Atomic Energy of Canada Limited

MOVEMENT OF RADIOACTIVE WASTES THROUGH SOIL

1. Soil and Ground-Water Investigations in Lower Perch Lake Basin

CRER-932

by

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June, 1960

REPRINTED OCT., 1960

A.E.C.L. No. 1038

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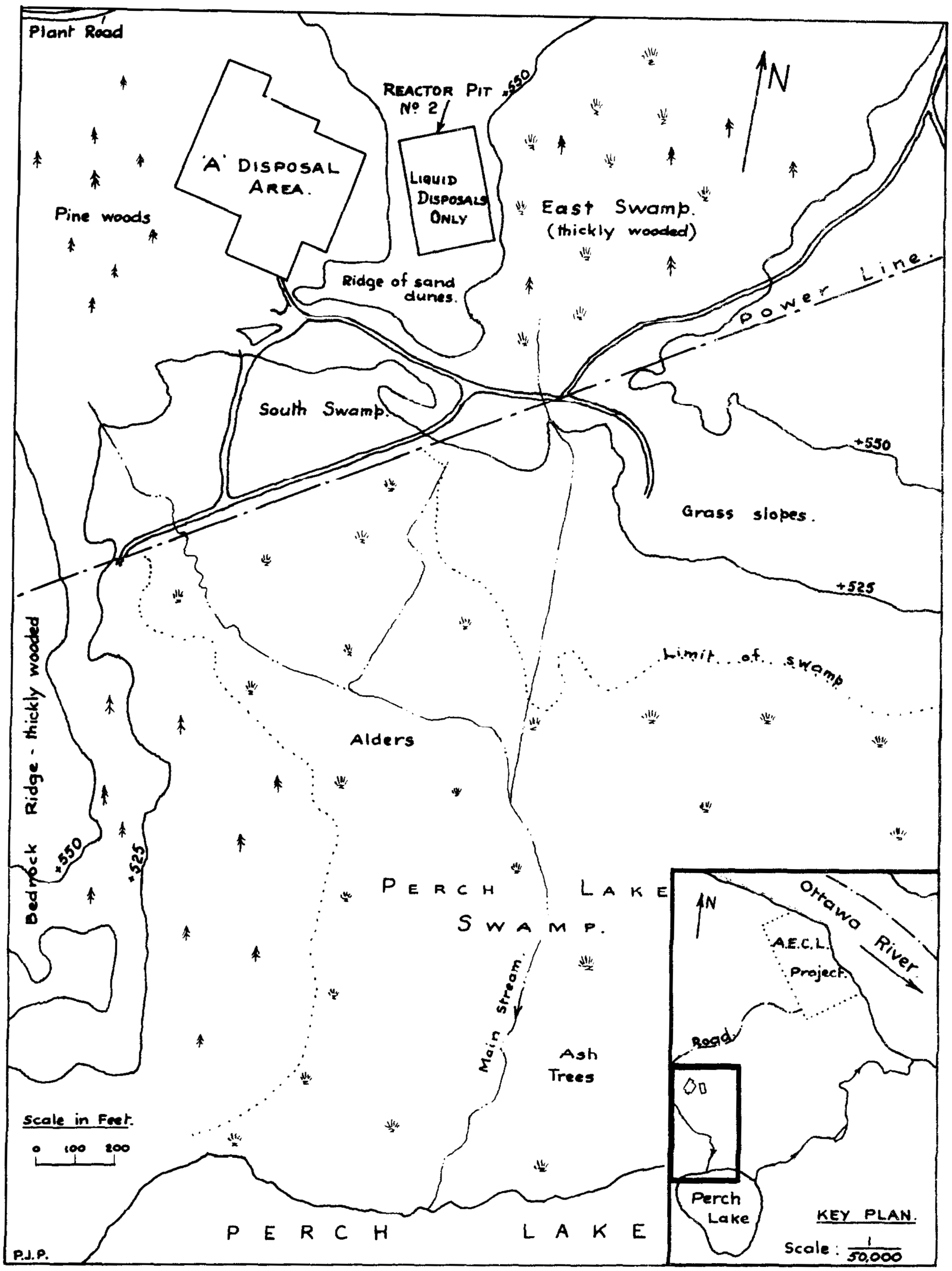


General Plan of lower Perch Lake Basin. The inner area of the A.E.C.L. Project lies 3/4 mile north-east from the disposal areas.

Summary

An investigation of soil and ground water has been made in Perch Lake Swamp where fission products are moving through the soil away from the waste disposal area 'A' towards Perch Lake situated 2400 ft to the south.

A network of standpipes was installed to supply elevations for contouring the water table and to estimate the direction of ground-water flow.

Soil samples were collected from boreholes in the overburden and tested for permeability and porosity. Results show that the swamp lies in a bedrock depression that is lined with glacial till and silt. The principal deposits are sands (50 to 70-ft thick) that contain a continuous clay band 35 ft beneath ground level. The fission products move through the sands above this clay layer and their predicted path has been plotted.

There is no known path by which radioactive ground water can seep into the fissures of the bedrock basin.

Results from tritium-tracer experiments by the Environmental Research Branch have been used to establish a local relationship between the measured ground water velocities and those calculated from soil test results.

It is estimated that the fastest stream of ground water will take 13 years to flow from South Swamp to Perch Lake.

A soil-sampling program is in progress, using a new type of sampler, to determine the exact limits of migration of the fission products in the soil outside the disposal area.

1. Introduction

The migration of radioactive fission products southwards from the waste-disposal area at Chalk River Project has been under observation since 1954. These radionuclides follow the path of the ground water: where they have emerged at the surface, as in the area known as South Swamp their subsequent movements have been studied by I.L. Ophel[1]. Those which have remained deeper have been tracked by radiation monitoring inside dry aluminum tubes sunk in the flow paths of the ground water. Details of the sub-surface movements together with experimental results on the ion-exchange properties of the soils have been reported by E.J. Evans[2].

1.1 Information available

The extent of the Perch Lake drainage basin, its probable properties as a ground-water reservoir, and a detailed geological report of the surficial deposits in the area has been made by N.R. Gadd[3].

An aerial survey map of the area was available with surface contours plotted at five-foot intervals[4] and the estimated contours of bedrock beneath the Perch Lake Swamp were plotted from a geophysical survey undertaken in 1955[5]. Gadd recommended an investigation to determine whether the fissured bedrock of the basin was mantled with glacial till, and to determine the rates of ground water flow in the overlying sand.

Soil samples from previous borings gave some indication of the nature of the subsoils but these were from widely separated drill holes remote from Perch Lake Swamp and were unsuitable for permeability measurements.

1.2 Object

The object of this investigation was to determine the nature of the over-burden in that part of the Perch Lake basin that lies ahead of the present front of fission products moving away from the disposal areas, and to estimate the direction of movement and velocity of the ground water in this region.

2. Procedure

2.1 Summary

1. A contoured plan of the water table was drawn.
2. Boreholes were drilled on lines approximately at right angles to the estimated direction of flow of ground water and down either to bedrock or to glacial till.
3. Drilling and soil-sampling methods were changed so that undisturbed soil samples could be collected.
4. Samples were tested for permeability and porosity and their grading was measured.
5. Experiments were conducted to estimate the ratio of maximum pore velocity to mean pore velocity of water flow through soil samples.
6. Attempts were made to measure directly the velocity of ground water in situ in Perch Lake Swamp.
7. Cross sections of soil strata were drawn along the drilling lines.

2.2 Establishment of water table (see drawing No. 1)

2.2.1 Swamp Area

Shallow standpipes were driven into the swamp at 400-ft intervals on a grid.

Each unit was assembled using 1 1/4 in. well point and piping which was small enough to be driven without mechanical equipment and was easy to manhandle across the swamp. In order to exclude surface flow without sealing the points in the surrounding soil no point was driven at a flooded intercept. It was driven on nearby slightly raised dry ground. Many such small raised patches occur in Perch Lake Swamp.

2.2.2 North of the Swamp

The pattern of wells outside the swamp was concentrated in two areas where detailed water-table information was needed. One was in the area of the first tritium-tracer experiment and the other was around the southern boundary of the A burial ground (drawing No. 1). Many of these wells were deep and had to be installed with a churn drill. Aluminum pipes for water sampling, which were already in place inside and to the west of the A burial ground and also near reactor pit No. 2, were surveyed, levelled and used for water-table measurements.

