PORT RADIUM

AN ENVIRONMENTAL SURVEY OF MINING WASTES

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SUMMARY

The survey of the Port Radium peninsula outlined several waste areas which had not been described previously. A very small area designated as West Adit 'area' and 'slope' is located below the silver waste rock pile. This area contains acidic tailings with high radionuclide concentrations, and is likely the only location on the peninsula where uranium mill tailings or remnants thereof can be found. Similar material may be contained in rock depressions in Murphy Creek. Further work is required to confirm these findings.

Silver tailings are neutral or slightly alkaline and low in radionuclides. Mine water effluents and tailings slurries which flowed through creek systems, such as Bear Creek and Murphy Creek have not damaged the vegetation cover in these creeks significantly. Mosses and horsetails were the only plants which were associated with waste material. On waste rock plants establish extremely slow, if at all. Therefore, potential uptake of radionuclides and metals from the rock to vegetation is very slight. Waste rock covers of tailings areas constitute a good close-out measure given the harsh environmental conditions of the Port Radium peninsula.

The water around the peninsula did not reveal any obvious characteristics which indicated lasting changes as a result of tailings and mine water discharge into Cobalt Channel and Labine Bay. Elevated metal and radionuclide concentrations in water and sediments were extremely localized. Those appear to be associated with waste rock and the ore body veins. Further work is required to confirm these associations.

The water in Garbage Lake is neutral and the electrical conductivity has decreased since the tailings discharged ceased. Monitoring data and studies of the area from the past were evaluated briefly in the context of the findings for this survey. In general, the results are in good agreement, tailings and natural sediments can be identified. **Only tentative conclusions can be made based on this brief survey.** The results provide, however, a focus to address the environmental concerns which are associated with the wastes of Port Radium. Some aspects of importance with respect to the long-term environmental development which might occur in the future remain to be addressed. Those are potential water quality changes in Garbage Lake, the waste site conditions during run-off and potential changes in biological productivity in Bear Bay associated with the seepage from Garbage Lake.

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INTRODUCTION

The extraction of silver and copper in Port Radium by Echo Bay Mines Ltd. ceased in May 1982. The small peninsula of Port Radium on the shores of Great Bear Lake has a long and varied history of different mining activities, and consequently, the mine wastes on the peninsula and in the surrounding waters are of the same character. Any mine site which is closing raises concerns with respect to potential long-term environmental implications as mining wastes remain thereafter unattended. Naturally, the frequency of monitoring the material left decreases, and remedial actions which might have to be taken are logistically extremely difficult and costly, should they need to be implemented on a dormant site.

Prior to August 1978 (p.c. B. Wilson), before the Northern Inland Waters Act was brought in effect at Port Radium, mining wastes were discarded in essentially what amounted to convenient locations. Tailings, mill process liquors and mine shaft water from the radium, uranium, silver and copper mining, generally ended up in Cobalt Channel or formed storage areas, such as Silver Point Tailings and Radium Lake (Map 1 and Tables 1a & b). Waste rock was used to build spits and to cover roads or old tailings areas to convert them to usable space.

Since the time that regulation went into effect, Echo Bay Mines Ltd. has made every effort to contain the silver tailings in a managed basin. McDonough Lake was studied in addition to several other options for tailings disposal. It was found to be the most suitable location. The lake had been used for some years as a garbage disposal site. It was a closed, confined basin and large enough to take tailings and wastes for an estimated 25 years of operation. It is commonly referred to as Garbage Lake, and deposition of scrap metal (Plate 1) by Eldorado Mining and Refining (Chambers, 1973) in the lake is said the have resulted in zinc contamination of the water (J.R. McLaren, 1975). Garbage Lake became the official tailings pond and has received barium chloride and ferric sulfate treated silver tailings since 1978. This treatment reduces the dissolved arsenic and radium-226 in the waste waters.

The above brief history of deposition of wastes and waste water discharges in Port Radium covers only some of the major events. The environmental assessment of the effects of these wastes and their potential long-term impact is, therefore, an extremely multi-faceted task. Super-imposed on the complex waste disposal history are those questions pertaining to the fate of long-lived radionuclides. Given that radium and uranium were mined prior to silver and copper, considerable concern is directed toward any potential radiological impacts of the wastes

Plate 1: **The scrap metal beach in former McDonough Lake suggests the common name of the tailings pond as Garbage Lake.**

on water and land in the long-term.

The abandonment of the mine site on Port Radium naturally includes reclamation plans prosposed by Echo Bay Mines Ltd. These are to cover all visible tailings areas, scrap yards and garbage dumps with waste rock (Swenson, 1979). These measures appear to be reasonable. However, they may mask potential problems that may appear in the future. A documentation of the environmental conditions of the mine site at the time of abandonment, is necessary to anticipate potential problems in the future. Consequently the Environmental Protection Service (Yellowknife, NWT) with the Departments of Indian Affairs and Northern Development and the Territorial Government initiated an environmental survey of the sites.

The survey of the Port Radium mine site in July 1982 addressed three main aspects. They can be summarized as follows:

a) The identification and characterization of waste materials on the peninsula in connection with the history of the site.

b) The collection of data that will give some indication of the interaction of the wastes with the environment.

c) The anticipation of potential changes that may occur in the future based on past and present information.

A field report entitled: 'In search of uranium mill tailings' (Kalin, 1982) summarized the basic physical characteristics of the wastes and identified the waste locations on the Port Radium peninsula. This report draws together the site description, the characterization of the wastes and some analytical results to provide a focus for the long-term potential environmental developments on the site.

2. MATERIALS AND METHODS

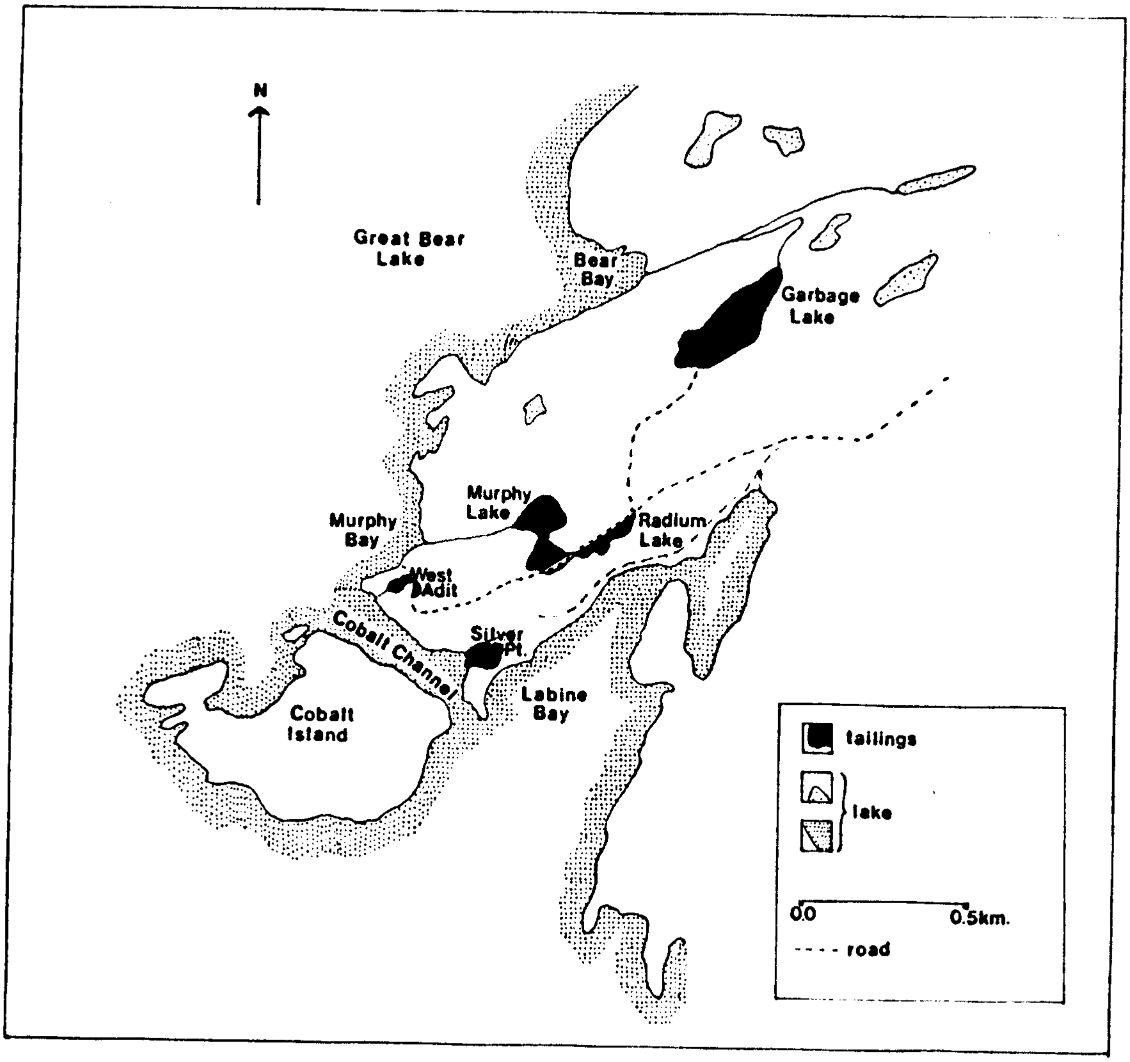
2.1 Site Description.

Port Radium is small peninsula at the eastern shores of Great Bear Lake about midway along the McTavish Arm. The shores are extremely steep in this area, dropping rapidly by 30 m or more from the land. Bathymetric maps of Great Bear indicate contour lines close to Port Radium of 300-424 m in depth (Johnson, 1975). The shores are generally rocky along Cobalt Channel and across on Cobalt Island (Map 1). Murphy Bay has a beach which consists mainly of large pebbles. Rocks show signs of waves, at least 20-30 m up a steep slope, leading towards Murphy Lake. The beach of Bear Bay is similar to Murphy Bay, except less steeply rising toward Bear Creek. The outer part of Labine Bay is bordered by waste rock embankments on the north side. The southern shore of Labine Bay is rocky. The harbour is located in the inner part of the bay. It has shallow vegetated shores on the southern tip and the northern tip was used as a general utility area for pleasure boats and activities related to Shaft No. 2.

This brief description of the shorelines around the peninsula suggests that wastes discharged from the mining operations will unlikely remain close to the points of discharge, as there is no protection from the open waters of the lake. They will be distributed over the sediments in the area surrounding the peninsula.

Four areas with waste material are located on the peninsula. The Silver Point Tailings (Plate 2) were established prior to 1974 and this area was used as storage space since. These tailings have a beach of about 100 m in width on Cobalt Channel, consisting of compacted tailings with a set-back embankment of waste rock. It appears from the history (McClaren, 1973) and from personal discussions with J. Zigarlick, Sr. that the Silver Point tailings have accumulated since the start-up of the silver operation. Eldorado Mining and Refining Ltd. was dredging radium waste rock from a considerably more inland point than indicated by the location of the existing tailings beach. This can be derived from photographs of the dredging operation (Hoffman, 1957).

During the extraction of uranium some tailings were discharged into Radium Lake and Murphy Lake (Map 1). Radium Lake has since been covered by waste rock. The area is utilized for many practical purposes. Murphy Lake can be reached through a narrow, man-made passage from Radium Lake and is presently being covered with waste rock (Plate 3). Uranium tailings were discharged into the small lake for a short period of time during the 40s and later silver tailings were deposited accidently. Murphy Creek leads from Murphy Lake westward down to Great Bear Lake (Plate 4). Occasional tailings slurries overflow from Murphy Lake occurred, leaving small depressions filled with tailings. Tailings depressions which retained some moisture are covered with horsetail.



Map 1: **Overview of the Port Radium peninsula.** Tailings areas investigated are indicated in black.

Plate 2: **Silver Point Tailings:** This area has been used as a storage space. The tailings form a beach on Cobalt Channel. The spit consists of bedrock.

The third area of interest appears to contain an assemblage of wastes, in a small depression below the silver waste rock pile, close to the West Adit (Plate 5). The steep slope immediately below the waste rock pile has remnants of fine tailings. Clearly, this area is not a 'classical' tailings site, but rather a collection point of run-off wastes. This area drains directly into Great Bear Lake, should water collect during the snow melt.

The fourth area which contains waste is Garbage Lake and its creek. The lake water level has experienced drastic changes since the lake received tailings and mine water from Shaft No. 2. The tailings beach (Plate 6) is small, located at the southern tip of the lake. The original

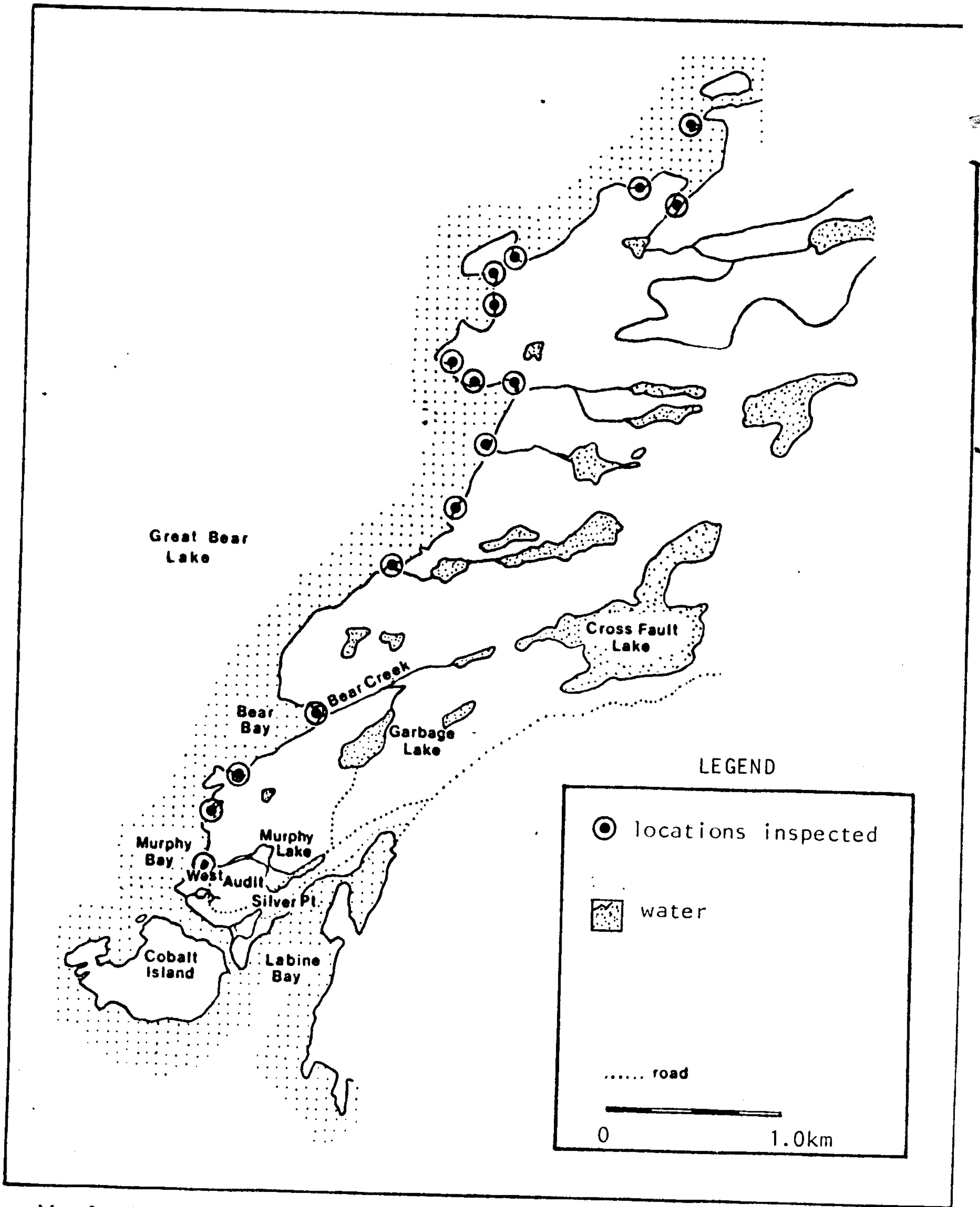
Plate 5: **West Adit:** Small depressions on the steep slope are filled with tailings (arrow) on the West Adit slope. The area in the foreground has received many different waste materials.

lake level was considerably lower than that of 1982, as can be seen from the nature of the shoreline and the submerged tree or shrub crowns in the lake (Plate 6 - arrow). In the past, water or tailings slurry containing suspended fines left Garbage Lake through Garbage Creek. In the now dry creek bed patches of horsetail provide contrast to the white stained creek bed (Plate 7).

No overland flow leaving Garbage Lake is noticeable, but at the junction with Bear Creek a seepage is apparent (Plate 8).

Plate 8: **Garbage Creek Seepage:** An indication of below ground seepage can be observed at the junction of Garbage Creek and Bear Creek.

The white, fine tailings cover rocks and carpets of horsetails grow in sufficiently moist areas. An overview of Bear Creek, however, reveals a lush green creek bed (Plate 9) with only sporatic indications of a stained creek. In depressions of the creek, definite traces of tailings slurries have remained (Plate 10). From the discharge on the beach of Bear Bay, a thick mat of algae (Ulotricales) has developed which extends along the entire beach (Plate 11). Shores toward the north along the peninsula were surveyed to determine if other creek inlets resulted in similar algal blooms (Map 2). All shores are gravelly, similar to Bear Bay, but had no algal blooms similar to the ones observed on Bear Bay (Plate 12). The arrow indicate dense mats of



Map 2: **Shoreline survey locations inspected on the east shore of the McTavish Arm of Great Bear Lake.**

attached periphyton. All locations which have been investigated or are referred to in this survey are briefly described in Tables 1a and b. Brief site descriptions are given along with the sample codes of water, tailings and the type of vegtation collected in these locations.

Table 1a: Names, descriptions and location codes of water, tailings and vegetation sample sites.

NAME	DESCRIPTION	WATER SAMPLE CODE	TAILINGS SAMPLE CODE	VEGETATION SAMPLE
Garbage Lake	Silver tailings lake, 1 small tailings beach, 1 active garbage disposal beach (regular burning), 1 old scrap metal and mining equipment garbage beach.	1W	1T	no vegetation
Cobalt Channel	Silver Point tailings beach, former sewage discharge, tailings on bottom of channel.	2W	2S	algae collected
Bear Bay	Discharge point of Garbage Creek and Bear Creek.	3W	3S	algae collected
West Bear Bay	Small bay south of Bear Bay with calm water.	3W	no tailings	algae collected
Bear Bight	Small bite on north shore of Bear Bay.	no water	no tailings	algae collected
Bear Creek	Relatively fast flowing creek, joins a presently dry Garbage Creek. Overland flow disappears completely some 500 m down creek from the junction of both creeks.	4W	4T	collected
Labine Bay	Marina, float-plane landing site, wasterock and overburden beaches: received mine water from Shaft No. 2.	5W	5S	not sampled
Murphy Bay	Steeply sloped bay, lake sediments and tailings well mixed in Bay.	6W	6S	rocky shore
Silver Point Tailings	Tailings area and beach built from silver tailings, used as a storage area for various materials.	no water	8T	no vegetation
Outside Lab	Overburden on top of wasterock outside the laboratory.	no water	no tailings	collected

Legend: Sampling locations within the described areas are given for waters in Map 3 and for tailings, soil or sediment in Map 4. The area is designated by a number, the sample types are W for water, T for tailings and S for sediments or soil. The vegetation sampling sites are given in Map 6.

Table 1b: Names, descriptions and location codes of water, tailings and vegetation sample sites cont'd.

