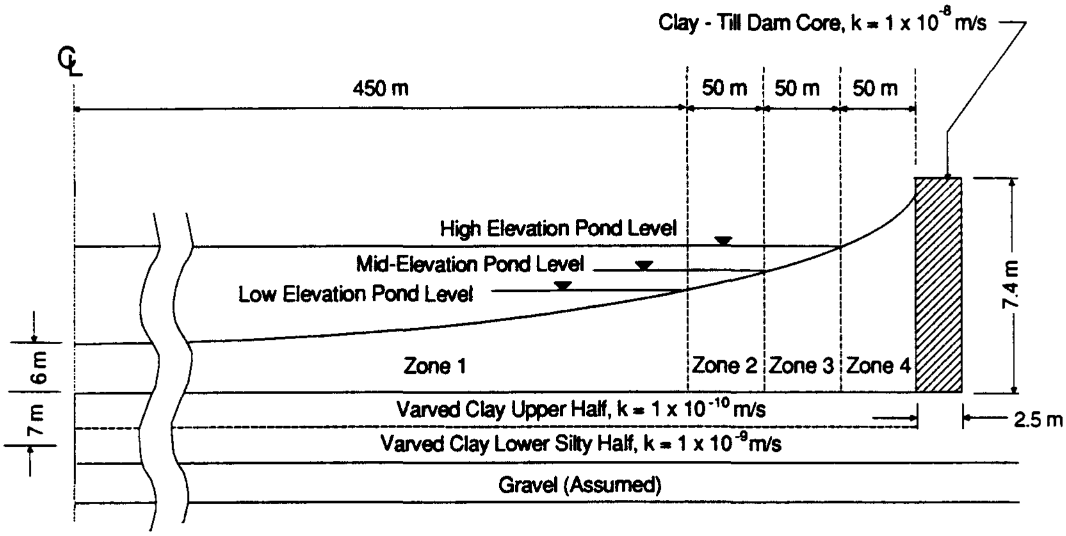
For the TTD model, the boundary conditions consisted of a specified climatic flux across the surface of the tailings, no flow boundaries at the base and left side of the model, and a constant head boundary equal to the natural ground surface elevation, applied along the surface outside of the tailings and along the right edge of the model. The model allows for the development of a free water surface along the surface of the tailings if the entire applied flux cannot infiltrate.

For the CTD system, the same boundary conditions were applied at the ground surface and along the edges of the model. Over the tailings surface, however, a constant head boundary, representing the development of a pond on the tailings surface, and a climatic flux boundary condition were applied. Three different pond levels were simulated. The elevations of these ponds are shown in Figure 7.

Evaluation of Climatic Flux Boundary Conditions

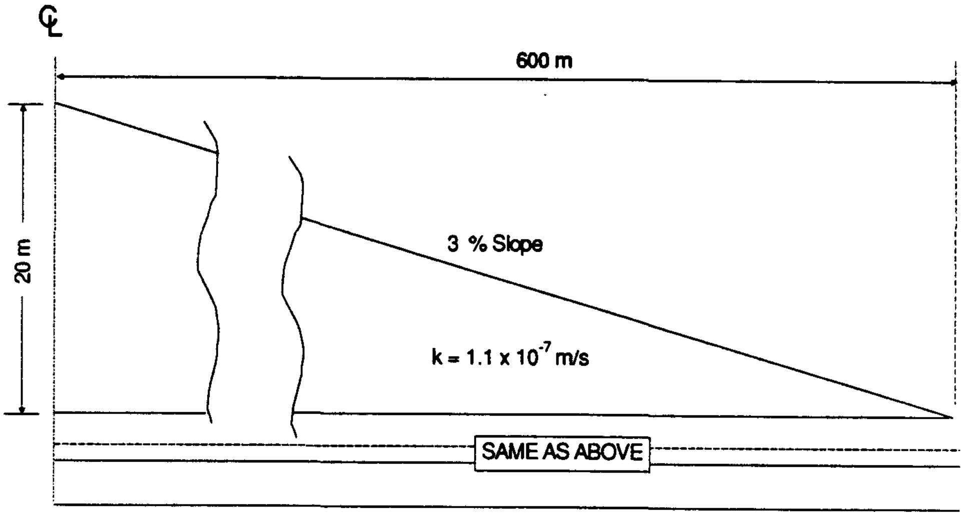
The flow of water between the atmosphere and tailings at the upper boundary of tailings depends on climatic conditions, surface topography, vegetative cover characteristics, soil properties and groundwater conditions. The actual flux boundary condition may only be correctly evaluated using a model which rigorously considers all of these factors. An analytical model which adequately satisfies these requirements is not currently available. However, the HELP (Hydrologic Evaluation of Landfill Performance) model (Schroeder et al, 1984) which was developed for landfill design, addresses many of these issues in a simple manner. It was therefore selected to estimate the climatic flux boundary across the surface of the tailings.

