Atomic Energy of Canada Limited

MOVEMENT OF RADIOACTIVE WASTE THROUGH SOIL

4. Migration from a Single Source of Liquid Waste Deposited in Porous Media

CRER-1077

by

P.J. PARSONS

Chalk River, Ontario

March, 1962

AECL-1485

CRER-1077

MOVEMENT OF RADIOACTIVE WASTE THROUGH SOIL

4. Migration from a Single Source of Liquid Waste Deposited in Porous Media

by

P.J. Parsons

SYNOPSIS

A soil survey has been carried out in a wooded region surrounding a disused plant where waste liquid fission products were concentrated. During operations in 1954 acid waste containing complexing agents and more than 1000 nominal curies of mixed fission products was poured into a pit excavated in dry sand and lined with limestone. Radionuclides migrated in the groundwater away from the disposal pit and the pattern of this movement has been investigated by intensive sampling with a multiple soil sampler.

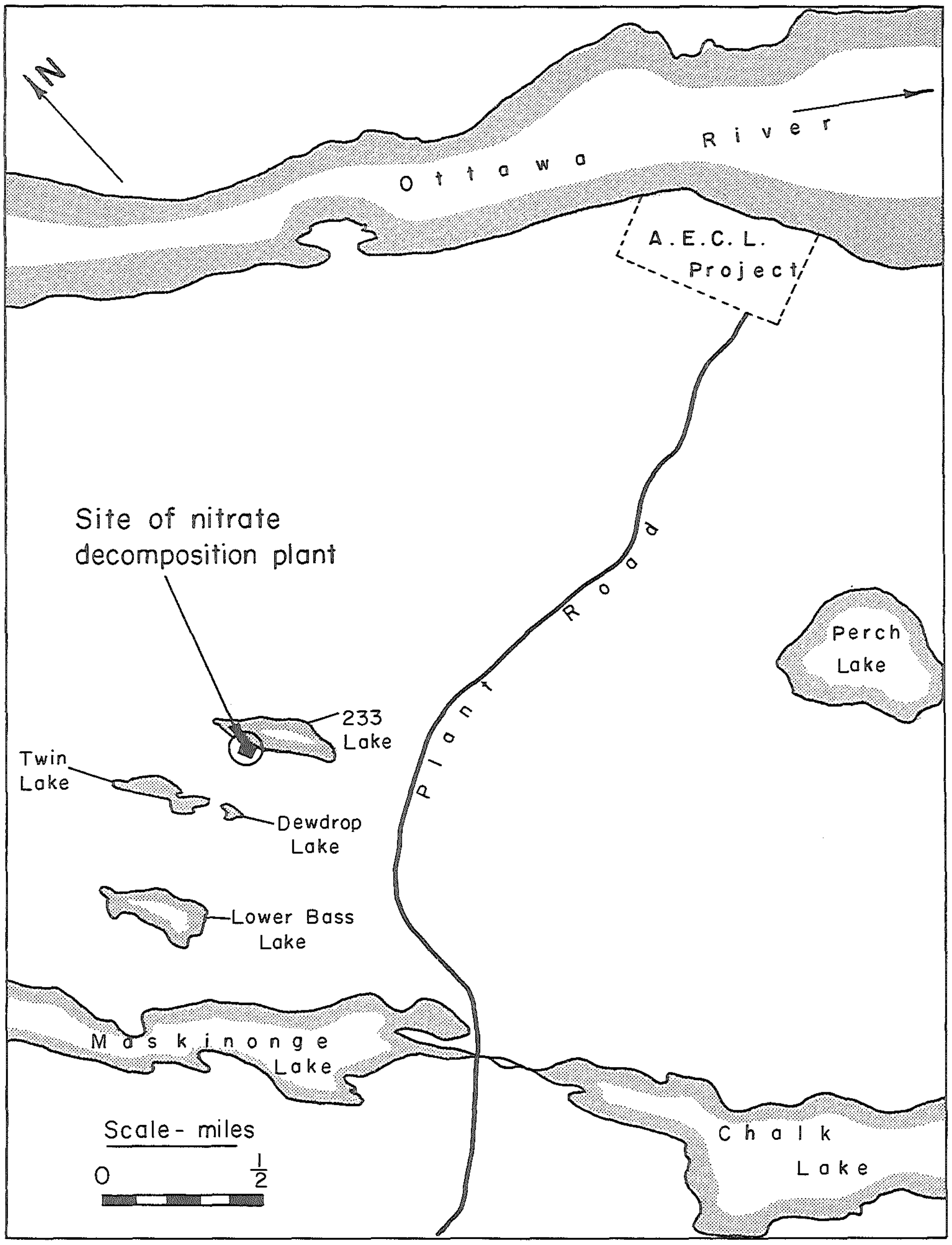
Ruthenium-106 migrated rapidly soon after the disposal. This was followed by slower moving strontium-90 that has now developed into a continuous tongue 650 ft long, containing 800 curies. No other radionuclides were found in the tongue. It is estimated that Sr-90 will escape into surface waters in about 130 years. However, the rate of release will not cause the concentration in a nearby drainage stream to rise above the maximum permissible concentration for occupational workers (ICRP).

The report is accompanied by 14 figures and 3 tables.

Chalk River, Ontario
March, 1962

TABLE OF CONTENTS

Figures



General Plan showing site of decomposition plant in outer area of Chalk River Project.

INTRODUCTION

During 1953/54, disposals of radioactive liquid were made into the soil at an isolated site in the outer area of the Chalk River Project. These disposals came from a small ammonium nitrate decomposition plant, in which solutions of aged waste fission products were treated to remove large quantities of dissolved ammonium nitrate and then concentrated by evaporation. A small pit had been excavated nearby and partially filled with limestone, to receive the condensate from the decomposer unit. After one year's operation the process was halted and by this time the pit had absorbed much more liquid than had been anticipated owing to spillage and malfunction of the equipment. An estimated[1] 1000 to 1500 curies of mixed fission products were discharged to the pit, of which 700-1000 curies were probably strontium-90.

The plant was situated in a wooded region where occasional outcrops of granite bedrock protrude through the overburden of sandy soil. There are lakes nearby and water samples from some of these have shown[2] that ruthenium-106 was present, having migrated with the ground water away from the site of disposal.

Since it was probable that this radionuclide was preceding a much larger migration of other fission products, an investigation of the subsoil was carried out to find the track of moving radionuclides, to determine their species and to measure their rate of movement. Another objective was to estimate when they would emerge from below ground and so contaminate surface waters.

Description of Site

The processing buildings (General Plan) lay near the boundary of a catchment area draining into Maskinonge Lake, which is one of a series of lakes that lie along an abandoned channel[3] of the Ottawa River. These lakes rejoin the main river about 5 miles downstream through Chalk Lake; thus run-off from the plant site passes via the Maskinonge system to the Ottawa River.

A more detailed plan of the area (Fig. 1) shows the site of the processing buildings on a ridge adjacent to 233 Lake. The ground slopes downwards to the west where, 800 ft away, lie Dewdrop and Twin Lakes, whose elevations are roughly 24 ft lower than that of 233 Lake. Dewdrop has no surface flow connections but the other two lakes are fed by inlet streams. No contamination was found in the higher (233) lake close to the disposal pit but ruthenium was detected in Dewdrop Lake, indicating that the direction of percolating ground water was from the higher lake down towards Dewdrop Lake. This conclusion was confirmed by measurements of radiation taken inside dry aluminum tubes that were sunk in the soil, intersecting the radioactive track to the west of the disposal.

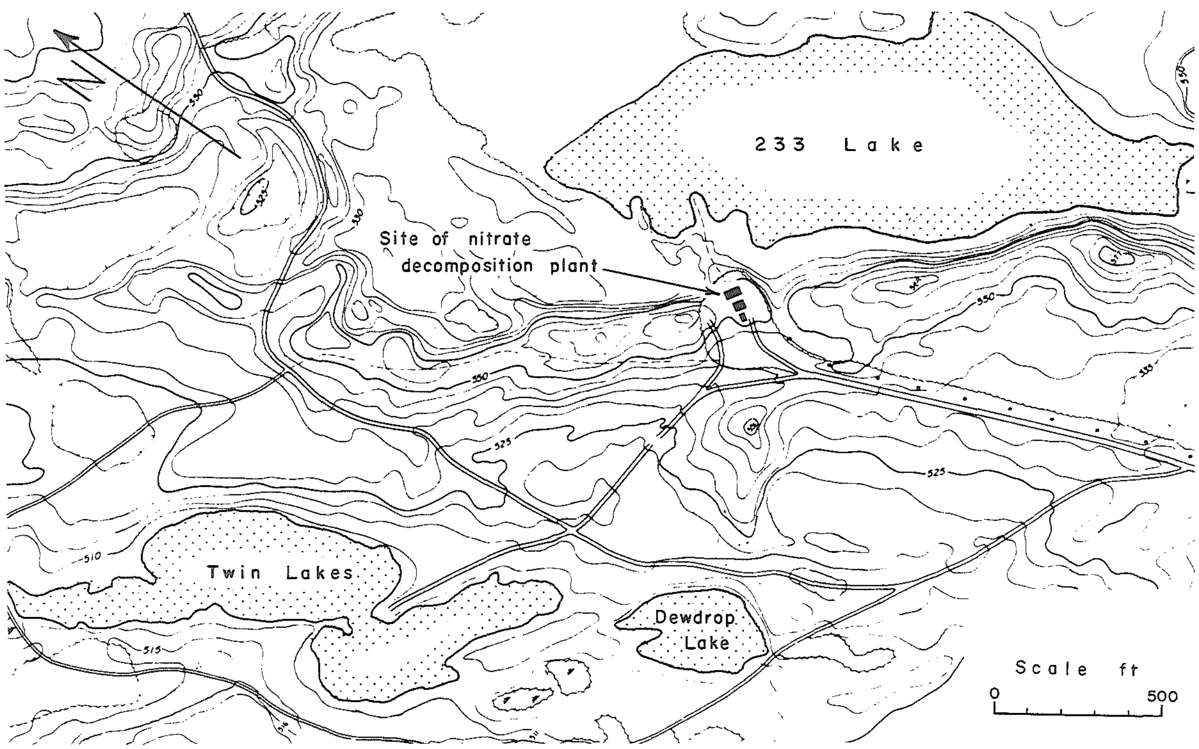


Figure 1. Plan of area surrounding the nitrate decomposition plant.