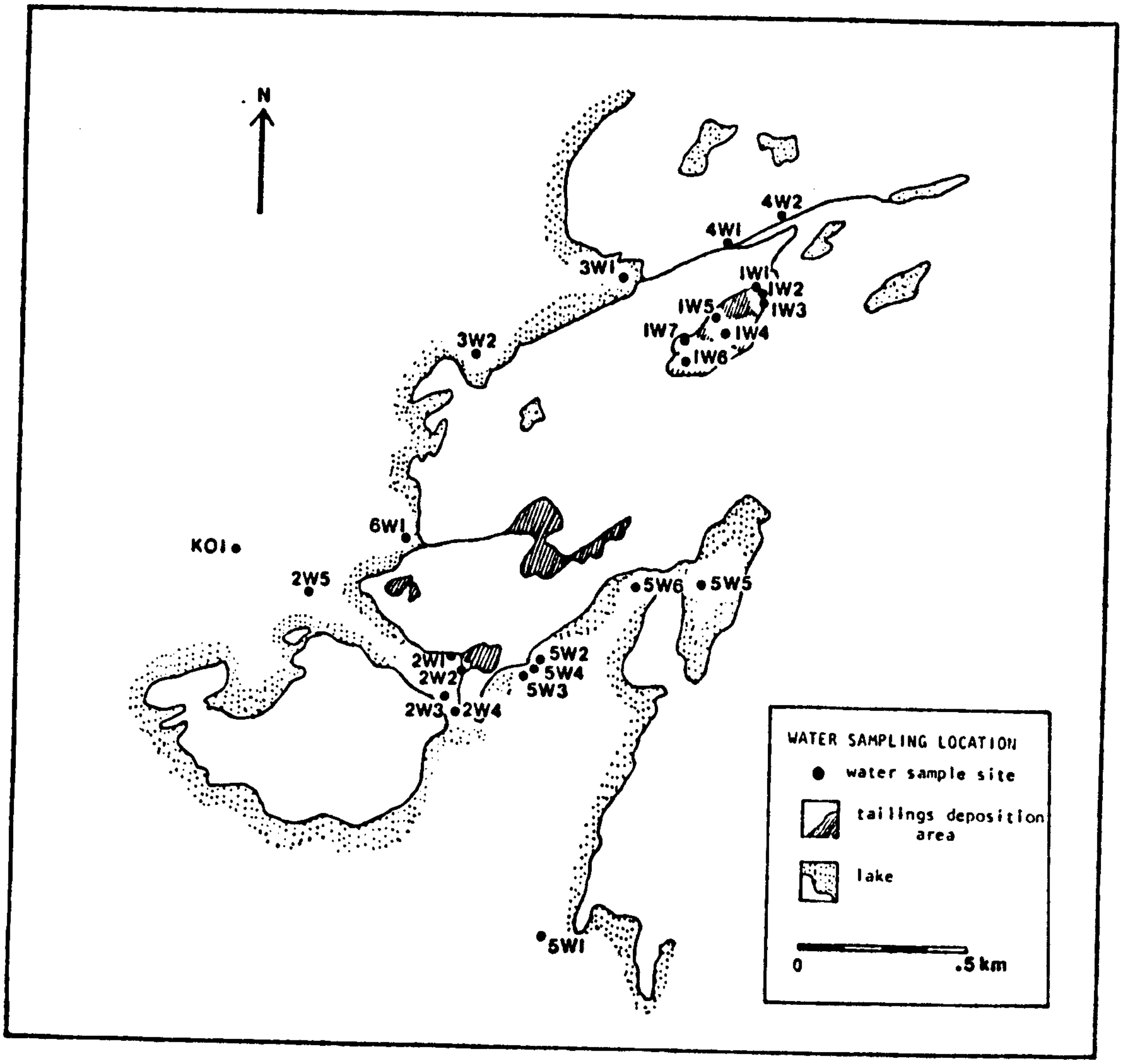
NAME	DESCRIPTION	WATER SAMPLE CODE	TAILINGS SAMPLE CODE	VEGETATION SAMPLE
West Adit	Rocky slope with mill tailings and small area with process wastes.	no water	9T	collected
Murphy Lake	Tailings area nearly all covered with a mixture of waste rock and overburden.	no water	10T	no vegetation
Murphy Creek	Weathered tailings in small puddles and depressions along a steep sloping creek.	no water	11T	collected
Radium Lake	Uranium mill tailings area, covered solid with waste rock and overburden used as ore storage from Contact Lake (waste rock), parts of former Radium Lake are now a road and some buildings are on the covered tailings.	no water	12T	no vegetation
Garbage Creek	Former creek leaving Garbage Lake and joining Bear Creek.	no water	13T	no vegetation sampled
Great Bear Lake (control)	Open water in McTavish Arm.	K01	no tailings	–
Shaft No. 2	Silver mine working and origin of mine water discharged into Garbage Lake	–	–	–
Control Bay	Gravel beach north of Port Radium Peninsula.	no water	no tailings	collected
Cross Fault Lake	Old mine working with waste rock beach on Cross Fault Lake. Vegetation surrounds the waste rock.	no water	no tailings	collected

Legend: The letter K designates samples not associated with mine wastes, i.e., control samples.

2.2 Field Sampling Methods.

2.2.1 Water and Sediments.

Sampling stations were determined after the bottom material was investigated from the contents of Eckman grabs. After the identification of tailings or natural sediments, dissolved oxygen, temperature and conductivity were determined in the water column. A water sample from the bottom was secured with a VanDorn sampler and a corresponding surface water sample within the top meter was collected. Sediments were collected with the Eckman grab. The grab was inserted carefully into a plastic pail, where pH, oxygen and conductivity were measured immediately. Unfortunately, the oxygen meter, the long conductivity meter probe and the VanDorn sampler became defunct during the survey, resulting in a more restricted sampling procedure in some locations. All water sampling locations are given in Map 3. The water was filtered within 6 h of collection through 0.45 μm filter and acidified to pH 1 or less with concentrated nitric acid. The acidification was checked after 48 h, as this water was suspected to have a high buffering capacity. Several samples received further acidification. The sediments were stored in plastic bags which were kept as free as possible of ambient air, and kept in the coolers which were stored in the freezer house before shipment to University of Toronto. Upon arrival, pH and conductivity was redetermined and the samples were frozen until further preparation proceeded.



Map 3: **Locations and sample codes of water sampling sites in the Port Radium vicinity.**

2.2.2 Tailings and soils.

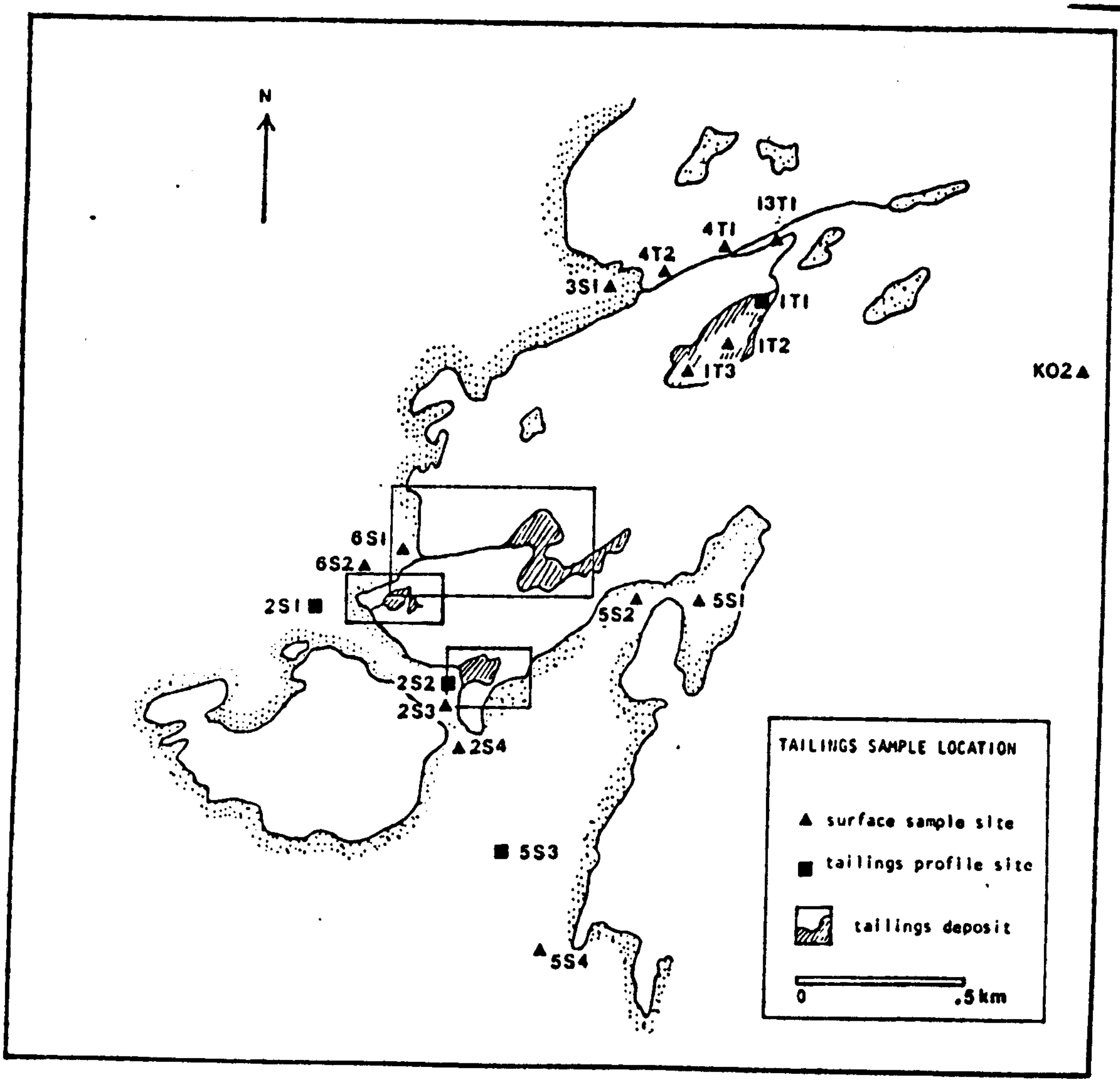
Grab samples of tailings or soil material were collected during the reconaissance of the waste locations and slurried (1:1 v/v) to determine pH and conductivity on the site. The instruments were calibrated with buffers and standard solutions after every measurement period. These preliminary field measurements were used to determine further sampling for some locations. Comparability of field measurements with subsequent laboratory measurements were discussed in the field report (Kalin, 1982). The pH and conductivity values were found to be in good agreement. Thus, differences which might have resulted from differing instruments, slurry ratios and waters, used to prepare the slurries are considered negligible. The pH and conductivities or the solid material reported are those determined in the laboratory based on a 1:1 (w/v) slurry prepared with distilled water. For the water samples pH and conductivity values reported were determined directly in the field.

The solids were collected with a hand trowel and transported in plastic bags. Sampling locations of tailings, soil or sediments are depicted in Map 4 for the entire area investigated. The sampling differentiated between grab samples (triangles) and sampling of profiles (squares) are indicated on Map 4. In a profile, if distinct strata were present, those were collected separately. The detailed stratification of the profiles and the description of the types of strata encountered, are presented in the field report (Kalin, 1982). Detailed locations are given for Murphy Lake, West Adit and Silver Point in Map 5.

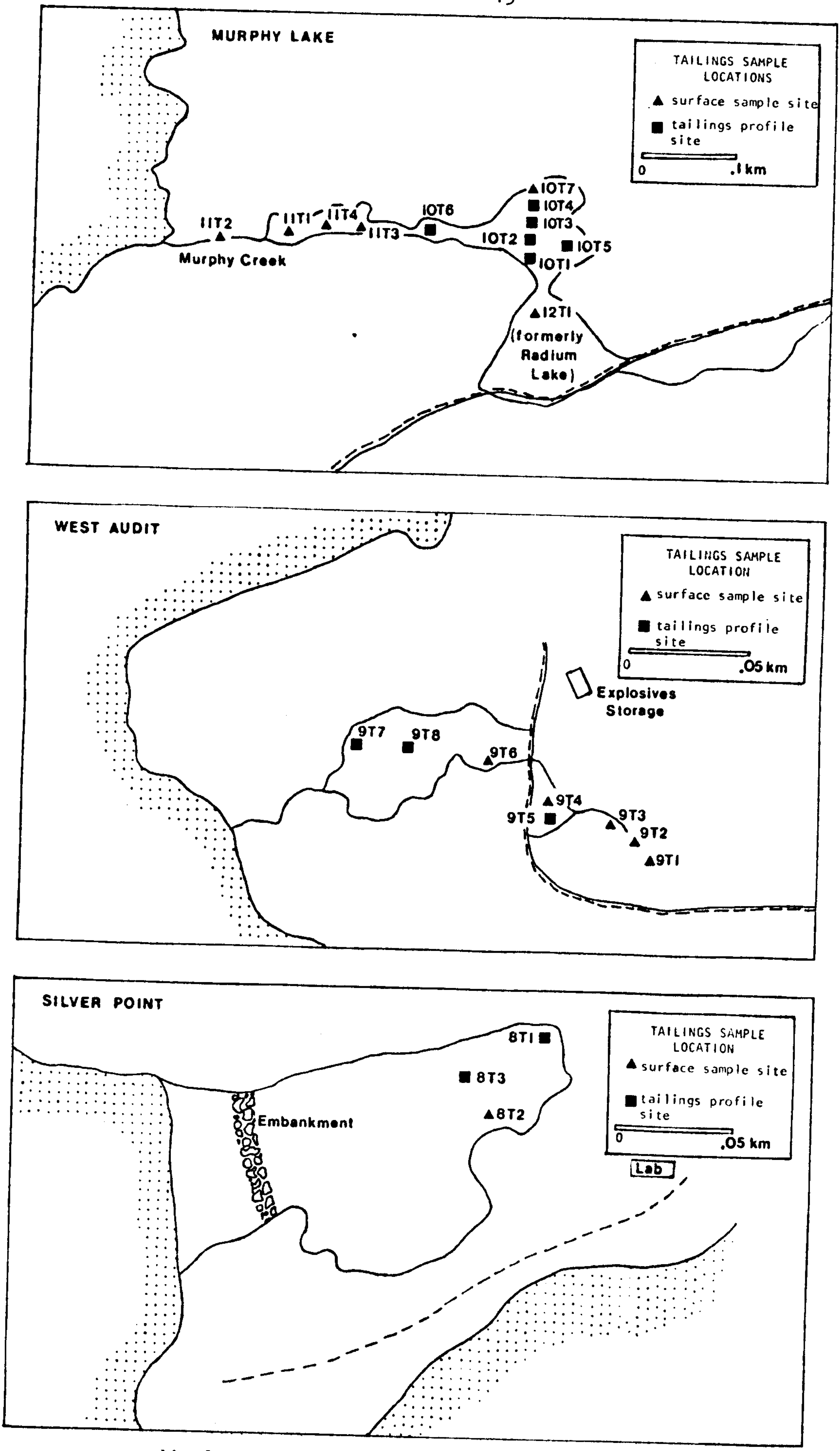
2.2.3 Vegetation.

An overview of all water sampling locations, water sample types and plant collection sites are given in Map 6. Terrestrial plants were collected in those locations where the plants could be associated with mining wastes or overburden which had been moved from its original location. In Table 1a and 1b, the type of plants collected are further differentiated. On beaches, attached algae were of interest, whereas on land, bryophytes and vascular plants were.

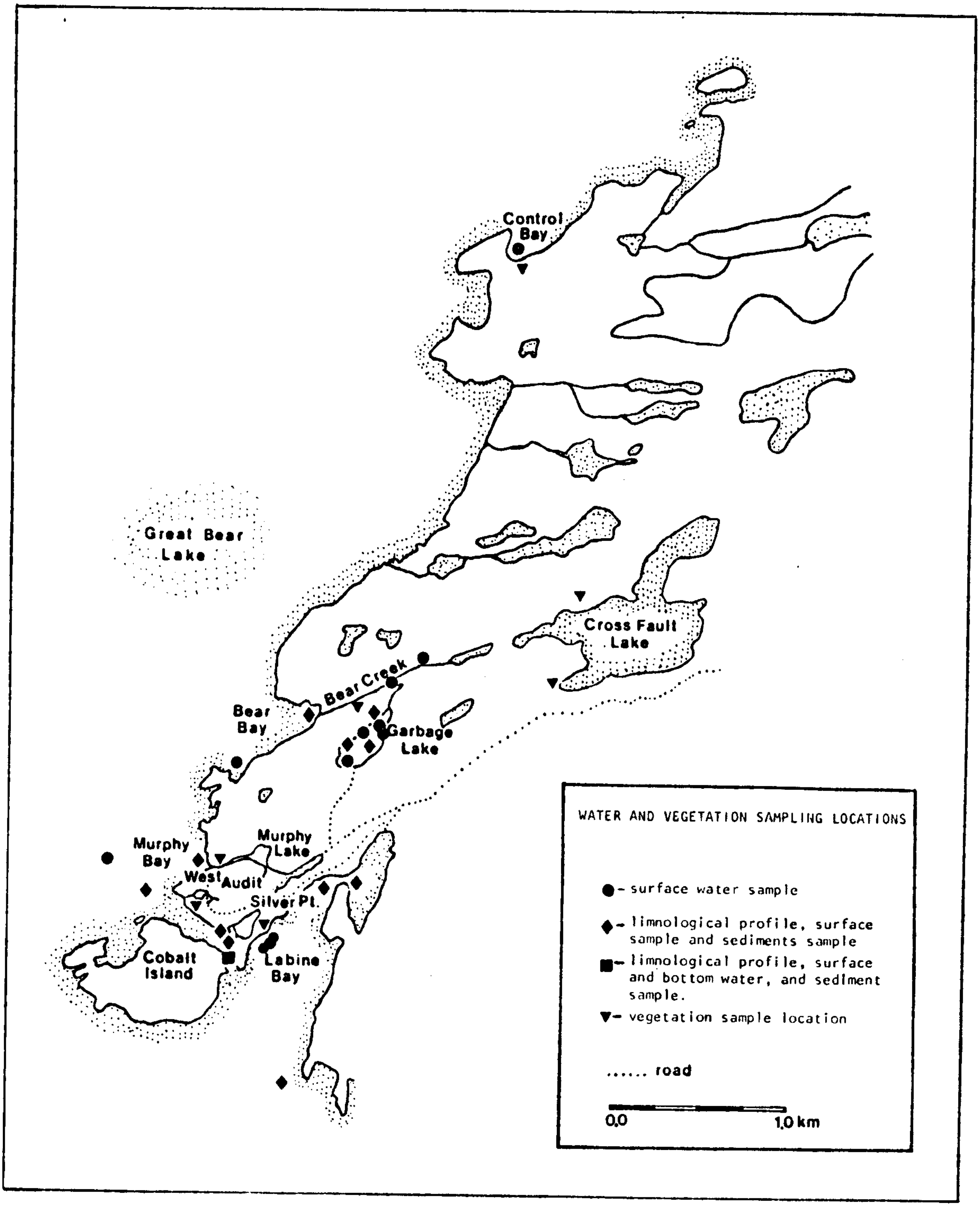
Vascular plants were preserved in a plant press and air dried. Bryophytes were collected in paper bags when dry and in plastic bags when associated with wet substrate. Algae were collected in Rigal vials and preserved with Lugol's solution and wrapped in aluminum foil. The algal collection were identified by J.H. Hellebust (Department of Botany, University of Toronto). The vascular plants were identified by C. Manville and are deposited at the Herbarium (Department of Botany, University of Toronto) with P.W. Ball. Bryophyte specimens were identified also by C. Manville and are at the National Museum in Ottawa with Dr. R. Ireland.



Map 4: **Tailings (T), soil and sediment (S) sample collection sites and codes in the Port Radium vicinity.** Sampling consisted either of surface samples or sampling of different strata of profiles in pits. The three enclosed tailings areas are magnified in Map 5.



Map 5: **Details of tailings collection sites and sample codes.**



Map 6: **Locations of water and vegetation sampling sites in the Port Radium vicinity.** Three levels of water sampling intensity are differentiated.

2.3 Laboratory Analysis.

2.3.1 Water analyses:

The filtered and acidified waters were analyzed unconcentrated by ICP (Inductively Coupled Argon Spectrophotometry). Detection limits are given in Table 6 for each element. In addition, arsenic values of selected samples were determined by Flow Injection Hydride Generation which has a detection limit of 0.0005 mg/l as compared to regular ICP analysis with a detection limit of 0.002 mg/l.

2.3.2 Tailings, soils, and sediments:

Subsamples of larger collections of sediments were taken from the thawed-out bags after thorough mixing of the bag. The material was oven dried at 45 *degree* C briefly to remove the water and then homogenized with a hand mortar. The ground samples were brought to a constant weight at 75 *degree* C. Dry material was homogenized directly and brought to a constant weight. For Neutron Activation Analyses, 0.5 g of material was filled into PCV capsules to be irradiated at the SLOWPOKE facility at the University of Toronto. The irradiation scheme used was 2 kW for 1 min with a delay of approximately 18 min before counting. The samples were counted for 5 min in positions 1, 4, 8 or 13. Correction factors were used to adjust for the differing counting positions.

The samples contained significant amounts of manganese which increased the detection limits considerably, as compared to other tailings irradiated under similar conditions. Further details of neutron activation analysis of tailings are given in Kalin (1981).

Radiometric determinations were carried out on approximately one gram of solids after diethylenetriaminepentacetic acid (DTPA) extraction. Details of the methods for Ra-26 and Pb-210 are given in Kalin (1981).

After the dry material was weighed out for the neutron activation analyses and the radiometric analyses, the remaining dry material of approximately 3 to 4 g was ignited at 450 *degree* C in a muffle oven for 4 h. After the samples had cooled to room temperature in a dessicator, they were reweighed and the weight loss is reported as percent loss on ignition (L.O.I.).

3 RESULTS AND DISCUSSION.

3.1 The Water Characteristics.

Tailings have been discharged into Great Bear Lake during the various mining activities. Essentially, two questions need to be addressed. Have these discharges altered the water quality around the peninsula and to what degree has this been associated with the discharges. As the lake around the peninsula is deep, and the water column is entirely mixed (Johnson, 1975 and Kalin, 1982), dilution is likely to be extremely effective in preventing persistent water contamination. Johnson (1975) who studied Great Bear Lake over several years states; "*due to the thorough mixing achieved during the 124 years residence time, the very low degree of biological activity and the absence of a strongly developed stratification, the chemistry of the basin is remarkably uniform. This uninformity is maintained irrespective of location or depth*".

The analytical results of this survey and data obtained before and after discharge of tailings into Labine Bay, Cobalt Channel, and later into Garbage Lake, can be employed to determine changes in water quality with reference to results obtained by Johnson (1975).

Calcium and magnesium concentrations are given by Johnson (1975) as 16 mg/l and 6.9 mg/l respectively. Ranges of calcium concentrations are plotted in Figure 1. Around the peninsula, all surface waters were within the range of 12-24 mg/l, in very close accord with the lake average concentration. All water samples collected, including Garbage Lake, had averages for calcium of 23.07± 8.12 mg/l. For magnesium, the values listed in Figure 2 also suggest similar concentrations to those obtained by Johnson of approximately 7 mg/l. The average magnesium concentrations ranged from 10.15± 3.4 mg/l.

Barium concentrations in the water were determined as this element is often associated with radium (Figure 3). Sebesta, et al. (1981) state that the main factors influencing concentrations and forms of radium in surface waters adjacent to uranium mine wastes are dilution with surface water and sedimentation of the particulate forms in the water body. The predominant particulate form of radium in these surface waters is postulated to be Ba (Ra) SO_4. Thus, if the distribution of barium concentrations are determined, radium is expected to be distributed similarly. In Figure 3, the distribution of barium concentrations is depicted. Around the peninsula, barium occurs in concentrations similar to average concentrations reported for freshwater of about 0.05 mg/l (Bowen, 1966).

