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Control of Seepage from Uranium Mill Tailings Ponds in the Elliot Lake Area

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ABSTRACT

Since the beginning of mining operations in 1955, some 105 million tons of uranium mill tailings have been produced in the Elliot Lake area. Current contracts will result in the production of an additional 300 million tons of tailings and presently uncommitted reserves could result in the production of a further 250 million tons. This paper reviews the history of past mining activities and tailings management in the area, describes the seepage control measures at two tailings management areas (one developed in the late 1960's and the other presently under construction) and considers possible techniques to control seepage from future tailings areas.

INTRODUCTION

The Elliot Lake mining area is located in north-central Ontario at about longitude 82 degrees 36 minutes west, latitude 46 degrees 24 minutes north (see Figure 1). The topography is fairly characteristic of the Canadian Shield and may be described as rugged but of relatively low relief; elevation differences being generally in the order of 100 to 200 feet or less. Topographic highs consist typically of rock knolls or ridges and topographic lows generally contain swamps, lakes or streams.

Figure 1 - Site Location Plan

The area experiences an average total precipitation of about 38 inches of rainfall per year and the average annual evapo-transpiration is about 20 inches. Thus, as illustrated on Figure 2, the area is characterized by abundant lakes and streams; about 20 to 25 per cent of the total area being covered by water.

In an area of significant net precipitation, it is not practically possible to construct non-effluent producing tailings facilities. Consequently, current practice in the Elliot Lake area is to collect and treat all effluent from the tailings facility prior to discharge to the environment.

Figure 2 - Typical Elliot Lake Topography

Because of the topography, tailings are generally discharged into existing lake basins to take advantage of natural containment by surrounding bedrock highs. As far as is practically possible, all fresh water is diverted away from the management area. Topographic lows around the perimeter of the tailings area are closed by dams.

Current draft guidelines (1) suggest that the average permeability of a tailings basin should not exceed 10^{-5} centimeters per second and that the permeability of containment dams should not exceed 10^{-6} centimeters per second. Because of the lack of impervious clay borrow in the area, this latter requirement has recently led to the incorporation of synthetic membranes or liners in the containment dams.

REGIONAL GEOLOGY

The uranium deposits in the Elliot Lake area are associated with an approximately 10 mile wide sedimentary basin of Pre-Cambrian Age which unconformably overlies metavolcanic and metasedimentary basement rocks. The ore occurs in 2 to 15 foot thick pyritized quartz pebble conglomerate beds located near the base of the sedimentary sequence and is generally of low grade (1 to 3 pounds per ton).

Regional faults tend to occur at 3 to 4 mile spacing and, with the exception of Quirke Lake over-thrust fault, are steeply dipping and strike northwest-southeast (ref. Figure 3). Local faulting tends to be more intense (2 to 3 features per square mile) and, while generally steeply dipping, exhibit variable strike and persistence. Intruded diabase dykes are associated with the faults.

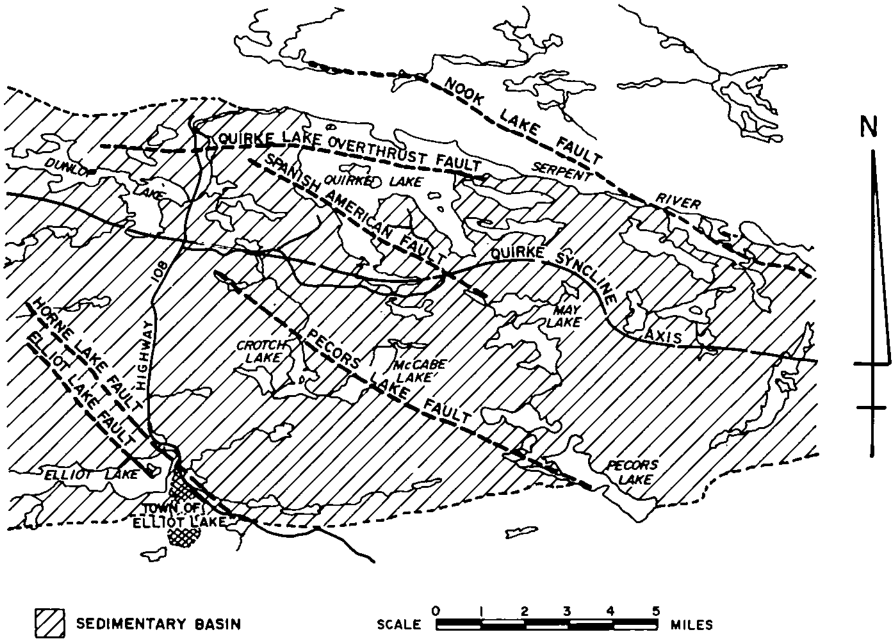

Figure 3 - Simplified Geologic Map

Overburden is restricted to topographic lows and, with the exception of recent bog or swamp deposits, consists predominantly of fluvial or outwash silty sands and gravels of glacial origin. Local deposits of essentially cohesionless silty to sandy till also occur in topographic lows or plastered on the flanks of bedrock highs. The permeability of the till is typically in the order of 10^{-4} to 10^{-5} centimeters per second.

Groundwater appears to occur as a complex series of local "perched" regimes associated with the lake systems. The majority of groundwater transport between these local regimes occurs through overburden infilled bedrock lows or major discontinuities (e.g. faults) in the rock. However, the results of mining experience and recent geotechnical borings suggests that, with two or three possible exceptions, the permeability of the faults at depth is low; typically less than about 10^{-5} centimeters per second.

HISTORY OF MINING AND MILLING ACTIVITIES

The discovery of uranium in the Elliot Lake area in 1953 preceded, by a short interval, a critical stage in the "cold war". Governments demanded enormous quantities of uranium for atomic weaponry for western defence. The result was a frantic crash program whereby twelve mines (eleven with mills) were brought into production in the area over a span of four years (1955-1958) by seven different mining companies (2). The locations of these mines are shown on Figure 4.

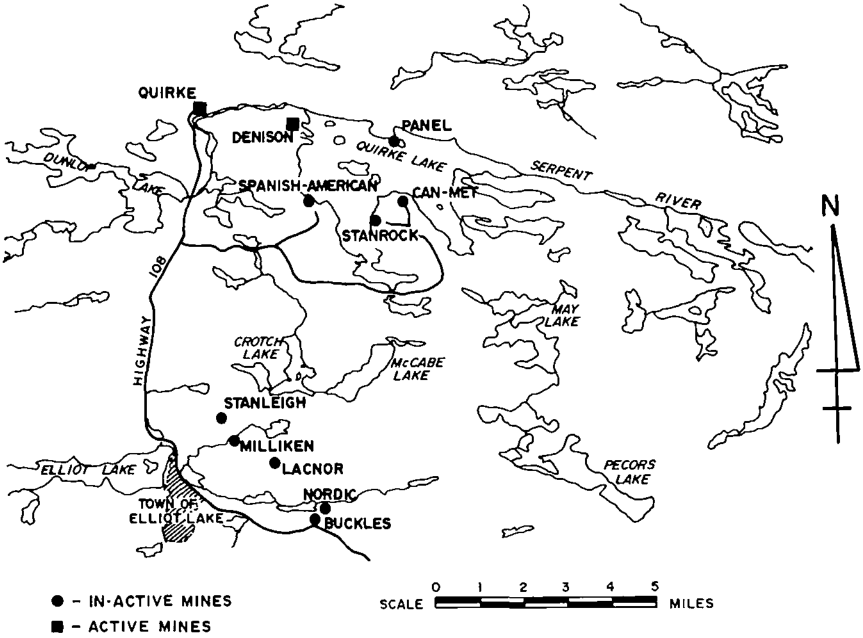

Figure 4 - Locations of Active and In-Active Mines

In 1959, the United States Atomic Energy Commission, to which most of the production was contracted, announced that it would not extend the contracts beyond 1962. As a result, most of the mines and mills closed, with only the Denison and Nordic operations remaining in production. The population of the Town of Elliot Lake subsequently dropped from in excess of 25,000 people in 1959 to about 7,000 in the early 1960's.