Nature of Radioactive Waste

The composition of the fission product solution poured into the pit was not known. The largest single discharge of 700 curies in November 1954 was composed of 68% Sr-Y, 23% Cs, 8% Ce and 1% Ru, and probably some dissolved ammonium nitrate. The remainder of the liquid disposals (> 300 curies) are known to have contained both acids and detergents.

PROCEDURE & RESULTS

The field work was divided into two stages; the first was a general examination of ground conditions in the surrounding area and the second a detailed investigation along the track of migrating radionuclides. The results of each phase will be presented separately with appropriate procedure and results.

Part 1. Procedure

A series of bore holes was made to establish the nature of the overburden and the configurations of bedrock and water table.

Twenty boreholes were sunk with 4-in. casings and undisturbed soil samples were collected using a compressed-air soil sampler[4] in conjunction with washboring. Sampling was carried out through the entire mantle of granular overburden and was halted only by bedrock or glacial till. Soil samples were taken in 2-in. diameter steel tubing and tested for permeability and grading. When each boring was completed a standpipe with an attached well-point was inserted into the casing before the latter was withdrawn. The pipes were surveyed, levelled and subsequently used to find the elevation of the water table over an area of 35 acres.

To the west of the region, where the overburden thins and there are granite outcrops, more information was needed to complete the contours of bedrock. The main drilling program was therefore augmented by an additional series of probings in which bedrock was proved by forcing down E drill rod with a light automatic hammer. In this way many additional bedrock levels were measured but no soil sampling was attempted.

Results of Part 1

The plan of the boreholes is shown in Fig. 2, together with contours of bedrock. The area of interest is bounded by two ridges of bedrock that rise to approximately the same elevation (+500 ft) and run roughly parallel in a northwest - southeasterly direction. The eastern ridge lies beneath the site of the decomposition plant; bedrock dips to the west to a depression 30-40 ft lower before it rises again to the western ridge. Part of the western ridge outcrops between Dewdrop and Twin Lakes and another section outcrops 1000 ft to the south. Between these there is a gap through the ridge about 100 ft wide that acts as an outlet to the bedrock bowl. A rock sill forms the base of this gap and its elevation (+ 473 ft) is about 10 ft higher than the bed of the depression.

Borehole results are plotted in Figure 3. Soil samples have shown that the overburden is composed of sands containing occasional bands of sandy or silty loam. At the site of the decomposition plant the overburden is over 50 ft thick, (shown at borehole L3, centre section Fig. 3); the top 20 ft being wind-blown sand and the lower section being water deposited laminated sands with pronounced horizontal bands of micas and garnets. Moving westwards the surface profile dips and finally levels out over the depression in the bedrock (boreholes L7, L11, Fig. 3) where the overburden is between 40-50 ft thick. In this region ground water lies about 10 ft below the surface.

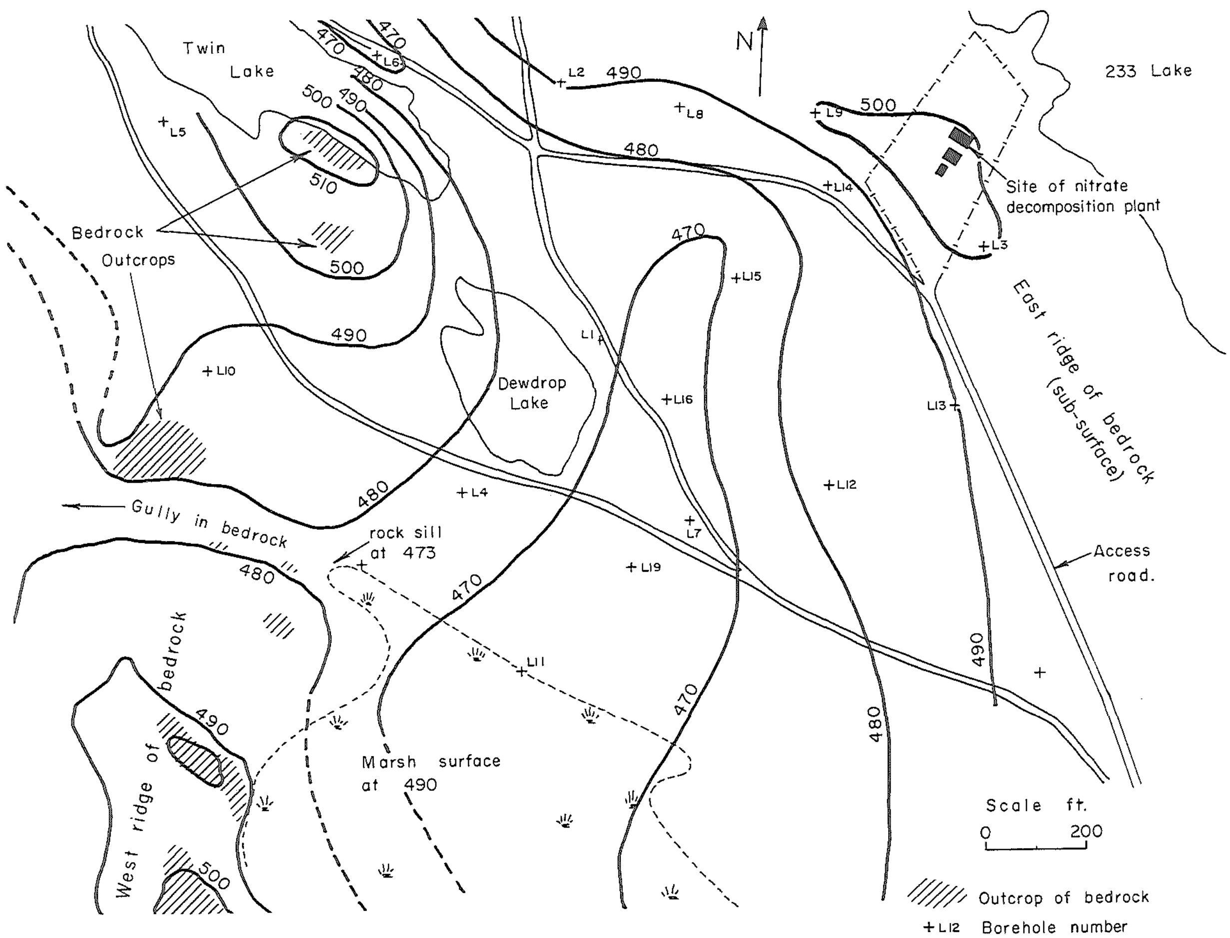
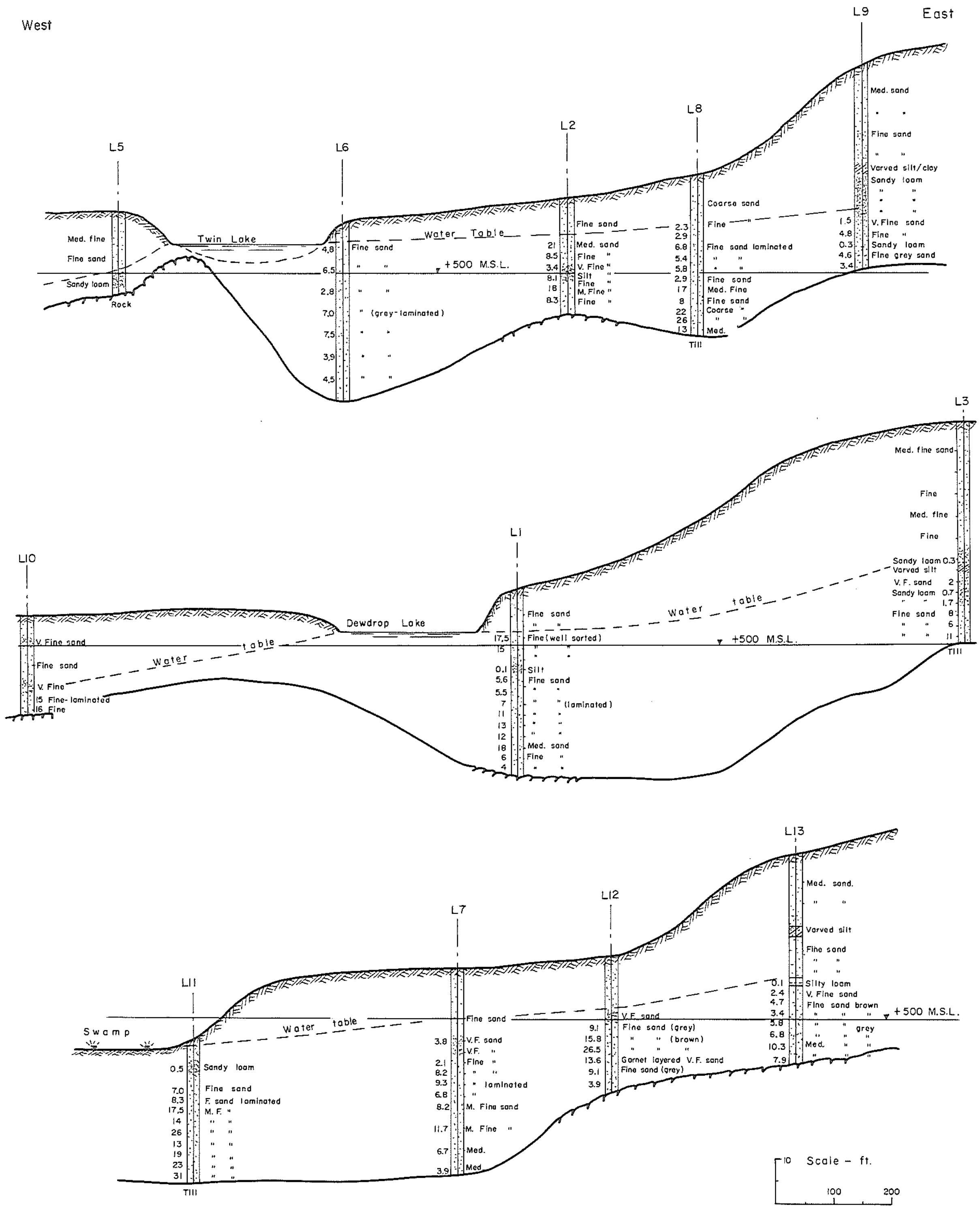