The HELP computer program uses a quasi two-dimensional saturated-unsaturated flow analysis to simulate the flow of water across the ground surface and into underlying soil layers. The model computes runoff, evapotranspiration and vertical seepage using climatic data such as daily precipitation values, air temperature and solar radiation. Soil properties such as permeability, porosity and field capacity are also utilized. The effects of vegetation are accounted for by specifying a Leaf Area Index representative of the vegetative cover.



	Zone 1	Zone 2	Zone 3	Zone 4
k (m/s)	8 x 10^{-8}	5 x 10^{-7}	1 x 10^{-6}	5 x 10^{-6}
Slope (%)	0.1	0.3	0.5	1.0

a) Conventional Tailings Disposal System



NOT TO SCALE

b) Thickened Tailings Disposal System

Figure 7 **Typical cross sections for the CTD and TTD systems.**

The flux boundary conditions for the CTD and TTD configurations were computed using 50 years of climatic data for a location near the site. This data was obtained from Environment Canada records. The HELP model does not explicitly provide for response of the groundwater system in the tailings. Consequently, the predicted net infiltration is calculated as an upper estimate of the potential net infiltration (i.e. total precipitation less runoff and evapotranspiration) across the surface of the tailings. Actual net infiltrative fluxes will be lower if vertical drainage is restricted by the groundwater flow regime.

Table 3 summarizes the results of the analysis carried out with the HELP model for both the CTD and TTD systems. The primary difference between these cases was the SCR (Soil Conservation Runoff) curve number selected for estimating runoff quantities. The HELP model does not explicitly account for surface slope, however, the effect of different surface slopes may be approximated by varying the SCR curve number. The use of a high perimeter dam in the CTD system restricts runoff, consequently, the lowest possible SCR curve number(i.e. 15) was selected for modelling the CTD system. Alternatively, a much larger SCR curve number of 93 was chosen to simulate runoff from the non-vegetated, TTD tailings surface.

The summary of analyses provided in Table 3 shows the mean annual precipitation varies between approximately 600 and 850 mm per year depending on the time period considered. In general, the HELP model predicts that between 11 and 14 percent of the mean-annual precipitation could infiltrate into the CTD tailings within the central area. This area has a lower permeability due to the finer texture of the tailings. The net infiltration increases to approximately 20 percent during the extreme wet year and decreases to zero during the driest year. Considerably larger quantities of infiltration were predicted in the segregated tailings area (Zones 2,3 and 4) where the permeability is higher. The HELP model predicts that between 17 and 35 percent of the mean annual precipitation will infiltrate into the segregated tailings depending on permeability. This quantity rises to between 27 and 49 percent during the wettest year considered and drops to between 6 and 22 percent for the driest year.

In general, the HELP model predicts less net infiltrative flux for the TTD. This occurs primarily because more runoff is generated on the 3 percent slope. Approximately 9 percent of the mean annual precipitation infiltrates into the TTD tailings compared to 12 to 14 percent for a CTD tailings with the same permeability. Table 3 also includes the net infiltrative flux for the TTD tailings assuming the surface is vegetated with an excellent cover of grass. In most cases, vegetation tends to decrease net vertical flux due to the increase in evapotranspiration. However, it is interesting to note that the quantities of net infiltration are almost identical for both the vegetated and non-vegetated surface. This occurs because the vegetation restricts runoff by interception and retention. The net reduction of runoff offsets the increased evaporative demand leaving the net infiltrative flux almost unaltered.

Table 3 - Summary of net vertical fluxes as calculated from HELP model.

Period of Climatic Data	K (m/s)	Mean Precipitation (mm/yr)	Net Vertical Flux mm/year and as (% of mean annual precipitation) Wet-Year	Mean-Year	Dry-Year
CONVENTIONAL TAILINGS					
Central Tailings Area (Zone 1)					
1940-1957	1x10^{-07}	593		72(12%)	
1958-1989	1x10^{-07}	819	185(23%)	114(14%)	0(0%)
1970-1989	8x10^{-08}	848	161(19%)	96(11%)	5(.6%)
Segregated Tailings Area (Zones 2-4)					
1970-1989	5x10^{-07} (Zone 2)	848	231(27%)	147(17%)	49(6%)
1970-1989	1x10^{-06} (Zone 3)	848	293(35%)	180(21%)	64(8%)
1970-1989	5x10^{-06} (Zone 4)	848	416(49%)	292(35%)	186(22%)
THICKENED TAILINGS DISCHARGE					
Non-Vegetated Surface					
1940-1957	1x10^{-07}	593		48(8%)	
1958-1989	1x10^{-07}	819	132(16%)	74(9%)	0(0%)
1970-1989	1x10^{-07}	848	136(16%)	78(9%)	0(0%)
Vegetated Surface					
1970-1989	1x10^{-07}	848	155(18%)	79(9%)	0(0%)