Water-table levels were measured by lowering a chalk-covered bar on a steel tape just into the water. The sharply defined limited of immersion gave water elevations to an accuracy of 1/8 inch.

Measurements were made in 103 wells and the water-table contours constructed from these results cover an area of 95 acres.

2.3 Pattern of drill holes (See drawing No. 2)

A line of six dry monitoring tubes sunk to bedrock or glacial till and situated 40 feet north of and parallel to the power line provided the only information about the lower boundary of the valley shown in cross section BB.

Since it was necessary to learn how this valley developed and the nature of the deposits it contained, roughly parallel drilling lines were established 500 and 1100 ft to the south and 200 ft to the north of the power line. (lines CC, DD, AA, respectively). Two holes were drilled near the cross section BB at points where radiation had been detected 40 ft beneath the surface.

After the drilling program in Perch Lake Swamp had been finished three bore holes were drilled on the East and South shores of Perch Lake to investigate the soils at the lake outlet and at other possible ground-water outlets.

2.4 Drilling and soil-sampling methods

Drilling was started along line CC using our usual churn-drill method. We drove a 4-in. iron casing two feet, churned the plug of soil in the bottom to a slurry, bailed it out, and then collected the soil at the base of the casing with a split-cylinder sampler fitted with a flap valve. The sample was transferred to a bottle for storage and the process repeated two feet deeper. Three holes (T117-118-119) were drilled by this method but the samples were not representative of the strata from which they were selected and they could not be used for permeability measurements because they were disturbed. Previous efforts to collect undisturbed samples from water-logged soil using Shelby tube samplers had been unsuccessful.

At this time a new sampler, constructed in the Chalk River machine shop, was ready for trials. The design for this was based on a prototype developed elsewhere[6] and modified as follows:

(a) Reduced in size to operate inside a four-inch casing.

(b) Changed to use standard E drill rod when applicable.

(c) Designed to use 2 in. dia. x 1/16 in. seamless steel mechanical tubing as a sample tube.

Figure 1 is a detailed drawing of the sampler. The plug of soil in the casing was removed by washing it to the surface so that the sampler could be thrust into undisturbed soil beyond the bottom of the driven casing. This is normally done by forcing water down hollow drill rods with a reciprocating pump and jetting the soil into suspension to carry it to the surface by the upward return flow of water between drill rod and casing. A centrifugal pump delivering up to 40 gallons per minute was

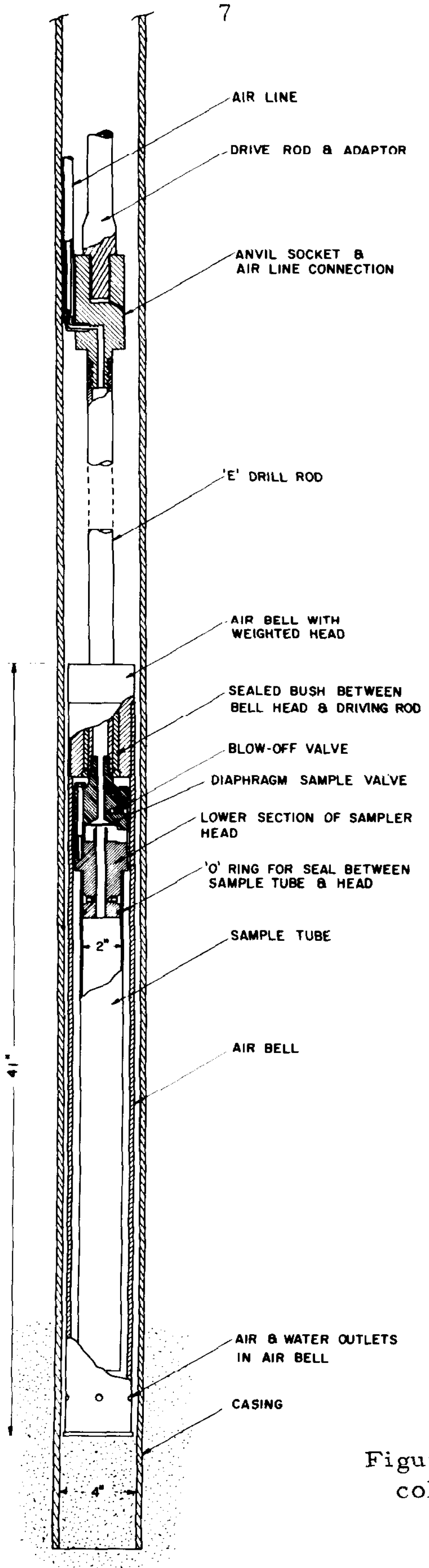


Figure 1: Cross section of cohesionless soil sampler.

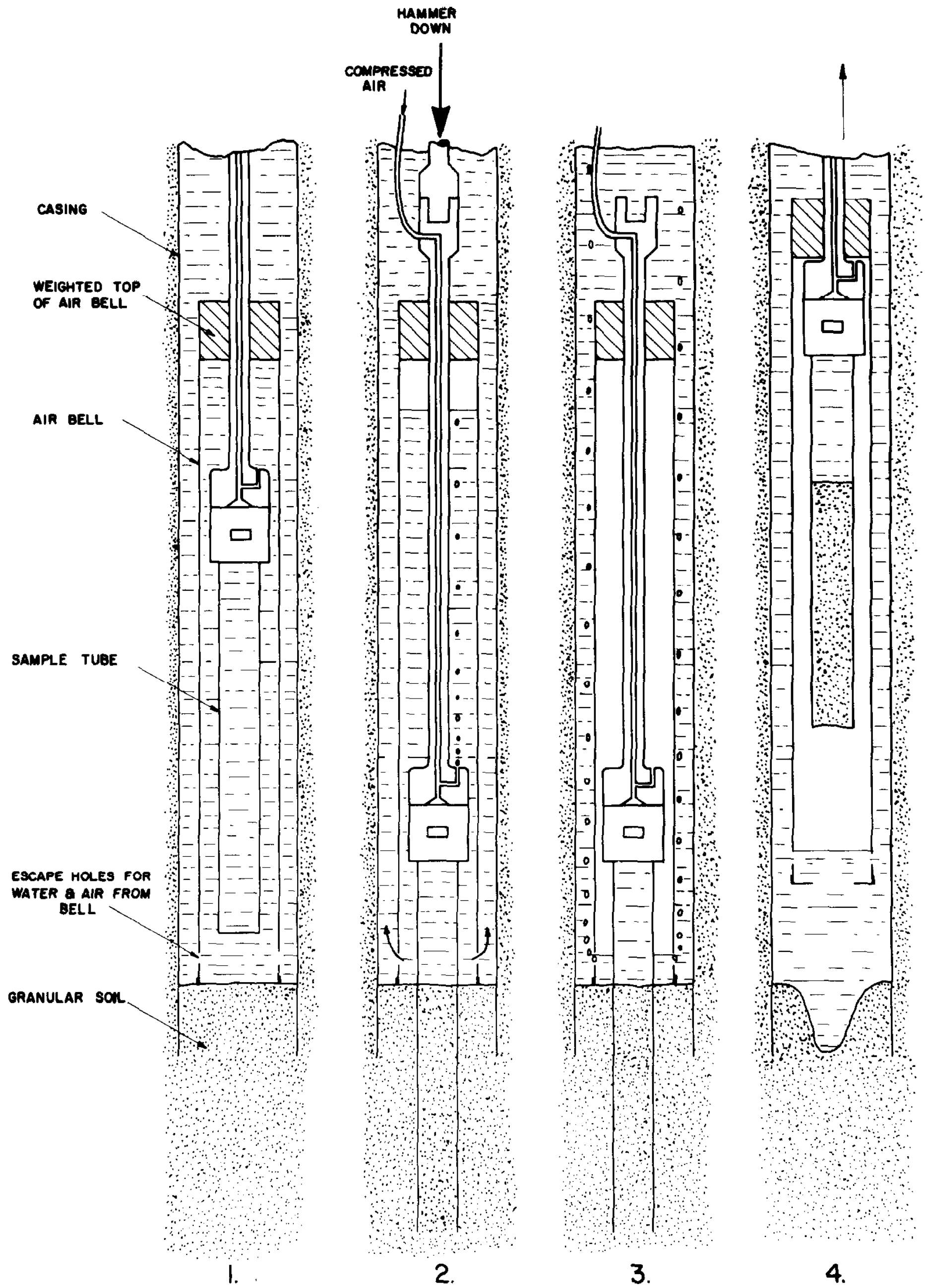


Figure 2: Operation of cohesionless soil sampler. (diagrammatic only)