Figure 2. Plan of boreholes and contours of bedrock. Eastern Ridge is covered but western ridge has numerous outcrops and a gully passing through it.



Figures denote permeability factor in cu. ft. per sq. ft. per day

Figure 3. Borehole results presented in three East-West cross sections. (Figures denote permeability factors in cu ft/sq ft/day)

Only soils within the saturated zone have been examined and it was found that the layers of silty loam, numerous beneath the decomposition plant, had almost disappeared in the depression. Thus the deposits in the depression are generally medium sands with a greater permeability than those above the eastern ridge. These sands continue over to the western bedrock ridge and into the gap through it.

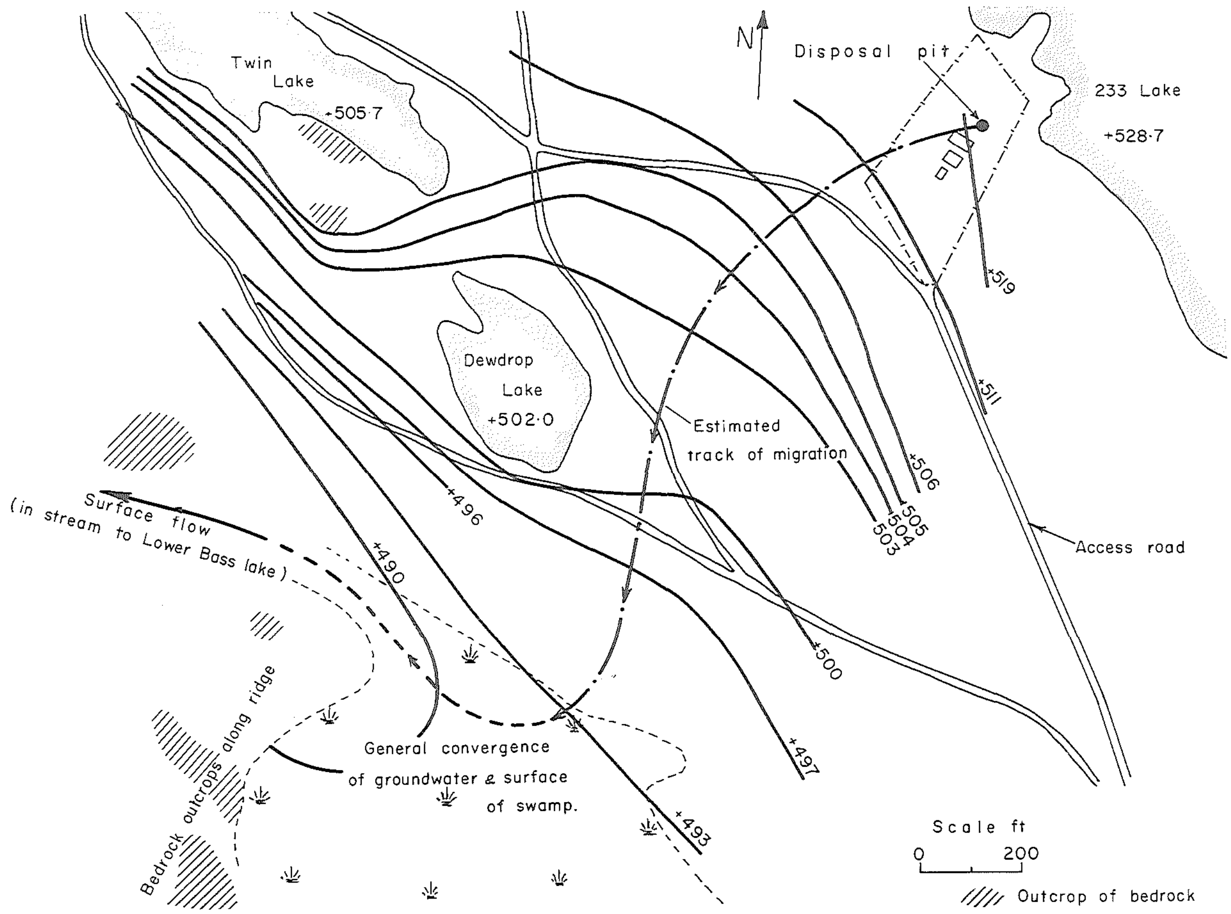


Figure 4. Contours of water table showing estimated path of ground water percolating from disposal pit to swamp.

Water Table

In Figure 4 the contours of the water table have been plotted, showing that the predicted flow-line from the disposal point curves westward to skirt the southern edge of Dewdrop Lake and enter the soil of the swamp adjoining the western ridge. The flow beneath this swamp is directed toward the gap in the ridge, where most of the ground water seeps to the surface. Water levels in the three lakes correspond to neighbouring groundwater levels and the shape of the groundwater surface has been controlled by boundary conditions of rising bedrock that sometimes intersect its surface.

Part 2. Procedure (Sampling for radioactivity)

The search for radionuclides moving from the disposal pit was concentrated along the predicted line of ground water seepage. (Fig. 4). This lay on a 1000-ft arc of 815-ft radius and transverse lines were set out at intervals along the arc. Borings were made 20 ft apart along each line and extended in both directions until the breadth of the migrating track had been spanned and soil samples had indicated the boundaries of radioactive seepage.

Sampling of soil for radio-assay was carried out using a multiple soil sampler[5], a portable device designed for the collection of large numbers of disturbed granular soil samples. In earlier work the sampler had been driven as a probe directly into the soil and had successfully penetrated depths exceeding 60 ft. However, in this area, deposits of compact coarser sands at depths below 40 ft proved impenetrable by this means and wash-boring was adopted.

E type casing (I.D. = 1.5 in.), a flush-jointed steel tubing, was forced into the soil using a "Cobra" automatic hammer. Driving and washing were carried out simultaneously by passing a 1/2 in. hose down the casing to direct a stream of water on the soil at the toe. The dislodged soil was carried in suspension with the return flow and was discharged through an overflow near the top of the casing into a nearby hole in the ground. In this manner the casing was driven down to bedrock or boulders; the assembled string of sampling units was then lowered down inside and left in the soil as the casing was withdrawn. The normal sampling procedure followed, in which soil was allowed to enter the bore of the sampler at selected points along its length. The method proved successful with no cross contamination between samples from different strata.

Samples were dried to constant weight and 50 mg of each were counted for total $\beta\gamma$ activity in an end-window β counter. Some samples were analysed for individual radionuclides.

Since boreholes had been made along lines at right angles to the radioactive track, the counts from soil samples could be plotted at appropriate positions and depths to illustrate in a vertical cross section the distribution of radionuclides in the soil. This showed the region of highest contamination and indicated where boreholes in the next line should be driven to intercept the radioactive track. This procedure was continued until a line of borings was driven ahead of the migration. At this point soil sampling was carried out along the predicted centre line of movement until the 'front' of radioactive soil was encountered.

After this phase of the work was completed, soil sampling was transferred to another source of possible migration; a limestone-filled pit 600 ft away (Fig. 5) where disposals of liquid thorium waste had been made. Radioactive soil was found no further than 10 ft from the pit, showing that migration from the source was negligible.

Water samples were taken from the same points where soil samples had previously been collected. They were taken by withdrawing 100-ml samples from porous bronze points[6], driven to position on the end of E drill rod. The samples were collected by suction through polyethylene tubing passed down the drill rod into the bronze cylinder. Samples (10 ml) were dried and counted for total $\beta\gamma$ activity and the results were plotted on a cross section to verify the distribution of contamination shown from earlier soil samples.

Results of Part 2

Figure 5 shows the transverse lines of boreholes that were needed to outline the radioactive tongue that had formed. These were spaced 150, 325, 525, 625 and 725 ft from the disposal point with an auxillary line at 575 ft. The four principal cross sections through these lines will be examined in this order. (The 725-ft section was not contaminated).