Simulation of Long-Term Steady State Seepage

The average long-term seepage through the CTD system was simulated using two different sets of mean-year fluxes for the period 1970 to 1989 as specified in Table 3, and the three pond elevations as shown in Figure 7. These two sets of simulations utilized the following applied surface flux:

(i) The lower values of surface flux as calculated for the Zone 1 tailings were applied uniformly across all zones,
(ii) The values of flux as calculated for each zone (Zones 2, 3, and 4) were applied to the tailings surface.

The different pond elevations were utilized in the simulation because the application of the total flux as predicted by the HELP model would result in hydraulic heads at surface far in excess of the surface elevation of the tailings. The pond elevations provide a limit to the maximum hydraulic head that can develop over the surface of the tailings.

For the simulation of seepage from the TTD system, a set of five simulations were run in which the mean-year fluxes (1970-1989) or fractions of the mean-year flux (1/2, 1/4, 1/5, 1/10) were applied to the entire tailings surface.

Figure 8 illustrates the flow systems that developed for the CTD system using the lower set of fluxes. Even with the presence of the clay-core in the dam, the water table is drawn down around the periphery of the tailings area allowing an unsaturated zone to develop. This results in potential for acid generation. Without the very low hydraulic conductivity clay layer and clay-core, the coarser segregated zones of the tailings would be completely drained.

Figure 9 illustrates the flow system that develops within the TTD system for the various simulations. Unless the applied flux is less than 1/2 of the mean-year infiltration flux predicted by the HELP model, the water table remains at surface over the entire tailings mass. With lower values of applied flux, the water table does drop below the tailings surface near the center of the cone. However, the tailings would still remain saturated due to the high moisture retention characteristics of the thickened tailings.

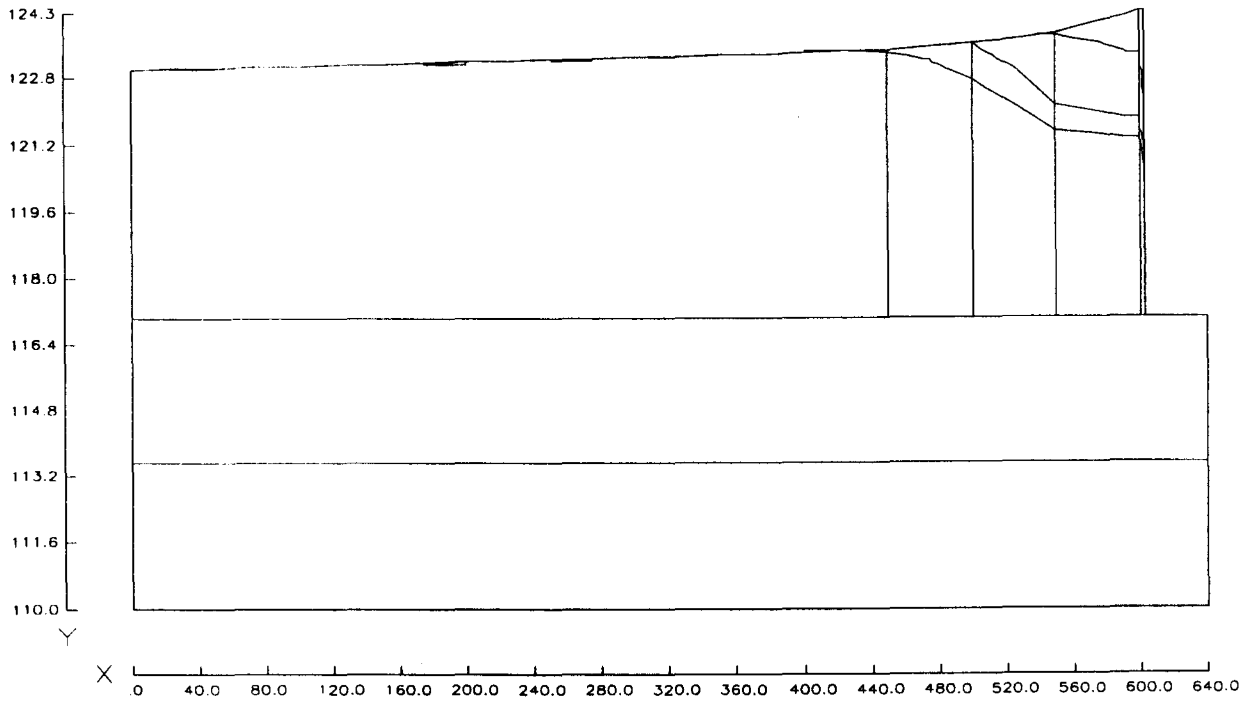
Figure 10 compares the flux applied to the tailings surface to the flux actually entering the tailings surface. It is apparent that although an order of magnitude difference in climatic flux conditions are applied, the actual flux entering the tailings mass only varies by a factor of 1.5 over the range of applied fluxes.