For all three elements discussed above, the concentrations in Garbage Lake are higher than in the water surrounding the peninsula (Figures 1, 2 and 3). Calcium was higher by about 12 mg/l, magnesium by 5 mg/l and barium by 0.5 mg/l in Garbage Lake. Barium chloride was added during the treatment of the tailings slurry to reduce dissolved radium, and $FeSO_4$ to reduce dissolved arsenic in Garbage Lake. Mine water dewatering, tailings and process liquors,

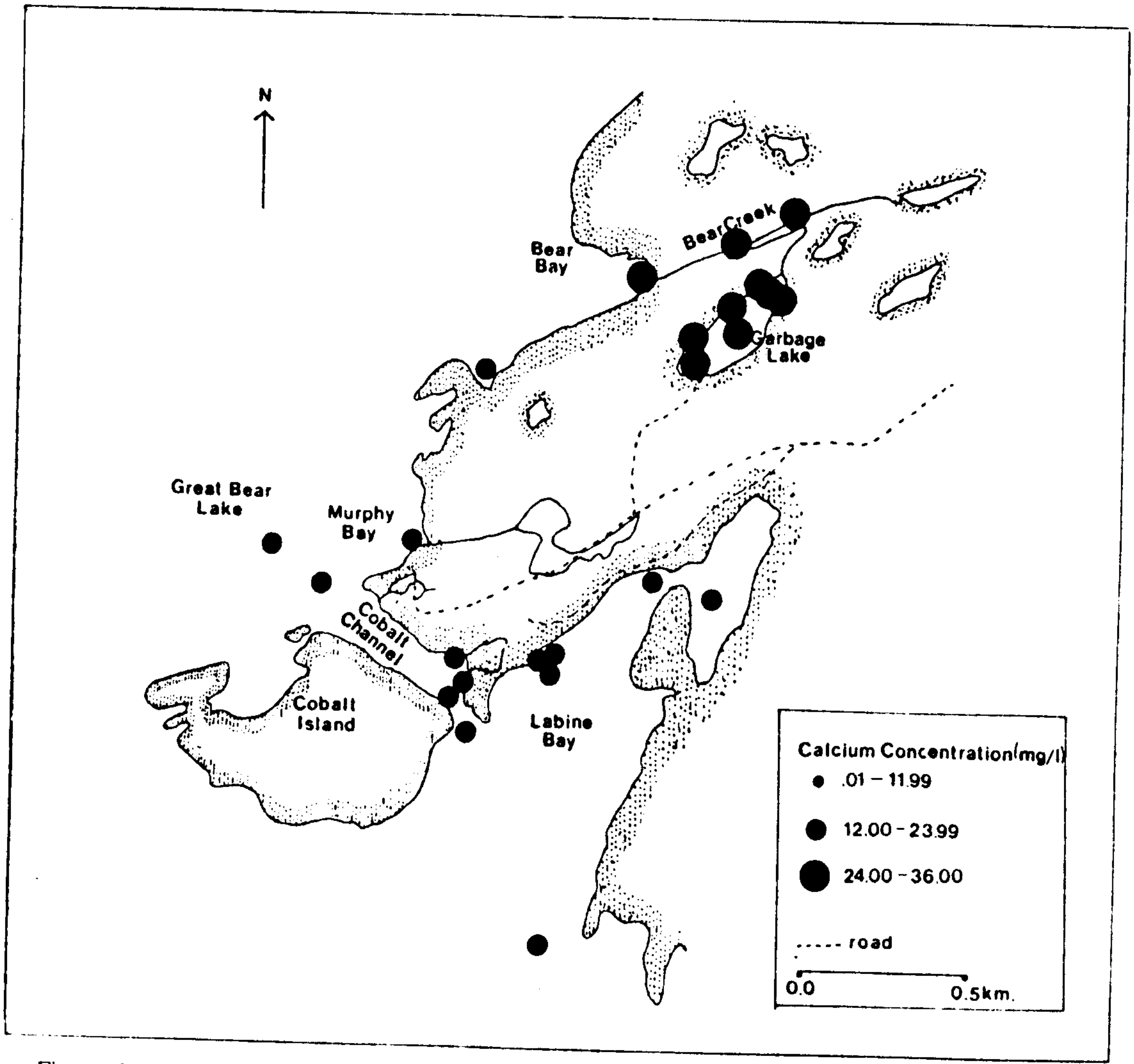


Figure 1: **Concentrations of calcium in water samples in the Port Radium vicinity.** Calcium concentrations ranged from 15.76 to 35.47 mg/l. Great Bear Lake has an average calcium concentration of 16 mg/l (Johnson, 1975).

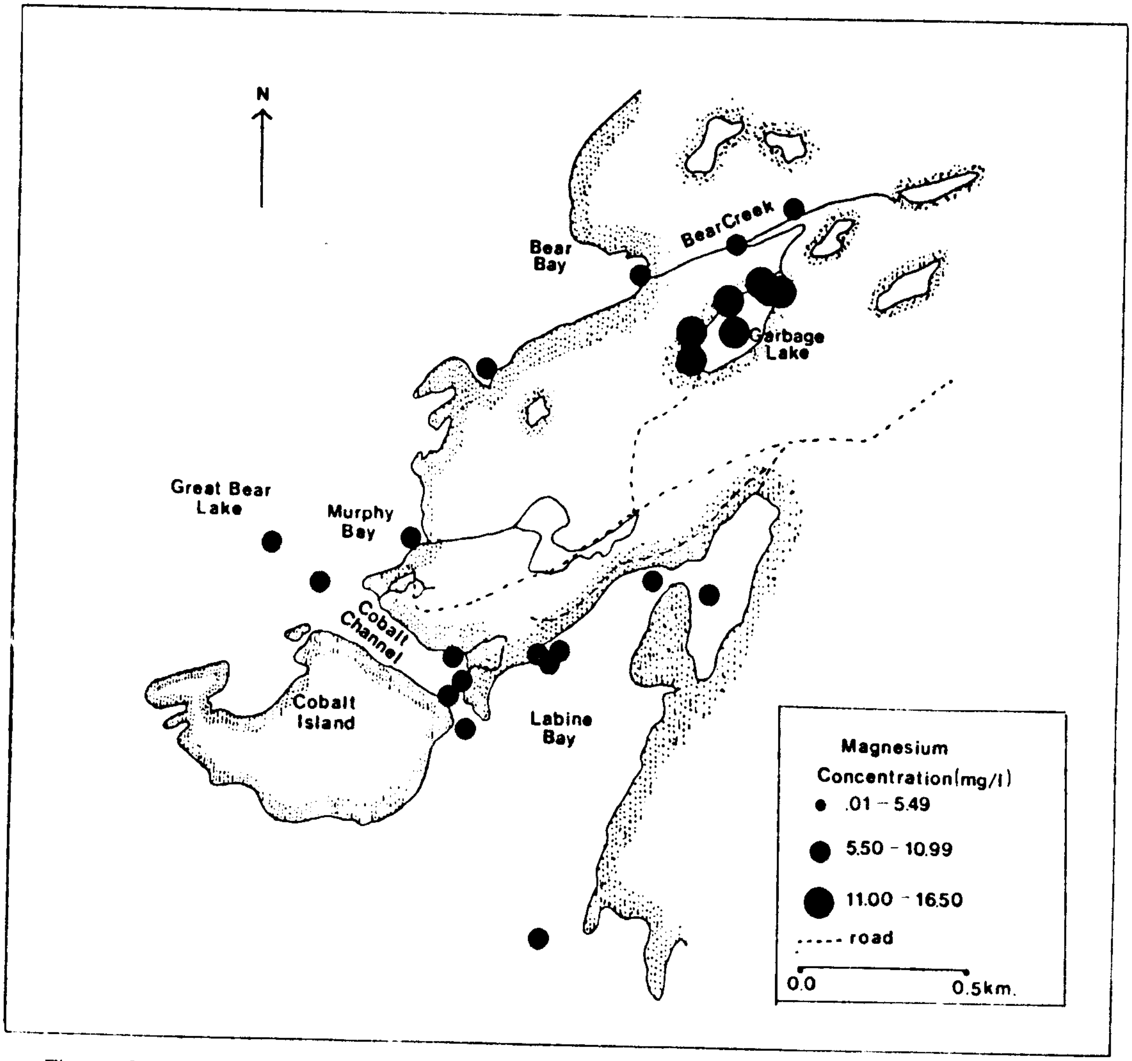


Figure 2: **Concentrations of magnesium in water samples in the Port Radium vicinity.** Magnesium concentrations ranged from 7.21 to 15.31 mg/l. Great Bear Lake has an average concentration of 6.7 mg/l (Johnson, 1975).

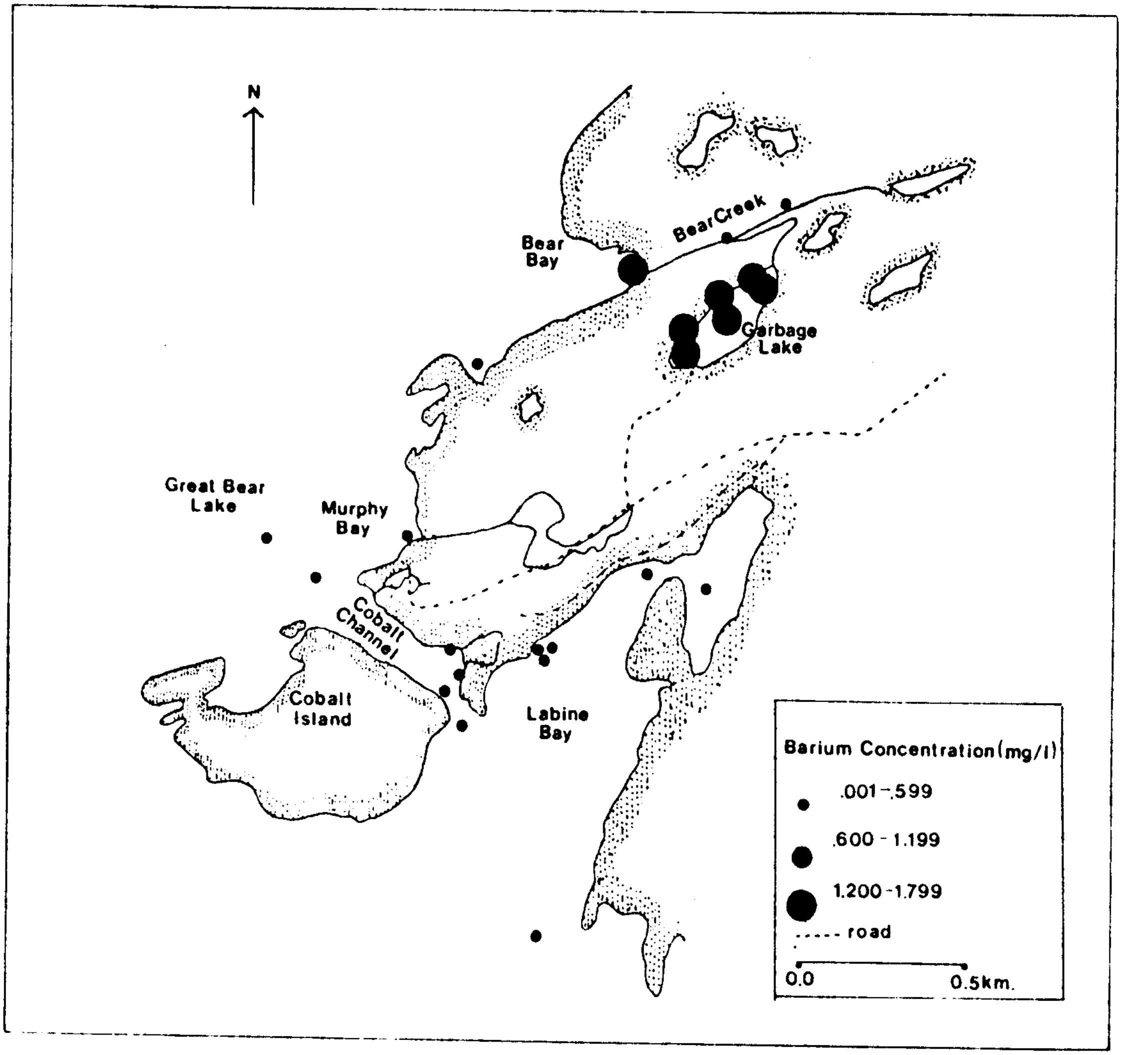


Figure 3: **Concentrations of barium in water samples in the Port Radium vicinity.** The concentrations ranged from 0.030 to 1.67 mg/l. Freshwater concentrations for barium are given by Bowen (1966) as 0.054 mg/l.

which were discarded untreated before environmental regulations come into effect into Labine Bay or Cobalt Channel. The relatively uniform concentrations of group two elements in the water around the peninsula, their clear separation from the concentrations ranges in Garbage Lake, and their closeness to the average concentrations for Great Bear Lake, strongly suggest that the water around the peninsula does not contain increased magnesium, calcium and barium concentrations, as a result of having received wastes in the past.

In Table 2, water quality data for the freshwater intake for the mine and mill are summarized from 1969 through to 1974 in addition to data for comparable sample locations 5W 2, 3, & 4 of this survey. The calcium concentrations available for these years are remarkably constant, given different sampling techniques, analytical methods and sampling times during the year and throughout the years. In 1974, an increase in pH of one unit was reported, along with an increase in copper, iron and zinc. It is suggested that the value obtained for pH at the freshwater intake is a result of a pH reading obtained without adjustment to the lower temperature. Furthermore, keeping the pump station ice free would likely increase the concentrations of metals from the pipes for air supply. The water for January and June in 1971, a similar sampling time as 1974, also have a pH of 7.9 and higher concentrations of zinc, lead and copper. These data may reflect winter conditions around the pump house sampling station. Generally, break-up occurs early to late June (Johnson, 1975).

The distributions of arsenic and thorium are given in Figures 4 and 5, respectively. The arsenic concentrations are elevated in Garbage Lake, in one sample on the Silver Point Tailings beach, and in one sample collected outside the laboratory in Labine Bay. In Table 2, the reported concentrations for the years 1969 to 1974 were generally in a range of 0.02 to 0.004 mg/l, which represents the lower range of concentrations in Figure 4.

Analytical problems are often encountered. Arsenic concentrations in selected samples were redetermined by Flow Injection Hydride Generation. In Garbage Lake the average of four reanalyzed samples was 0.033$\pm$ 0.055 mg/l. This is in the same range as reported in Figure 4. The high concentration on the Labine Bay shores was also confirmed with a concentration of 0.206 mg/l. Similarly, the concentration for the Silver Point tailings beach was 0.055 mg/l of arsenic. The distribution of concentrations of arsenic in the water suggests that arsenic is elevated locally.

The contamination does not appear to be widespread. The highest arsenic concentrations in unfiltered water was associated with waste rock in Labine Bay. Two of the other waters samples collected on the same waste rock beach were filtered through 0.45 μm and were considerably lower in arsenic, and in the same concentration range as water in Garbage Lake. The second location of high arsenic-containing water was collected on Silver Point tailings beach, close to a steeply rising rock face, above which waste rock piles are located. This suggests that

Table 2: Water quality in outer Labine Bay station 38-4 (1969 - 1982).

ELEMENT & QUALITY	REDSHAW[1] JUNE 1969	JUNE - AUGUST 1970	JANUARY & JUNE 1971	JULY 1972	MAY - NOVEMBER [3] 1973	JANUARY 1974	KALIN[2] JULY 1982
No. of samples	n = 1	n = 4	n = 2	n = 1	n = 6	n = 1	n =3
pH	7.6	7.9±0.1	7.9±0.1	6.6	7.9±0.1	8.6	7.5±0.0
Cond.[4]	181	155±4.5	167±2.5	nr	155±5.3	155	100±0.0
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Ca	17.2	16.2*	16.9±1	17.5	16.3±1.6***	16.0	16.7±1.1
As	0.022	0.005±0.007**	0.02*	< 0.004	< 0.01	< 0.004	0.13±0.13
Cu	< 0.01	0.01±0.01	0.16±0.21	< 0.001	< 0.015	0.055	0.00±0.00
Fe	0.19	0.11±0.03**	0.07±0.04	nr	0.03±0.05	0.61	0.01±0.01
Pb	nr	nr	0.016*	< 0.004	0.01±0.01	0.004	0.03±0.02
Ni	nr	nr	nr	nr	< 0.03	0.004	0.00±0.00
Zn	nr	nr	0.025*	< 0.01	0.002±0.002	0.009	0.00±0.00
Co	nr	nr	nr	0.004	< 0.02	0.001	0.02±0.01 ±0.01

[1]Redshaw (1974): sample station 38-4.
[2]Kalin: ICP analyses for sample stations 5W-1, 2, 3, & 4.
[3]May-November: with the exception of September.
[4]Cond.: μmhos/cm.
*n = 1
**n = 2
***n = 3
nr = no results

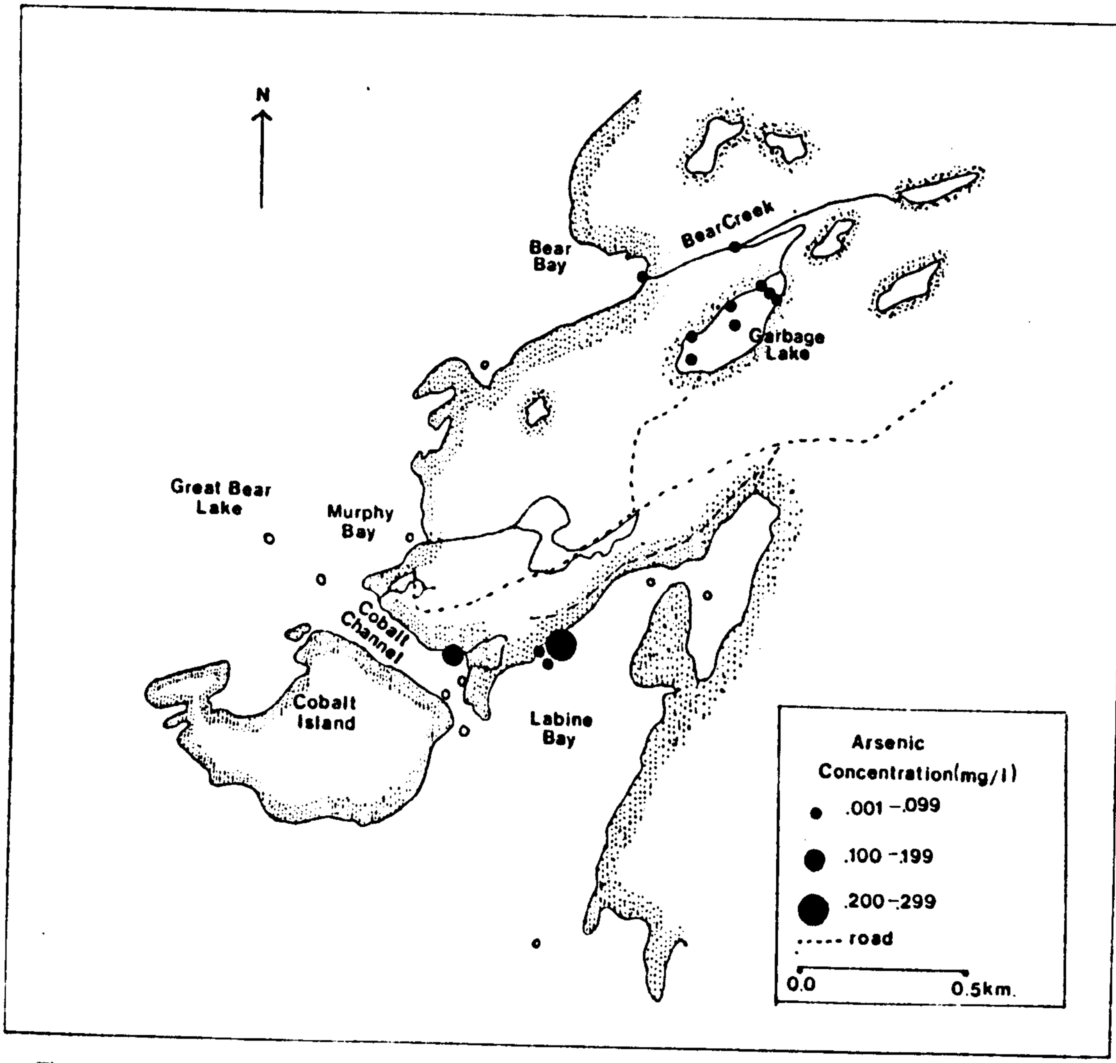


Figure 4: **Concentrations of arsenic in water samples in the Port Radium vicinity.** Arsenic concentrations ranged from 0.0000 to 0.280 mg/l. Freshwater average background concentrations are between 0.002 to 0.01 mg/l (Allen, 1974). Open circles are less than the detection limit of 0.002 mg/l for ICP or values of 0.0000 mg/l.