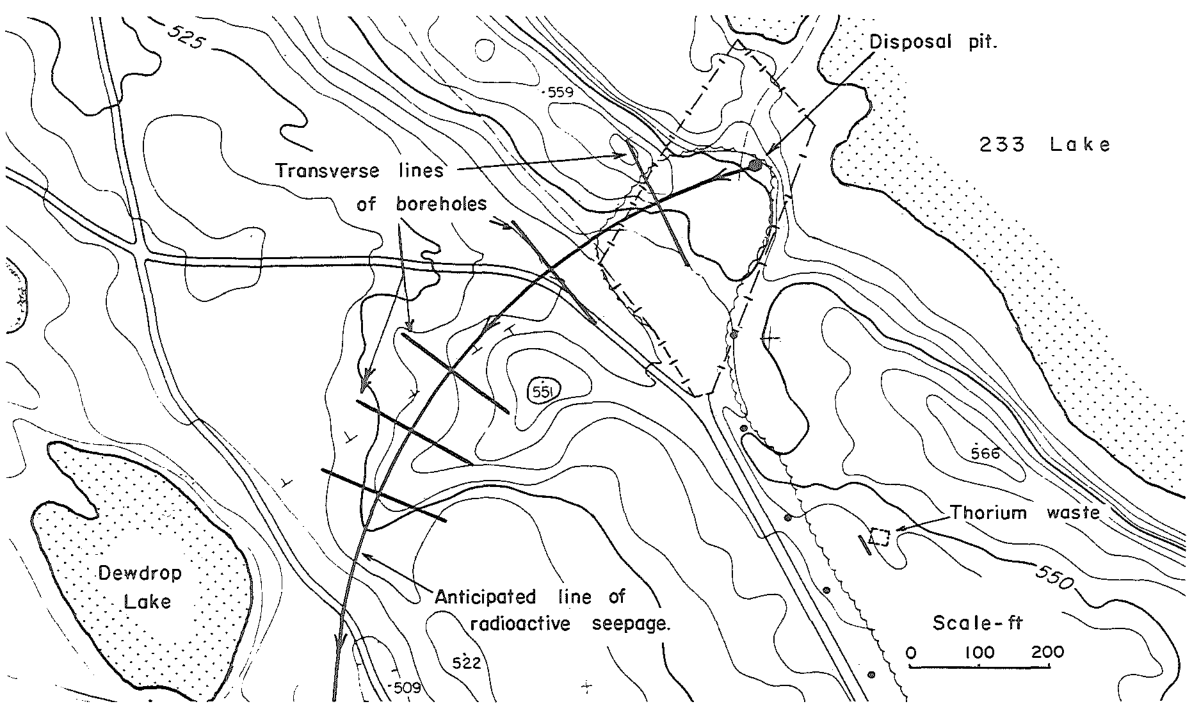


Figure 5. Lines of boreholes driven normal to the direction of seepage. A pit nearby used for disposing thorium waste has caused no migration of radionuclides.

Cross Section at 150 ft

At this distance the radioactive region lay 40-50 ft below the top of the dune ridge in a band 125 ft wide and 5-12 ft thick. The top surface was almost coincident with that of the ground water although, where the latter had seasonal variations of over 2 ft in level, some dry radioactive soil was sampled. The lower boundary of the contaminated soil lay above a continuous deposit of relatively impermeable sandy loam, consisting of narrow horizontal bands of very fine sand sandwiched between equally narrow (1/16 in.) bands of silt. Beneath this layer laminated fine sands extended a further 10 ft down to bedrock. Strontium-90 was the only radionuclide present and 1.23 curies were contained in the whole cross section considered as a slice 1 ft thick.

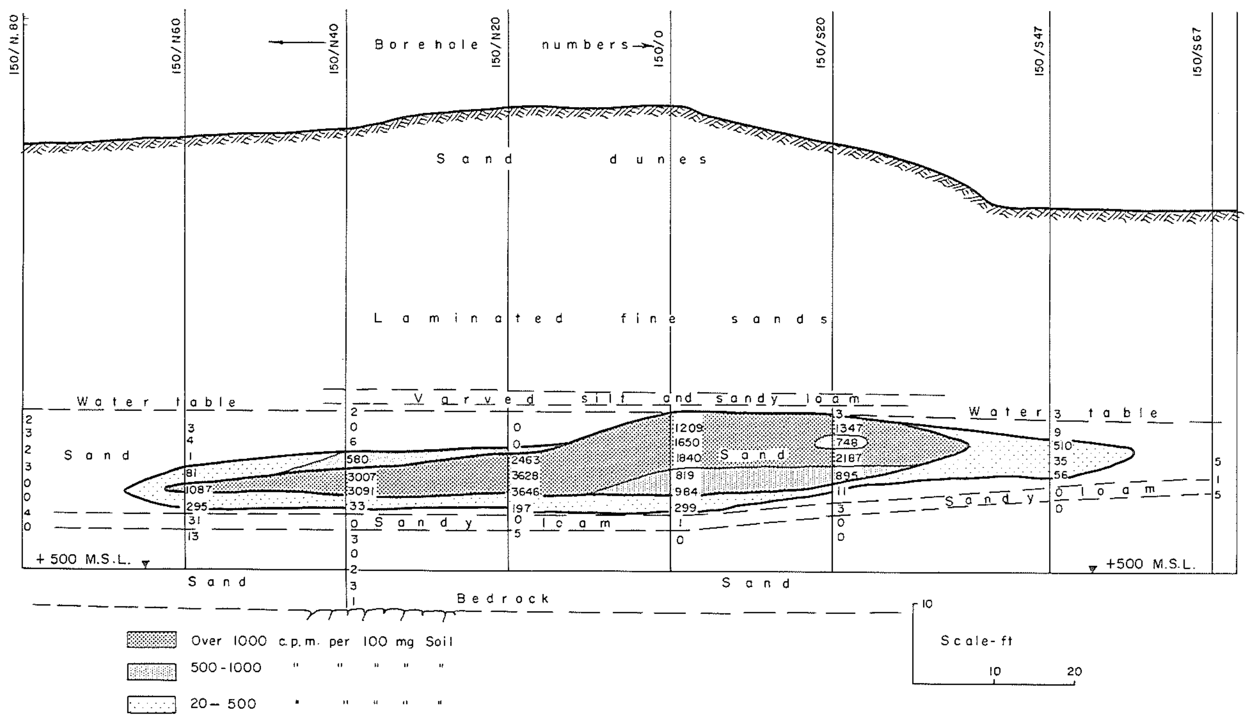


Figure 6. Cross section through radioactive track 150 ft from disposal pit. Contains Sr-90 only (concentration 1.23 curie/ft) along track.

Cross Section at 325 ft

This position lay outside the boundary fence surrounding the decomposition plant. The track of radiostrontium had increased in width to 150 ft and in general thickness to 12-14 ft. The total strontium content in this section was 2.54 curies/ft, the highest of all the sections. The highest measured concentration of radio-strontium on the soil was 0.2 μc/g (9,460 c.p.m/100 mg).

The upper limit of contamination remained coincident with the ground water but the lower limit did not follow any clearly defined silt band. Numerous layers of silt were present throughout the contaminated horizons but below this there were 10 ft of medium sands down to bedrock. The most permeable region of this section lay directly beneath the band of contamination.

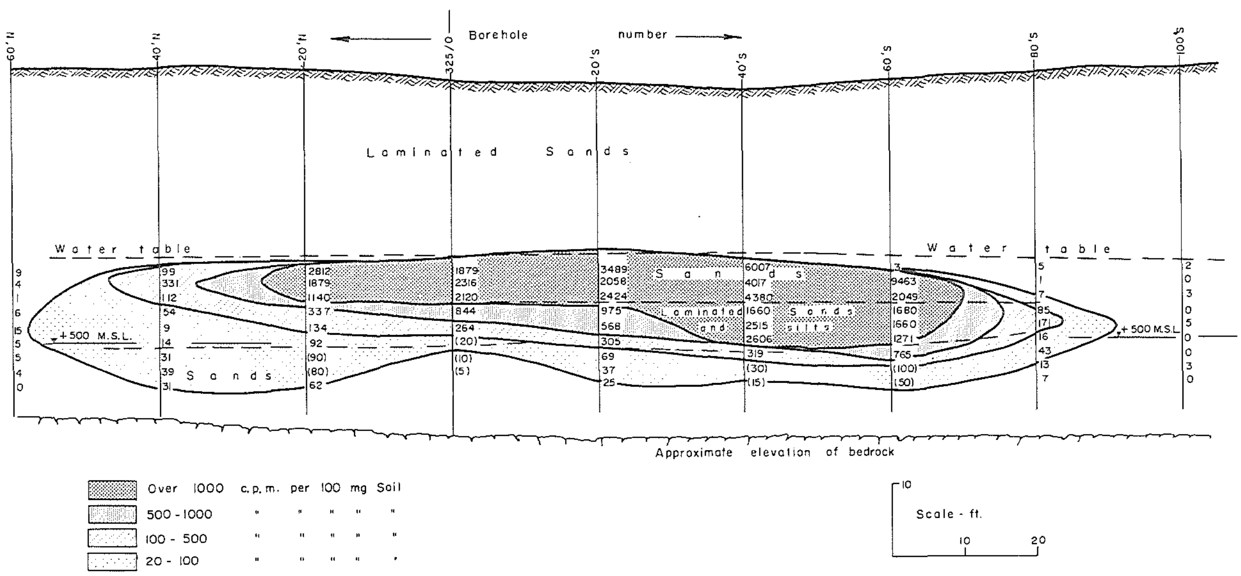


Figure 7. Cross section through track 325 ft from disposal point. Contains the highest concentration of Sr-90 (2.54 curies/ft)

Cross Section at 525 ft

Both the size and concentration of the strontium-90 track was smaller at this section; its width was reduced to 115 ft and the region of high contamination was limited to a band 30-40 ft wide. The upper limit of radio-strontium lay 5-6 ft below ground water level and the base lay about 8 ft above bedrock. The whole track was passing through sands with no well-defined bands of silt.