It is important to note that for these simulations the underlying clay plays a dominant role in controlling the water table elevations and the seepage from the tailings. Further analyses will be necessary to compare the performance of these disposal schemes under different foundation conditions.

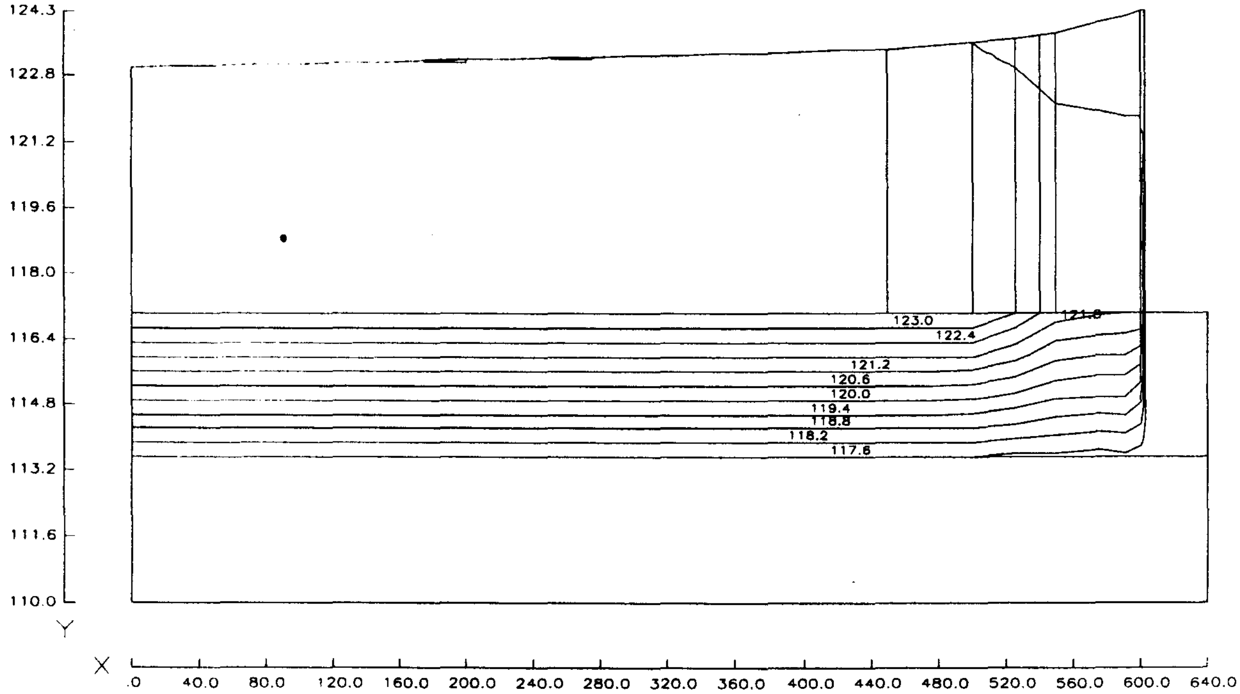
The average fluxes through the tailings surfaces and into the underlying aquifer system are summarized in Table 4. In order to be able to compare values for the two systems, the fluxes from the TTD system were multiplied by 1260 meters. This represents a 630 meter symmetrical ridge of tailings with the same volume as the circular CTD system.

The CTD flow system would not be able to accept all the flux specified for the mean-year condition (approximately 300 m^3/day). The constant head boundary condition provided by the pond limits the influx to much smaller values over the area of Zone 1. The presence of the pond is assumed to provide elevated levels of evaporation approaching the total potential evaporation rate. Calculations still need to be undertaken in order to verify that the pond would provide sufficient levels of evaporation to prevent a progressive buildup of the ponds with time. A preliminary estimate of potential evaporation equal to 1000 mm/year was calculated on the basis of available solar radiation using the Makkink Method (Rosenberg et al 1983). Since the mean annual precipitation is less than 850 mm/year it appears that the presence of a seasonable pond over a portion of the tailings surface is likely.