In 1968, the Nordic Mine closed and the Quirke mill was reactivated. Thus, at present only two mine/mills are in operation, Quirke and Denison, both of which have recently increased rated mill production to about 7,000 tons per day.

The history of past mining/milling operations in the Elliot Lake area and an indication of tailings production from the various mills are summarized in Table I. As indicated in this table, the total tailings production to date in the area has been of the order of 105 million tons.

TABLE I

SUMMARY OF URANIUM MILLING HISTORY

Mill	Operating Period	Nominal Mill Capacity (T.P.D.)	Total Quantity Milled (10^6 tons)
North Limb Mines			
Can-Met	May '58 - Mar. '60	3,000	6.1
Denison	May '57 - Present	4,500 - 7,000	33.0
Panel	Feb. '58 - June '61	3,100	3.6
Quirke	Sept. '56 - Feb. '61	3,000	4.1
	Aug. '68 - Present	4,500 - 7,000	23.0
Spanish-American	May '58 - Feb. '59	2,000	0.4
Stanrock	Mar. '58 - Nov. '60	3,000	6.1
South Limb Mines			
Lacnor	Sept. '57 - July '60	4,000	3.0
Milliken	Apr. '58 - June '64	3,000	6.3
Nordic	June '57 - July '68	3,700	13.2
Stanleigh	Mar. '58 - Jan. '60	3,000	2.0
Pronto	Sept. '55 - Apr. '60	1,500	2.3
	June '60 - 1970*	-	2.5
TOTAL MILLED TO DATE			105.6

*Copper tailings from adjacent property.

As indicated on Figure 5, tailings from the various milling operations are located in seven main areas; combined facilities having been used for some mines. During the 1950's and early 1960's, the most common form of tailings disposal was to end-discharge tailings into a nearby lake basin as shown on Figure 6. At that time, it was not recognized by either the companies or government regulatory bodies that radium would appear in the effluent (see

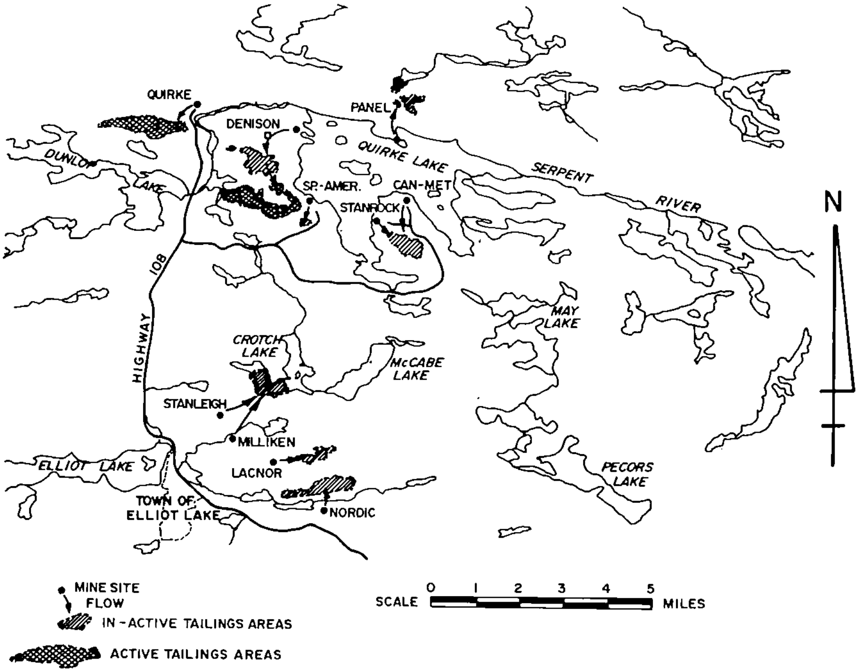

Figure 5 - Locations of Active and In-Active Tailings Areas

Figure 6 - Typical 1950's Tailings Area

following section) and no attempt was made to collect or treat the effluent from the tailings basins; the overflow went directly into the streams.

Where tailings encroached on topographic lows around the lake basin perimeter, pervious sand and gravel berms were constructed to contain the solids. However, no positive measures were taken to prevent or collect seepage through these structures.

At some properties, natural basins suitable to provide adequate containment were not available and conventional tailings "sand" dams were constructed by the upstream method (with or without cycloning) or waste rock perimeter dams were provided. Again, no positive seepage control or collection systems were incorporated into these structures, one of which is illustrated on Figure 7.

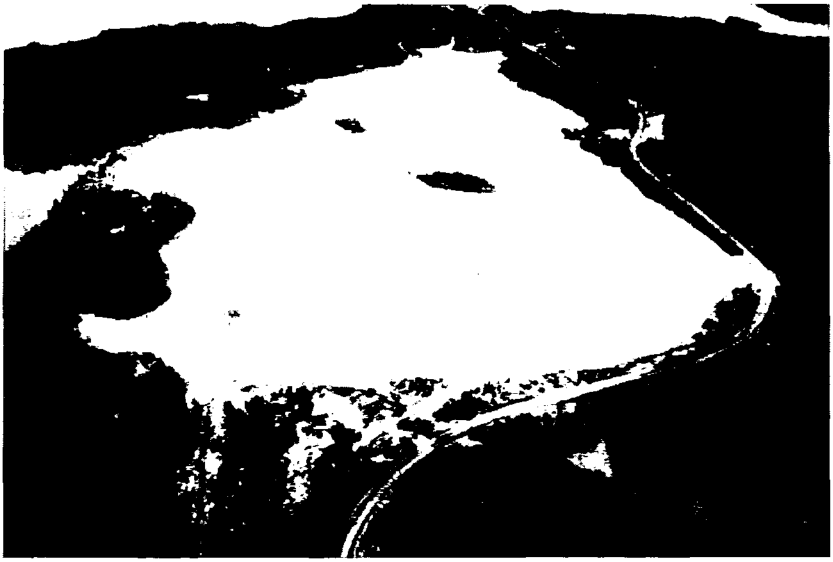

Figure 7 - 1950's Tailings Dam

By the late 1960's, stringent criteria had been established regarding the quality of effluent which could be discharged to the environment. Consequently, with the reactivation of the Quirke mill in 1968, measures were taken to either prevent or collect and treat seepage from the tailings management area as described subsequently in this paper, Concurrently, extensive works were undertaken at Denison's active tailings area to minimize and collect seepage. This system is described by Milligan et al., 1977 (3).