The strontium-90 content of this section was 0.88 curies/ft.

Beyond the 525-ft line, the broad track of radiostrontium became discontinuous and one pocket of uncontaminated soil (575-ft line) was found

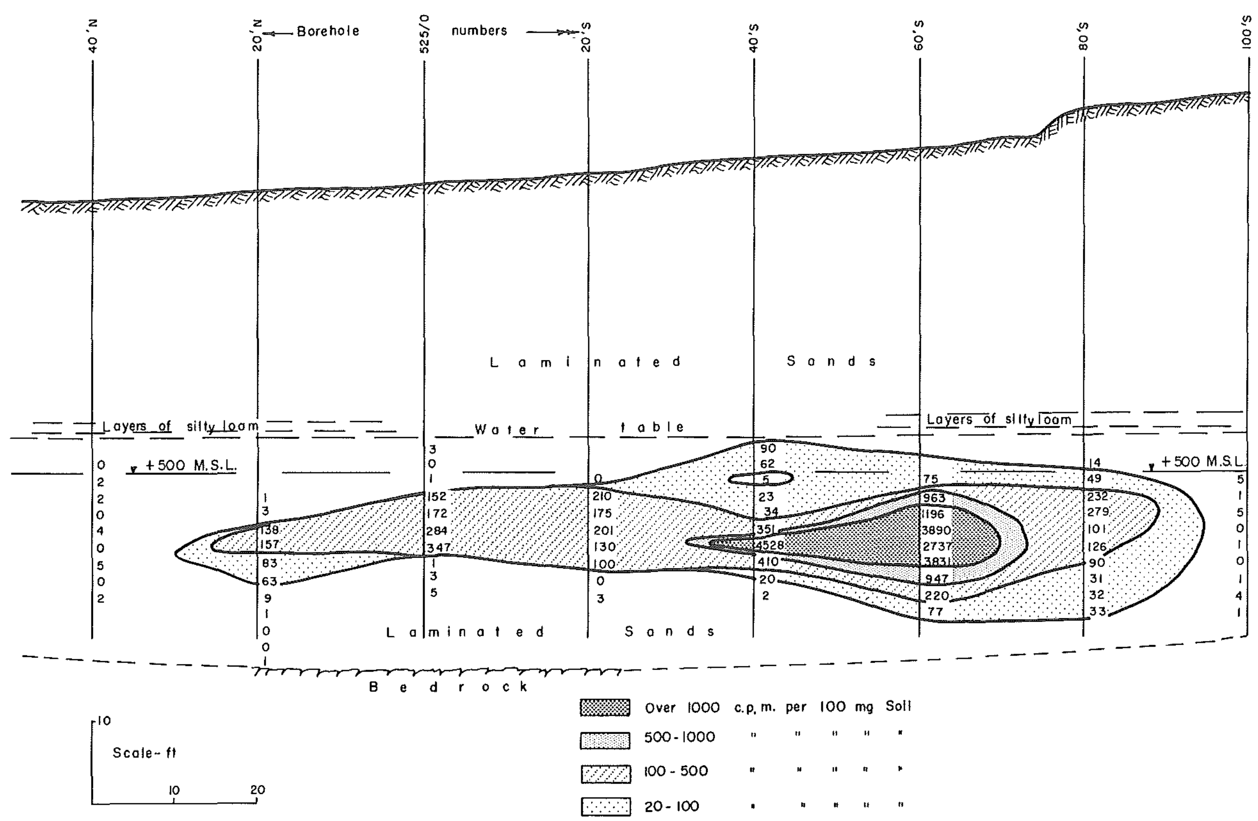


Figure 8. Cross section through radioactive track 525 ft from disposal point. Sr-90 concentration 0.88 curies/ft.

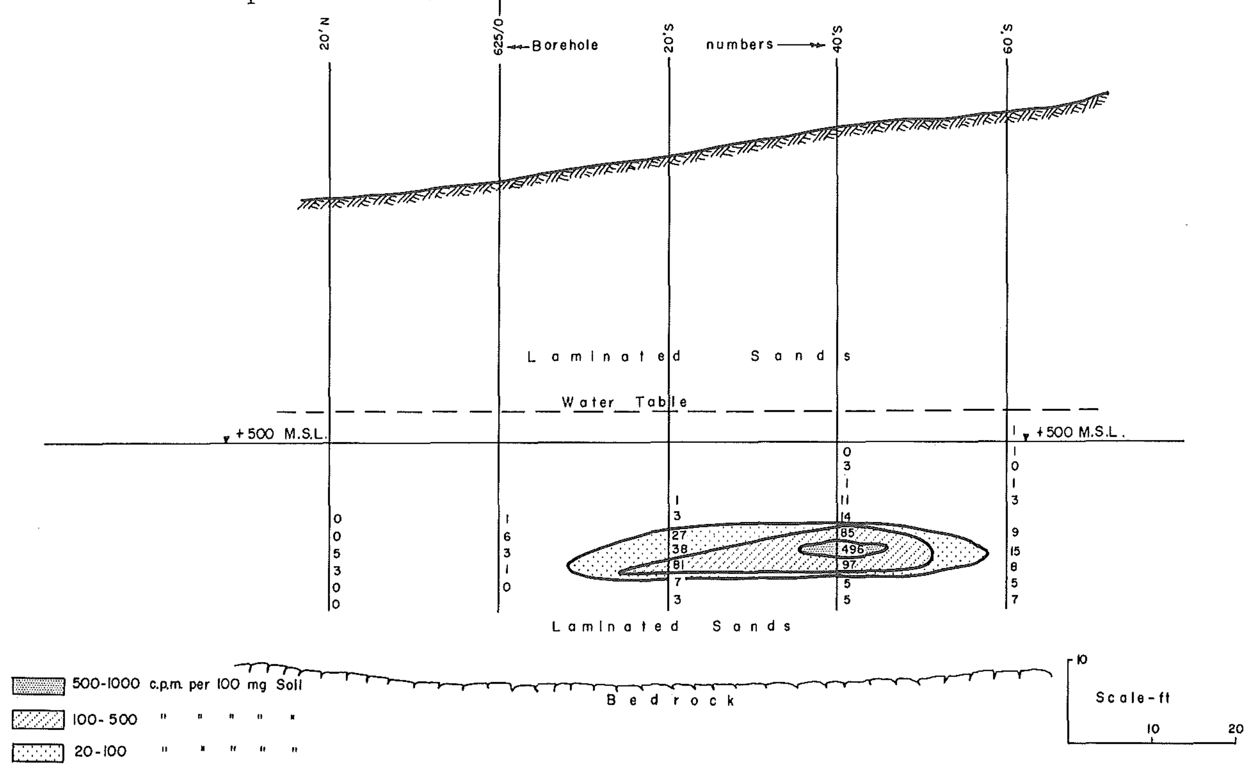


Figure 9. Cross section through track 625 ft from disposal pit. This section was 25 ft behind the 'front' of Sr-90, and contained 0.03 curie/ft Sr-90.

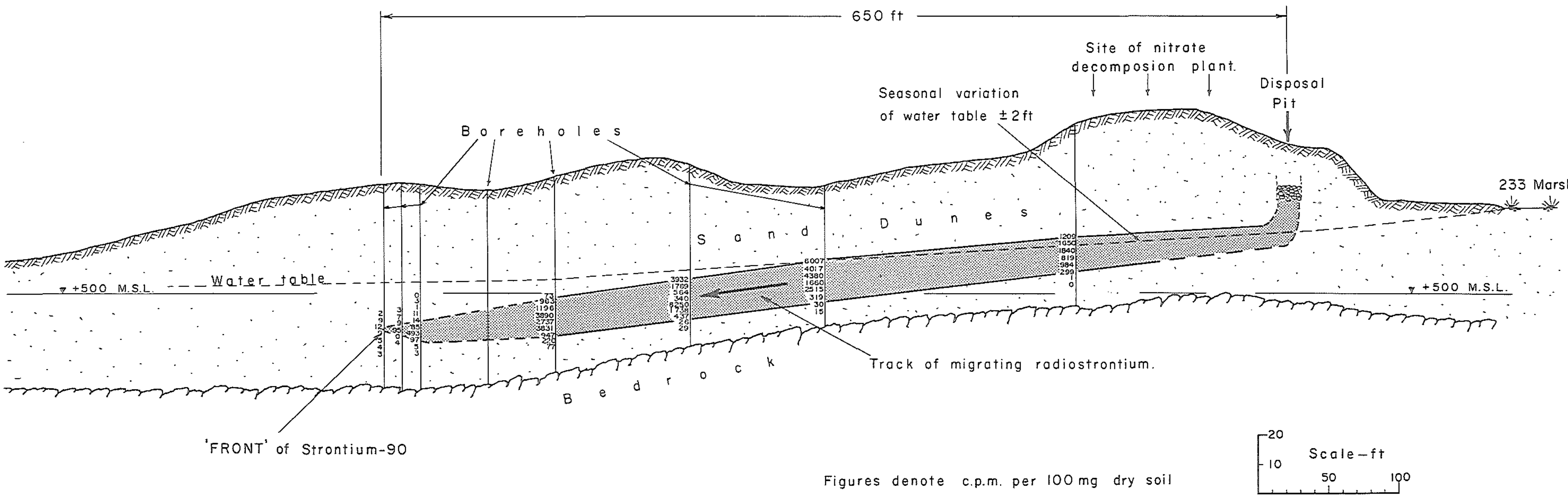


Figure 10a. Longitudinal section along track of migrating radiostrontium.