1. Sampler being lowered. Air-bell already resting on bottom of hole.
2. Sampler driven beyond end of casing. Air pumped in to close valve above sample. Excess air enters bell to displace water.
3. Driving rods removed. All water expelled from bell.
4. Sample tube withdrawn into air-bell and apparatus lifted to surface.

connected in this way and was unsatisfactory because the velocity of the return flow was insufficient to maintain the larger sand grains in suspension. A second attempt using fifty-foot lengths of 1 3/4 in. dia. rubber hosing (O.D. = 2 1/4 in.) with a nozzle at the end, was successful and very much faster to operate because the work of assembling and uncoupling drill rods was avoided. A bulldozer which hauled the drill into position was used to dig a ten-foot square hole which rapidly filled with ground water. This acted as a supply reservoir for the pump and as a settling basin for the soil-laden wash waters which were returned to it to maintain a water circulating system. The soil was washed from the casing until only 6 in. remained in the toe and then the hose was slowly withdrawn, keeping the pump running to maintain the casing full of water and to stop any tendency of the soil to rise.

2.5 Sampling with cohesionless soil sampler

Fig. 2 is a diagrammatic illustration of the sampling method. The sampler was lowered on a wire rope attached to the drill winch, stopping at intervals on the way down to connect sections of E drill rod. When the sampler had reached the bottom of the hole the length of protruding drill rod was driven down with a 100-lb hammer, thrusting the sample tube into the soil ahead of the casing. The driving rods were hoisted and disconnected.

Compressed air from a foot pump was fed into the sampler head to close a diaphragm valve over the sample tube and, when

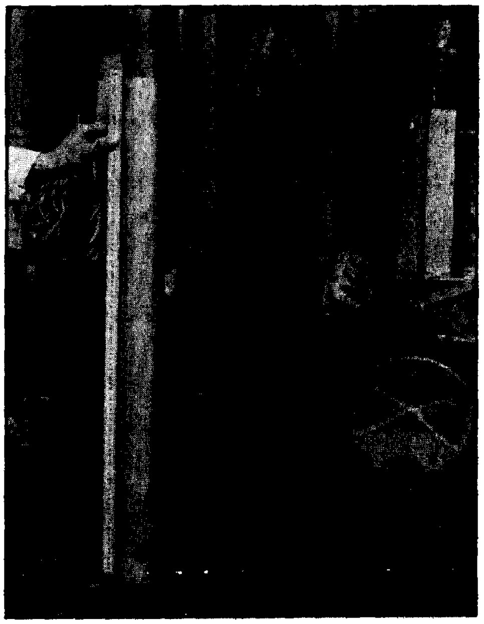


Figure 3.

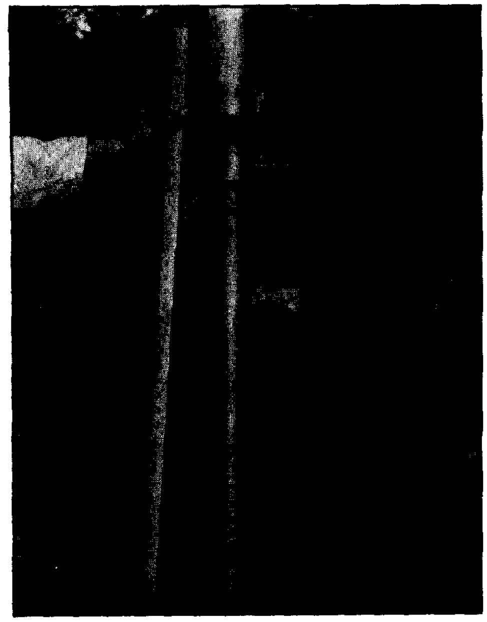


Figure 4.

Cohesionless soil sampler.

Fig. 3: Showing air bell lowered.

Fig. 4: Air bell raised showing full-length sample tube.

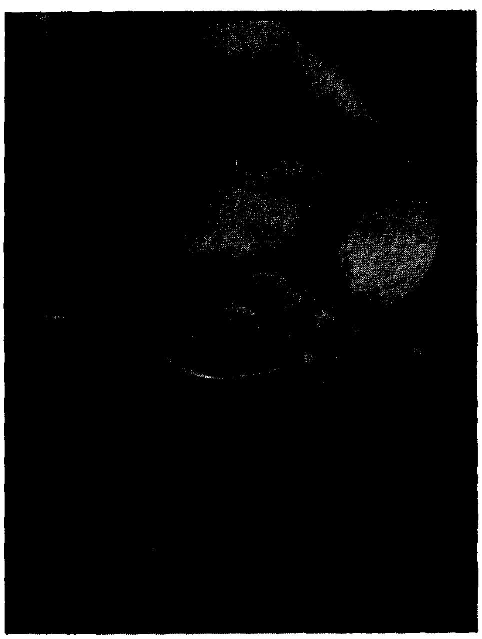


Figure 5.

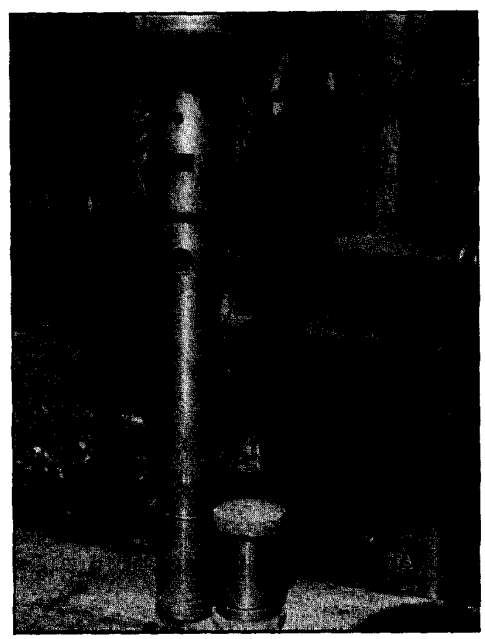


Figure 6.

Sample cut from tube and capped before storage under water.

the pressure had built up to 15 lb/in.^{2} greater than the surrounding water pressure, it escaped through a blow-off valve into the bell. Water was thus displaced from the chamber which had been resting on the bottom of the hole. The water level rose in the casing until the bell was filled with air and excess bubbled to the surface.

The sample tube was winched up into the air bell and both were rapidly raised to the surface. Figure 3 shows the sampler with the air bell covering the sample tube and in figure 4 the bell is raised on the air-tight bearing against the drill rod, to expose the sampler head and tube. A sample is usually extruded from its collecting tube into a storage and testing tube, but because our samples generally consist of cohesionless sand particles and disintegrate very easily they were retained in the collecting tubes. At least 50 cm of soil were collected in the sampler. The bottom 10 cm of tubing was cut off and this sample was capped and stored under water. (Figs. 5 and 6). The remainder of the soil was tapped out, visually examined and discarded. Each sample tube, initially 70 cm long, was used for four sampling operations, the last sample was taken with only 40 cm remaining, this being considered the minimum to ensure that the 10-cm sample was selected from undisturbed soil beyond the toe of the casing. Scribe lines 0.020 in. deep were cut at 10-cm intervals to provide the drillers with a guide line for their tube cutter. Alternative lines for an 8-cm sample were provided if the sample was short of the tube end.

Figure 7: Example of a closely laminated cohesionless sand sample.

Samples were normally taken at 5-ft intervals unless the drillers observed changes in the sediments borne by the wash water indicating a major change in the character of the soil.