In 1976, a decision was made by Rio Algom Limited to reactivate their Panel Mine (described subsequently in this paper) and in 1978 long-term contracts between Ontario Hydro and both Denison Mines Limited and Preston Mines Limited (an affiliate of Rio Algom Limited and owners of the Stanleigh Mine) were announced. Preliminary design of tailings facilities to service both these contracts is currently underway.

A summary of the total past and possible future tailings production in the Elliot Lake area is given in Table II.

TABLE II

SUMMARY OF POSSIBLE TOTAL TAILINGS PRODUCTION

Total tailings produced to date (from Table I)	105×10^6 tons
Additional future production to fulfill existing contracts	300×10^6 tons
Additional uncommitted reserves	250×10^6 tons
Total potential tailings production	655×10^6 tons

As indicated by this table, based on existing contracts alone the total tailings production in the Elliot Lake area will be of the order of 400 million tons (dry weight basis) which equates to a total volume of storage required of about 350 million cubic yards.

TREATMENT OF TAILINGS EFFLUENT

Elliot Lake tailings are relatively coarse with 40 per cent passing a minus 200 mesh screen. For the low grade ores (typically about 2 pounds per ton and lower), the radium activity is about 250 pico-curries per gram or less.

During the 1950's and early 1960's while all properties were in operation, acid generation was not a significant problem and the elevated levels of radium 226 were an unknown quantity. Thus, as previously noted, impervious containment structures were not provided and attempts were not made to prevent or control seepage from the tailings areas.

Following the closure of all but two properties in the early 1960's, two major environmental problems emerged. The first problem was acid generation from pyrite oxidation in the inactive tailings areas which resulted in a serious pH depression in the regional river system. The second problem which came to light was the elevated levels of radium 226 in the discharges from the tailings areas.

During the mid 1960's both operating properties (Denison and Nordic) commenced the use of barium chloride for the control of dissolved radium 226. This was followed by the installation of seepage collection systems and lime and barium chloride treatment plants at all non-operating properties. This has resulted in the control of acidity and a great reduction in radium discharges to the receiving waters.

Current practice in the Elliot Lake area is to extract uranium in an acid leach circuit with ion exchange for uranium recovery and to neutralize the tailings with lime and limestone before discharge to the tailings basin. The resultant decant flows from the tailings areas, which include all process water discharged plus runoff, are characterized as a saturated calcium sulphate solution with neutral pH, very low levels of heavy metals and elevated levels of dissolved radium 226. Therefore, treatment consists of barium chloride addition for precipitation of radium barium sulphate followed by settling in large engineered clarification ponds. Typically, dissolved radium levels are reduced from between 300 and 1000 pico-curries per litre to 3 to 7 pico-curries per litre after treatment.

Although current contracts will extend mining and milling operations well into the twenty-first century, a primary area of concern to both the mining companies and regulatory bodies is the development of long-term abandonment strategies. A primary abandonment strategy developed for properties in the mid-western United States has been to "encapsulate" the tailings. This involves the application of as much as 10 to 20 feet of clean overburden and clay to reduce infiltration of water and exhilation of radon gas. This strategy is NOT applicable for Elliot Lake as virtually no clay exists in the area and overburden for fill is scarce.

Major research and development plans have been initiated to deal with long-term abandonment strategies. This work includes investigations into chemical fixation techniques, alternate encapsulation techniques, removal of radionuclides from the tailings and vegetative stabilization. The work carried out to date involving contouring and vegetation to promote runoff and increase rates of evapo-transpiration have proved to be very encouraging (see Figure 8 for example). Thus, vegetative stabilization is receiving the major research and development effort at this time.

Figure 8 - Example of Re-Vegetated Tailings

QUIRKE TAILINGS MANAGEMENT AREA

The Quirke mill was initially operated from September, 1956 until February, 1961 and tailings were discharged into the east end of a small lake basin known as Manfred Lake. The general location of the Quirke tailings management area is shown on Figure 5 and a more detailed view is shown on the 1964 aerial photograph, Figure 9. During this period, clarified effluent from the tailings area followed a local stream course around a high rock ridge to the north and thence to the Serpent River. Shortly before shut-down a rockfill starter dyke was constructed across the west end of the area (ref. Figure 9 for location); the intention having been to construct a "sand" dam by spigotting from west to east.

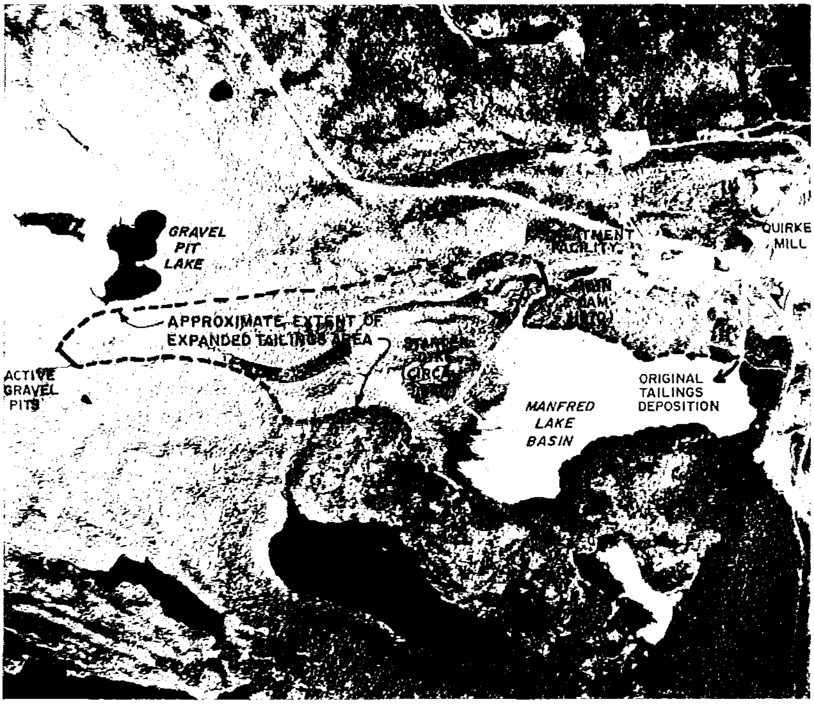

Figure 9 - 1964 Aerial Photograph of Quirke Tailings Area

In August of 1968, milling was resumed at Quirke and tailings were initially discharged into the west end of the Manfred Lake basin from the previously constructed starter dyke. Subsequently (1969) it was decided to incorporate the entire valley to the west of this initial area into a major tailings management scheme. To this end, a relatively short (550 foot long) "Main Dam" was constructed across the eastern outlet to the valley (ref. Figure 9). It was further decided to construct this Main Dam to an initial height of about 50 feet and to raise the water level in the basin to about elevation 1257 feet (an average depth of about 40 feet) prior to allowing discharge. Effluent was then "decanted" through an overflow spillway cut in the rock of the south abutment of the Main Dam and thence led by overland flow to a treatment facility located immediately downstream of the Main Dam.