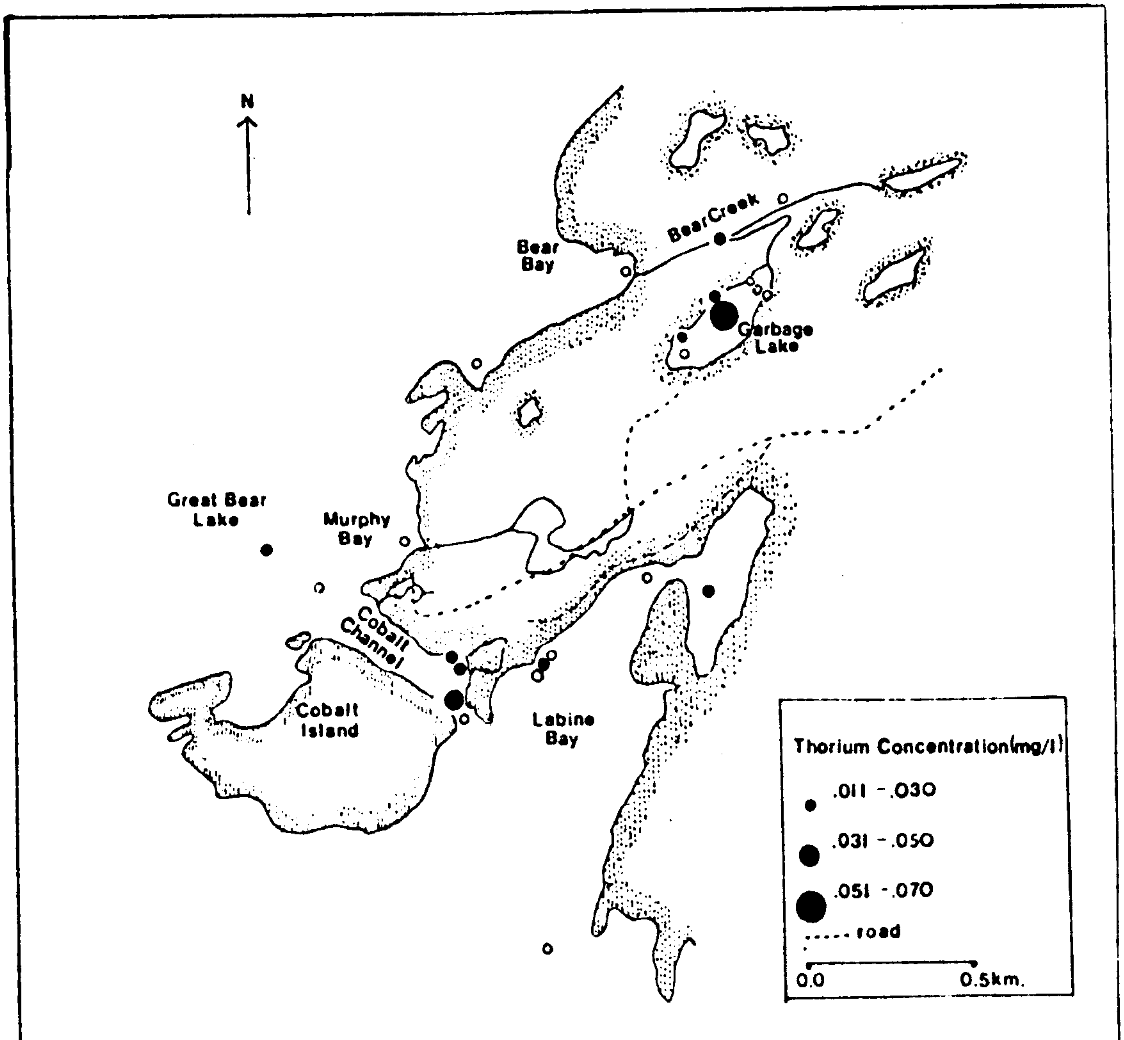


Figure 5: **Concentrations of thorium in water samples in the Port Radium vicinity.** Thorium concentrations ranged from 0.01 to 0.07 mg/l. Background concentrations in freshwater are reported to be less than 0.00002 mg/l (Bowen, 1966). Open circles are less than the detection limit of 0.011 mg/l in ICP analyses.

waste rock run-off could result in locally increased arsenic concentrations. This tentative suggestion awaits confirmation.

For thorium, the concentrations in water do not follow any particular pattern (Figure 5). In Garbage Lake some samples contain thorium, others do not. In Cobalt Channel, the concentration of thorium is similar to that in the control sample (K01), secured as far away from the mouth of Cobalt Channel as possible (difficult weather conditions and small boat). This 'control' sample falls in the same, or an even higher concentration range than some samples from Garbage Lake.

The environmental mobility of thorium is extremely low. Actinides in aquatic systems readily absorb to surfaces (Whicker and Schultz, 1982). The uneven distribution of thorium in water (Figure 5) likely reflects its association with suspended particulates and desorption during the filtration process. Clearly a uniform distribution of thorium concentrations around the peninsula, or in Garbage Lake, are not apparent. The mean thorium concentration in samples, for which the values were not at the detection limit of 0.001 mg/l (ICP), was 0.035± 0.008 mg/l (six samples). The freshwater concentration of thorium given by Bowen (1966) of 0.0002 mg/l, is quite low in comparison. The isotopes Th^{234} and Th^{230} are the decay products from the natural uranium series. The natural presence of uranium might result in the increased concentrations for certain locations. As the thorium distribution was found to be random, it is reasonable to suggest that thorium does not pose a problem associated with mining wastes around Port Radium. the negligible uptake of thorium by plants and animals (Whicker and Schultz, 1982) further negates thorium as an environmental threat at Port Radium. As the biological activities in Great Bear Lake are low (Johnson, 1975), accumulation of thorium by fish is unlikely.

Distributions of aluminum, uranium and lead concentrations in water are depicted in Figures 6, 7 and 8. Aluminum and uranium display similar distributions of the concentration ranges. Generally, high concentration ranges are associated with West Bear Bay, Cobalt Channel and some samples in Garbage Lake. For aluminum the background concentration in freshwater for Canada is reported to be 1 mg/l (Environment Canada, 1979). The water around the peninsula and in Garbage Lake is, therefore, indeed somewhat lower than the reported average background concentrations for aluminum of 0.913± 0.288 mg/l for all waters of this survey (Figure 6).

The uranium concentrations are in some locations higher than the background given by Environment Canada (in press). Waters from approximately 37,000 Canadian Shield Lakes, sampled between 1976 and 1978, ranged in uranium concentrations from 0.001 to 170 μg/l with a median value of 0.05 μg/l (Figure 7). West Bear Bay (Map 1) is not associated with any waste material, but had the highest uranium concentration of the survey with 9.41 μg/l. Likely, this

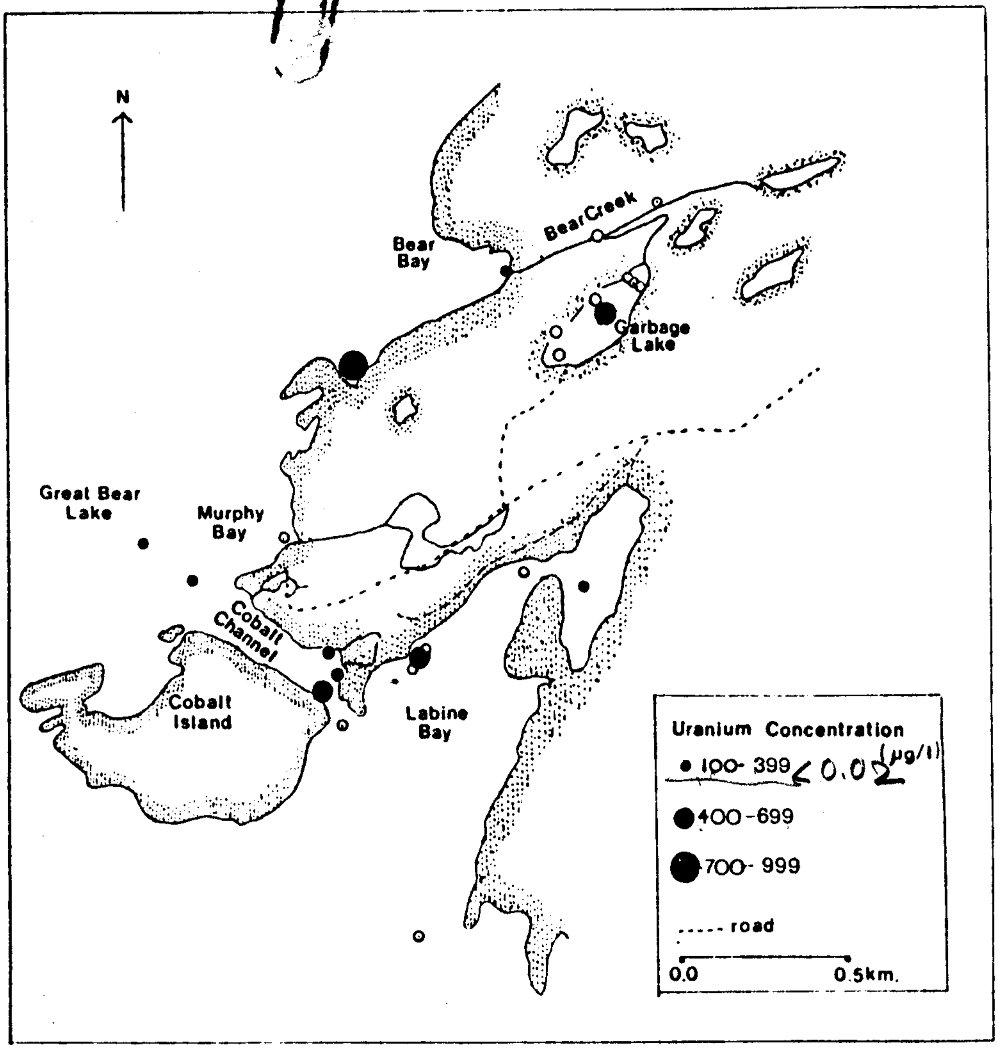


Figure 6: **Concentrations of uranium in water samples in the Port Radium vicinity.** Concentrations ranged from 100 to 941 µg/l. Open circles are values below the detection limit of 100 µg/l or values of 100 µ. Canadian Shield Lakes ranged in uranium concentrations from 0.001 to 170 µg/l with a median value of 0.05 µg/l (Environment Canada, in press).

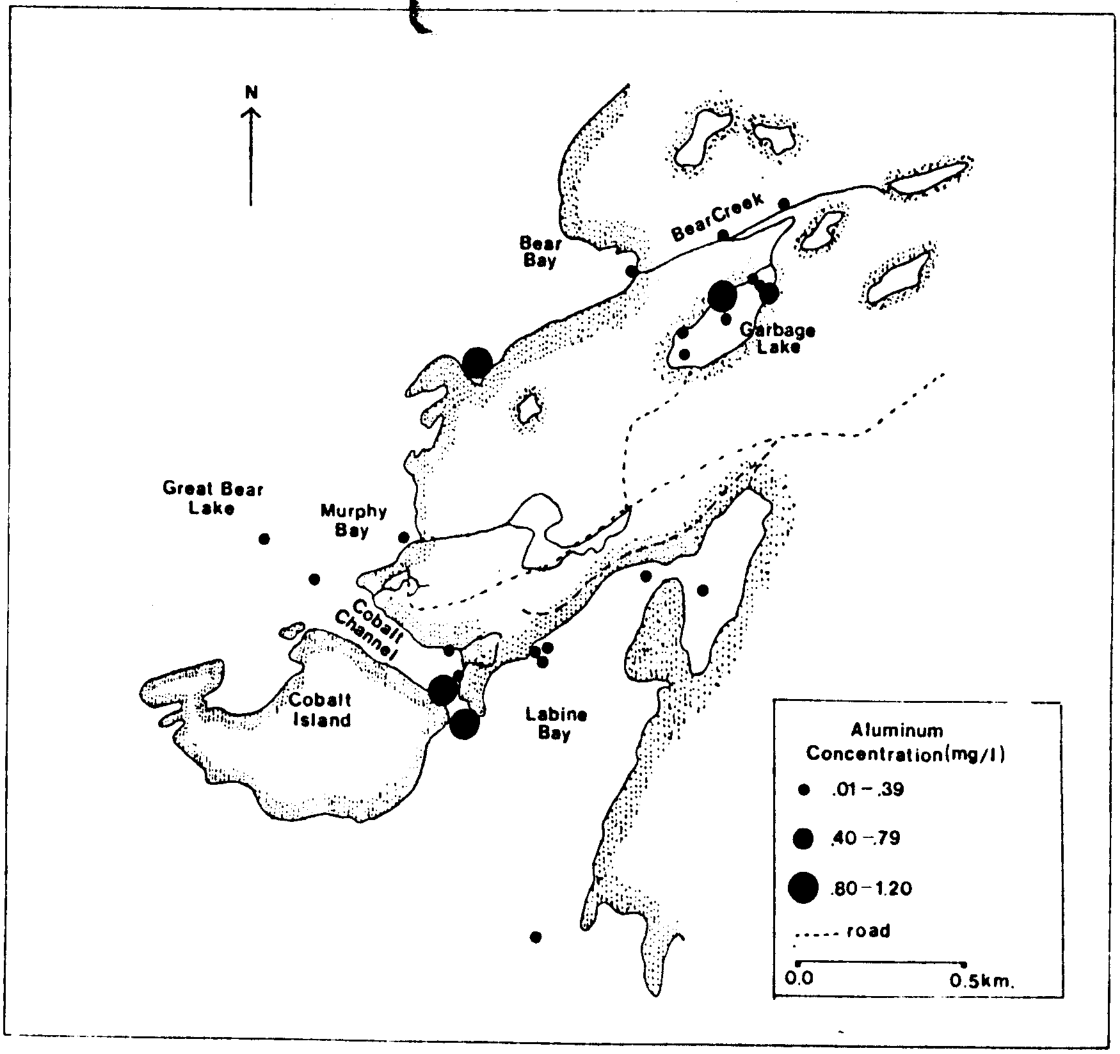


Figure 7: **Concentrations of aluminum in water in the Port Radium vicinity.** Aluminum concentrations ranged from 0.06 to 1.10 mg/l. Background concentrations of aluminum in Canadian freshwater are reported to be less than 1 mg/l (Environment Canada, 1979).

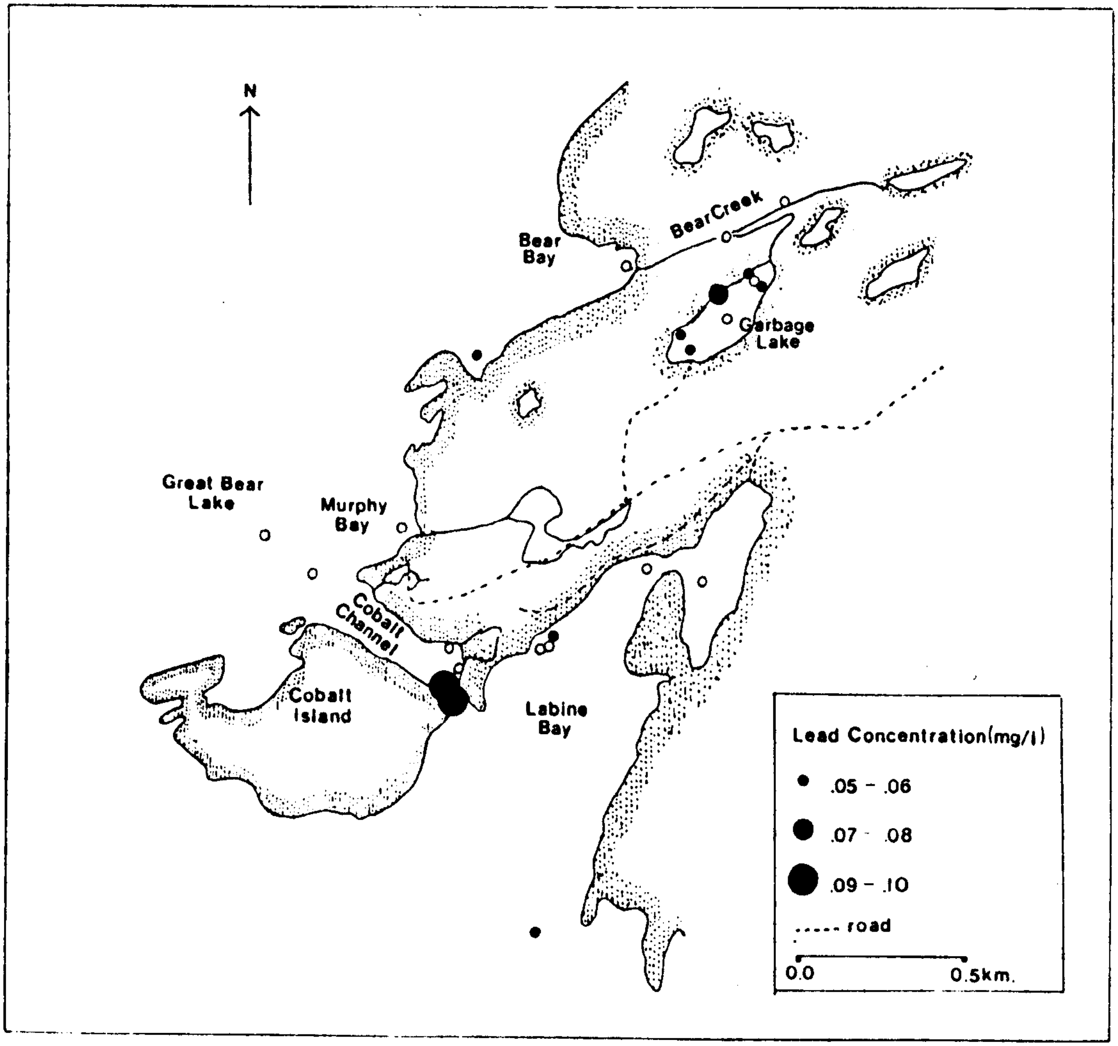


Figure 8: **Concentrations of lead in water in the Port Radium vicinity.** Concentrations of lead ranged from 0.05 to 0.09 mg/l. Open circles are below detection limit of 0.05 mg/l. Background concentrations of lead in freshwater are reported as 0.005 mg/l (Environment Canada, 1979).

small bay of surface water is directly in contact with a fault fracture zone, or vein running along West Bear Bay according to Griffith (1967). This results in an increased uranium concentration in the water.

The recommended upper limit for uranium concentration for the protection of aquatic life and wildlife in freshwater has been set at 300 μg/l by Environment Canada (in press). The concentrations of uranium in a uraniferous area, such as Port Radium, are expected to be higher than the natural background concentrations. The data indicate that despite the uranium occurrence in nearly all samples, the uranium concentrations are close to the limits recommended by Environment Canada. The average uranium concentration in the survey was 252± 112 μg/l. This average uranium concentration includes values for samples collected from Garbage Lake. Fifteen samples were above the detection limit, and nine samples were below the detection limit of 100 μg/l (Figure 7).

The analysis of lead concentrations in samples in the Port Radium vicinity (Figure 8) yield unsatisfying results. The concentrations recommended for the protection of aquatic life are 25 μg/l. The ranges which could be established from an ICP analysis of unconcentrated water, realistically are those values which are above the detection limit of 50 μg/l. Therefore, reliable concentrations are around 100 μg/l or 0.1 mg/l, i.e. twice the value of the detection limit of the instrument. All concentrations are below, or at, the detection limit. Because the recommended water quality concentration for the protection of aquatic life by Environment Canada is 25 μg/l or 0.025 mg/l, the data cannot be used to evaluate the water quality with respect to lead.

Analysis of Cobalt Channel samples produces the highest concentrations of lead. In Table 3, the available monitoring data are summarized for the period of 1971 to 1978 and are compared to the results of this survey for the sampling locations in Cobalt Channel. The concentrations of lead reported from the monitoring program are all considerably lower than in this survey, ranging from concentrations of 5 μg/l to 10 μg/l. It is, reasonable to suggest that the lead concentrations are at or around the reported background value given for lead in freshwater ranging from traces of 0.04 mg/l by Environment Canada (Table 5).

In Table 3, all water quality characteristics which can be compared to values obtained in this survey, are reported. These sampling locations represent sites directly associated with the Silver Point Tailings beach and the Cobalt Channel bottom, which is covered with tailings. Arsenic is generally low in Cobalt Channel, ranging from 0.002 to 0.03 mg/l compared to 0.004 to 0.1 mg/l in outer Labine Bay. Given the variation in the available data, and the values frequently reported smaller than the given number (e.g., < 400), comparisons with respect to possible differences in the water quality in Cobalt Channel and Labine Bay are tenuous. If differences exist in metal concentrations, then they are local and not long lasting. A general

Table 3: Cobalt Channel water characteristics (1969 - 1982).

ELEMENT & QUALITY	REDSHAW [1] JUNE 1969	JUNE 1971	JULY-JAN. [4] 1973	JAN. 1974	SUTHERLAND [2] JULY-AUG. 1978	KALIN [3] JULY 1982
No. of samples	n = 1	n = 1	n = 6	n = 1	n = 2	n = 4
pH	7.7	7.5	7.75±0.14	8.0	nr	8.3±0.08
Cond.[5]	167	163	160.5±10.1	200	170±0	145±28.9
	mg/l	mg/l	mg/	mg/l	mg/l	mg/l
Ca	15.6	16.2	18±0*	20	11**	17±0.48
As	0.002	0.02	0.02±0.03	< 0.004	< 0.005	0.03±0.06
Cu	0.01	< 0.001	0.0033±0.0004	< 0.001	< 0.02	0±0
Fe	0.08	0.05	0.11±0.14	< 0.02	0.02±0.02	0.11±0.19
Pb	–	< 0.003	0.01±0.01	0.005	< 0.005	0.05±0.05
Ni	–	–	0.01±0.01	0.003	< 0.03	0.01±0.01
Zn	–	0.002	0.0048±0.01	0.007	< 0.01	0.01±0.02
Co	–	–	0.0013±0.0016	< 0.001	< 0.05	0±0

[1]Redshaw (1974): samples for 1969, 1971, 1974 at site (38-6), 1973 (38- 5,6).
[2]Sutherland (p.c.): samples for 1978 at site 11.
[3]Kalin: ICP analyses for sample stations 2W-1, 2, 3, & 4.
[4]July-Jan.: with the exception of Sept., Nov. & Dec. 1973
[5]Cond.: μmhos/cm
*n = 3
**n = 1
nr = not reported.

impression which might be derived from comparing the data in Tables 2 and 3, is that the results are in good agreement with each other and with the present survey. Therefore, outer Labine Bay and Cobalt Channel do not differ persistently in water quality characteristics despite having received different mining discharges.