2.6 Methods used in soil testing

The sample was cooled to 20°C by submerging it in water. Brass adaptors with filter papers were fitted to replace the sealing caps and the sample was fixed to a permeameter. Water at 20°C was passed through the soil under constant pressure head (normally less than 50% of the sample length) the rate of flow measured and the permeability factor calculated. An example of this calculation is given below. Example:-

Length of sample (L) = 10.1 cm

Cross sectional area (A) = 20.25 cm^2

Upstream head (h_1) = 52.7 cm

Downstream head (h_2) = 48.4 cm

Head difference across sample h = 4.3 cm

Rate of discharge

($K. \frac{AH}{L}$ where K is permeability factor) = 1.2 ml/min

$$\therefore K = \frac{1.2 \times 10.1}{4.3 \times 20.25} = 0.139 \text{ cm/min}$$

$$= 6.56 \text{ ft/day}$$

The sample was then carefully shaken out of its tube (in one piece if possible), weighed, slit longitudinally to examine whether the material was uniform or laminated (see figure 7) and then placed in an oven at 105°C. After drying, it was reweighed to determine the water content and hence an adequate estimate of the

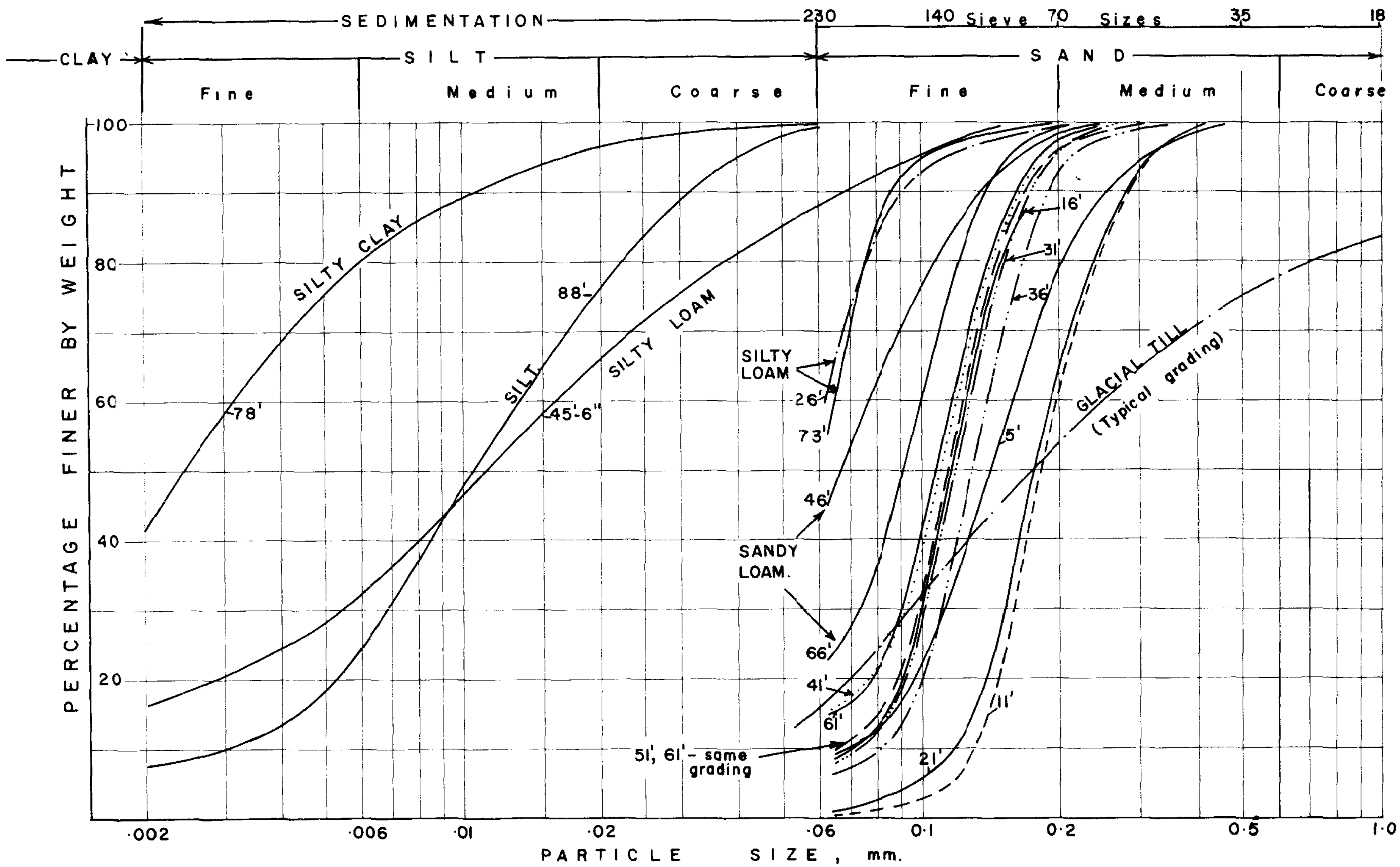


Figure 8: Typical gradings of soils in Perch Lake Swamp.
(Results from borehole B. 30.)

the pore volume.

A portion of the dried sample was placed in a nest of sieves and vibrated for 20 minutes. The weight retained on each sieve was measured and a grading curve drawn. Figure 8 is a typical series of curves derived from the samples from one hole.

If the sample was predominantly finer than sand-size particles (d = 0.06 mm) then the grading was determined by measuring the settling time and applying Stokes law to find the distribution of particle size. The approximate velocity with which particles will settle is given by Stokes law as

$$\text{velocity } (v) = \frac{2}{9} \frac{(s - s_1)}{n} \left[\frac{d}{2}\right]^2$$

s = specific gravity of soil grains n = viscosity of the liquid

s_1 = specific gravity of liquid d = diameter of soil grains

This equation is valid for particle sizes between 0.0002 and 0.2 mm. An example of its use is given below.

Weight of soil sample = 38.340 g.

2.6.1 Sieve test

Sieve size	weight retained g	% retained	% passing
70	Nil	0	100
140	1.885	4.5	95.5
230	2.250	6.5	89.0
pan	34.205	89.0	

2.6.2 Sedimentation test

The silt and clay fractions in the pan were blended with water and the solution made up to one litre. This was shaken up and allowed to settle and samples of solution were taken, using a pipette, from 15- and 5-cm depths at calculated times. By substituting known values for s, s_1 and n in the equation above, the relationship between grain size and settling velocity was established.

A preliminary table was drawn up showing the sampling times for selected particle sizes from convenient depths.

Diameter of grains mm	Velocity cm/s	Settling distance cm	Settling time
0.035	0.1079	15	2 min 19 s
0.02	0.0352	15	7 min 6 s
0.006	0.00312	15	1 h 19 min
0.002	0.000352	5	3 h 56 min

For example a 25-ml sample collected 15 cm beneath the surface at 7 min 6 s after set down, will only contain particles smaller than 0.02 mm diameter. The weight of this dried sample compared with the weight contained in 25 ml of the initial turbulent solution gives the percentage of particles finer than 0.02 mm.

Typical table of result for silt grading

Initial soil concentration = 34.205 g/litre

Reading No.	Time	Sampling Depth	Vol. Sample ml	Wt. of soil in sample g	% of initial concentration	% of total sample
1	0	Any depth	25	0.855	100	89.0
2	2 min 18 s	15 cm	25	0.735	86	76.5
3	7 min 5 s	15 "	25	0.658	77	67.7
4	1 h 19 min	15 "	25	0.427	50	44.5
5	3 h 56 min	5 "	50	0.420	24.6	21.9

The sieve and sedimentation results were tabulated to show the combined grading of the sample.

Sieve No.	Particle Size mm	% Finer
70	0.2	100
140	0.1	95.5
230	0.06	89.0
—	0.035	76.5
	0.02	67.7
	0.006	44.5
	0.002	21.9

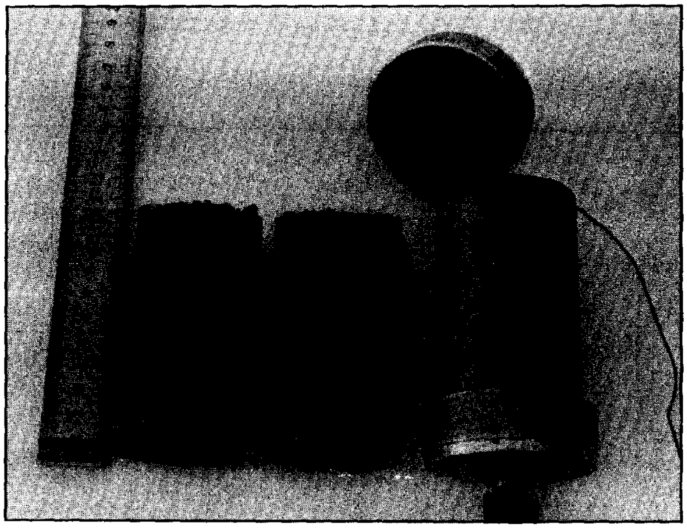


Figure 9a: Adaptors for sample tube. (sample slit longitudinally.)