In raising the water level to elevation 1257, it was recognized that, although there was adequate freeboard at the west end of the basin, a potential seepage problem existed through what were known to be extensive, pervious sand and gravel deposits which separated the tailings basin from an environmentally sensitive freshwater lake, Dunlop Lake, to the west. Further, diversion of the flow from Gravel Pit Lake through this area was required (see Figure 9 for location).

Main Dam and Treatment Area

The results of borings put down at the Main Dam site indicated that while the valley walls were composed of exposed rock, the valley floor was underlain by as much as about 50 feet of pervious sand and gravel (coefficient of permeability of 10^{-2} to 10^{-4} centimeters per second) and the groundwater level was essentially at ground surface. The underlying rock was found to be sound with a permeability (based on borehole packer tests) of between 10^{-5} and 10^{-6} centimeters per second.

At that time, it was considered impractical to construct an impervious cut-off to rock beneath the dam and, considering the fact that the treatment facility was located downstream of the dam, it was decided to permit foundation seepage; this seepage being collected and treated with the decanted effluent. Initially, it was proposed to install gravity relief wells along the downstream toe of the dam to collect the seepage. This proposal was abandoned in favour of a seepage collection pond between the toe of the dam and the treatment facility. This revised scheme is illustrated in plan and section on Figure 10.

Considering the lack of impervious (clayey) borrow material in the Elliot Lake area and the fact that controlled foundation seepage was to be permitted, it was decided to construct the Main Dam of pervious mine waste rock. A toe drain of select sand and gravel was provided to collect seepage and a tailings "beach" was spigotted along the upstream face during initial filling of the basin to minimize seepage (see Figure 10). With the provision of this tailings "beach" the total seepage through the dam and the foundations was estimated to be of the order of 700 to 800 gallons per minute.

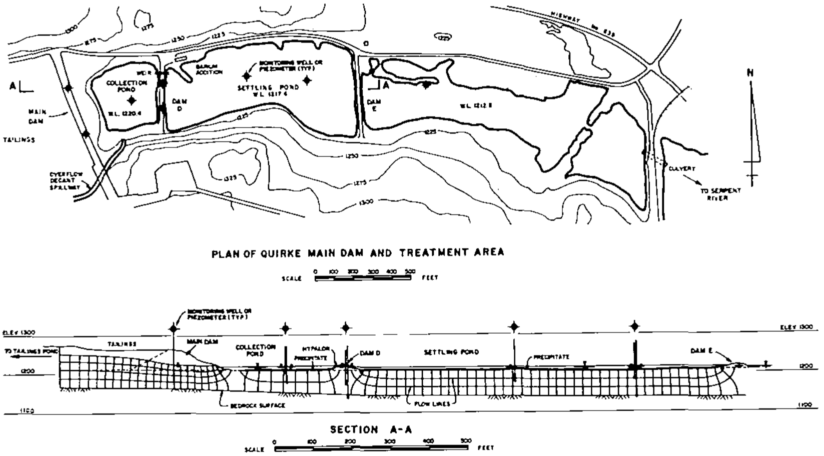

Figure 10 - Quirke Main Dam and Treatment Area

In 1977, an extensive investigation consisting of geophysical surveys and borings together with the installation of monitoring piezometers and groundwater sampling wells was undertaken (see Figure 10). The results of these studies indicated that NO "untreated" seepage was escaping to the environment. The piezometric water levels in the Main Dam were very low and most of the foundation seepage was emerging in the collection pond (i.e. between the Main Dam and the treatment plant) with only a small amount, computed 2 to 3 gallons per minute, of "untreated" seepage passing Dam 'D' (ref. Figure 10). Further, the results of chemical analyses of groundwater samples obtained from sampling wells installed immediately downstream of the settling pond indicated that the filtered radium content approached "background" levels. It is interesting to note also that samples of groundwater obtained from wells installed in the foundations of the Main Dam contained only 2 to 4 pico-curries per litre of radium 226, suggesting that the radium was adsorbed by the local granular soils.

Gravel Pit Lake Diversion

As previously noted, a potential seepage problem was recognized at the west end of the basin where borings put down in 1969-70 indicated pervious sand and gravel deposits extended as low as elevation 1220 or some 40 feet below the proposed tailings pond level. Further, it was necessary to divert the outflow of Gravel Pit Lake (which originally flowed eastward) through this area towards the west.

Several alternative methods of constructing "conventional" impervious dams and cut-offs were investigated. Because of the lack of suitably impervious clay borrow, various types of synthetic core materials and synthetic liner materials were considered as well as various methods of extending the core/liner to rock.

Because of the high cost of providing "conventional" impervious dams, a scheme was evolved which utilized the diverted Gravel Pit Lake discharge (required in any case) to form "back-up" ponds behind two relatively small PERVIOUS sand and gravel dams (Dams 'A' and 'B') as illustrated on Figure 11. This scheme involved the construction of a control dam at the outlet of Gravel Pit Lake and the creation of two relatively small lakes, Ponds 'A' and 'B' behind the

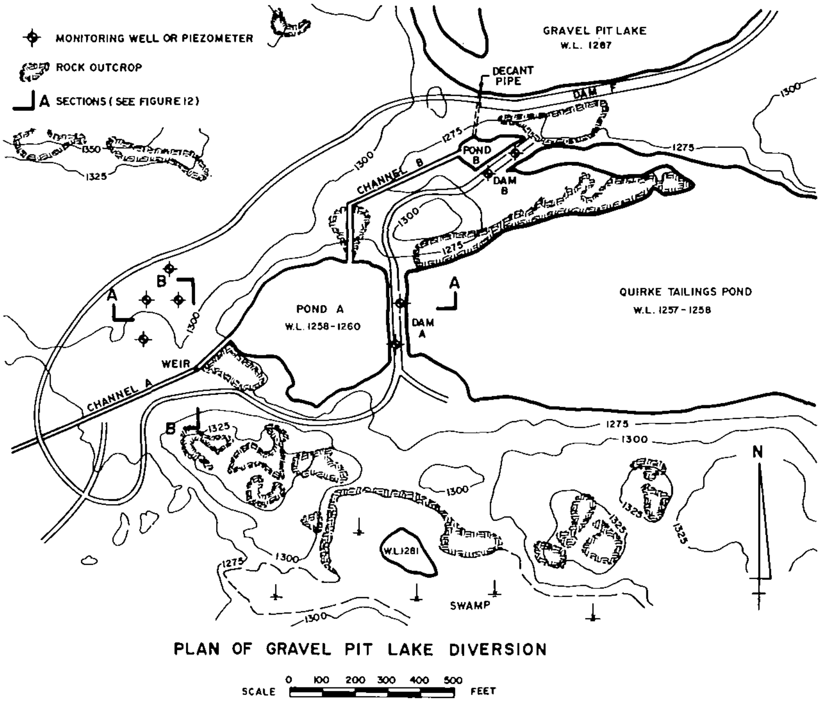

Figure 11 - Gravel Pit Lake Diversion

two pervious dams. The water levels in Ponds 'A' and 'B' were regulated to provide a positive head of "fresh water" across the dams and thus prevent the seepage of contaminated water out of the tailings area (see Figure 12 for illustrative section).