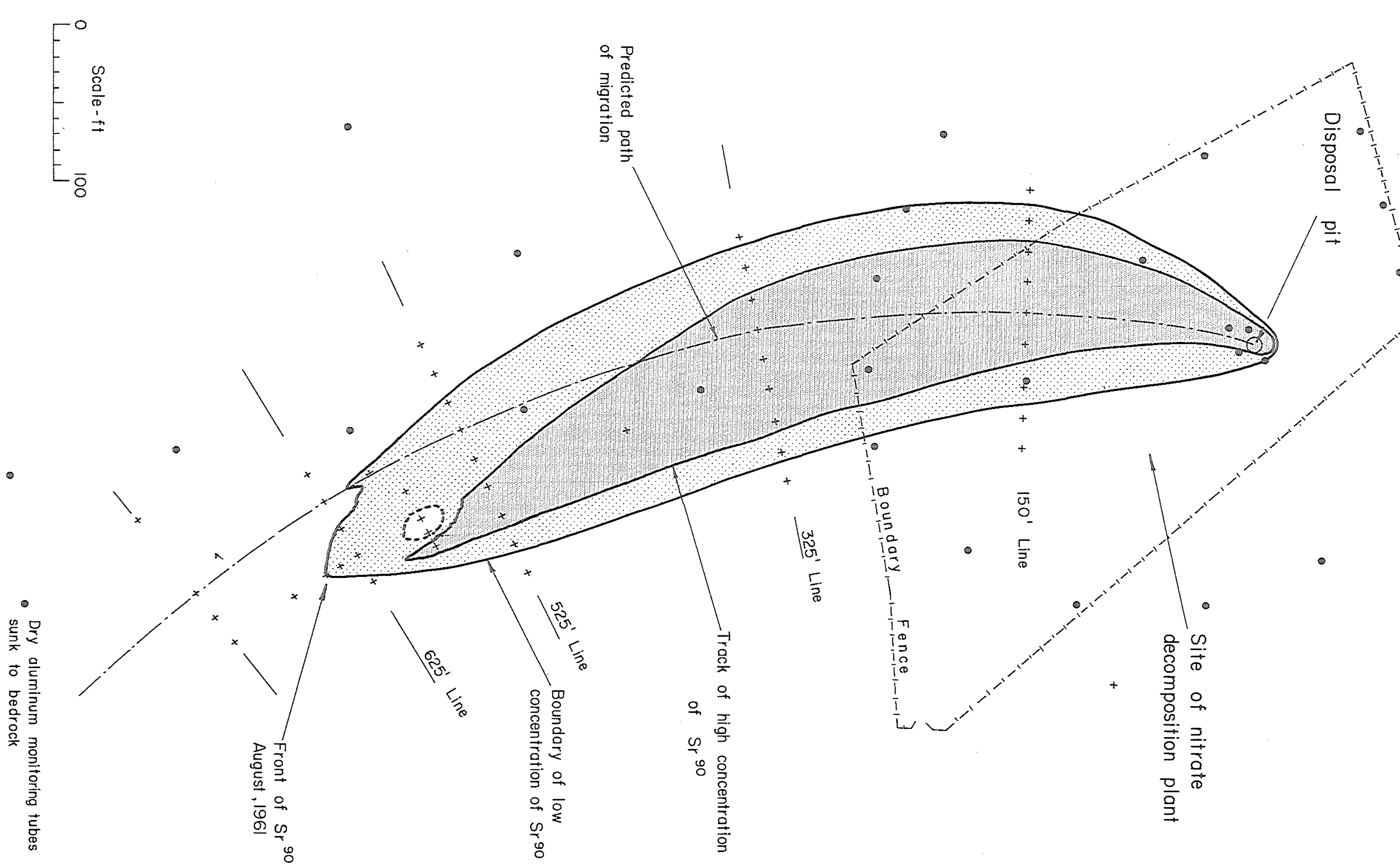


Figure 10. Plan of migration. Heavily shaded area indicates region of highest contamination. Boreholes along transverse lines are marked by crosses.

surrounded by radiostrontium that extended in a narrowing tongue into the next (625 ft) section. In this section (Fig. 9) the band of contamination was only 40 ft wide and lay 14 ft below the water table; there was no region of high concentration and the tongue was passing through permeable sands. This section lay 25 ft behind the front and contained 0.03 curie/ft Sr-90.

The results of this work have been assembled in Figure 10 to show a plan of the entire track of radiostrontium from the disposal pit to the 'front' in 1961. The estimated centre line of flow has been plotted; this was used as a base-line for the boreholes and lay parallel to the actual flow path but offset 40 ft from it. The track was wider than expected; this could have been caused by differential variations in the level of the water table from season to season.

A longitudinal section (Fig. 10a) has been plotted along the centre line of the radioactive track. Despite additional soil sampling between sections and the use of a gamma ray spectrometer lowered down a monitoring tube 90 ft from the disposal pit, no radionuclide except strontium-90 was found. The section shows that vertical dispersion of the radiostrontium was small after its initial movement down to the groundwater beneath the disposal pit. Layers of silt within the first 350 ft of track probably limited the dispersion. However, the front has now entered more permeable sands and there is no evidence of increased dispersion.

Further soil sampling along the track between the disposal pit and the 150 ft line had shown that the present leaching rate of strontium-90 from the pit was very low. An auxiliary line of boreholes 25 ft from the pit centre confirmed this expectation with a low concentration of Sr-90 of 0.01 curies/ft. This value has been used in Table I for the concentration of migrant radiostrontium at the origin. However, since the pit lies in dry sand about 20 ft above groundwater, this value is no measure of the quantity of radiostrontium that remains in the unsaturated zone within and beneath the disposal pit.

A summation of the total quantity of Sr-90 that has migrated has been made in Table I, showing that an estimated 810 curies of Sr-90 lay along the 650-ft track.

Table I

Summation of Strontium-90 in Track of Migration from Disposal Pit

Distance of cross section from disposal ft	Concentration of Sr-90		Sr-90 between sections Curies	Total Sr-90 along track Curies
	at Section Curies per ft	mean between sections Curies per ft		
0	0.01			
		0.620	92.8	
150	1.23			
		1.885	329.9	
325	2.54			
		1.710	342.0	
525	0.88			
		0.455	45.5	
625	0.03			
		0.015	0.4	810.6 Curies
650	0			

Tracer Tests

In order to estimate the time taken for ground water (and strontium) to move from the disposal pit to the swamp, tracer tests were made to measure the rate of groundwater flow in situ. Fluorescein dye was injected into the groundwater at four points along the predicted path of migration in order to measure its direction and rate of flow in the ground water. Selected horizons were chosen for these tests, either in the centre of the contaminated regions or at points calculated to intercept the future course of the radioactive track. In each test six porous bronze injectors were driven 8 in. apart and twelve gallons of water containing 24g of fluorescein were injected. This formed a volume of tracer in the soil estimated to be 4 ft wide x 8 in. thick x 1 ft deep. Other bronze water collecting points were driven in lines at 4 ft, 8 ft, 12 ft etc. "downstream", to sample the dye as it passed in the groundwater. The dye was followed as far as possible in each test until it became too difficult to find, owing to its convergence into an increasingly narrower stream.

Since it was necessary to relate the percolation rate of both fluorescein and strontium to that of groundwater, a fifth test was carried out in which fluorescein was mixed with tritium and strontium-85 and injected as a single solution. The rate of movement of each tracer was measured.

The positions of the five tests are shown on the plan of the predicted path (Fig. 11). The measured directions of percolation in all tests confirmed the direction predicted from water-table contours.

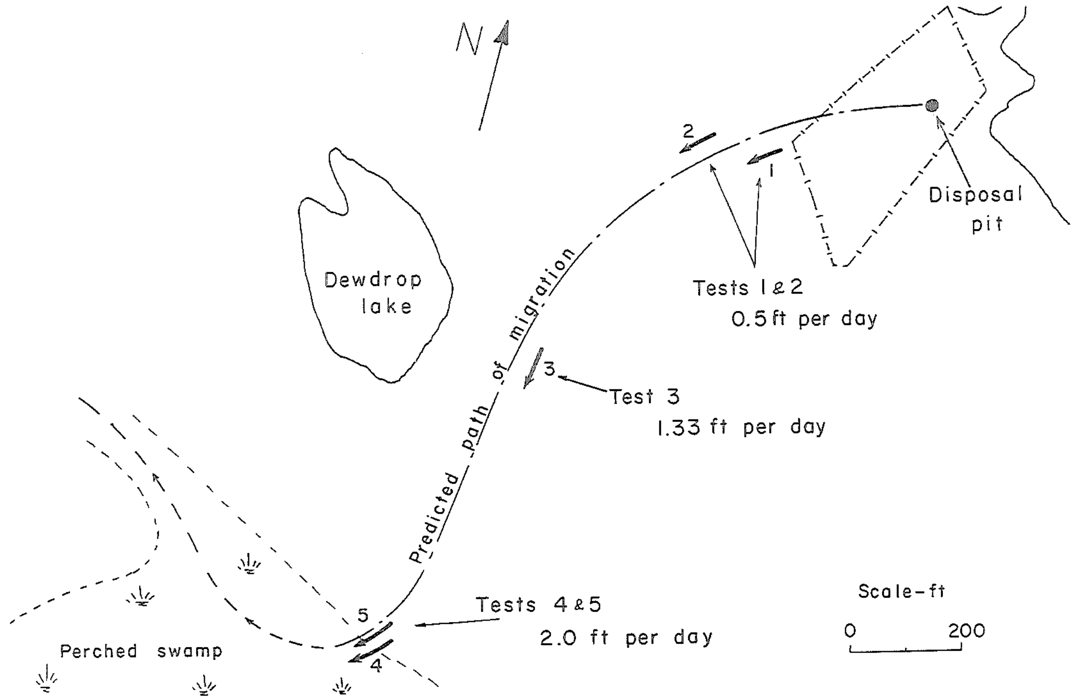


Figure 11. Positions of tracer tests along predicted line of migration. Test numbers are noted with measured rates of percolation.