It is evident from Table 4 that the flux entering the tailings is much higher for the CTD scheme and that most of this flux is discharged out laterally through the perimeter dam, directly to the surface environment. The reason for this is that nearly all the head loss between the tailings surface and the aquifer is occurring within the foundation clay (Figure 7).

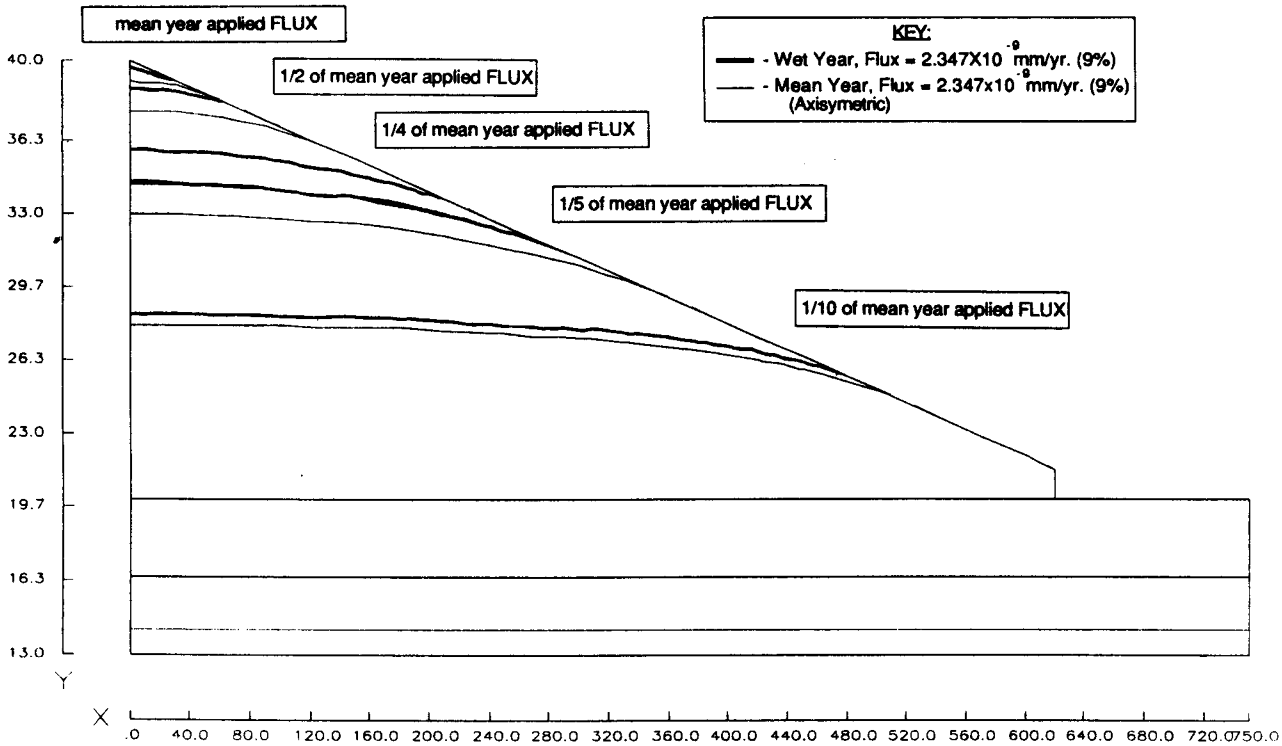


a) Water table configuration under the lowest values of applied flux

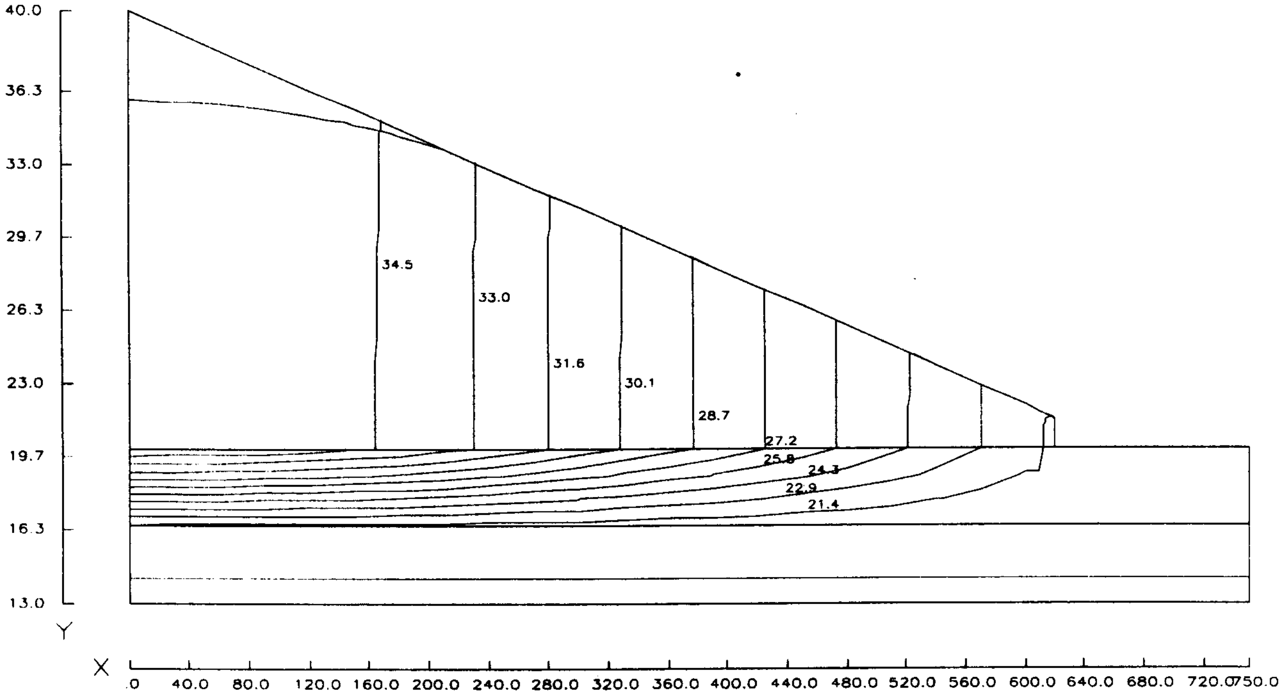


b) Equipotential contours for under lowest values of applied flux and middle pond elevation.