Some metal concentrations in water such as lead and arsenic vary in the Port Radium vicinity by a factor of 10, thereby possibly exceeding the recommended concentrations for the protection of aquatic life. In Figure 9, an attempt is made to place the results of this survey in relation to those limits. The hatched bars are analytical detection limits, the background freshwater concentrations, and recommended concentrations by the Ministry of Environment (Ontario) and Environment Canada, respectively. The limits are those which apply to the hardness which is encountered in the waters of Great Bear Lake of 76 and in Garbage Lake of 147 (calculated based on magnesium and calcium concentrations). The evaluation of arsenic indicates differences in the concentrations considered as limits for protection of aquatic life (Bars C & D). From the limit of 100 μg/l given by MOE, some locations in the area are at that level. Given the distribution of the concentrations (Figure 4), the six samples which are at or above that limit cannot be considered to indicate the overall contamination of the water. If, however, the recommended concentrations of Environment Canada are considered, then half of all samples are at the recommended limit. Given the indications of increased concentration during the winter (Tables 2 and 3) and the association of higher numbers with waste rock, it might be of importance to follow the fate of arsenic in more detail in the future.

The assessment of the toxicity of lead concentrations is limited by the combination of the detection limit, and the usage of unconcentrated water samples. Ten samples are only slightly above the detection limit which does not yield reliable results. The recommended concentrations of lead for aquatic life differs again with respect to the agencies. The monitoring data (Tables 2 and 3) are generally around recommended concentration limits, and the distribution of the lead concentrations around the peninsula (Figure 8) indicates that only locally elevated concentrations might occur, similar to arsenic. The concentrations of lead should be followed in connection to the waste rock and water contact in Port Radium.

Monitoring data are summarized for station 38-4 (freshwater supply for mine) in Figure 10 for lead and arsenic concentrations, for pH and for conductivity for the years 1979 to 1982, determined either by DIAND or Echo Bay Mines Ltd. Data of previous years are presented in Table 2 for the same station. Unfortunately, the records are sparse both within and over the years, making a long range evaluation of Labine Bay water quality difficult. The results of Figure 10, however, seem to suggest seasonal fluctuation of pH, conductivity and lead concentrations, as noted in Table 2. This survey indicate lower conductivity, with similar pH values, higher arsenic concentrations but identical lead concentrations. Though sparse, these records

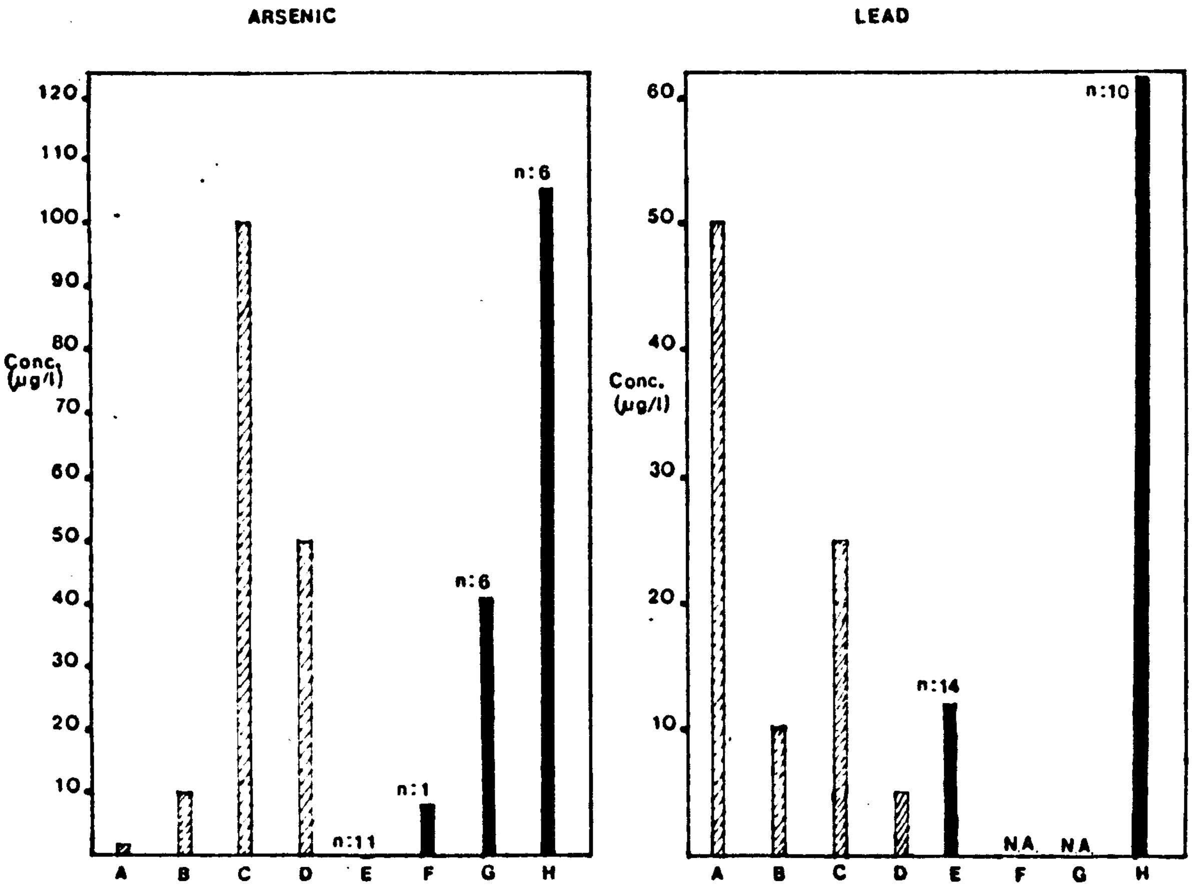


Figure 9: **Perspectives on concentrations of arsenic and lead.** The hatched bars (A-D) are detection limits background concentrations and recommended concentrations. The bars labelled 'A' represent ICP detection limits. Bars 'B' are background freshwater concentrations, and 'C' are the MOE toxicity levels given for aquatic life with respect to the hardness of the sampled water. Bars 'D' represent the same limit reported from Environment Canada. Concentrations at which aquatic life is considered to be protected can differ from agency to agency. The solid bars 'E-H' are summaries of the concentrations in water from the entire survey. Bars 'E' are mean concentrations of the samples below the detection limit of ICP. Bars 'F' are the means below the background concentrations. Bars 'G' are means of the waters which are above background concentrations but less than hardness protection limits. Bars 'H' are the means of samples which are above hardness protection limits for aquatic life.

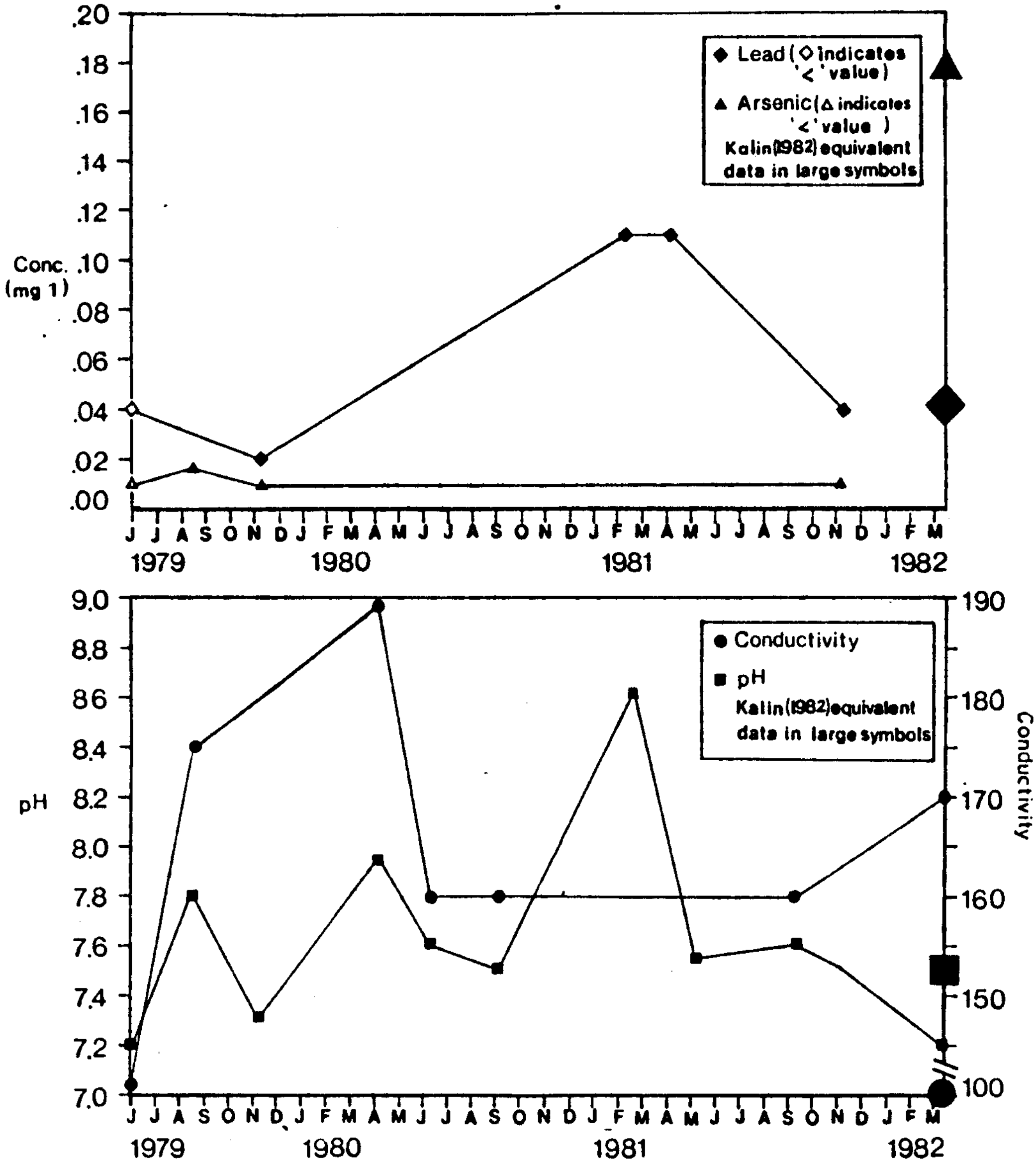


Figure 10: **Lead and arsenic concentrations along with pH and electrical conductivity for station 38-4 in the outer Labine Bay (1979-1982).** Seasonal changes in these parameters are suggested.

do suggest that natural fluctuation, such as run-off, may be important in assessing toxicity problems.

In Table 4, all of the water characteristics determined in the 24 samples are summarized. The average concentrations are reported for only those samples for which the concentration was above the detection limit of ICP. The detection limits for each element are given in the table along with the concentrations determined by Johnson (1975) for those instances where data are available. For all elements the available natural background concentrations given by Environment Canada (1979) are listed along with the concentrations which are recommended for the protection of aquatic life. The simplistic approach for comparing analytical results with only the natural background concentration and recommended concentration limits for aquatic life is unsatisfactory, given that toxicity is also highly dependent on the ionic form of the metal, water hardness, pH, and organism sensitivity. The concentrations reported in Table 4 are generally around background with the exceptions of arsenic, lead and uranium as discussed in detail earlier. Great Bear Lake has characteristics which differ from those of other Canadian Lakes, particularly with respect to biological productivity (Johnson, 1975). The metal sensitivity of the aquatic system may, therefore, differ as compared to more productive lakes.

Most elevated concentrations represent those found in Garbage Lake. Clearly, Garbage Lake, a tailings pond is expected to exhibit considerably higher concentrations of elements as the discharge of waste water and tailings slurries had ceased only for three months. Metal solubility is strongly influenced by pH. Given the high pH of the water in Garbage Lake (pH 8.01), low metal concentrations can be expected. All collected water was analyzed of gold, chromium, cadmium, cobalt, and copper concentrations, but all those elements were not detected with ICP. For elements determined by Johnson (1966 and 1975) averages were reported and derived from the values of the McTavish-Smith-McVicor-Arm and Conjuror Bay. All the concentrations for elements available are in good agreement with the corresponding averages for Great Bear Lake. The phosphorus concentrations in this survey are considerably higher and the silicon values are lower. This could indicate that some changes in phytoplankton population closer to the shores might have occurred.

The evaluation of elemental concentrations in Table 4 strongly suggests that environmental effects from seepage of Garbage Lake have not posed any major problem. Any effects which might be anticipated will be subtle and depend largely on the changes which might take place in Garbage Lake. The tailings in Cobalt Channel, Labine Bay and the vicinity have not exerted any lasting effect on the water characteristics based on these evaluations.

The subtleness of an evaluation of potential impacts of effluent water to extremely oligotrophic water bodies is exemplified with the element nickel. When the nickel concentrations are plotted for the Port Radium vicinity and Garbage Lake (Figure 11), the highest

Table 4: Water parameter evaluation for Port Radium, NWT.

ELEMENT & QUALITY	ALL WATERS	JOHNSON[1]	ICP DETECTION LIMITS	ENV. CANADA REC. CONC.	ENV.[2] CANADA BACKGROUND
pH	8.01±0.66 (23)	7.83±0.25 (4)	–	4-9	6.5-9.0
Cond.[3]	196.5±103.3 (23)	155.9±26.9 (4)	–	50-1500	no guidelines
	mg/l	mg/l	mg/l	mg/l	mg/l
Pb	0.08±0.01 (4)	nr	0.05	0.010 for <95 hardness.	traces to 0.04
Mn	0.04±0.07 (7)	nr	0.0006	bad taste at ≥0.2	
Mo	0.001±0.00 (7)	nr	0.006	1 freshwater	insufficient data
Al	0.310±0.337	nr	0.016	<1	0.1 (tentative)
Zn	0.014±0.009 (5)	0.003 (1)	0.004	0.05 for <120	0.03 aquatic life, highly dependant on pH and conductivity.
Ni	0.056±0.019 (9)	na	0.014	< 0.10	0.025
Fe	0.064±0.132 (8)	0.08±0.09 (4)	0.001	<0.5	
Mg	10.16±3.42 (22)	7.23±1.30 (4)	0.014	< 0.2 freshwater	0.05 distasteful
Co	0.017±0.006 (3)	na	0.003	Plants ≈ 0.1	Daphne 1.0
Si[1]	1.46±0.37	2.72±1.44 (11)	0.008	5	not toxic
V	0.010±0.00 (21)	na	0.002	< 0.05	na
As	0.75±0.066 (13)	na	0.002	<0.01 freshwater	< 0.05 dependant of ionic form.
Ba	0.076±0.050 (23)	na	0.0003	0.340	0.5 toxic lead
Th	0.035±0.022 (6)	na	0.011	na	
U	0.16±0.24 (9)	na	0.1	aquatic life < 0.25	0.001-0.017
Ag	0.001±0.001 (2)	na	0.006	0.002-0.039	no freshwater guidelines.
P[1]	0.12±0.19 (7)	0.003±0.01 (16)	0.036	0.01	0.025 algal blooms, esthetics.
Ca	23.07±8.13 (23)	16.25±2.90 (4)	0.061	15	harmless

[1]Johnson (1966 & 1975).
[2]Environment Canada (1979).
[3] = μmhos/cm
na = no analysis
nr = not reported
( ) = number of samples

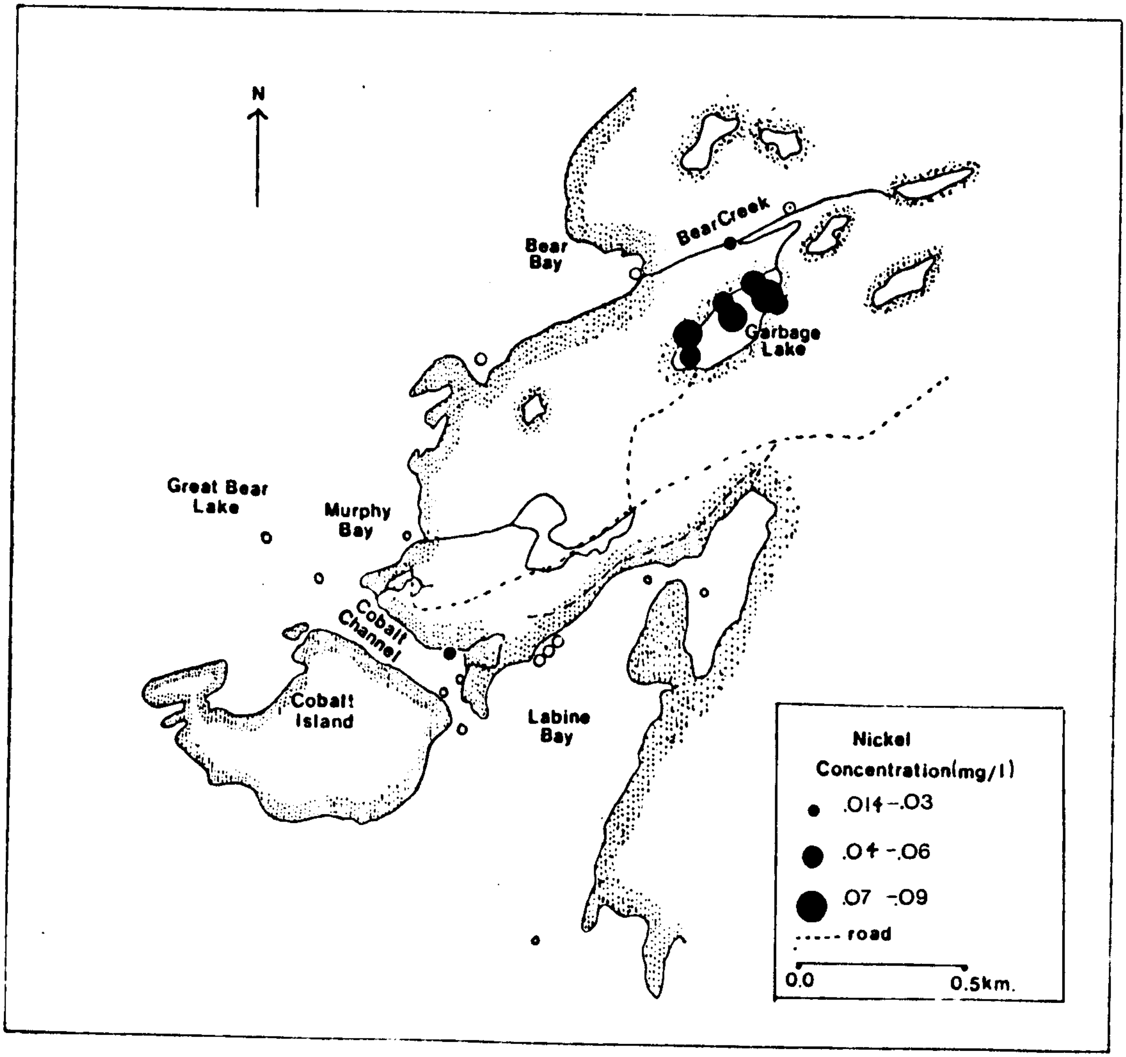


Figure 11: **Nickel concentrations in waters in the vicinity of Port Radium.** The concentration ranges of nickel are 0.02 to 0.08 mg/l. Natural background concentrations for freshwater are reported by Environment Canada (1979), as 0.1 mg/l. Open circles are at the detection limit of ICP of 0.014 mg/l or values lower than of 0.0000 mg/l.

concentrations are all found in Garbage Lake. The natural background of nickel, however, in freshwater is around 0.1 mg/l, i.e., the Garbage Lake concentrations are lower than the natural background, but higher than Great Bear Lake in the vicinity of Port Radium. The concentrations in the water around Port Radium are at or below the detection limit of 0.014 mg/l. Differences in the composition of water entering Bear Bay for long periods of time, may affect biological processes ultimately.

To gain some understanding of the changes in water quality which might occur as the water leaves Garbage Lake, those elements which were present in sufficient concentrations, were studied in detail. In Figure 12, the creek system is schematically presented from station 4W 2, the water collected from Bear Creek, before it joins Garbage creek at the sampling station 4W 1 (Map 5). Water was collected at the beach of Bear Bay (5W 1) after having passed underground through the creek. The concentration of this sample is is then compared to that of the control sample (K01), representing Great Bear Lake water. To accommodate all elements, a logarithmic scale had to be used. Therefore, the units on the graph are 10-fold increments. The only element which is drastically increased at 4W 1 is uranium, which is subsequently retained in the creek system and, furthermore, decreases on the beach. In Great Bear Lake, however, the concentration in the water at a higher level than on Bear Beach. This suggests that uranium is retained in the creek system, and by the periphyton on the beach.

For all the other elements, calcium, magnesium, aluminum and barium the concentrations differ only slightly on the beach compared to Great Bear Lake water. The concentrations in the algal mat differ in their ratio of increase possibly reflecting their biological role. Calcium and magnesium concentrations (wet weight) are 40 and 35 times higher in the biomass than in the water of Bear Bay. Barium was concentrated 140-, and aluminum 2900-fold in the algae and uranium, the only non-essential element, was concentrated only 20 times. Concentrations of elements in algae based on dry weight are generally 1000 to 10,000 times higher than the water concentrations. The concentration in wet biomass were estimated at 90 percent water content. Loss on ignition (L.O.I) was determined for the biomass at 86.9 percent, which indicates that most of the material collected was indeed organic nature. The dry weight concentration factors (dry biomass/water) are generally low with the exception of aluminum. Aluminum appears to be accumulated in *Ulothrix* spp.

Radium-226 and lead-210 concentrations in the algal biomass were determined as 11.5± 1 and 23.3± 0.7 pCi/g dry weight respectively. Given that these concentrations accumulated since the discharge of tailings ceased, during the brief growing season through an investigation of radium-226 and lead-210 in the water is required. As the barium concentrations indicate that this element passes through the creek system and is slightly higher than in the control sample, it does suggest that radium will behave similarly.