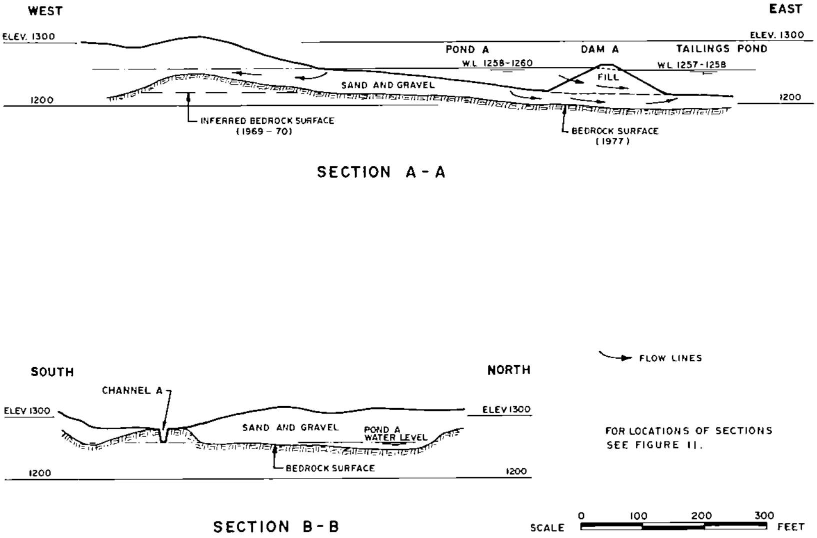

Figure 12 - Sections Through Gravel Pit Lake Diversion Area

Over the years, some problems have been encountered in maintaining the design water levels in the freshwater back-up lakes, particularly Pond 'A'. As a result, the water level in Pond 'A' has, on occasion, fallen to within a few inches of the tailings pond level but has never fallen below the pond level.

Although on-going surface water monitoring has indicated no leakage problem in this area, Rio Algom undertook a major study in 1977 to confirm that untreated effluent was NOT escaping into the groundwater from the tailings area and entering Dunlop Lake. The results of this investigation indicated that, while not as extensive as had been inferred from the 1969-70 borings, an overburden "window" existed between Pond 'A' and the freshwater lake to the west (ref. Figure 12). Further, while the overburden was highly pervious (coefficient of permeability of 10^{-1} to 10^{-3} centimeters per second) the bedrock was relatively impervious (coefficient of permeability generally less than 10^{-5} to 10^{-6} centimeters per second).

Piezometers installed in Dams 'A' and 'B' and their foundations confirmed that seepage was occurring from the freshwater ponds INTO the tailings basin. Further, samples of surface water from the Pond 'A' outlet and samples of groundwater obtained from sampling wells installed in Dams 'A' and 'B' and in the overburden "window" between Pond 'A' and Dunlop Lake all had the same chemical composition, including filtered radium, as did samples of the Gravel Pit Lake discharge. NO evidence of contaminated process water from the tailings basin was found. Thus, even with the relatively small differential head that occasionally exists between Pond 'A' and the tailings pond, the system is effective in preventing the escape of contaminants to the surrounding area.

Current and Future Activities

Following spigotting of the initial "beach" on the face of the Main Dam in 1971, a diagonal dyke was constructed across the "beach" from the south abutment to the north side of the valley (Dyke Number 1 on Figure 13) and open end discharging of tailings continued from the north valley wall. Subsequently, construction of a longitudinal waste rock and "sand" fill causeway across the beach from the south abutment of the Main Dam was begun. Dyke Number 2 (Figure 13) was constructed and "stacking" of tailings was commenced between the Main Causeway and the north valley wall.

At present, the capacity of the existing basin has almost been reached and studies are currently in progress to increase the capacity to about 80 to 100 million tons by major internal "stacking" and/or by raising the perimeter containment structures.

Figure 13 - Current Quirke Tailings Area

PANEL TAILINGS MANAGEMENT AREA

During previous milling operations at Panel Mine (February 1958 to June 1961) approximately 3.6 million tons of tailings were discharged into the west end of Strike Lake, a small lake basin located about one mile north of the mine and, to a lesser extent into a low-lying area immediately to the south (see Figure 5 for general location).

In 1976 a decision was made to reactivate the Panel Mine with a planned total production of 12 million tons of tailings. On the basis of site selection studies, it was decided to develop the Strike Lake basin as a controlled tailings management area, mainly because of the presence of the previously deposited tailings. Excluding geologic and topographic constraints, the development of this area was complicated by two factors.

(i) It was originally anticipated that milling could commence as early as April, 1979. As the period available for design and construction precluded completion of the effluent treatment facility before the Autumn of 1979, the system was to be designed to store all process water and precipitation runoff for a period of at least 9 months.

(ii) The 1950's tailings beach in the area south of the Strike Lake had to be treated.

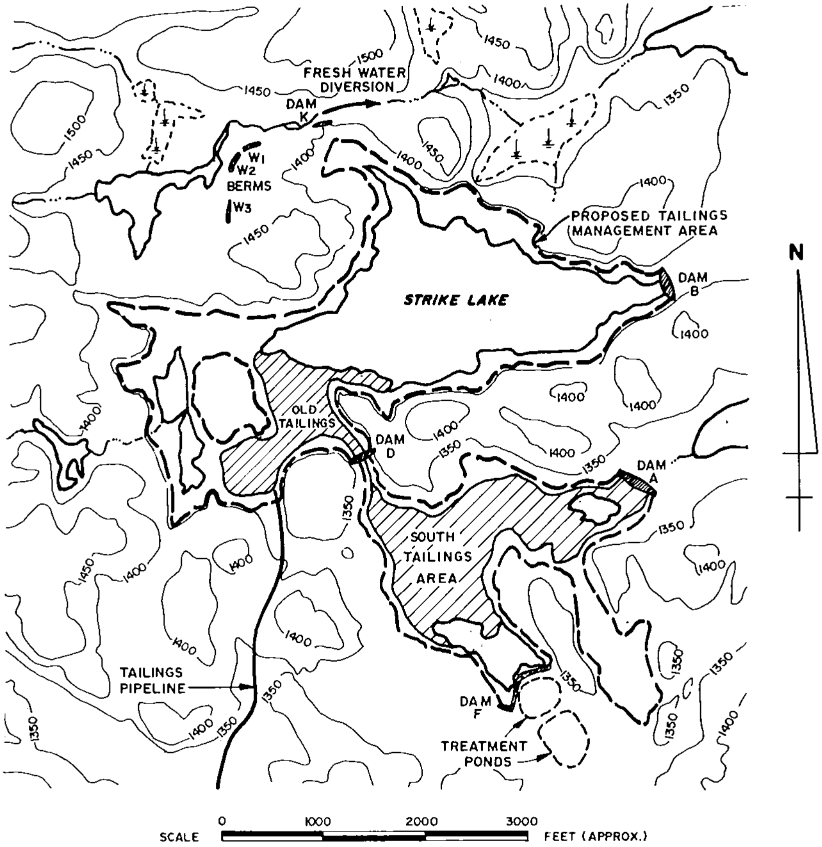

Figure 14 - Panel Tailings Management Area

To accommodate the various constraints, the scheme illustrated on Figure 14 was developed. This consisted basically of:

(a) Diverting the majority of freshwater inflow from the north away from the basin by the construction of Dam 'K', berms 'W1', 'W2' and 'W3' and diversion channel 'Y'.