Figure 8 Water table configuration and equipotential contours for CTD System.



a) **Water table configuration for the TTD system under applied fluxes of 1/10, 1/5, 1/4, 1/2 and 1 times the mean year value predicted by the HELP model.**



b) **Equipotential contours for the TTD system using an applied flux equal to 1/4 of the mean year flux.**

Figure 9 **Water table configuration and equipotential contours for TTD System (2-dimensional plane section model)**

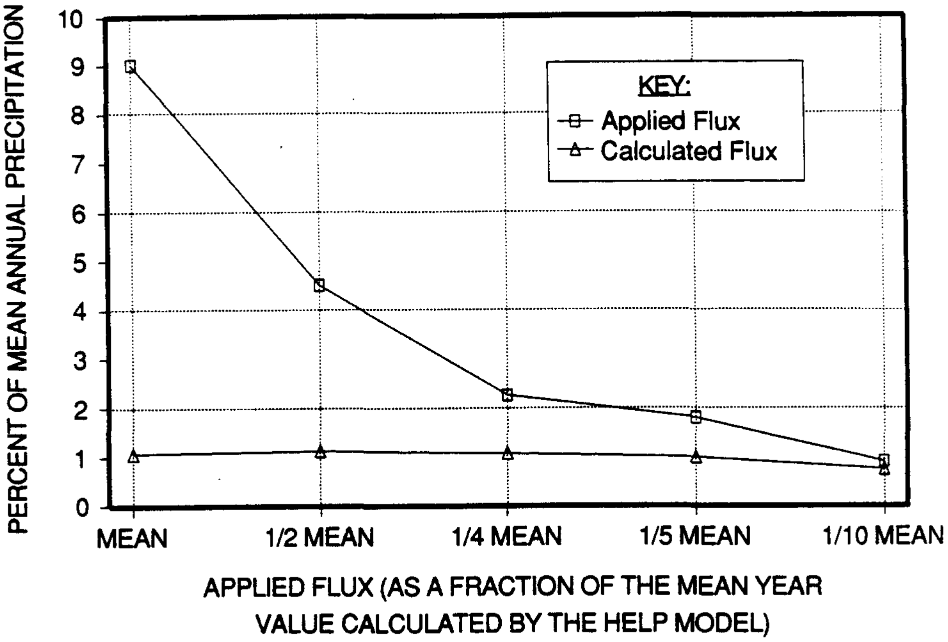


Figure 10 **Comparison of flux rates applied to the TTD system versus the flux rates actually infiltrating into the tailings surface.**

Table 4 - Calculated seepage fluxes.