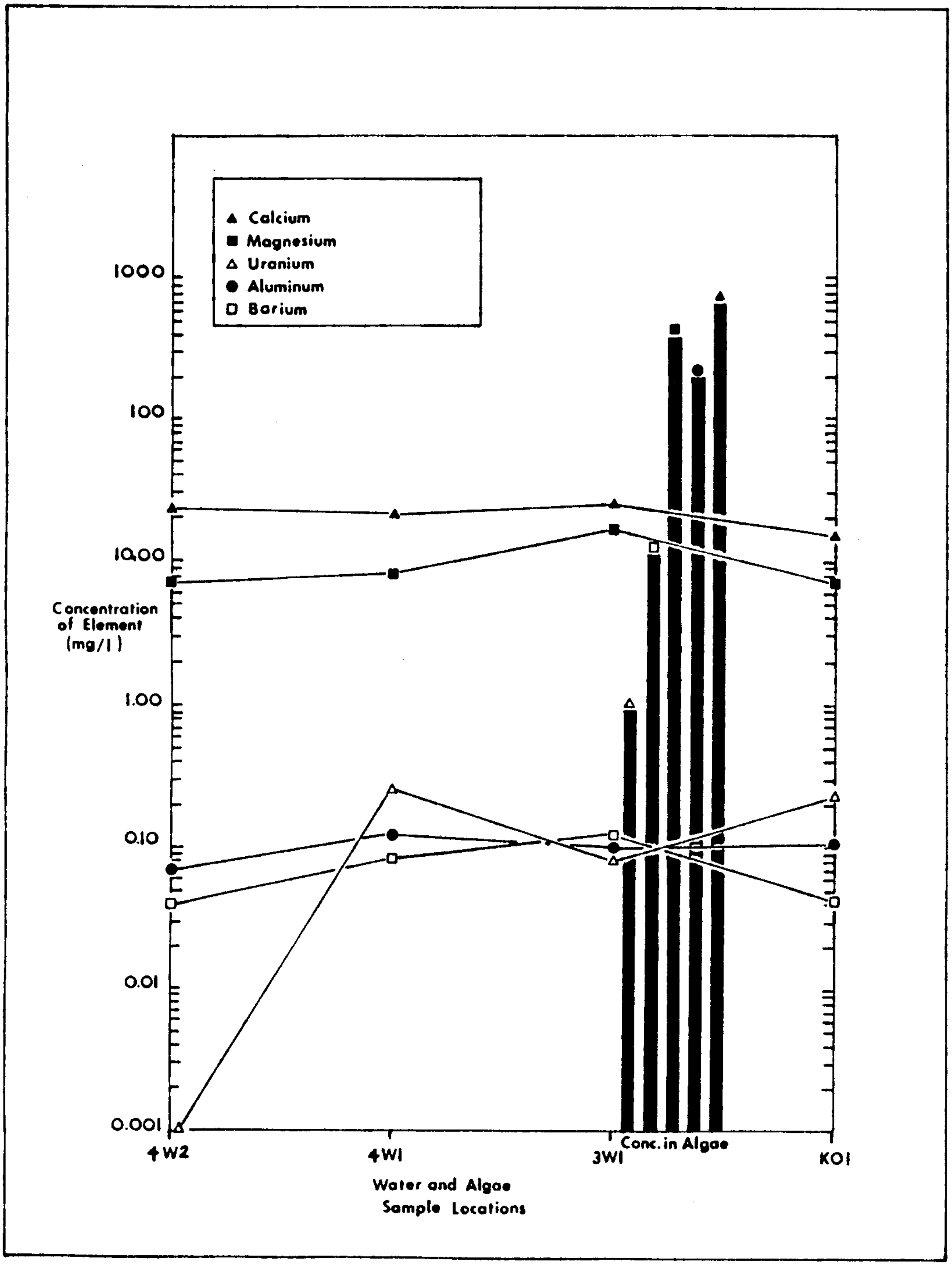


Figure 12: **A perspective on the Garbage Lake and Bear Creek System.** The dark bars are the concentrations (fresh weight) of calcium, magnesium, uranium, aluminium, and barium in the algal biomass on Bear Bay beach.

A listing of periphyton collections is given in Table 5. Typically *Ulothrix* spp. species were the dominant component in all locations was periphytic growth was noted. Growth was most extensive on Bear Bay beach. To a lesser degree *Ulothrix* spp. colonized the tailings beach along Cobalt Channel. Here growth occurred close to the sewage discharge pipe. From this limited survey it appears that where any increase occurs in elements from incoming waters, be it tailings effluents, sewage, or small trenches which collect run-off from land, permits *Ulothrix* spp. to grow.

Johnson (1975) reports from investigation of tributory streams that their effects on the water chemistry are very local. The data presented in Figure 11 also appears to indicate a very limited effect on the water quality.

In Table 6, the chemical characteristics of Garbage Lake and its effluents at the V-notch station are summarized and reported with the results obtained in this survey for the same station. The data of H.R. Wilson were collected during the lowering process of effluent water from Garbage Lake and Redshaws' data-set are of historical data for five years prior to the lowering of Garbage Lake. These records represent untreated conditions of the water in Garbage Lake. In 1974, the characteristics are similar to those in 1983 in the lake, with the exception of iron and zinc concentrations. These metals might have resulted from the scrap metal depositions on the beaches (Plate 1). The water and waste slurries additions to the lake between 1974 and 1978 definitely changed the water characteristics drastically. The estimated total discharge in 1978 were given by Wilson (1978) in pounds as 145.8 arsenic, 5.45 cadmium, 9.55 copper, 478.35 iron, 22.59 lead, 116.15 nickel and 15.0 zinc. This discharge clearly represents a major event in one month contained in 60,024,000 U.S. gallons of water. Nevertheless, in 1982 the water at Bear Bay beach does not indicate any remnant from the event of discharging the above-stated contaminants. In 1982, after cessation of discharge, the water leaving Garbage Lake appears to be affected over the short distance in which it is passing from the lake through the overburden dam and Garbage Lake creek bed. This is evident in calcium, arsenic, nickel, zinc and magnesium concentrations which decreased between the lake and the seepage (Plate 8). The creek bed appears to have retained some ability to absorb dissolved material. It may, however, be possible that the retention is mainly due to the new overburden material placed as a dam at the end of the lake.

The chemical conditions of Garbage Lake water resemble those of previous untreated tailings waer for electrical conductivity, which is lower by 235 μmhos/cm and for pH which is reduced by one unit from 8.2 to 7.2. The characteristics of the water through Bear Creek bed do not change significantly (Figure 11). No dilution or filtration effect could be observed as a result of the clean water of Bear Creek entering Garbage Creek. The change observed in Table 6, is likely due to the dam.

Table 5: Identification of algal samples in Port Radium, NWT.

LOCATION	DOMINANT	CO-DOMINANT & MINOR COMPONENT	DESCRIPTION
Bear Creek Upstream	*Tolypothrix* sp.	–	filamentous blue-green
		Navicula spp., *Nitzschia* spp., *Eunotia* sp., *Cymbella* sp.	pennate diatoms
		Tabellaria funestrata, *Acnanthes* sp.,	pennate diatoms
		Oedegonum sp.	filamentous green
Garbage Creek	bryophytes	–	–
		Navicula spp., *Amphora* sp., *Eunotia* sp.,	pennate diatoms
		Anabaena sp.	filamentous blue-green
Bear Bay Beach	*Ulothrix* spp.	not present	–
Bear Bight	*Ulothrix* spp.	not present	filamentous green, two species: large and small cells.
		Closterium sp.	desmid
		Chlamydomonas sp. and coccoid greens.	unicellular greens.
West Bear Bay	*Ulothrix* spp.	–	filamentous green, large and small cells.
		Closterium sp.	desmid
		Navicula spp., *Amphora* sp.	pennate diatoms
Control Bay	*Ulothrix* spp.	–	filamentous green, large and small cells.
		Pinnularia sp., *Navicula* sp.	pennate diatom
		Uronema sp.	filamentous green
Cobalt Channel (tailings beach)	*Ulothrix* spp.	–	filamentous green, two species: large and small cells.
		Navicula spp.	pennate diatoms
		Oscillatoria sp.	filamentous blue-green

Based on this limited amount of information, it is not possible to determine the nature of the changes which might take place in the long-term in Garbage Lake and Bear Creek system. The effluents and water characteristics during run-off and the amount of water remaining over the tailings are all questions pertinent to the long-term implications.

Table 6: Characteristics of effluents from Garbage Lake (1973 & 1982).

ELEMENT & QUALITY	WILSON[1] MAY 1978 V-notch	REDSHAW[2] MAY-AUG. 1973 GARBAGE LAKE	KALIN JULY 1982 GARBAGE LAKE	JULY 1982 V-notch
No. of samples	n = 22	n = 4	n = 7	n = 1
pH	7.52±0.24	7.48±0.15	8.21±0.13	7.2
Cond.[3]	603±742	377±79	345±5	110
	mg/l	**mg/l**	**mg/l**	**mg/l**
Ca	42.93±13.79*	29.20±10.75**	34.76±1.32	**23.01**
As	29±0.31	0.01±0.004	0.050±0.010	**0.008**
Cu	0.02±0.01	0.02±0.003	0.00±0.0	**0.00**
Fe	0.96±1.12***	0.63±0.14	0.01±0.01	**0.02**
Pb	**< 0.05**	0.01±0.01	0.04±0.03	**0.04**
Ni	0.23±0.09	0.02±0.02	0.06±0.01	**0.02**
Zn	0.03±0.02	0.29±0.05	0.003±0.004	**0.00**
Cd	**< 0.01**	**nr**	0.0±0.0	**0.0**
Mg	13.03±4.43****	**nr**	14.95±0.26	**8.06**

[1]Wilson (1978).
[2]Redshaw (1974).
[3]Cond.: μhos/cm.
*n = 13
**n = 2
***n = 18
****n = 12

3.2 The Characteristics of the Sediments.

Moore (1981) found in the Port Radium vicinity sediments with large variations in metal and radionuclide concentrations. This raised some concern with respect to the interaction of the sediments with the water column. However, if sediments with high concentration are natural sediments, then radionuclides and metals are likely permanently bound to the sediments. Release of substances would depend on the overlaying water column and sediment characteristics. Basic physical characteristics of the sediments and the overlaying water column were not reported by Moore (1981). Therefore, interpretation of the results with respect to environmental effects of these sediments is difficult. One of the tasks was to determine the nature of the sediments and the characteristics of the overlaying water column in the Port Radium vicinity.

Sediments covered with tailings are depicted in Plate 13. The Eckman grab samples in

Plate 13: **Lake Sediment:** At station 5S3 (Map 3) the sediment is covered with a thin layer of silver tailings. The open arrow points to the natural sediment, while the closed arrow points to the tailings layer.

Cobalt Channel were filled completely with tailings, but as the distance from the channel increased, in the direction of the water flow, some natural sediment was contained in the grabs. Indeed, the tailings layer decreased relatively rapidly as the distance from the channel increased. In Plate 13, the tailings layer was only about 0.5 cm at location 5S3 (Map 4). By selecting matching sampling locations of this survey and the EPS study by Moore (1981) it was possible to identify the sediment type from the metal characteristics. In Table 7, four sampling locations are compared. In the inner Labine Bay, natural sediments are found. The organic content (L.O.I) is high (10-11%) and calcium compared to other locations is low in this material. The concentrations of uranium, cobalt, vanadium and manganese are considerably lower than in the other locations. The a very close agreement between the two data-sets of inner Labine Bay exists. Aluminum, mangesium, barium and sodium concentrations are either extremely variable or present in similar concentrations.

Sediments in outer Labine Bay are similar to the tailings in Cobalt Channel in their elemental concentrations. The material from Murphy Bay is variable and differs for uranium and cobalt concentrations and L.O.I. from the silver tailings. The material in Murphy Bay likely contains uranium tailings. In Murphy Bay manganese and cobalt concentrations do not agree between the two investigations. To obtain sediment material in Murphy Bay was a difficult matter, as the bottom is gravelly interspersed with tailings areas. The Eckman grab was utilized in areas which were visually identified from the boat as tailings. Only small amounts of tailings could be secured after many trials, as the tailings were very compact. It is quite likely that the material from the EPS survey was obtained further away from the shores, and as a result, mixtures of tailings and natural sediment were analyzed.

Falk, et al (1973) studied the biological effects of mining in the Northwest Territories. One of the mine sites investigated was Echo Bay Mines Ltd. The investigation concluded that: *fish collected off the Echo Bay mining operation during 1971 and 1972 possessed higher levels of arsenic, copper, lead, zinc, cadmium and nickel as those from control areas.* The sediments in the vicinity contained high concentrations of all metals. In this survey, only cobalt in sediments was determined, however, the nature of the sediments was identified. Natural sediment and tailings were found to be neutral to alkaline likely due to the acid consuming nature of the ore. Metals and radionuclides contained in the sediments are unlikely to be released to the water under those conditions in order to result in fish contamination. Furthermore, the electrical

Table 7: Sediments around the Port Radium Peninsula.

ELEMENT & QUALITY		INNER LABINE BAY		OUTER LABINE BAY		COBALT CHANNEL		MURPHY BAY	
		EPS	KALIN	EPS	KALIN	EPS	KALIN	EPS	KALIN
U	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	na	48	910	270	700	443	na	163
	sd	na	0	693	0.6	898	498	na	0
	% error	–	1.7	–	0.6	–	3.6	–	0.8
Co	n	1	1	2	1	5	3	1	1
μg/g	$\bar{x}$	69	58	571	224	282	171	452	794
	sd	0	0	216	0	282	7.7	0	0
	% error	–	7.7	–	3.3	–	11.4	–	0.8
	DL	–	–	–	–	–	<242		
	"	–	–	–	–	–	<76		
	"	–	–	–	–	–	<82		
Ba	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	846	114	880	1349	1089	4816	696	–
	sd	0	0	124.5	0	206.4	2633.5	0	–
	% error	–	11.3	–	14.5	–	23.1	–	–
	DL	–	–	–	–	–	–	–	<544
Mg	n	1	1	2	1	5	5	1	1
μg/g	$\bar{x}$	14700	16203	23400	13328	21680	12267	25800	23629
	sd	0	0	7071.1	0	5965.5	5001	0	0
	% error	–	7.9	–	11.1	–	25.2	–	6.48
	DL	–	–	–	–	–	<71879.4	–	–
Na	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	10800	12023	7100	13328	898	11399	3800	2087
	sd	0	0	3252.7	0	3389.2	0	0	0
	% error	–	1.8	–	11.1	–	10.2	–	5.8
V	n	1	1	2	1	5	4	1	1
μg/g	$\bar{x}$	104	109	268	179	222	321	332	356
	sd	0	0	128.7	0	108.3	78.0	0	0
	% error	–	5.3	–	5.9	–	13.9	–	2.7
	DL	–	–	–	–	–	<180.0	–	–
	"	–	–	–	–	–	<321.8	–	–
Al	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	68100	63953	52500	51492	60480	43741	50400	40713
	sd	0	0	240.4	0	13854	6244.8	0	0
	% error	–	1.5	–	1.8	–	11.3	–	2.8
Mn	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	702	504	2995	2105	13841	17786	5070	927
	sd	0	0	1067.7	0	13062.8	4757.4	0	0
	% error	–	2.1	–	1.0	–	0.8	–	1.4
Ca	n	1	1	2	1	5	6	1	1
μg/g	$\bar{x}$	9080	7764	15800	13745	38218	35650	14800	12624
	sd	0	15.7	0	0	29431.1	13507.4	0	0
	% error	–	15.7	4525.5	13.0	–	23.9	–	12.6
L.O.I	n	1	1	2	1	5	6	1	1
	%	11.5	10.6	3.6	3.9	4.0	3.1	0.8	0.3
	sd	–	–	0.1	–	1.3	1.9	–	–

n = No. of samples with conc. $\bar{x}$ = mean of conc.
sd = variance of conc. mean % error = mean of errors of NAA Kalin.
DL = samples of Kalin (NAA) which were less than detection limit in μg/g.

conductivity, a rough measure of dissolved ions, was around 105 to 160 μmhos/cm in the sediments (Table 9), literally identical to that in the water column above (Kalin, 1982; page 20) in all sampling stations.

Falk, et al. (1973) investigated the site during or shortly after mine water and tailings were discharged into Labine Bay. It is suggested that fish contamination might have been related to this discharge event alone. Nevertheless, the authors report that the metals in the mill effluent were extremely low, as toxicity test of the effluent revealed a surprisingly low acute toxicity. If metals were not contained in the discharge itself in a dissolved form, then the sediment concentrations are difficult to explain. The solubilities of metals are unlikely to change, as the tailings settle.

Water and sediment data were summarized for those stations where sample pairs existed. In Table 8, only those elements are considered which exhibit differences in water concentrations. For most sampling locations, the results are from the surface water. The assessment is, therefore, a preliminary one, and can only permit suggestions of trends concerning the relationship between sediment and water concentrations. The only bottom water sample was 2W 4 from Cobalt Channel. Here, aluminum and manganese concentrations are increased slightly compared to the surface waters. The concentrations in the sediments, however, do not relate in any way to the water concentrations. These increased concentrations are very slight and might be due to increased amount of particulates in the water from which aluminum and manganese might be absorbed during filtration. The water column was completely saturated with oxygen, but the electrical conductivity increased at the bottom in Cobalt Channel from 100 to 160 μmhos/cm. Unfortunately, further profiles could not be obtained due to equipment failure. It would be useful to obtain further profiles. In Garbage Lake the stratification was pronounced. In the deeper locations between 5-6 m depth (Kalin, 1982), oxygen concentration, temperature and conductivity decreased. A stratification was not expected, as the lake is shallow and wave action should mix the water completely. These data suggest no relationship between sediments and water, however, the stratification of the water should be obtained, along with bottom samples to confirm these results.

Of particular interest are the conditions in Garbage Lake, as changes in oxygen concentrations above the sediment might result in chemical changes in the water quality in Garbage Lake. Roy and Vezina (1973) suggest, based on a four day experiment in which pH was observed in air free tailings water, that in the long-term acidification of tailings zones might constitute a small possibility. McLaren (1975) placed considerable importance on the absence of oxidation, as he states: *"should the board permit the use of McDonough Lake, as a tailings area, restoration will not be necessary since the tailings will be completely underwater and subject to limited oxidation".* The water characteristics to date on the shallow beaches do not suggest any

Table 8: Water and sediment concentrations for individual sites.

Site Code	U	Ba	Mg	Al	Mn	Ca
	mg/l μg/g	mg/l μg/g	mg/l %	mg/l %	mg/l %	mg/l %
1W1	0.13	0.13	14.8	0.10	0	33.9
1T1	113	DL	8.94	4.75	3.2	8.2
1W4	0.54	0.13	15.0	0.22	0.00	34.3
1T2	47.9	977	1.53	6.62	0.10	1.2
1W7	0.36	0.15	15.3	0.38	0.01	35.4
1T3	3.69	3069	4.62	4.29	1.56	5.1
3W1	0.00	0.13	10.8	0.10	0.00	27.6
3S1	9.58	1208	0.67	6.02	0.73	1.1
6W1	0.00	0.03	0.00	0.06	0.00	16.4
6S1	479	1099	4.33	4.49	0.07	1.9
2W5	0	0.04	7.59	0.09	0.00	16.3
2S1	154	4491	2.96	3.92	12.27	5.6
2W1	0.29	0.03	8.02	0.35	0.01	17.6
2S2	112	DL	3.88	4.18	1.72	4.0
2W2	0.18	0.03	7.76	0.05	0.00	16.8
2S3	130	6677	DL	3.86	1.82	3.7
2W4	0	0.06	7.89	0.93	0.19	16.7
2S4	186	4544	3.42	5.0	1.53	3.0
5W6	0.12	0.04	7.65	0.06	0.00	16.4
5S2	270	1349	1.33	4.95	0.21	1.4
5W5	0.24	0.03	7.67	0.09	0.00	16.5
5S1	47.8	1114	1.62	6.40	0.05	0.89

DL = detection limit
W = water concentrations
T = sediment concentrations

oxidation of tailings. The water is saturated with oxygen on the tailings beaches which facilitate oxidation.

Water leaves Garbage Lake as seepage and only small amounts will be added by yearly precipitation. The lake water level, as observed in 1982, might not represent the level at which water accumulates naturally in the lake. Therefore, water might not cover the tailings in the future. Should the lake dry-up, acidification, as a result of oxidation of the tailings, appears also unlikely given the following observation.

The Silver Point tailings are dry and deeper parts are saturated. The tailings are neutral with a pH of 7.3 and the sediments in Cobalt Channel are alkaline with a pH of 8.0. The tailings in Garbage Lake are also alkaline with a pH value of 8.1 (Table 9). The gangue rock contains some acid consuming minerals, such as carbonates (Wollett, 1972; Griffith 1967). Therefore, the slightly alkaline nature of submerged tailings, could be a result of carbonates in the tailings. Given the pH of the tailings, acidification is not anticipated. Furthermore, microbial acid generation would be limited by the temperature of the water. If this process operates in the long-term then it should be noticeable on the beach of the Silver Point tailings, deposited eight years prior, and in the tailings of outer Labine Bay. No indication of acidification was obtained from the water and tailings data.

3.3 The Characteristics of the Tailings.

The locations at which tailings or other materials were sampled have been described in Table 1a and 1b, and the locations are designated on Maps 4 and 5. The objective of this sampling program was to identify those locations of wastes which could be sources of persistent and hazardous substances to the environment. However, before a potential contamination source can be derived, waste material has to be identified. Tailings are generally low in organic matter expressed as percent loss on ignition (L.O.I). In Figure 13, materials are sorted by the description of the material. Tailings contain two to four percent of organic matter, whereas soil and other materials are extremely varied in organic matter. Organic matter is important for plant growth and the colonization of the waste material. Another parameter which is important for plant growth is the pH of the growth substrate. Acidic soils have been collected in the area above Shaft No. 2 and in the West Adit area (Table 9). These samples have a high electrical conductivity (3202 μmhos/cm), which is related to the pH of the material. All of the other locations investigated had neutral pH values, and conductivities ranged from 400 to 1600 μmhos/cm. Noteworthy, are the low conductivities of tailings covered with water as compared to those of the dry silver tailings (Silver Point & Murphy Lake).