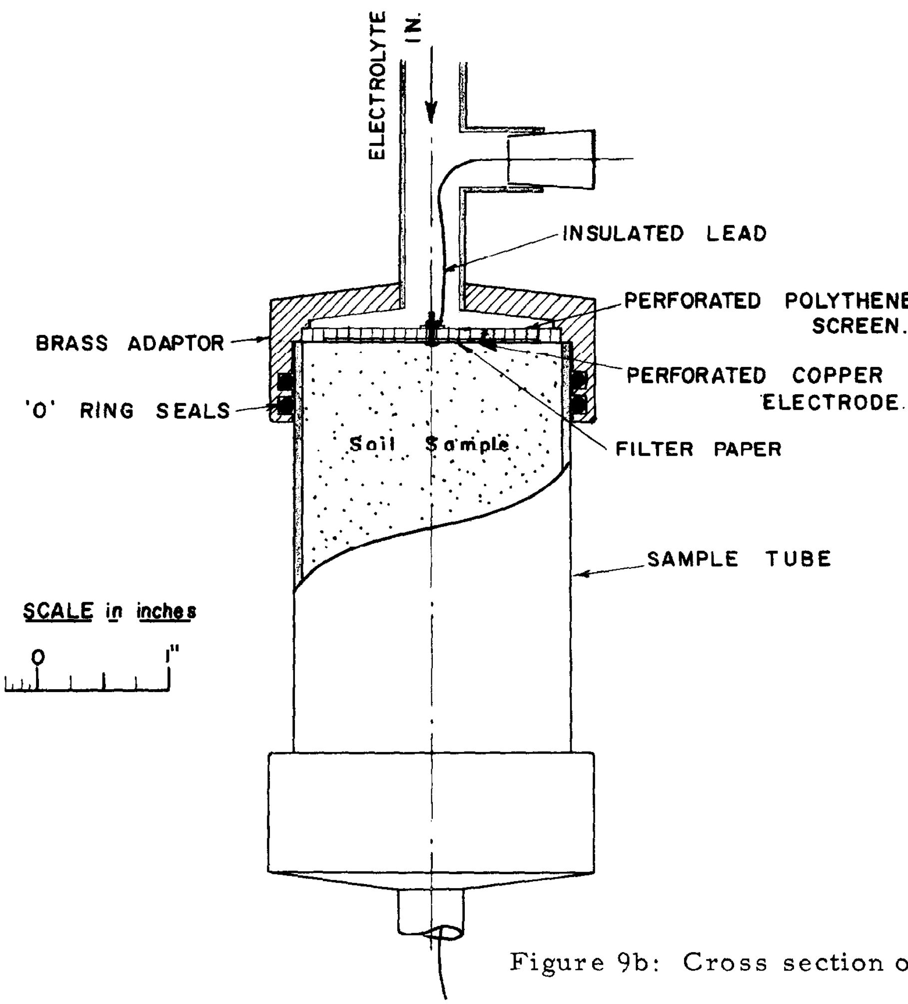


Figure 9b: Cross section of adaptor

The sample therefore contained

11% Fine sand
67% silt
22% clay

and was classified as silty clay loam.

2.7 Estimate of pore velocities in samples

After a soil sample had been tested for permeability and its porosity and void cross-section calculated, the mean pore velocity of water passing through the sample was calculated by the method shown in Fig. 10.

A resistivity test on the sample was used to determine whether tongues of faster-moving pore water preceded the front which moved at the mean pore velocity.

Brass adaptors for the ends of the sample tube were fitted with insulated perforated copper electrodes set against filter papers (see Fig. 9). Insulated leads were taken to an ohmeter. The supply reservoir was emptied of water and refilled with 0.2 M ammonium chloride solution and the permeability test repeated taking readings of resistance every minute.

A graph of resistance against time was drawn as shown in Figure 10. The growth of electrolyte concentration at the first electrode, the arrival of the electrolyte at the second electrode and the point of minimum resistance when the electrolyte front reached the second electrode are indicated on the graph together with the calculations. This test was limited to samples of fine sand.

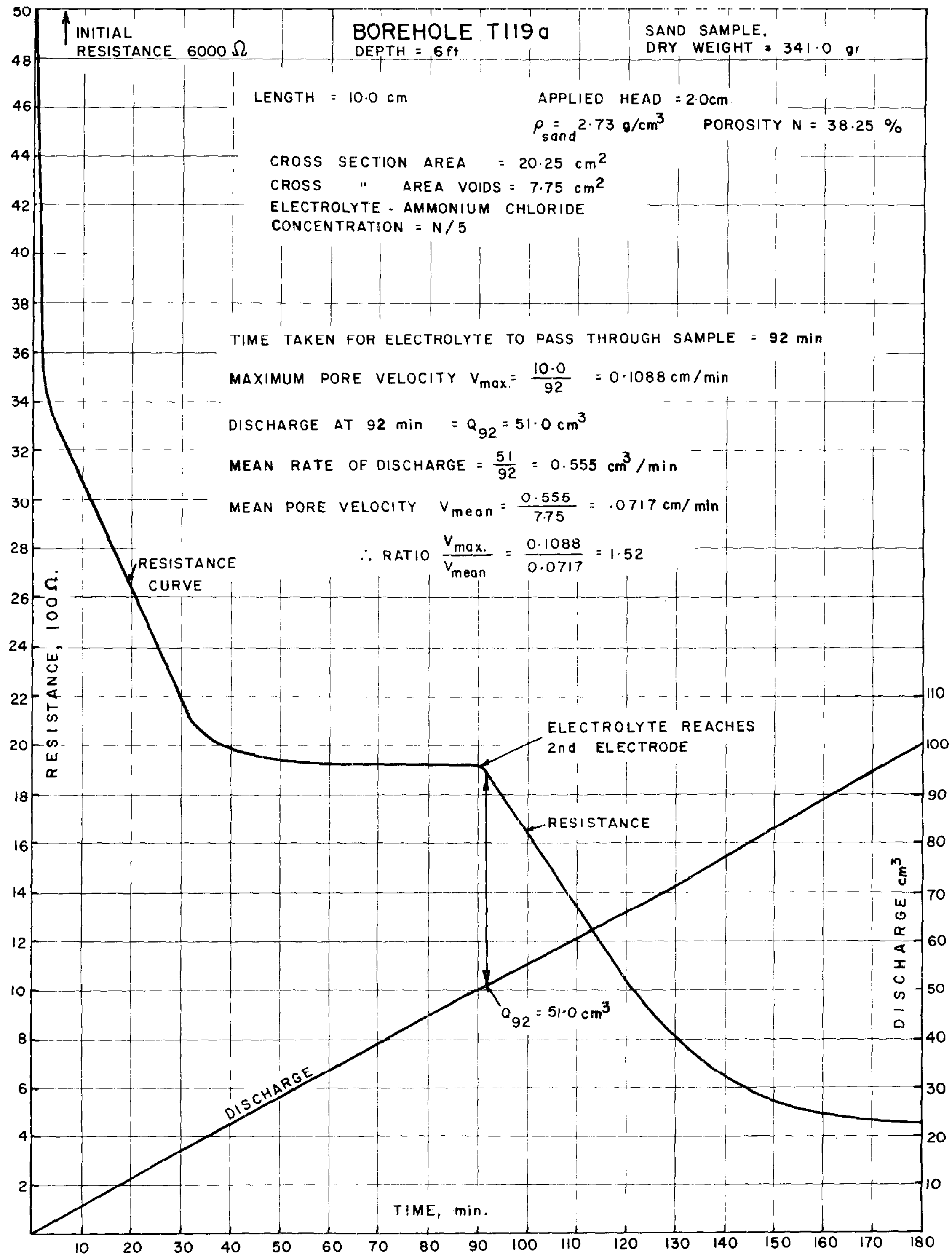


Figure 10: Graph of variation of electrical resistance to determine the ratio of maximum to mean pore velocities through a soil sample.

2.8 Ground-water-velocity measurements in situ

From the permeability and porosity values, and water-table contours, estimates of the pore velocities of ground water may be made for any chosen horizon. However, these indirect results should be confirmed with direct measurements of the pore velocities at selected points in the field.