Tests 1 and 2, 325 ft and 425 ft respectively from the disposal point, were carried out in fine sands sandwiched between thin layers of silt. In both tests the dye was followed for 16 days and the fluorescein moved at a rate of 6 in. / day. Test 1 lay in the centre of the radioactive track (+ 507 ft) and test 2 lay to the side of the track at an elevation (+ 501) corresponding to the lower level of contamination.

Tests 3 and 4 (925 and 1525 ft from the origin) were conducted in medium sands at selected horizons on the predicted line of migration. The measured rates of fluorescein movement (1.3 ft/day and 2.0 ft/day respectively) showed that the permeability of the soil increased with distance from the disposal point. The 4th test, at 1525 ft, was carried out at the edge of the swamp, about 300 ft short of the area of emergence for groundwater.

In the fifth test fluorescein and tritium were followed for 45 ft and over this distance the movement of fluorescein was only slightly less than that of the tritium or groundwater (> 95%). The rate of percolation of groundwater was 2 ft/day but the strontium-85 took 37 days to traverse 13 in.; it therefore travelled at about 0.015 x velocity of groundwater. In all tests the tracers converged into narrowing paths as they moved further from the injection point; after 45 ft, the stream had narrowed to less than 1 ft in width and was difficult to find.

DISCUSSION

The region lying between the nitrate decomposition plant and Maskinonge Lake is divided into terraces in the bedrock forming the channel of the Maskinonge system (Fig. 12). The first terrace, about 15 ft above Maskinonge Lake, holds Lower Bass Lake; bedrock here is thinly veneered with glacial till and continues thus up the next slope of 100 ft to the 2nd terrace. This terrace is mantled with granular overburden that was water-deposited during inundation of the channel. Soils were sorted into bands oriented along the terrace with the coarser material lying over the inner regions and the finer material deposited near the outer limits of the terrace. The disposal pit lay over laminated silts and fine sands in the outer region and the track of migrating Sr-90 has advanced across part of the terrace.

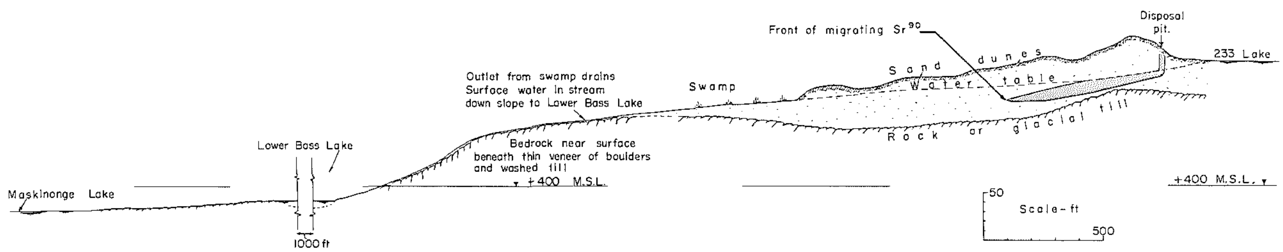


Figure 12. Cross section between Maskinonge Lake and disposal pit.

Ruthenium Movement

Routine water sampling from the lakes and the absence of ruthenium in soil or ground water samples showed that this radionuclide had moved away rapidly with the groundwater soon after disposal. Since it was discovered in the shallow Dewdrop Lake in 1957 it must have moved close to the surface of the water table taking a more direct route across the terrace than the deeper and slower-moving strontium. Also the insignificant delay between arrival times of ruthenium in Dewdrop and Lower Bass Lake (on the lower terrace) showed that a direct path was taken from the upper lake to an emergence region at the edge of the terrace. When ruthenium first reached Lower Bass Lake in the winter of 1957/58 it emerged into surface water after a 3-year undergound migration at approximately the same rate as groundwater.

Strontium Movement

The movement of strontium soon after disposal may be gauged from two drilling logs, taken when monitoring tubes were being sunk in the soil (1955-58). One borehole, 250 ft from the disposal, yielded radioactive soil samples in October 1955 and another a further 240 ft beyond was similarly contaminated with radiostrontium in 1957. The latter borehole was 160 ft behind the present position of the front. Thus within the first year after disposal the strontium had moved more than 250 ft and in the last 4 years it has moved less than 160 ft. It is suggested that this early rapid advance was roughly equal to the rate of groundwater movement and that it was caused by a low pH and high concentration of ions in the disposal pit (ammonium, calcium, nitrate etc) that reduced the retention characteristics of the soil. Thus it is probable that, following dispersion and dilution for seven years, the rate of progression has been reduced to an equilibrium value of 0.015 x the rate of groundwater movement.

The predicted sub-surface path for Sr-90 (Fig. 13) continues through sands until it enters a swamp that is bordered on the opposite side by an outcropping rock ridge. The ridge thus forms a rock rim to the terrace and water in the swamp is turned and directed towards the gully through the

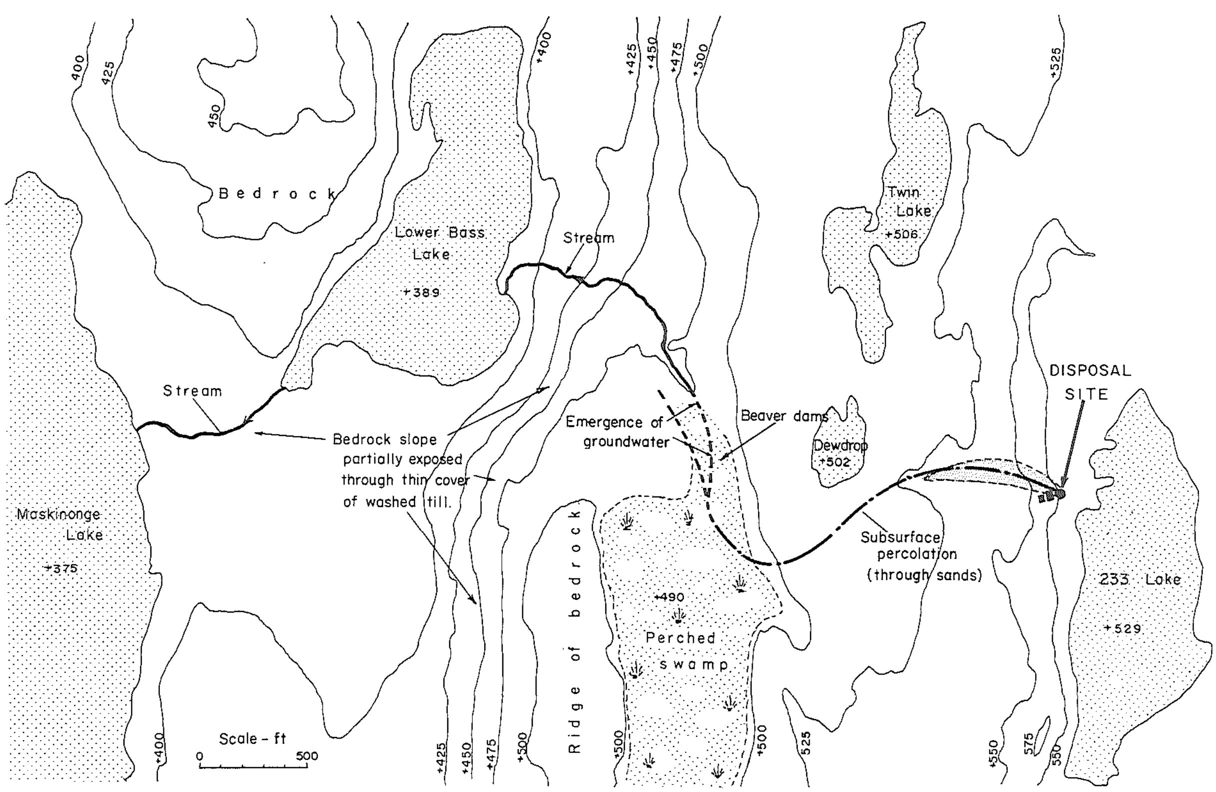


Figure 13. Plan of area between Maskinonge Lake and disposal pit.

ridge. A rising rock sill and a declining swamp surface cause most of the groundwater to emerge and discharge in a stream through the gully. Some may remain submerged in a short alternative route, to seep to the surface on the upper face of the terrace slope.