The average concentrations of elements (in μg/g) in samples collected from designated areas are presented in Table 9. An attempt was made to differentiate waste material. Tailings from silver and copper extraction by jigging and floatation can be expected to differ from those derived from uranium extraction by acid leaching. The locations are arranged in order of anticipated similarity of material as discussed in the field report (Kalin, 1982).

The sediments of Garbage Lake are definitely silver tailings and should resemble the material in Cobalt Channel, which has originated from the Silver Point tailings. The agreement of the elemental concentrations is generally good, being within the variation and the analytical errors of all elements, with the exception of chlorine. However, chlorine is determined frequently as a detection limit, and therefore, real concentrations are rarely obtained. Large variations in elemental concentrations are noticed between the sites. Differences in elemental composition are suggested for material from Murphy Bay, West Adit and Murphy Creek. However, overburden from the Parking Lot or Radium Lake and the soil collected above Shaft No. 2 are just as different from each other as they are similar to the elemental composition of the silver tailings. Typically, trace elemental composition of wastes and soils, do not yield ascertive information to differentiate wastes. Statistical analyses of a larger sample set and fingerprinting techniques might suggest some definitive results. A more complete set of elemental concentrations would be desirable, but this was beyond the scope of this survey.

Data for elements occurring in percent quantities are summarized in Table 10, as such macro-components of waste materials are possibly more useful to differentiate silver tailings

Table 9: Elemental composition of tailings, overburden, and soil in μg/g.

SITE		pH	Cond.	Co	U	Dy	Ba	V	Cl
Garbage Lake:	n	6	6	4	17	2	2	6	1
	$\bar{x}$	8.1	150	88.7	161.1	2.3	3980	351.1	421
	sd	0.21	16	52.1	212.2	0.69	4247	226	–
	% error	–	–	17.4	6.9	21.0	11.2	12.3	22.5
Cobalt Channel:	n	6	6	3	6	1	4	2	6
	$\bar{x}$	8	105	159	130	0.33	5571	325	<1532
	sd	0.5	37.8	14	35	–	2995	112	578
	% error	–	–	13.7	6.9	25.3	22.4	16.3	–
Labine Bay:	n	7	7	6	7	7	7	7	2
	$\bar{x}$	7.5	145.7	101	224	0.21	1790	173	292
	sd	0.24	58.3	80	260	0.11	1110	107	73
	% error	–	–	8.6	1.4	15	16.2	8	29.4
Silver Point:	n	5	5	4	5	1	5	4	5
	$\bar{x}$	7.3	456	629	70	3.4	<3971	213	<1264
	sd	0.11	262	1015	35	–	2962	92	232
	% error	–	–	17	10.9	22.5	–	22.4	–
Murphy Lake:	n	13	13	10	11	6	9	11	6
	$\bar{x}$	6.9	1615	292	198	3.61	7514	374	680
	sd	1.36	3745	327	332	1.92	7191	110	929
	% error	–	–	10.8	5.2	10.3	20.3	10.6	21.43
Murphy Creek:	n	5	5	5	5	5	5	5	5
	$\bar{x}$	7.4	180	1127	1254	4.01	1925	502	<340
	sd	0.27	34	523	212	0.33	309	30	129
	% error	–	–	0.32	0.32	9.4	16.4	3.7	–
Murphy Bay:	n	2	2	2	2	2	1	2	2
	$\bar{x}$	8.0	160	1435	321	3.8	1099	392	326
	sd	0.78	28	906	223	2.04	–	51	30
	% error	–	–	0.6	0.6	5.9	14.8	2.3	18.6

Table 9: Elemental composition of tailings, overburden, and soil in $\mu g/g$ cont'd.

SITE		pH	Cond.	Co	U	Dy	Ba	V	Cl
West Adit:	n	13	13	9	12	11	8	12	4
	$\bar{x}$	4.7	3202	120	1001	5.4	3450	449	249
	sd	1.61	3385	210	821	2.2	4646	185	60
	% error	—	—	7.9	1.5	7	16.3	3.4	22.9
Garbage Creek:	n	1	1	1	1	1	1	1	1
	$\bar{x}$	7.9	230	<42.0	21.5	0.18	2879	76.3	<656
	sd	—	—	—	—	—	—	—	—
	% error	—	—	—	11.1	29.5	16.3	27.3	—
Bear Creek:	n	2	2	1	2	2	2	2	2
	$\bar{x}$	7.1	955	168	<0.20	<0.20	3494	133	<883
	sd	0.28	206	—	0.05	0.05	4247	20	345
	% error	—	—	11.6	—	—	17.9	20.6	—
Parking Lot:	n	2	2	1	2	1	2	1	2
	$\bar{x}$	7.6	490	149	75.9	1.36	1609	162	<482
	sd	0.57	14	—	8.8	—	588	—	419
	% error	—	—	3.6	2.7	17.6	22.2	4.6	—
Bear Bay:	n	1	1	1	1	1	1	1	
	$\bar{x}$	8.2	110	36.7	9.6	0.10	1208	95.2	<330.1
	sd	—	—	—	—	—	—	—	—
	% error	—	—	11.8	8.3	13.9	11.5	8.1	—
Control soil:	n	1	1	1	1	1	1	1	1
	$\bar{x}$	3.1	1200	<13.4	2.7	0.045	741	103	<357
	sd	—	—	—	—	—	—	—	—
	% error	—	—	—	29	30.2	18.7	6.9	—

Table 10: Elemental composition of tailings, overburden and soil in percent.

SITE		L.O.I.	Mg	Na	Al	Mn	Ca
Garbage Lake:	n	8	7	5	6	7	6
	$\bar{x}$	4.53	5.47	0.91	4.58	1.65	4.31
	sd	3.67	3.90	0.76	1.27	1.16	2.40
	% error	–	21.33	12.73	10.67	1.01	16.91
Cobalt Channel:	n	6	4	5	5	6	6
	$\bar{x}$	3.15	4.48	1.42	4.23	1.97	4.23
	sd	1.88	2.16	0.52	0.48	0.36	0.89
	% error	–	26.75	8.96	13.92	0.92	23.86
Labine Bay:	n	7	7	7	7	7	7
	$\bar{x}$	4.56	1.71	1.22	5.52	0.51	1.37
	sd	4.20	0.93	0.40	0.95	0.77	0.62
	% error	–	23.19	4.34	3.81	1.36	17.25
Silver Point:	n	5	2	5	4	5	5
	$\bar{x}$	1.52	3.68	1.44	4.53	1.90	4.91
	sd	0.52	0.19	0.24	1.03	0.45	0.61
	% error	–	22.82	8.17	14.10	0.82	18.39
Murphy Lake:	n	13	7	7	11	13	10
	$\bar{x}$	7.06	3.03	0.30	3.59	1.70	4.06
	sd	12.20	0.66	0.21	0.81	1.48	2.08
	% error	–	11.45	9.53	13.42	1.44	17.80
Murphy Creek:	n	5	5	5	5	5	5
	$\bar{x}$	0.94	5.33	0.26	5.22	0.18	2.99
	sd	0.58	1.20	0.04	0.87	0.03	0.53
	% error	–	7.14	10.96	3.34	1.67	12.96

Table 10: Elemental composition of tailings, overburden and soil in percent cont'd.

SITE		L.O.I	Mg	Na	Al	Mn	Ca
West Adit	n	13	11	12	12	13	12
	$\bar{x}$	5.90	3.80	0.30	5.28	0.30	3.08
	sd	5.52	1.27	0.14	1.41	0.69	3.53
	% error	–	8.08	7.78	3.67	2.13	15.26
Garbage Creek	n	1	1	1	1	1	1
	$\bar{x}$	2.1	1.64	1.71	5.66	0.51	1.37
	sd	–	–	–	–	–	–
	% error	–	25.39	3.70	4.26	1.29	28.34
Bear Creek:	n	1	1	2	2	2	2
	$\bar{x}$	8.01	1.49	1.42	4.40	1.07	1.64
	sd	–	–	0.27	1.39	0.91	0.50
	% error	–	25.10	5.20	8.13	1.08	26
Parking Lot:	n	2	2	2	2	2	2
	$\bar{x}$	3.45	2.47	1.52	5.08	0.49	1.21
	sd	2.05	0.04	0.22	0.14	0.47	0.45
	% error	–	15.85	3.42	3.72	1.09	20.67
Bear Bay:	n	–	1	1	1	1	1
	$\bar{x}$	–	0.67	1.71	6.03	0.07	1.14
	sd	–	–	–	–	–	–
	% error	–	12.71	1.37	2.67	1.76	14.02
Control Soil:	n	1	1	1	1	1	1
	$\bar{x}$	11.6	1.85	2.63	4.72	0.04	<0.36
	sd	–	–	–	–	–	–
	% error	–	8.26	1.02	3.10	2.22	–

from uranium tailings, or process wastes. Sodium and manganese are low in West Adit, Murphy Creek and Murphy Bay. The material from the West Adit is acidic with a pH of 4.7, but Murphy Creek and Murphy Bay are neutral materials with pH 6.9 and 7.4 (Table 9). The similarity in elemental concentrations despite the pH differences suggest similar material with differing discharge histories. Considering the location of the sites and the sequences of events of discharging mill tailings on Port Radium, these locations likely contain some uranium mill tailings or remnants thereof.

Uranium tailings were discharged unneutralized after a sulfuric acid leach process. This explains the acidic nature, and the relatively high uranium concentrations of West Adit. The ore was relatively rich in uranium and the extraction process likely not very efficient. Though Murphy Creek, has received uranium tailings discharged from Murphy Lake, it has since been neutralized by liquors of accidential spills of silver tailings into Murphy Creek. The liquid/solid ratio of the silver tailings was high. Large amounts of mine water passed through the tailings line and the treatment facility. The amount of silver tailings which would have reached Murphy Creek during the tailings line disfunction would have been small. The amount of alkaline liquid was sufficient to neutralize the acid which remained in the old uranium tailings material. Such an event could not have occurred in the West Adit area the tailings acidic. The material in Murphy Bay is, therefore, also closer in character to uranium tailings. The elemental characteristics of material in outer Labine Bay, are as varied as the wastes which went into the Bay.

If this interpretation reflects the waste identified on West Adit, Murphy Creek and Murphy Bay, the radionuclide concentrations should confirm their character. Due to a completely different chemistry of the extraction processes of uranium and silver, silver tailings will contain less radium-226 and lead-210 as compared to uranium tailings. In Figure 14, the concentrations of radium-226 and lead-210 are presented for the Silver Point tailings, West Adit area and Murphy Lake and Creek. The Silver Point tailings are low in radium-226 and lead-210, ranging from 3.4± 0.6 to 20.1± 0.8 pCi/g and 3.4± 0.5 to 23± 0.8, respectively. In Murphy Lake, the concentrations of radium-226 are slightly higher, ranging from 8.2± 0.7 to 75.9± 2.0 pCi/g for radium-226 and 2.6± 0.4 to 30.7± 1.0 for lead-210. The error reported is the analytical error associated with the counting statistics and not the standard deviation. In West Adit area and Murphy Creek, the radium-226 and lead-210 concentrations are significantly higher, compared to the silver tailings areas (Figure 14). If the elemental concentrations in Tables 9 and 10 suggest differences beween these sites tentatively, the radionuclide concentrations leave little doubt that these locations differ. The postulated events in Murphy Creek would result in relatively lower concentrations of radium-226 than those in the West Adit, as this area was not subject to neutral liquor discharges during the silver operation.

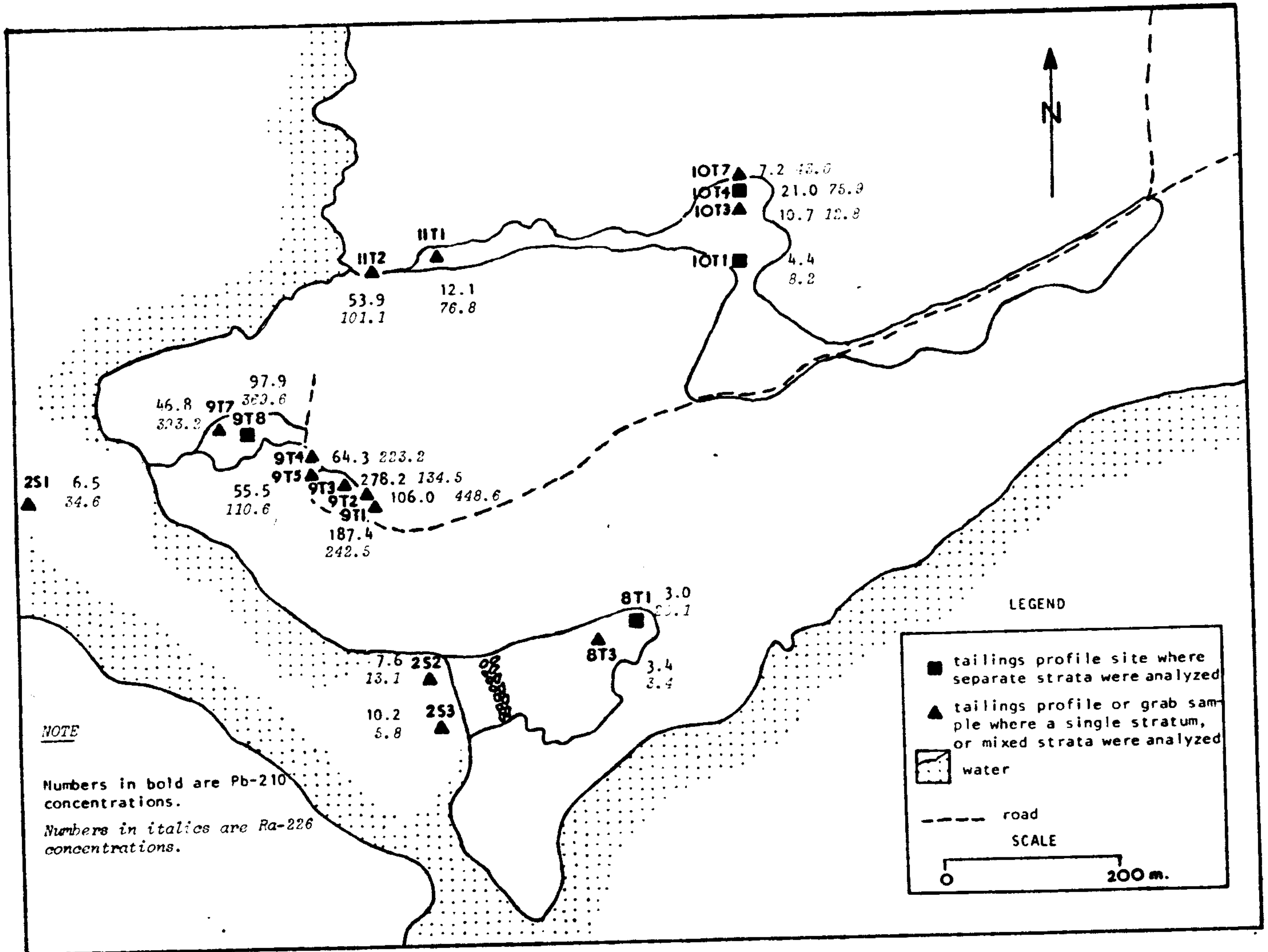


Figure 14: **Radium-226 and lead-210 (pCi/g) concentrations collected from Silver Point Tailings, West Adit, Murphy Lake and Creek are given with respect to their locations.** Mean concentrations are reported for the sites were strata in profiles were analyzed separately.

In this survey, only a limited number of samples for radionuclide concentrations were analyzed due to financial constraints. Some of the results can be associated with the depth of the sample and the material characteristics. Generally, higher concentrations of radium-226 and lead-210 are expected in 'fines' or clay-like material. The profile 10T4 (Figure 15), at the edge of Murphy Lake, contains varied material and radium-226 concentrations of 102-114 pCi/g in coarse light brown and dark brown material in the lower strata. This material was similar in texture to that found in the West Adit area (Plate 14 - site 9T8). The material in profile in West Adit, however, contains more radium and lead-210 than the material in the profiles 10T1, 3 and 9. The fines (grey strata) at the bottom of pit (Plate 14) have the highest radium-226 concentration determined of all samples. This material is different from the grey fines in the pits on Murphy Lake (10T1, 10T3) and in the Silver Point tailings pit. A second location in the West Adit area was sampled (9T7) where fines and brown coarse were separated. The coarse brown material here had extremely high concentrations of radium-226 at 521± 4 white fines contained 266± 2 pCi/g.

A surface encrustment (Plate 15), found on the West Adit slope has been analyzed separately. The layer can easily be separated from the tailings material underneath. The radim-226 concentration in the layer was 112± 2.5 pCi/g and a composite sample of the material below contained 109± 2.5 pCi/g of radium-226. The respective lead-210 numbers are 60± 1.4 pCi/g in both samples These results suggest that radium-226 is not in a water soluble form in the material, as the concentrations are the same. The encrustment is likely a result of evaporation and subsequent upward movement of salts which is frequently observed on tailings sites.

The limited number samples does not allow any definite conclusions about the textures which are associated with high radium concentrations. The radionuclide concentrations encountered are very high, compared to other uranium tailings investigated.

In Figure 16, the concentrations of radium-226 and lead-210 in sediments in Labine Bay, at the mouth of Labine outer Bay and in the Garbage Lake system are depicted. The distribution is consistent with the previous findings for all locations, namely, low concentrations in silver tailings. The sites 5S3 and 5S4 consist mainly of natural sediment (Plate 13). Those are in contact with ore body veins (Griffith, 1967) as was the water sample in West Bay Bear.

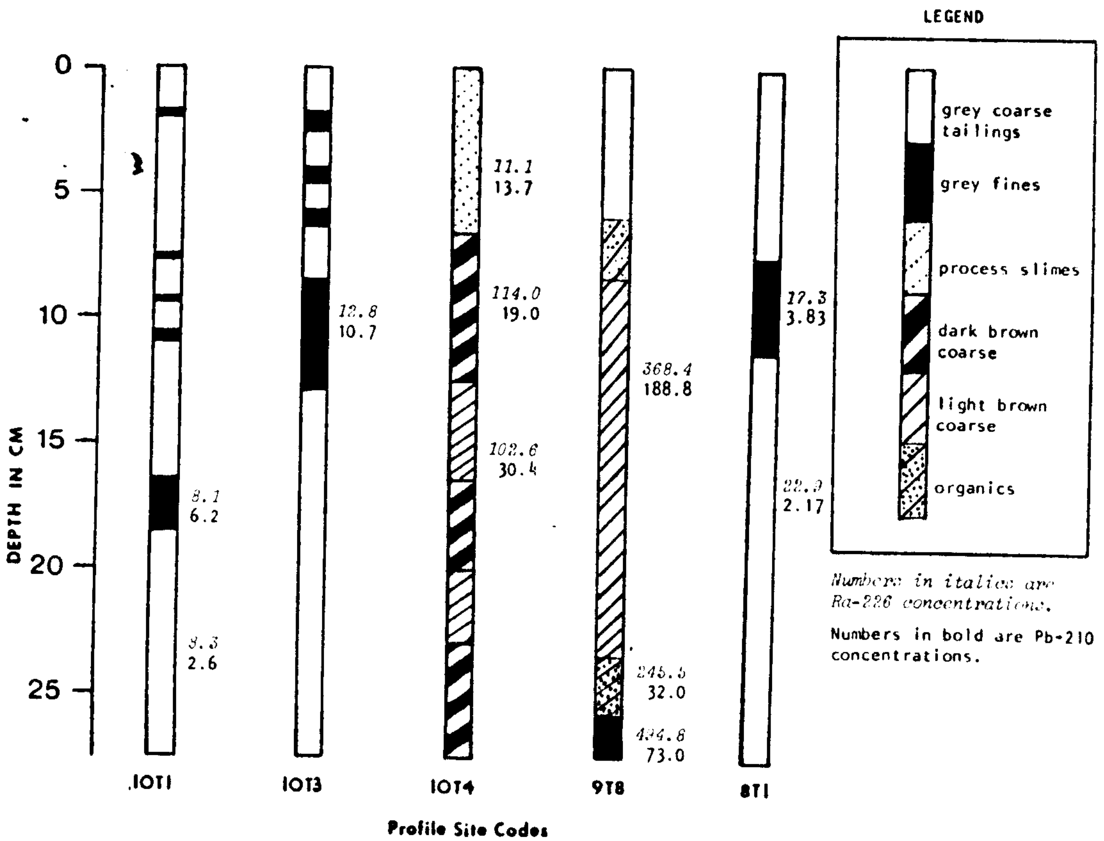


Figure 15: **Radium-226 and lead-210 concentrations (pCi/g) for strata.** Strata analyzed separately are presented with respect to depth of stratum.

Plate 14: **West Adit Area:**
The heterogenous layers with differing materials can be observed in the sample pit (9T8 - Map 4).