(b) Raising the water level in the Strike Lake basin to elevation 1325 to maintain a water cover over the tailings by the construction of Dam 'B' across the existing eastern outlet of the lake and Dam 'D' across a narrow valley joining the Strike Lake basin to the South Tailings Area. Provision was made for subsequently raising this water level to elevation 1335 to accommodate future tailings production

(c) Raising the water level in the South Tailings Area to elevation 1315 by the construction of Dams 'A' and 'F' to flood the existing tailings and control runoff.

(d) Decanting water from the Strike Lake basin into the South Tailings Area by means of a side-hill decant at Dam 'D' and removing effluent from the South Tailings Area via a decant at Dam 'F'; the treatment facility being located immediately downstream of Dam 'F' and discharging via overland flow to Quirke Lake.

Containment Dams

In accordance with governmental guidelines, all of the perimeter containment dams, including Dam 'D', were to be made "impervious" and were to be capable of storing the 100 year design storm; excess precipitation being discharged untreated from the South Tailings Area via an emergency spillway east of Dam 'F' (because of operational considerations, the Strike Lake basin was capable of storing the maximum probable flood and no interim emergency spillway was provided).

Detailed geotechnical investigations carried out at the site in 1977 disclosed that, with the exception of Dam 'B', all of the dam sites were underlain by relatively thin overburden typically consisting of recent organic deposits and fluvial sands and gravels. At Dam 'B', located across the east end of Strike Lake, geophysical surveys indicated that within the valley floor area the depth of overburden ranged from about 40 feet (a local bedrock high) to in excess of 100 feet. Borings put down at the site indicated that the overburden varied from pervious sands and gravels to sandy till of moderate permeability.

Borrow investigations carried out in the area disclosed adequate localized deposits of granular borrow suitable for dam construction. In addition, two fairly extensive deposits of glacial till were located, one on the flank of the south valley wall immediately downstream of Dam 'B' and the second on the south side of the South Tailings Area. Although the permeability of the till, when compacted, was about 10^{-4} to 10^{-5} centimeters per second it did not meet governmental guidelines of 10^{-6} centimeters per second for "impervious" core material.

Based on the results of the pre-design investigations and considering the requirements of the draft governmental guidelines for the storage of uranium mill tailings, it was decided to construct the best (i.e. least pervious) dam consistent with good engineering practice and available borrow materials and to then incorporate into the design a synthetic impervious membrane. Several membrane materials were considered and eventually unreinforced hypalon was selected because of its ductility, ease of installation and resistance to chemical deterioration.

Where the overburden was thin (e.g. Dams 'A' and 'F') the overburden was stripped over the full base width of the dam, the surface of the exposed rock treated with "dental" or "slush" concrete beneath the core area and the dam founded directly on the rock. Where the overburden was thick (Dam 'B') or the site very restricted (Dam 'D' - a narrow "vee-notched" valley) a cut-off trench was excavated and the impervious membrane extended completely through the overburden and sealed onto the rock. In all cases, the membrane was secured to the rock by means of a concrete anchor beam and the rock was cement grouted to minimize seepage through joints and fissures.

Typical sections through Dam 'B' (sloping membrane with cut-off trench to rock) and Dam 'F' (founded on rock with a vertical membrane and concrete cut-off wall) are shown on Figure 15. Both sections incorporate a core of low permeability till, a chimney drain and a toe drain with collector (primarily for monitoring). In the case of Dam 'B', provision was made to raise the crest of the dam to accommodate the proposed future higher pond water level and the cut-off trench was located upstream of the toe of dam to permit work to proceed simultaneously on the dam and the cut-off. It is interesting to note that even with the omission of the impervious (hypalon) membrane, the total seepage through Dam 'B', the largest dam in the system, was computed to be less than 10 gallons per minute under the maximum design pond level (water level at elevation 1335).

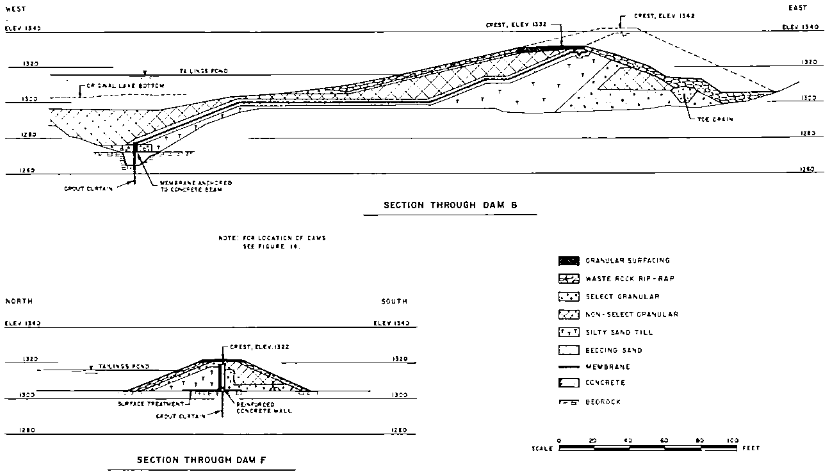

Figure 15 - Typical Sections - Dams 'B' and 'F'

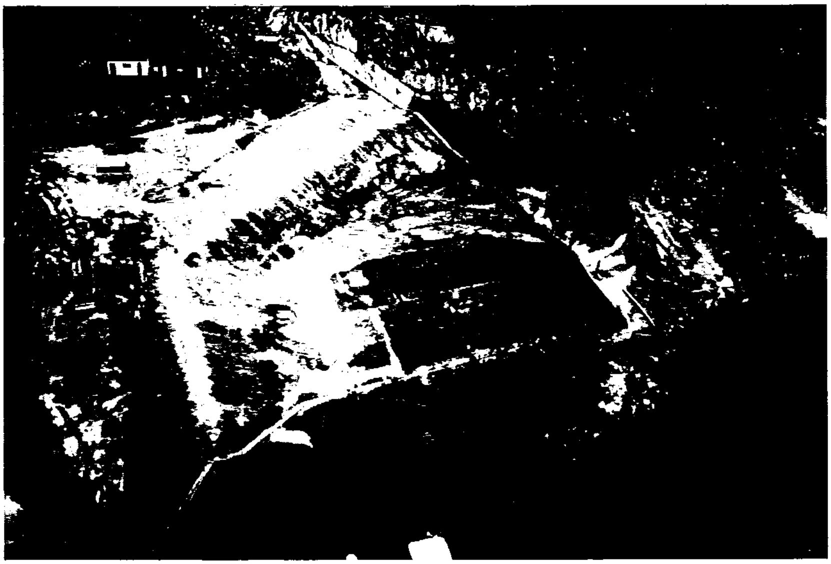

Figure 16 - Installation of Hypalon Membrane - Dam 'B'

Work commenced on the freshwater diversion and on the Strike Lake containment dams (Dams 'B' and 'D') in early Spring, 1978 and the structures were completed and ready to receive tailings by the Autumn of 1978. A general view of Dam 'B' from the air showing the installation of the hypalon membrane is shown on Figure 16. The following quantities regarding this dam are interesting.