A trial was conducted beyond the western edge of Perch Lake Swamp. Six copper electrodes were sunk 12 ft into the ground on a 6-ft diameter semicircle and a central electrode was installed where the electrolyte (ammonium chloride crystals) was introduced into the soil. The site of the experiment was close to that of a tritium and fluorescein tracer experiment which was being conducted by W. F. Merritt and both experiments were started at the same time. Daily measurements of resistance were made between the central electrode and each of those on the 6-ft ring. A sudden decrease in one of these resistances clearly showed the arrival of the electrolyte at that point. The pore velocity indicated by this tracer was similar to that shown by the fluorescein tracer in the neighbouring experiment.

Three tests of this type were tried in Perch Lake Swamp but resistance readings varied in an uncertain fashion depending upon surface water from rainfall and nothing could be interpreted from the readings. A similar test in the swamp using sulfur-35 and fluorescein as tracers was not satisfactory and further work on these lines is to be carried out.

2.9 Cross sections

Cross sections have been compiled from the bore-hole sample results and plotted on an exaggerated vertical scale. (Figs. 11-14, 16). Permeability and soil classifications are noted at the elevation from which each sample was selected. The greatest depth shown for each hole was that reached when the steel casing could be driven no further.

Experience has shown that large boulders embedded in glacial till will resist further driving as effectively as bedrock, so it is not known whether the casing reached bedrock. If the final wash waters were silt laden and contained granite grit and it was impossible to clean out the casing to its end, it is likely that glacial till was present with the casing jammed between boulders or stones.

The binding material between the boulders of glacial till consists of compact sand and silt which can occasionally be collected if the sample tube does not strike a stone - this material has been sampled only four times in this investigation.

3. Results and Conclusions

3.1 Grouping of soil samples

The majority of soil samples examined have been fine sand. Fig. 8 shows the range of grain sizes in this classification and the results from a series of soil samples taken from one bore hole.

Because interest is centred around the higher water velocities found in this fine sand it has been divided as follows into four sub-groups which conveniently fit local gradings:

Classification of sand samples

Medium sand	- Less than 40% finer than 0.2 mm.
Medium fine sand	- Between 65% and 40% finer than 0.2 mm and less than 5% finer than 0.06 mm.
Fine sand	- 65% - 100% finer than 0.2 mm and 0 - 10% finer than 0.06 mm.
Very fine sand	- 10 to 20% finer than 0.06 mm. (Silt)

For soils which contain more than 20% silt the standard grouping is shown below in the following table:

Table I

Classification of Soils

% of Soil Separates Present			
	Sand Coarser than 0.06 mm	Silt 0.06 - 0.002 mm	Clay Finer than 0.002 mm
Sandy Loam	50 - 80	0 - 50	0 - 20
Silty Loam	0 - 50	50 - 80	0 - 20
Silt	0 - 20	80 - 100	0 - 20
Silty Clay Loam	0 - 30	50 - 80	20 - 30
Silty Clay	0 - 20	50 - 70	30 - 50

3.1.1 Summary of sample results

The results of permeability and porosity measurements on 223 samples are summarized in the following table.

Table II

Permeability and Porosity Results

	Measured range of Permeability Factor K* ft/day	Measured Range of Porosity N+ %	% of Total Samples
Medium Sand	2.4 - 11.5	33.5 - 39	3.6
Medium Fine Sand	3.7 - 16.3	37 - 41	5.4
Fine Sand	1.5 - 13.5	33 - 43	53.8
Very Fine Sand	0.5 - 1.9	35 - 39	9.4
Sandy Loam	0.4 - 1.2	35 - 46	4.5
Silty Loam	0.2 - 0.4	37 - 39	4.5
Glacial Till	0.02 - 0.1	18.5 - 33	1.8
Silt	0.004 - 0.01	39 - 47	6.3
Silty Clay (Varved)	0.0001 - 0.001	39 - 57	10.7

*K is a permeability factor that represents the flow of ground water in cubic feet per square foot of soil cross section per day when the loss in head is equal to the length of soil column.

+N is the porosity, which is the ratio of the pore volume to total volume expressed as a percentage.

The large variations in permeability are caused by the following:

1. Variations in soil grading within a soil classification.
2. Variations in porosity.
3. Insufficient samples in some groups to give a representative range of permeabilities.
4. The division of a well graded sample into layers which are composed of particles uniform both in material and grain size within the layer.

The laminations which exist in most of the soil samples are typical of alluvial deposits. They represent successive sedimentations, each of which occurred under a different regime of river flow. Their uniformity in grain size and material is a distinctive characteristic.

Laminated sands exhibit their greatest permeability when the flow is parallel to the bedding but the permeability measured from soil samples is that for flow across the layers. The extent of lamination is not known until the test is completed and the sample removed and examined. Embedded layers of very fine sand or silt will give an answer much smaller than the field permeability which is for horizontal flow parallel to the laminations.

3.2 Water table (see drawing 1)

The highest elevation of the water table is in reactor-pit No. 2 where it lies approximately 42 feet above the lowest drainage area, Perch Lake.

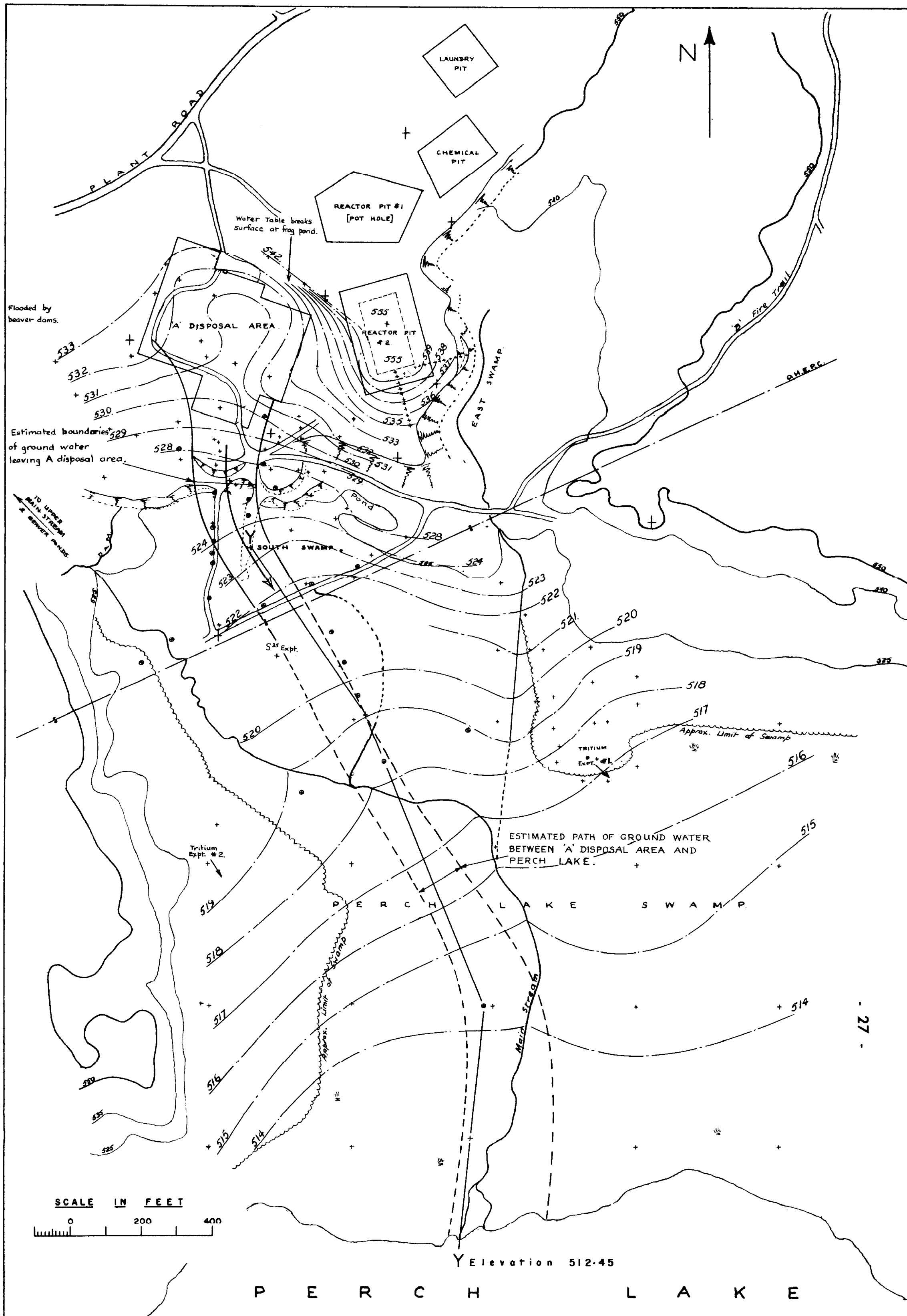
3.2.1 Effects of Reactor Pit 2

A mound in the water table has been produced by the water pumped into reactor pit No. 2. The ground-water flows away from this mound in all directions except north. To the east the water table intersects the surface of the East Swamp and water flows away in a stream which passes 220 ft to the west of the site of the first tritium experiment (drawing No. 1). The stream does not drain this area but supplies a lower and variable water table. The contours on drawing No. 1 indicate that the ground-water flow is directed away from this stream.