The area of emergence in the swamp probably starts about 1800 ft from the disposal pit. The soil lying along this path between pit and swamp is the only obstruction offered to the passage of Sr-90 before the radionuclide appears in the surface waters of Lower Bass and Maskinonge Lakes.

A longitudinal section covering this 1800-ft path (Fig. 14) shows the region of fine sands and silts beneath the disposal pit and the tongue of radiostrontium passing through it and penetrating more permeable medium sands.

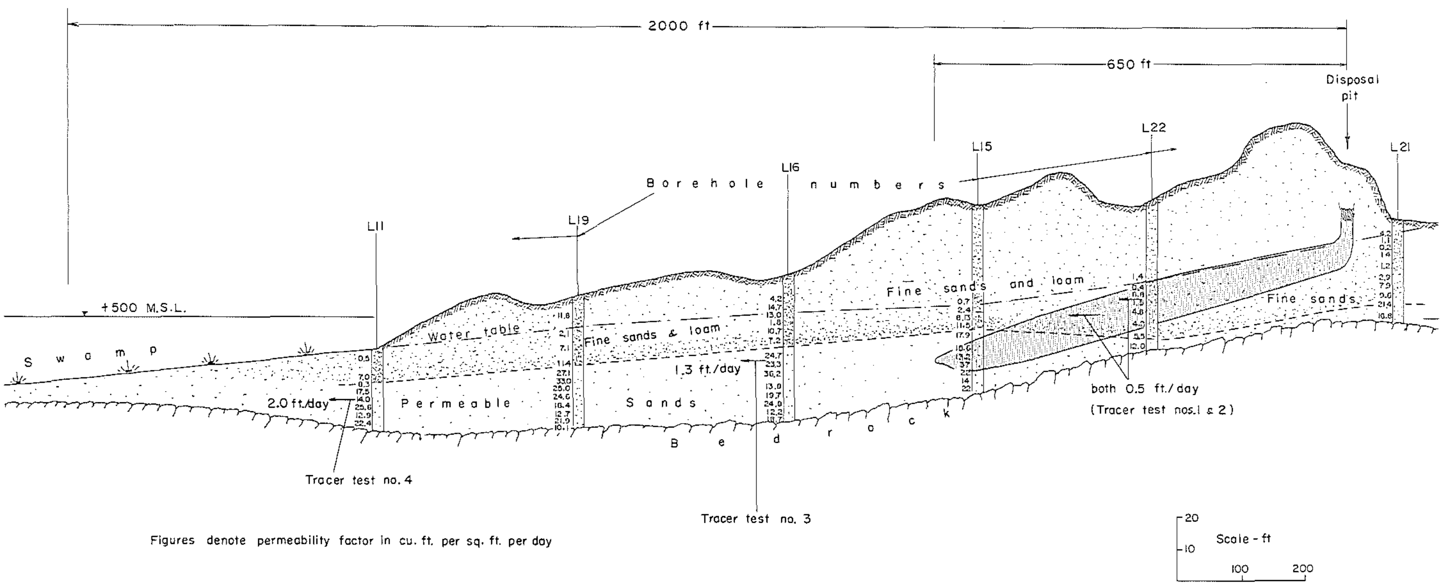


Figure 14. Longitudinal section along predicted migration line where radiostrontium will remain below ground.

The section shows permeability results of soil samples from six boreholes, the horizon of each tracer test, and the region of seepage to the surface in the swamp.

An estimate has been made (Table II) of the time taken for groundwater to travel along this section. Since the measured flow rate of 0.5 ft/day (325 ft line) occurred under a hydraulic gradient of 1/42.5 it was estimated that the flow rate beneath the disposal pit, with a gradient of 1/12, was $\frac{42.5}{12} \times 0.5 = 1.77$ ft/day. Also, borehole results (Fig. 14) showed that fine sands finish 450 - 525 ft from the disposal point; it has been assumed therefore that the groundwater flow rate of 1.3 ft/day was realised at the 525-ft position.

With these two assumptions, used in Table II, it has been estimated that groundwater flowing beneath the disposal pit emerges in surface water four years later.

Table II

Time Taken for Groundwater to Travel from Disposal Point to Perched Swamp (1800 ft away).

Dist. from disposal ft	Rate of groundwater movement ft/day	Mean rate between sections ft/day	Dist. between sections ft	Time of travel Between sections Yrs	Total Yrs
0	1.77*				
		1.13	325	0.79	
325	0.5				
		0.5	100	0.55	
425	0.5				
		0.9	100	0.30	
525	1.3*				
		1.3	400	0.84	
925	1.3				
		1.65	600	1.00	
1525	2.0				
		2.0	275	0.38	3.86
1800	2.0*				

* Estimated values.

Since the measured rate of radiostrontium movement was 0.015 x velocity of groundwater, the time taken for this radionuclide to move from the disposal pit to the swamp, in a normal environment, would be

$$\frac{3.86}{0.015} = 258 \text{ years}$$

From Table II the time taken for groundwater to move from the present position of the 'front' (at 650 ft) and emerge in the swamp would be

$$\frac{275}{113 \times 365} + 1.00 + 0.38 = 1.96 \text{ years}$$

Sr-90 will therefore take $\frac{1.96}{0.015} = 130$ years. (approx)

When this break through takes place, the estimated length of radioactive track, trailing behind the 'front' will be 1100 ft and the varying rates at which Sr-90 will be released in the swamp have been summarised in Table III.

Table III

Rate of Release of Sr-90 in Swamp

Present position of Sr-90	Time taken to reach swamp	Sr-90 between sections		Mean rate of release
		At present	At release	
	Yrs	curies	curies	curies/year
Pit	260			
		422.7	1.65	0.03
325'	205			
425'	168	342.0	5.33	0.09
525'	148			
		45.5	1.41	0.1
625'	134			
		0.4	0.16	0.004
650'	130			

The maximum anticipated release of Sr-90 (100 mc/year) will enter a stream draining into Lower Bass Lake. This stream has been gauged by measuring the dilution rate of a dye (Rhodamine B) injected at a constant rate; the minimum flow (winter) is estimated at 5 litres/sec. These results predict a maximum anticipated concentration of Sr-90 in the stream of 6.5×10^{-7} μc/ml. This value is less than the maximum permissible concentration (40 hr occ. $MPC_w = 4 \times 10^{-6}$ μc/ml) in The Recommendation of the International Commission on Radiological Protection. (1959).

Disposals of radioactive liquid have been poured into the soil, on several occasions, in the area surrounding the Chalk River Project. However, this was the largest disposal of fission products in high-ionic solution and its behaviour after burial has been similar to a smaller disposal made in 1955 about $1\frac{1}{2}$ miles away. This was an experimental disposal of strongly acid solution[6], containing mixed fission products; it was poured into the sand and caused a continuous tongue of Sr-90 to migrate with the groundwater. The movement was rapid at first and later slowed to an equilibrium velocity. In both disposals there has been no apparent migration of cesium-137. However, there is one anomaly between the rates of fluorescein and strontium flow through the soil. At the other site, the percolation ratio of fluorescein/groundwater = 0.75 and strontium/groundwater = 0.027; at this site the corresponding figures are >0.95 and 0.015. These results may form a basis for further experiments.

CONCLUSIONS

The nitrate decomposition plant and disposal pit were situated on the outer edge of the second terrace above Maskinonge Lake. Sand deposits cover this area, but the lower terrace and the steep slope down to it are almost bare, having only a patchy veneer of washed till. Thus, when radioactive liquids entered the soil at the disposal pit, they were destined to remain below ground only while they stayed in the soil and groundwater of the second terrace; subsequent transportation would be in surface water.

Following a rapid movement of ruthenium-106, a migration of strontium-90 occurred, and this has developed, in seven years, into a continuous tongue stretching 650 ft from the disposal and containing an estimated 800 curies. It has a further 1150 ft to move before the 'front' will emerge in surface water and this is calculated to occur in 130 years time. However, owing to the decay of radiostrontium and its longitudinal dispersion in the soil there will be no large and sudden release of strontium-90.

This disposal is a good demonstration of the safe disposal of radioactive liquid waste into a porous medium. The soil delays the passage of strontium-90 while it decays through several half-lives and then its rate of release into surface water is similar to the decay rate of the radionuclide. Thus, from a disposal of about 1000 curies of Sr-90, the eventual escape of this radionuclide via a small stream into surface waters will not contaminate the stream above the recommended (I. C. R. P.) maximum permissible concentration in water.

ACKNOWLEDGEMENTS

The writer is grateful to Mr. W.F. Merritt for his assistance in the radioactive tracer and other experiments and to Mr. G.G. Gunter for his collaboration in field and laboratory work.

REFERENCES

1. Murray N.F., 1955 Summary of activity released to the limestone pit at building 233 plant site, AECL-unpublished report ICI-53.

2. Ophel I.L., AECL Progress Report April-June 1958. PR-B-38 (Official use only).

3. Gadd N.R., 1958 Geological aspects of radioactive waste disposal, Chalk River, Ontario. Geol. Survey Canada prelim. report.

4. Parsons P.J., 1960 Movement of radioactive wastes through soil. 1. Soil and groundwater investigation in Perch Lake Basin. AECL-1038

5. Parsons P.J., 1961 'Multiple Soil Sampler'. Am. Soc., Civil Eng. 87, S.M. 6 Dec., 1961.

6. Parsons P.J., 1961 Movement of radioactive waste through soil. 3. Investigating the migration of fission products from high-ionic liquids deposited in soil. AECL-1325