Total Volume of Earthfill	- 56,000 cubic yards
Total Area of Membrane	- 53,000 square feet
Total Length of Proof Grout Holes	- 2,250 feet
Total Volume of Grout Injected	- 114 bags

Foundation preparation for Dams 'A' and 'F' in the South Tailings Area commenced in 1978 and these dams together with the effluent treatment facility are to be completed during the Summer of 1979.

Containment Basin

As previously noted, current draft governmental guidelines suggest a maximum average basin permeability of 10^{-5} centimeters per second for a uranium mill tailings facility. This guideline is difficult to assess as it does not directly address the question of permissible seepage losses from the tailings area and, for rock rimmed basins where seepage is controlled by discrete joints and fractures in an otherwise impervious rock mass, average permeability is very difficult to measure by conventional methods.

In an attempt to establish the average basin permeability, an initial program of aerial photographic interpretation and detailed field mapping was undertaken to establish both major (e.g. faults) and minor (e.g. joints) structures around the basin. The results of this work indicated that the tailings area was located outside the sedimentary basin, the north shore of Strike Lake being composed of diorite and the remainder of the area being underlain by granite. The rock was more-or-less uniformly jointed with an average joint spacing of about 6 to 12 inches. Although the majority of the joints were steeply dipping, there was no evidence of a strong preferential seepage direction related to jointing; rather the various joint sets appeared to be uniformly distributed in strike. Although many of the joints evidenced moderate surface apertures due to stress release and surficial weathering, the results of borehole packer testing suggested that the permeability decreased rapidly with increasing depth.

As indicated on Figure 17, two major faults transect the area. The first, a regional fault known as the Nook Lake Fault strikes northwest-southeast and passes between the Strike Lake basin and the South Tailings Area. The second strikes northeast-southwest, passes under the western end of the Strike Lake basin and appears to terminate on the Nook Lake Fault.

Figure 17 - Panel Tailings Area Faults

To examine the average permeability of the rock (excluding major discontinuities) more definitively, a nearby "perched" lake which had a clearly defined catchment area and no discernible outlet was investigated (see Figure 17 for location). Careful examination indicated that while the lithology and general structure of the rock in the area of this lake were similar to that of the tailings area there were no faults. On the assumption that the rate of seepage through the rock was equal to the net precipitation falling on the basin (to maintain the "perched" lake level without overland outflow) an axisymmetric finite element flow analyses was carried out using known surrounding lake and stream levels as boundary conditions. Successive iterations indicated that the average mass permeability of the rock required to maintain the "perched" lake under average rainfall conditions was about $5x10^{-6}$ centimeters per second.

Using this average permeability value, the maximum proposed operating level in the Strike Lake basin, known boundary conditions and "best estimates" of the geometry (width) and permeability characteristics of the known faults, a similar analyses was carried out for the tailings management area. The results of this analyses indicated that, for normal infiltration rates, seepage would generally be INTO the basin from the surrounding rock; the only seepage out of the basin would be to the southeast and northeast along the faults and the total seepage rate would be only about 10 to 15 gallons per minute. As these computed seepage rates were considered acceptable and as there is at present serious doubt as to whether radionuclides actually migrate through a low permeability fractured rock, it was decided to monitor the faults by means of deep sampling wells rather than to institute perhaps inappropriate seepage control measures at this time.

Current Deposition Scheme

Commencement of milling operations at Panel is now scheduled for August, 1979 and, consequently, no tailings have yet been discharged into the Strike Lake basin. As a result of on-going studies a deposition scheme has been developed which involves the creation of exposed tailings beaches from elevated discharge points and the construction of internal dykes to divert tailings away from the decant at Dam 'D'. With this scheme, the maximum operating pond level in the Strike Lake basin can be maintained as low as about elevation 1316 or some 20 feet below the previously proposed maximum level. Thus, future raising of Dams 'B' and 'D' should not be necessary for current planned production.

FUTURE TAILINGS MANAGEMENT SCHEMES

To this point, typical tailings management schemes adopted in the Elliot Lake area during the mid to late 1950's have been reviewed and two specific types of seepage control measures conceived and approved in the late 1960's and in recent years have been described. As previously indicated, however, preliminary studies are currently being carried out for major expansions of both Rio Algom Limited's Quirke tailings management area and Denison Mines Limited's Long Lake tailings management area as well as for Preston Mines Limited's Stanleigh rehabilitation program.

Various schemes are being considered for these future operations; ranging from conventional impervious earthfill dams incorporating synthetic membranes (i.e. similar to the Panel scheme discussed above) to pervious "sand" dams constructed of the tailings themselves. Because of the scope of these future projects and the general lack of suitable borrow material in the area, schemes which minimize the size of perimeter containment structures (either through the use of internal "stacking" or "coning" by thickened slurry discharge methods - Robinsky, 1978 (4), or which include the use in whole or in part of mine waste rock or tailings "sands" are gaining increased favour. Further, although final solutions have yet to be defined, alternatives for abandonment are receiving increased consideration in the initial design stages.

Current thinking favours maintenance of as low a pond water level as possible and the development of long tailings beaches developed from elevated discharge points. This not only minimizes the size of the perimeter containment structures but also results in a sloped tailings surface which can be drained and stabilized upon abandonment. Although some dusting problems may result during operations, experience at Denison's Long Lake tailings area, where there is an approximately one mile long beach, indicates that the surface remains sufficiently moist to minimize dusting. If the discharge point has to be moved, however, the exposed beach could, if necessary, be temporarily stabilized by chemical or mechanical surface treatment.

The universal use of impervious containment dams is also being seriously questioned. During operations, impervious dams are not necessary if the seepage can be readily controlled, collected and treated (e.g. if the dam is located upstream of the treatment facility). Following abandonment, impervious dams may provide a false sense of security and may in fact be dangerous; the consequences of the failure of a dam retaining saturated tailings may be far more serious than the consequences of the failure of a dam retaining "drained" tailings. The fundamental question, however, is whether impervious dams are necessary or even effective at abandonment.

If the tailings are in fact perfectly isolated from surface water infiltration by a cover, as yet undefined, seepage through the pervious dams will gradually reduce over a period of a few years as the tailings drain. Thus, one would be left with essentially dry tailings producing no effluent as opposed to the "bowl of jelly" which could result with perfectly impervious dams.

If, on the other hand, the surface of the tailings is not covered by an impervious material (e.g. if the surface is vegetated) and if IMPERVIOUS dams are provided, in an area of net infiltration the water level in the tailings will rise until it overtops the dams. Thus, effluent will be produced, possibly in an uncontrolled fashion, despite the presence of the IMPERVIOUS dams. Consequently, as effluent production is inevitable, it is better to provide pervious dams so that the water can be removed in a controlled fashion and the water level in the tailings maintained at as low a level as possible.