Simulation (Applied Flux)	Calculated Flux into: Tailing Surface (m^3/day)	 Lower Aquifer (m^3/day)
Conventional Tailings		
(mean-year Zone 1 flux)		
- high pond elevation	44	17
- middle pond elevation	32	16
- lower pond elevation	28	15
(mean-year Zone 2,3,4, flux)		
- high pond elevation	46	17
- middle pond elevation	44	16
- lower pond elevation	44	16
Thickened Tailings - Plane Model*		
(mean-year flux)	19	18
(1/2 mean-year flux)	20	18
(1/4 mean-year flux)	19	17
(1/5 mean-year flux)	17	16
(1/10 mean-year flux)	13	11.5

* - the fluxe/meter width of tailings, has been multiplied by a length of 1263 meters to provide an equivalent volume of tailings as the CTD

Consequently, the average head across the clay is approximately the same for both systems. However, the CTD system also promotes high lateral gradients and fluxes across the perimeter dam.

Simulation of Transient Draw-down of the Water Table

During dry periods, the water table within the TTD tailings will begin to drop as a result of evaporation and seepage from the tailings. It is understood that the evaporation losses during a dry period could be quite substantial. However, further analyses will be required to define the rate of evaporation that occurs as drying proceeds. To illustrate the effect that a prolonged dry period would have on the water tables within the TTD system as a result of seepage losses, two simulations were conducted.

First, a transient simulation was run in which the steady state mean-year seepage regime was used as initial conditions and the applied flux was set to zero. An average slope from the moisture retention curve over 100 kPa (i.e. 0.0005/kPa) was input to represent the storage available in the tailings as the water table is lowered. No storage of water was considered to be available from the saturated tailings or other materials.

Figure 11 illustrates the drawdown that occurs over an 8 month period in which no climatic flux is applied to the surface of the tailings. It is interesting to note that the average drawdown is less than 2 meters, with the drop occurring fairly uniformly along the entire tailings slope. The near surface tailings would remain saturated; however, as the thickened tailings do not begin to dewater until the matric suction exceeds at least 100 kPa (i.e. 10 meters of negative pressure head).

In the second simulation, an evaporative flux of 4 mm/day was applied to the surface of the tailings and the adjacent ground surface. Three different values for storage within the saturated and unsaturated tailings were used. Figure 12 illustrates the change in seepage flux through the base of the tailings with time. As negative pressures heads develop at the tailings surface due to evaporation, the downward gradients begin to diminish, and consequently the vertical flux through the base of the tailings decreases.

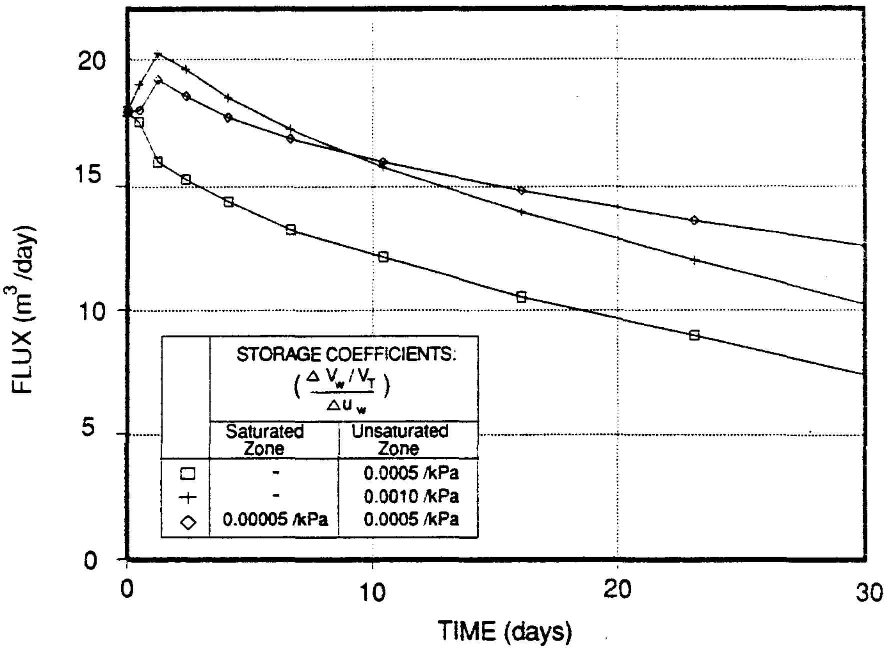


Figure 11 **Drawdown of water table during an 8 month period in which there is zero net climatic flux to the tailings surface. Water table shown is for the following elapsed times: (20, 64, 108, 151, 194, 206, 215, 225, 235 days).**