Seepages from the reactor pit to the west and south remain underground except over a short length at the junction with South Swamp. The mound of ground water has distorted the water table in the A disposal area and diverted its natural flow pattern. Ground water leaving the A disposal area probably flows in a much narrower stream than it did before reactor pit 2 came into use.

3.2.2 Variation of water table

The seasonal variation of water-table level is greatest where it is deeply submerged beneath the surface around the disposal areas. This variation is normally



LIQUID DISPOSAL PITS, A DISPOSAL AREA, PERCH LAKE SWAMP.

—·—·— CONTOURS OF WATER TABLE. (on Nov. 5th. 1959.)

⊕ DRY MONITORING TUBES

+ WELLS

DRAWING I.

less than 12 inches except in the area around the reactor pit where changes up to three feet have been recorded. However, large variations in the peak level of this mound in the water table do not alter the configuration of the surrounding lower ground-water contours. The water table in the swamps varies little and is dependent on immediate rainfall rather than on seasonal precipitation.

3.2.3 Direction of Ground Water flow from A Disposal Area

The anticipated direction of ground-water flow is shown on drawing No. 1. Its path lies curving beneath south swamp in a band between 120 and 160 ft wide; it travels down the axis of Perch Lake Swamp where it widens to 260 ft before entering Perch Lake.

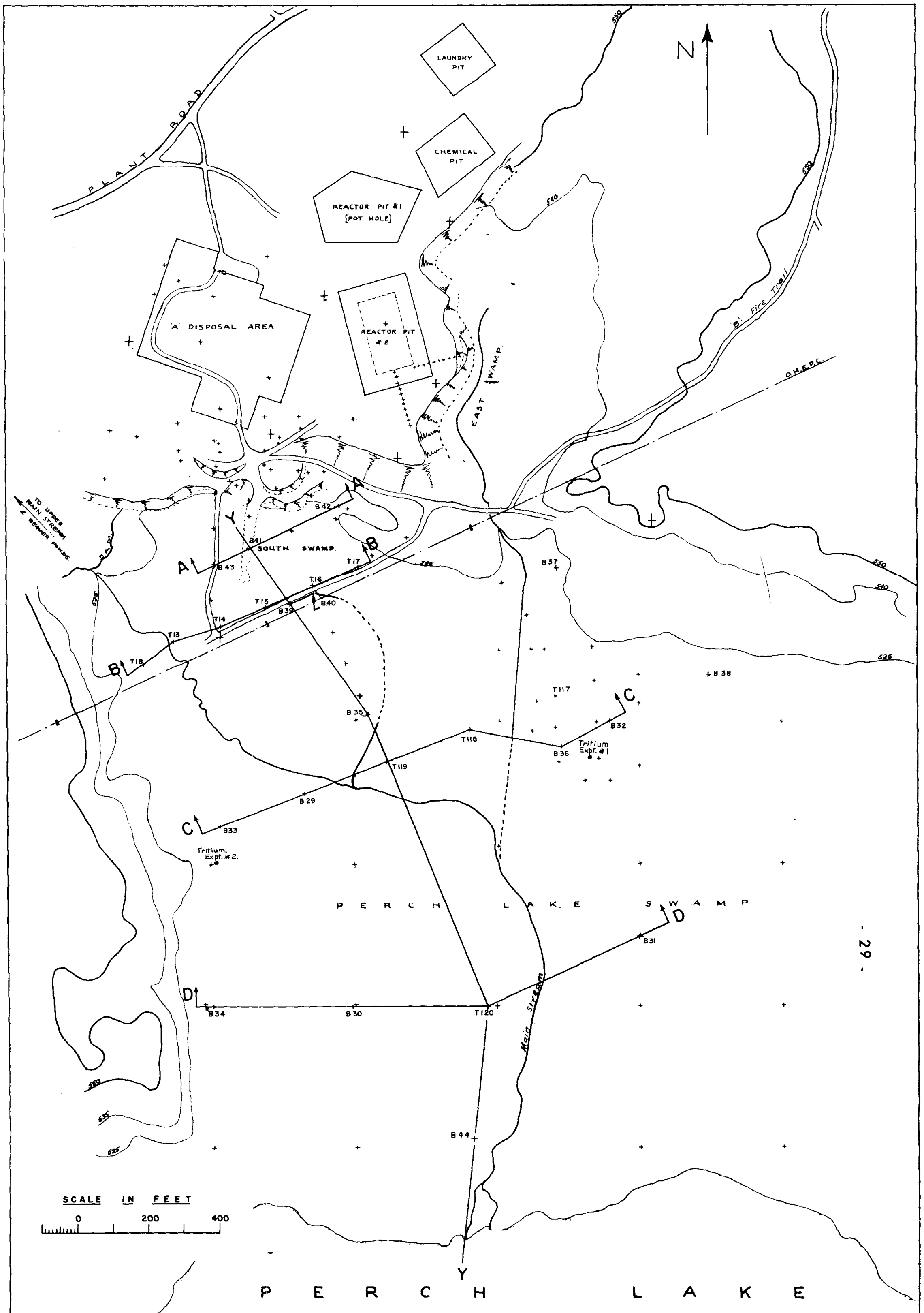
3.3 Description of Cross Sections

3.3.1 (a) Cross Section AA (Figure 11)

This is a cross section through South Swamp 200 ft north of the power line and 330 ft south of the A disposal area.

Borehole B.43* at the eastern extremity of the figure is approximately half way across a submerged valley. This is composed of glacial till and generally lies between 50 and 60 ft beneath the surface. The bed of the valley shelves 30 ft near the eastern end where borehole B.42 is only 23 ft deep.

* See map (Drawing 2) for location of boreholes



LIQUID DISPOSAL PITS, "A" DISPOSAL AREA & PERCH LAKE SWAMP

PLAN OF BOREHOLES & CROSS SECTIONS

DRAWING 2.