Plate 15:;T{ West Adit Slope Encrustment T};63

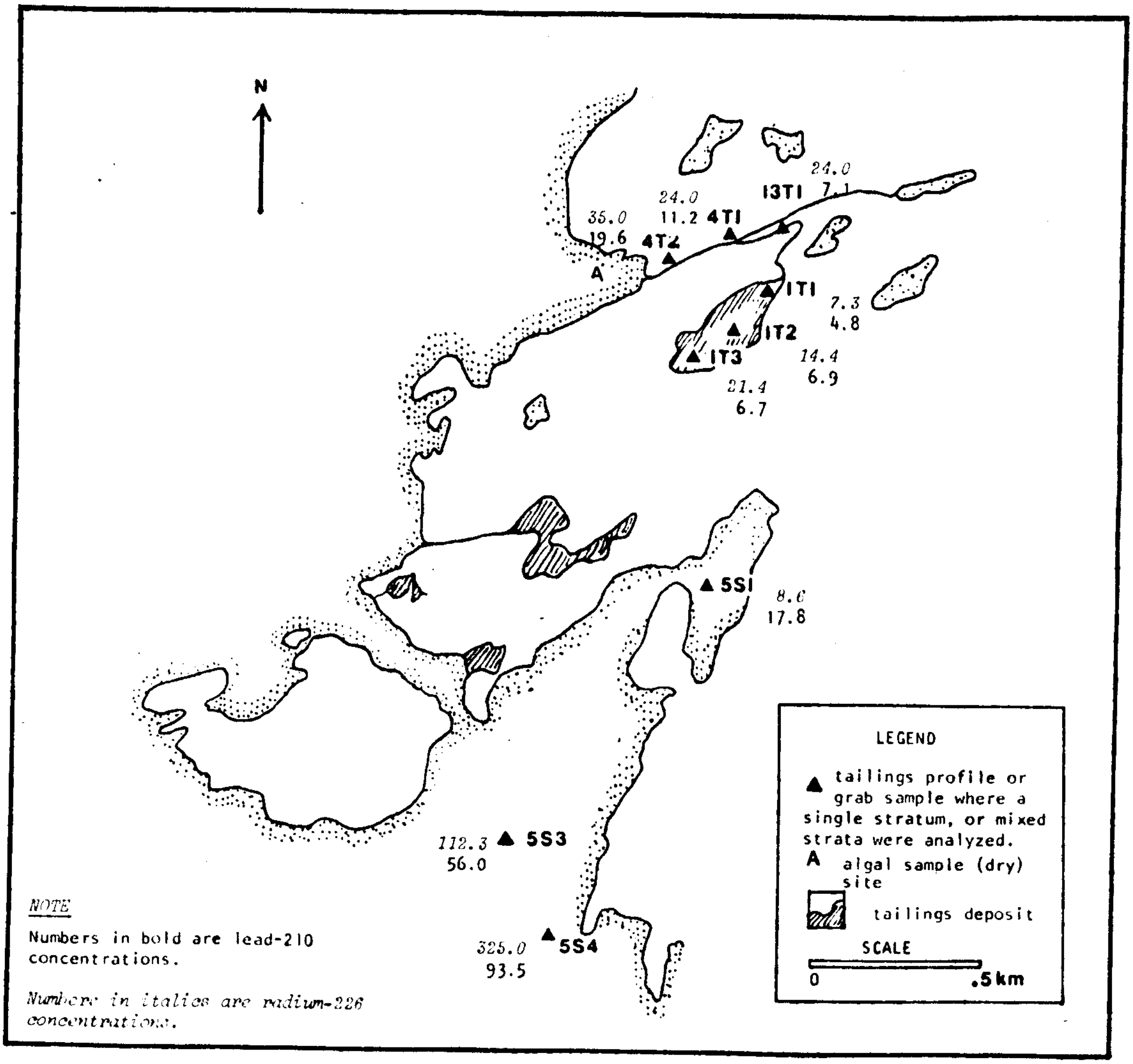


Figure 16: **Radium-226 and lead-210 concentrations in sediments and tailings for the Port Radium vicinity.**

3.4 Terrestrial Vegetation.

Waste areas were sampled for plants which could be associated with tailings or waste rock. The collection is not a complete list of plants which can be found, but rather represents those species which were most frequently encountered. These species can be considered as the major components of the plant communities, which are in close association with the wastes. In Table 11, the species listed for the surveyed areas are grouped by families. Bear Creek was not surveyed, due to lack of time, but is expected to be similar to Murphy Creek in species composition. In Murphy Creek, 15 species from 11 families were collected, which is the most diverse community which had been exposed to tailings effluents. An overview of the vegetation for Bear Creek (Plate 9) suggests that its vegetation might be similar to Murphy Creek. Effluent discharge damage is very local (Plate 10) evidenced by the overall vegetation cover. The species richness in the West Adit area was slightly lower than in Murphy Creek with a total of ten species from six families. Vegetation has either survived the discharges of the acidic slurries on re-established since.

The waste rock from the silver mining beside Shaft No. 1 is was too recently deposited for plants to have established yet. An old waste rock pile was visited on the northern slope of Cross Fault Lake. This small working is probably at least 40 years old. Lichens and mosses have established in cracks. As well occasionally some Kentucky blue-grass (*Poa praetenses*) is present. One Paper birch (*Betula papyrifera*) was found and collected to determine the age of the specimen. Though the tree was only about 25 cm in height ring counts showed through the tree to be 24-26 years old. The tree rings indicate that the recent four to six years had experienced more extensive growth than the previous years. The number of years required to obtain such a small height of the Birch suggests that colonization of waste rock is extremely slow in this area. The waste rock piles close to Shaft No. 1 are more exposed than the waste rock heap visited in Cross Fault Lake. It is, therefore, reasonable to suggest that vegetation will colonize the silver waste rock very slowly, if at all.

Some waste rock from the uranium mining has been used to build the spit along Silver Point tailings. This material has also been surveyed for plants. No plants had established on the waste rock, but slopes which receive some overburden had some species of Mustard and Pea family. Rock cress (*Arabis alpina* and *A. hirsuta*) and oxytrope were most frequently found, but never extensive in cover.

During the shoreline survey (Map 2) vegetation on a control beach was collected. The flora is relatively rich with 13 species from 11 families. Generally, on all beaches, patches of vegetation were found. On Bear Bay beach, the vegetation appeared less diverse. Unfortunately, samples of plants were not collected.

Table 11: Major terrestrial plants associated with waste material in Port Radium.

FAMILY & SPECIES	OUTSIDE LAB	CROSS FAULT LAKE			MURPHY CREEK	WEST ADIT	CONTROL BAY	RANGE	HABITAT
	WRO	SWR	SHO	OWR		TLS			
LICHENS									
Cetraria cucullata (Bell.) Ach.				X			X	AAA	In meadows and among rocks.
Cetraria nivalis (L.) Ach.							X	AAA	In meadows and among rocks.
Cladonia cf. pyxidata (L.) Hoffm.				X				ATM	On humus and soil over rocks in open areas.
Cladonia spp.				X					
Stereocaulon cf. tomentosum Fr.							X	ATM	On soil over rocks and on humus.
BRYOPHYTES									
Aula cominium turgidum (Whal.) Schwaegr		X						ASA	Moist mossy areas.
Dicranum cf. majus Sm.							X	ABO	Rocky scree slopes.
cf. Dicranella spp.				X					
Bryum cf. capillare Hedw.					X			COS	
Indeterminate Bryaceae cf. Pohlia						X	X		
Bryum argenteum Hedw.						X		COS	Most prevalent on rocks at high elevations in Arctic and Antarctic.
Thuidium abietinum (Brid.) B.S.G.							X	ATM	On soil and rocks, usually calcareous.
Ptilidium ciliare (L.) Hampe				X				ATM	On soil over rocks.
EQUISITACEAE									
Equisetum arvense L.		X			X			ATM	Habitat and soils variable; weed.
Equisetum hyemale L.			X					BOT	Sandy soils and woods.
Equisetum scorpiodes L.						X		BOT	Conifer woods, tundra, heaths, swamps.
CYPERACEAE									
Carex aquatilis Wahlenbb. ssp. *aquatilis*			X					ABO	Shallow water, marshes, along rivers.
Eriophorum cf. angustifolium Honck.			X					ATM	Wet bogs and shores.

AAA = arctic and arctic alpine
ASA = arctic and sub-arctic
COS = cosmopolitan
WRO = waste rock and overburden
SHO = shores
TLS = tailings

ATM = arctic and temperate
ABO = arctic and boreal
BOT = boreal and temperate
SWR = side of waste rock
OWR = waste rock

Table 11: Major terrestrial plants associated with waste material in Port Radium cont'd.

FAMILY & SPECIES	OUTSIDE LAB	CROSS FAULT LAKE	MURPHY CREEK	WEST ADIT	CONTROL BAY	RANGE	HABITAT
	WRO	SWR SHO OWR		TLS			
ERICACEA							
Pyrola asarifolia Michx. *v. purpurea* (Bunge) Fern.					X	BOT	Woods, meadows.
Ledum groenlandicum Oeder					X	ATM	Heaths, dry rocky places.
EMPETRACEAE							
Empetrum nigrum L.				X		ARC	Heaths, bogs.
Arctostaphylos uva-ursi (L.) Spreng.				X		ABO	Dry sandy places.
ONAGRACEAE							
Epilobium angustifolium L.		X				ATM	Meadows, forests, river bars, burnt areas.
Epilobium latifolium RL.					X	ABO	River bars, along streams, scree slopes.
CRUCIFERAE							
Descureana cf. sophoides (Fisch) Schutz		X				BGA	Gravel bars, disturbed soil.
Arabis alpina L.	X						
Arabis hirsuta (L.) Scop *var. pyono carpa* (Hopk.) Hult.	X					ATM	Dry rocky places.
Rorippa hispida (Desv.) Britt.	X					BOT	Waste places open soil.
LEGUMINOSAE							
Oxytropis varians (Rydb.) Hult.	X		X			AMT	Dry sandy places.
Hedysarum alpinum v. americanum			X		X	BOR	Rocky slopes, spruce forests, gravel bars.
SAXIFRAGACEAE							
Saxifraga tricuspidata					X	ABA	Dry, sandy places; rock crevaces, ridges.
PRIMULACEAE							
Androsace septentrionalis L.	X					ABO	Dry rocky, sandy places in mountains.
COMPOSITAE							
Aster cf. sibericus L.			X			BAB	Stony slopes, river flats, meadows.

BOT = boreal and temperate
ARC = arctic
BGA = Beringian arctic
BOR = boreal
ABA = arctic, boreal, North America
WRO = waste rock and overburden
SHO = shores
ATM = arctic and temperate
ABO = arctic and boreal
AMT = arctic and mountain
BAB = Beringian arctic and boreal
TLS = tailings
SWR = side of waste rock
OWR = waste rock

Table 11: Major terrestrial plants associated with waste material in Port Radium cont'd.

FAMILY & SPECIES	OUTSIDE LAB	CROSS FAULT LAKE			MURPHY CREEK	WEST ADIT	CONTROL BAY	RANGE	HABITAT
	WRO	SWR	SHO	OWR		TLS			
GRAMINEAE									
cf. Agnopyron viplaceum (Hornem) Lang.							X	ABO	Sandy gravelly river bars.
cf. Calamagrostis canadensis (Michx.) Beauv.		X				X		BOT	Meadows, wet places; common.
cf. Calamagrostis neglecta (Ehrh.) Gaetn.		X						BOT	Shores, wet places; variable.
Poa cf. alpigena (E. Fries) Lindm.	X				X		X	ABO	Grassy, slopes, gravel bars (variation of *P. praetensis*).
Poa cf. praetensis L.				X		X		BOT	Waste places, roadsides, yards; weed.
PINACEAE									
Picea glauca Moench.					X			BNT	Forest tree.
Juniperus horizontalis					X			BNT	Rocky and sandy places.
SALICACEAE									
Salix bebbiana Sarg.					X	X	X	BOT	Moist or wet places.
Salix cf. lanata L. *spp. richardsonii* (Hook) Skrorte.						X		ARC	Wet places, heaths, riverbanks.
Salix cf. athabascensis Raup.		X						WBA	Pool margins, treed bogs.
BETULACEAE									
Betula glandulifera (*B. glandulosa* Michx.)					X	X		ANA	Wet places, swamps, bogs.
Betula papyrifera				X	X			BOT	Forest tree to shrub.
ELEAGNACEAE									
Shepherdia canadensis (L.) Nutt.					X			NBT	Woods, gravel bars.
ROSACEAE									
Potentilla fruticosa L.					X			NBT	Wet and dry ground; forests, heaths, muskeg, scree.
Rosa acicularis Lindl.					X			BOT	Woods, heaths, bogs, thickets.

ABO = arctic and boreal
BNT = boreal and northern temperate
WBA = west boreal, North America
ANA = arctic, northern temperate, North America
WRO = waste rock and overburden
SHO = shores
BOT = boreal and temperate
ARC = arctic
NBT = northern boreal and temperate
TLS = tailings
SWR = side of waste rock
OWR = waste rock

In summary, the brief survey of vegetation associated with mining waste material suggests the following trends. Waste rock will not be colonized to any extent by vegetation. Tailings patches are bare or covered with cushions of moss and horsetails (*Equisetum* spp.). Overburden spread over waste rock supports some herbaceous species. The vegetation damage due to discharges of tailings slurries through creek beds is limited and only noticeable in small depressions (Plate 10). Some tailings are retained in the depressions. Locations where any potential uptake of contaminants might be possible are West Adit, and some depressions in Murphy Creek and possibly around Murphy Lake. However, a waste rock cover of these areas, as proposed by Echo Bay Mines Ltd. would likely curtail plant growth. The vegetation analysis reveals that the only species which invade tailings are the horsetails and mosses. The silver tailings are low in radium-226 and thus contamination of vegetation in Bear Creek is unlikely.

4. CONCLUSIONS.

Port Radium (NWT), an historical place on the shores of Great Bear Lake, is a small mine site compared to other abandoned uranium mine sites in Ontario and Saskatchewan. The old uranium tailings sites are also small and covered with waste rock or silver tailings on land and under the water of Cobalt Channel and Labine Bay. One area (West Adit), likely associated with the uranium tailings, is approximately 1000 m^2 and is located below Shaft No. 1 in a depression with a small concrete V-notch vier. The waste material in this depression consists of many layers of organic material interspersed with tailings and slimes, the latter containing high concentrations of radium-226 and lead-210. The material is acidic, whereas the silver tailings, in addition to having low radionuclide concentrations, are neutral to slightly alkaline whether on land or under water. For all other uranium mill tailings locations it is suggested that the acidic wastes which have been covered with silver tailings have been neutralized. Therefore, detrimental effects which could arise due to acidification of the water have been ameliorated.

Microbial or chemical acid generation processes in the silver tailings in Cobalt Channel and Labine Bay are not apparent to date. They are unlikely to occur, as the temperatures in the water are generally low (3.5-4.0 *degree* C) and the gangue contains acid consuming minerals.

Water characteristics of Labine Bay and Cobalt Channel from past monitoring records were compared to characteristics measured in this survey. These represent conditions of several months after mining had ceased. The results suggest that the water quality parameters are similar to the conditions reported by Johnson (1975) for Great Bear Lake. Further information has to be obtained on the stratification of the water column in the area where submerged tailings remain before definite conclusions can be drawn with respect to the interaction of tailings and the water column. Observations on stratification in the immediate vicinity of the peninsula are sparse. Characteristics of natural lake sediments and water not in contact with mining wastes in Great Bear Lake appear to reflect the highly mineralized ore conditions. Confirmation of these preliminary observations are required. However, to date, no permanent effects of environmental consequence were apparent.

The water in Garbage Lake is stratified, despite the shallowness of the lake. Water characteristics in this tailings pond cannot be predicted based on the existing information. Some seepage occurs from Garbage Lake through the creek bed to Bear Bay. Slight increases of elemental concentrations were observed in Bear Bay which have resulted in extensive algal blooms of *Ulothrix* spp. which might accumulate heavy metals and radionuclides. The concentrations determined in algal biomass indicate accumulation of aluminum, but suggest only slight increases of other metals and radium-226 above background concentrations. It is concluded that the Garbage Lake/Bear Creek system requires further assessment.

Past water quality records suggested lead, arsenic, and iron contamination of the water. The water characteristics in Garbage Lake for 1982 are similar to those reported in the past. These conditions have to be evaluated in relation to the biological processes in these waters before potential long-term environmental trends in this tailings pond can be outlined. They are important as the tailings seepage reaches Bear Bay. At this point recommendations for the conditions under which the site should be abandoned cannot be made.

REFERENCES

1. **Allen, S.E., H.M. Grimshaw, J.A. Parkison and C. Quarmby,** "Chemical Analysis of Ecological Materials." S.E. Allen (ed.). Blackwell Scientific Publications, Oxford, 1974.

2. **Bowen, G.,** "Trace Elements in Biochemistry." Academic Press, New York, N.Y. 1966.

3. **Chambers, H.,** "Report: Field Trip to Echo Bay Mines, Port Radium." Environmental Protection Service, Department of Energy, Mines and Resources, May 22-25, 1973.

4. **Conard, H.S. and P.L. Redfearn,** "How to know the mosses and liverworts." Wm. C. Brown, Dubuque, Iowa. 302 pp. 1979.

5. **Environment Canada,** "Guidelines for Surface Water Quality, Volume 1: Inorganic Chemical Substances - Uranium." by John S. Langan, MacLaren Plansearch, Inc. Environment Canada, Water Quality Branch, Ottawa, Pub. No. 82-063(Eng.) and 82-064(Fr.). In press.

6. **Environment Canada,** "Water Quality Sourcebook: A Guide to Water Quality Parameters." by R.N. McNeely, V.P. Neimanis and L. Dwyer. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada, 1979.

7. **Falk, M.R., M.D. Miller, S.J.M. Kostiuk,** "Biological Effects of Mining Wastes in the Northwest Territories." Environment Canada, Technical Report Series No. CEN/T-73-10, Resources Management BR, Central Region, 1973.

8. **Griffith, J.W.,** "Chapter 4: Northwest Territories - Eldorado Mining and Refining Limited (Port Radium Mine)." IN: The Uranium Industry - Its History, Technology and Prospects. Department of Energy, Mines and Resources, Mineral Resources Division, Mineral Report 12, Ottawa, 1967.

9. **Hale, M.E.,** "How to know the lichens." **Wm. C. Brown, Dubuque, Iowa. 226 pp. 1969.**

10. **Hoffman, R.R.,** "Eldorado Mining and Refining Port Radium, NWT." IN: The Milling of Canadian Ores, 6th Commonwealth Mining and Metallurigical Congress, 1957.

11. **Johnson, L.**, "Temperature of Maximum Density of Fresh Water and its Effect on Circulation in Great Bear Lake." *J. Fish. Res. Board Canada*, 23(7):963-973, 1966.

12. **Johnson, L.**, "Distribution of Fish Species in Great Bear Lake, NWT., with reference to Zooplankton, Benthic Invertebrates, and Environmental Conditions", *J. Fish. Res. Board Canada*, 32:1989-2004, 1975.

13. **Johnson, L.**, "Physical and chemical characteristics of Great Bear Lake, Northwest Territories", *J. Fish. Res. Board Canada*, 32:1971-1987, 1975.

14. **Kalin, M.**, "Identification of Potential Environmental Problems at Port Radium. Field Report: In search of uranium mill tailings." Submitted to: Environmental Protection Service, Environment Canada, Yellowknife, NWT, in fulfillment of Contract No. 0183, 1982.

15. **Kalin, M.**, Long-term Ecological Behaviour of Abandoned Uranium Mill Tailings. 1. Synoptic Survey and Identification of Invading Biota." Environment Canada, Atomic Energy Control Board, and Energy, Mines and Resources Canada, 1982.

16. **McLaren, J.R.**, "Inspection Report on Echo Bay Mines Limited: Mine-Mill Operation." Water Management Section, Department of Indian and Northern Affairs, Yellowknife, NWT. Ref. File: N2A3-0331, 1975.

17. **Moore, J.W. and D.J. Sutherland**, "Distribution of Heavy Metals and Radionuclides in Sediments, Water and Fish in an Area of Great Bear Lake Contaminated with Mine Wastes." *Arch. Environm. Contam. Toxicol.*, 10:329-338, 1981.

18. **Ministry of the Environment**, "Guidelines for Surface Water Quality. Volume 1: Inorganic Substances." S.W. Reeder (ed.). Inland Waters Directorate, Water Quality Branch, Environment Canada, 1979.

19. **Redshaw, A.G.**, "Correspondence re: Summaries of Water Quality Data from Operating Mines." Indian and Northern Affairs, Yellowknife, NWT., 1974.

20. **Roy, M., and S. Vezina**, "Studies of Mine Waste Containment at Mining Sites on Great Bear Lake." ALUR 1972-73, Indian Affairs and Northern Development. DIAND Pub. No. OS-3039-000-EE-A1, 1973.

21. **Schuster, R.M., W.C. Steere, and J.W. Thomson**, "The terrestrial cryptograms of northern Ellesmere Island." *National Museums of Canada Bull.*, 164, 1959.

22. **Sebesta, F., P. Benes, J. Sedlacek, J. John, and R. Sandrik,** "Behavior of radium and barium in a system including uranium mine waste waters and adjacent surface waters." *Environ. Sci. & Tech.*, 15(1):71-75, 1981.

23. **Sutherland, D.J.,** Environmental Protection Service, Environment Canada, Yellowknife, NWT., personal communication, 1983.

24. **Sveinson, F.J.,** Correspondence re: Water Licence No. N2L3-0038 - Part C-21. Echo Bay Mines Ltd., 1979.

25. **Whicker, F.W. and V. Schultz,** "Radioecology: Nuclear Energy and the Environment, Volume 1." CRC Press, 1982.

26. **Wilson, B.,** Environmental Protection Service, Environment Canada, Yellowknife, NWT., personal communication, 1983.

27. **Wilson, H.R.,** "Report on Echo Bay Mines Limited: Modifications to the McDonough Lake Tailings Area." Water Resources Division, Department of Indian Affairs and Northern Development, Yellowknife, NWT., 1978.

28. **Woollett, G.,** "The Eldorado Mine and the Echo Bay Group." Presented at the 1972 Exploration Symposium, Yellowknife, NWT., 1972.

29. **Zigarlick, J., Sr.,** Personal communication, 1982.