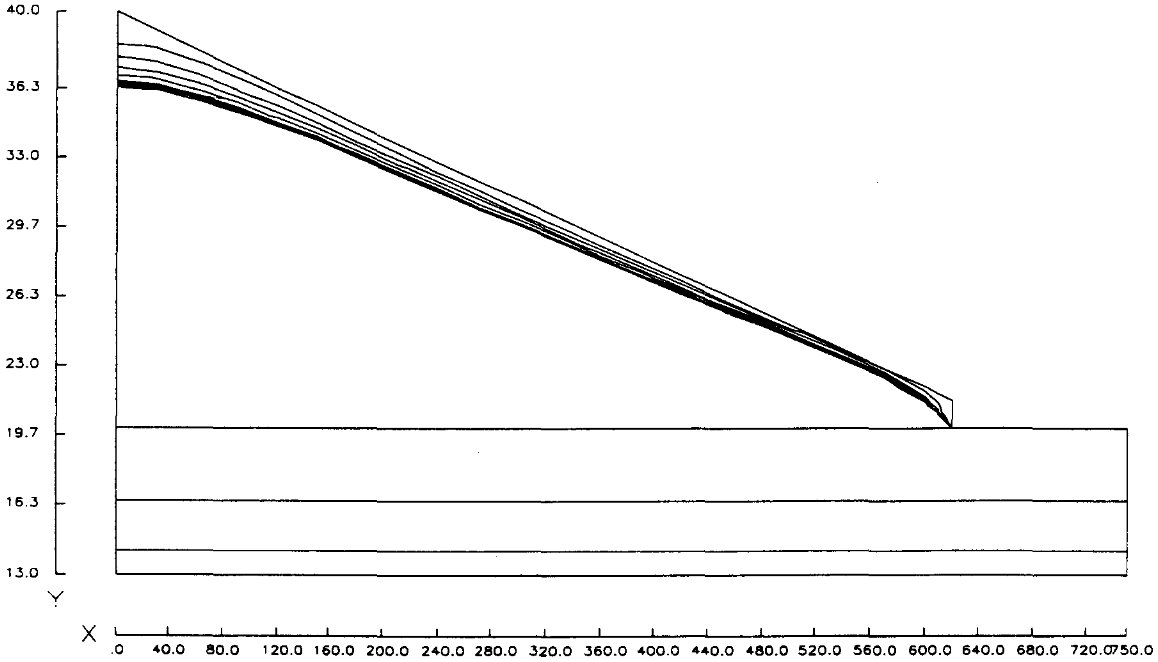


Figure 12 **Reduction of seepage flux through the base of the TTD system during a period of evaporation at 4 mm/day from the surface (Total flux is calculated for a 630 long ridge of tailings)**

4.0 CONCLUSIONS

The performance of an operating thickened tailings disposal scheme has demonstrated that many of the benefits that have been proposed for the TTD system have been realized in the field. Tailings disposal at the Kidd Creek has produced a thickened, gently sloping deposit of homogeneous tailings which exhibit a low hydraulic conductivity and high moisture retention characteristics.

Numerical modelling of the seepage within the tailings under average long term climatic conditions has demonstrated that in comparison to a conventional disposal scheme the thickened tailings disposal scheme has a number of advantages, including:

1. Low rates of infiltration due to climatic precipitation. As a result of the low hydraulic conductivity and hydraulic gradients within the TTD system only a fraction of the infiltration rates predicted by the HELP model can actually enter the flow system.

2. The seepage losses from the TTD system were lower. The seepage through the tailings for the TTD system was less than 1/2 of the seepage through the CTD system.

3. A majority of the seepage from the CTD system was released directly to the surface, adjacent to the perimeter dam. For the TTD system nearly all seepage through the tailings had to pass through the underlying clay layer prior to reaching the underlying aquifer. This allows maximum use to be made of any natural attenuation provided by the clay prior to the release of contaminants to the environment.

4. Shallow water tables were maintained within the TTD system over a variety of climatic conditions. The high moisture retention characteristics of the tailings allow saturated conditions to be maintained to surface even when the water table drops. In the CTD system unsaturated zones developed within the segregated zones of tailings. This would allow oxygen to penetrate the tailings and promote acid generation. These unsaturated zones were also located in the regions of highest flux through the tailings nearest the perimeter dam. Consequently, contaminants mobilized as a result of acid generation would be near the point of release to the environment. (i.e. adjacent to the perimeter dam.)

5. The shallow water table throughout the tailings would provide easier reclamation for the TTD system than for the CTD system. Placing a cover and establishing vegetation within the central zone of the CTD tailings, where very soft clayey material is present, would be particularly difficult.

The simulations in the paper only provide a preliminary assessment of the relative merits of the TTD and CTD systems. Further work is still required. For example, it is important to note that typical sections were assumed for the simulations. The foundation soils and natural groundwater flow system played a significant role in determining the relative merits of the two systems. Further work is required to define the relative performance of these systems for other hydrogeologic conditions.

In addition, only long-term average climatic fluxes were considered in these simulations. Further work is required to predict the impact that transient cycles of evaporation and infiltration may have on the performance of these disposal schemes.

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