The status of some current thinking regarding tailings management and seepage control can perhaps be best illustrated by considering the hypothetical tailings basin illustrated on Figure 18. Assume that the site consists of a rock rimmed lake basin. Geological and hydrogeological studies indicate that, with the exception of the upper few feet, the rock is essentially impervious. Outlets from the lake flow east and west through relatively wide valleys and a stream enters the lake through a narrow valley from the southeast. The basin is separated from an environmentally sensitive river to the north by a low saddle. Treated effluent from the tailings is to be discharged through the valley to the west.

As illustrated on Figure 19, development of the basin as a tailings facility involves the construction of four dams across the topographic lows and the diversion of the inlet stream from the southeast. The basic principle of development involves discharging tailings along the north, east and south walls of the valley to form a long beach terminating in a tailings pond or pool at the west end of the site where it can be discharged to treatment. As the average slope of this beach will be about 0.5 to 1 per cent, on a major project the height of tailings at the east end of the basin (i.e. at Dam 'C') could be several tens of feet above the pond level (i.e. above the crest of Dam 'A').

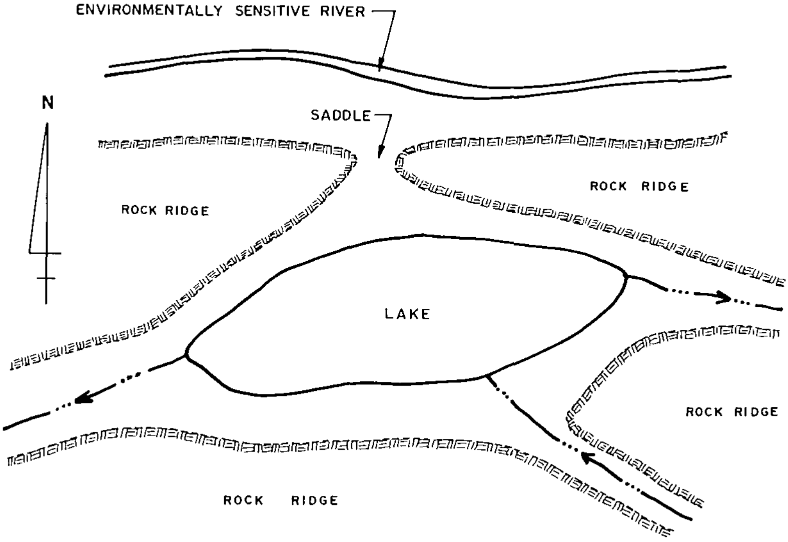

Figure 18 - Hypothetical Tailings Basin

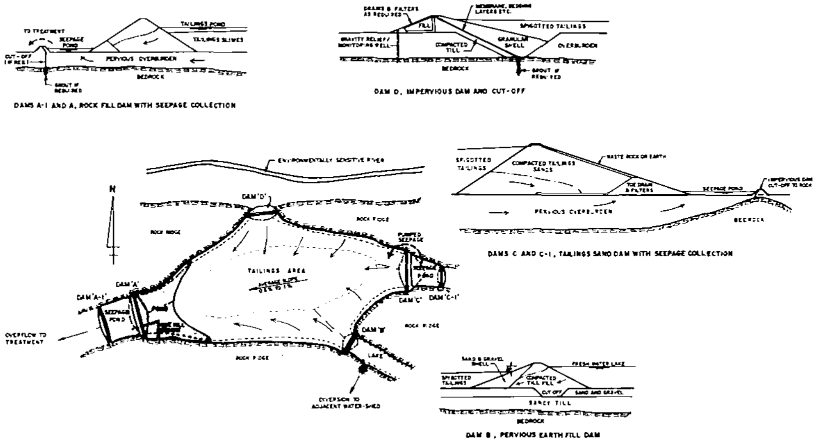

Figure 19 - Development of Hypothetical Basin

Each of the dams in this hypothetical basin serves a unique function and must be designed to meet specific criteria. Consequently, there are no engineering reasons, apart from government regulations, why they should have the same cross-section. The requirements and a possible design for each dam are discussed below.

Dam 'A'

This dam is located immediately upstream of the treatment facility and the tailings pond impinges directly against the face of the dam. In an emergency the dam could be subjected to overtopping. Thus, the dam must be stable both gravitationally and hydraulically but need not be impervious provided all of the seepage through and beneath the dam is collected and treated. Consequently, the dam may be constructed of mine waste rock provided appropriate drains and filters are incorporated into the design to control seepage and prevent migration of slimes. Seepage can be collected between the main dam and a downstream impervious but low head dam, Dam 'A-1'. To ensure that all seepage is collected, Dam 'A-1' may require a positive cut-off to rock; in this case a slurry trench diaphragm wall is illustrated. All seepage and decantec effluent collected between Dams 'A' and 'A-1' would be led to treatment.

Upon abandonment, a spillway could be constructed in Dam 'A' or it's abutment to drain the tailings pond and maintain a "dry" tailings surface.

Dam 'B'

Dam 'B' must fulfill two functions; firstly to divert fresh water into an adjacent watershed and secondly to retain tailings. If, by judicious design of the diversion, a positive head of fresh water can be maintained across the dam, the tendency will be for seepage to occur INTO rather than OUT OF the tailings area. Consequently, although seepage should be minimized, there is no need to provide an "impervious" dam. Thus, a conventional earthfill dam designed to minimize seepage as much as possible using locally available borrow material could be employed.

Dam 'C'

Dam 'C' is located at the far end of the basin from the tailings pond and will extend considerably above the pond level. Thus, overtopping of this dam is not possible.

Because of the long tailings beach, seepage at this dam will be minimal, particularly following abandonment, and, provided such seepage is collected and pumped back into the tailings area during operation, it can probably be tolerated. Construction of a tailings "sand" dam thus appears practical provided adequate filters and drains are incorporated into the design to control seepage gradients during operations. However, the use of a centreline or downstream method of construction is recommended rather than the more traditional upstream method.

Dam 'D'

At this site seepage must be completely prevented to avoid contamination of the environmentally sensitive river to the north. Consequently, an impervious dam and positive seepage barrier to rock must be provided. Although a dam incorporating a synthetic membrane and cut-off excavation to rock similar to the scheme adopted for Dam 'B; at the Panel tailings management area is illustrated on Figure 19, several alternative "impervious" dam sections are presently being studied for use at future tailings areas.

CONCLUSION

Control of seepage from the low activity tailings in the Elliot Lake area has ranged from minimal in the 1950's to, ideally, total control and long-term prevention in the 1970's. Neither extreme is necessarily correct; no control is unacceptable in the light of present technology - total long-term prevention is not practically possible in an area of high precipitation. The optimum practical solution lies somewhere between these extremes.

It must also be recognized that the control of seepage is very site specific. Not only do regional, geologic and climatic conditions affect the method of control but also the fundamental purpose and hence design of each dam within a given tailings area may be quite different.

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