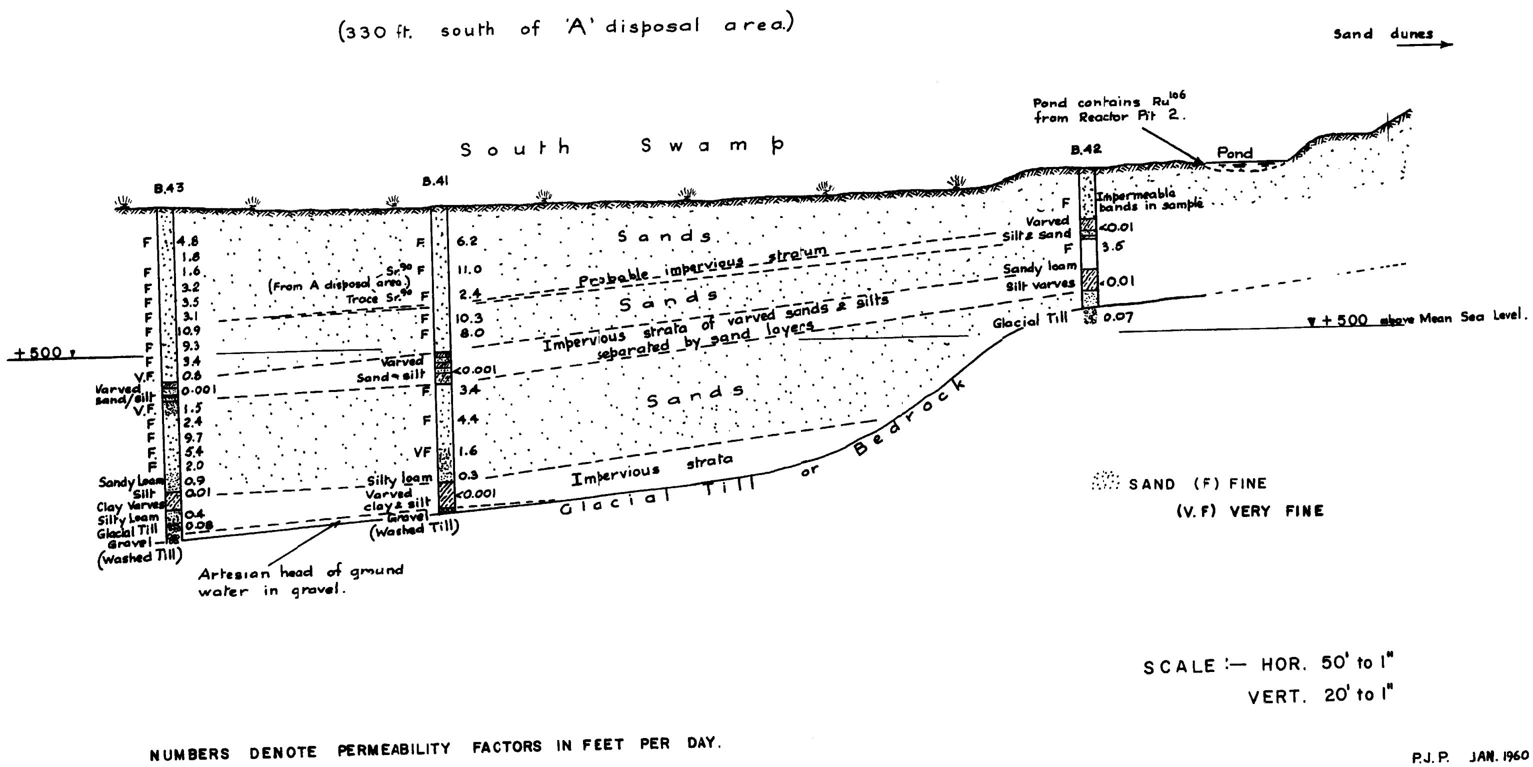


Figure 11: Cross section AA. Through South Swamp 200 ft north of Power Line.

The bottom of this valley is covered with impermeable deposits of varved clay and silt more than 3 ft thick. Boreholes B.41 and B.43 have revealed artesian conditions to exist beneath this clay layer where the surface of the glacial till has been washed free from fine material and coarse gravel remains.

The material of South Swamp overlying this impermeable layer comprises between 40 and 50 ft of grey laminated sand. Varved sands and silts are present in thin layers at certain horizons in these sands. Some have been located and it is thought that others exist.

Strontium-90 has been found at depths of 11 ft and 16 ft beneath the surface in borehole B.41 - it is thought that it is kept at these levels by thin impermeable layers of silt or clay.

3.3.2 (b) Cross Section BB

The outline of this cross section is plotted from the depths of the dry aluminum tubes that are sunk on the boundary between South Swamp and Perch Lake Swamp. It lies approximately 60 ft north of and parallel to the power line.

A bedrock ridge outcrops 210 ft beyond T.18 but it is not known whether this profile, which is 700 ft long, is composed of rock or glacial till.

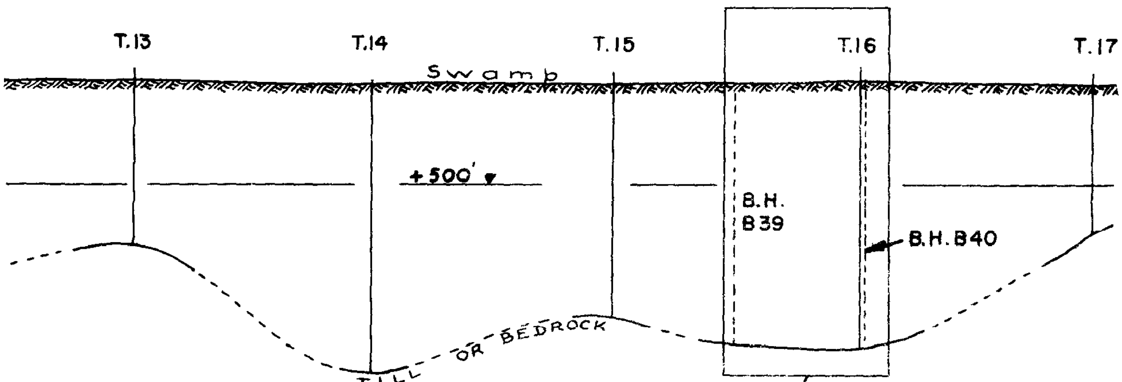


Figure 12a: Cross section BB.
(40-ft north of power line.)

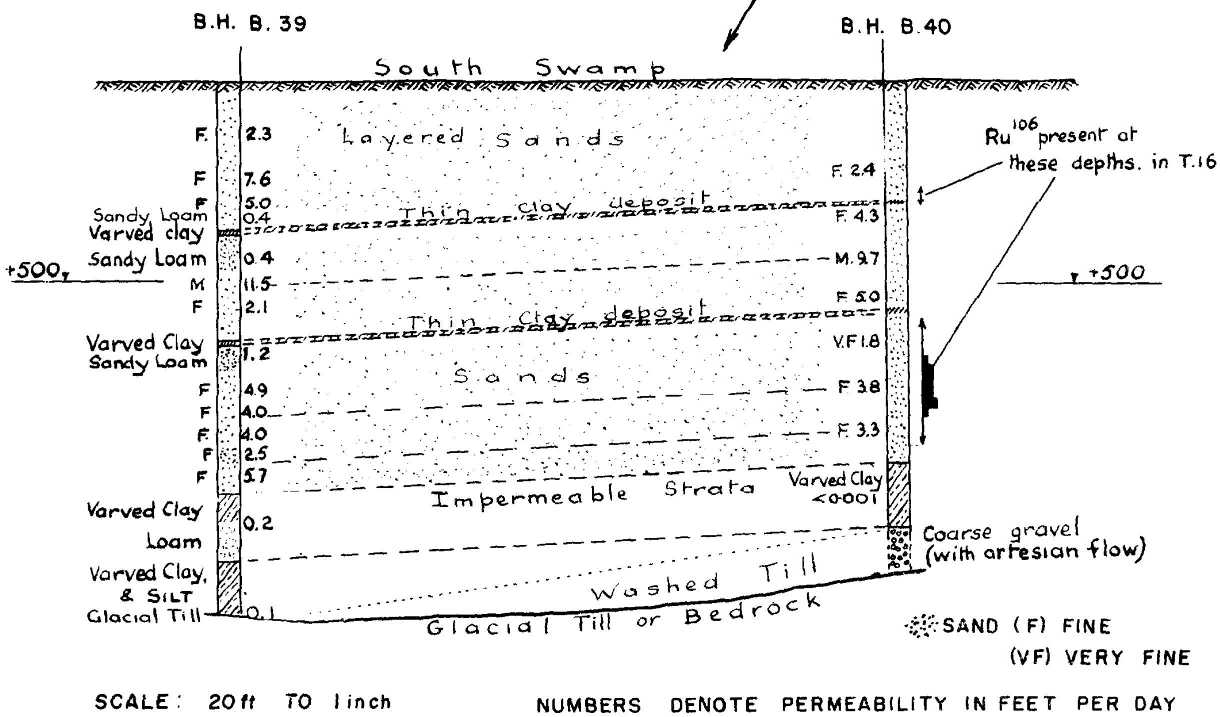


Figure 12b: Detailed cross section near T.16
(20-ft south of section BB.)

A detailed cross section is drawn between boreholes B.39 and B.40 situated 20 ft south of section BB. This shows that the broad picture described for section AA is maintained. The depth of sand is unchanged but the impermeable clay and silt varves underneath, which begin at about the same elevation, become thicker in extending down to a deeper bed of the valley. In borehole B.39 the bed was found to rest directly on glacial till but in B.40, which is 75 ft away, the till was washed and sufficiently transmissible to maintain an artesian flow of one gallon per minute against a head of 55 ft 6 in.

Two varved clay layers less than 3 in. thick lie in the sands, embedded in deposits of sandy loam.

The presence of ruthenium-106 in the ground water has been verified at certain elevations indicated in Fig. 12 and it appears that the contamination is restricted by ground-water flow along the thin clay layers. The artesian waters are uncontaminated.

3.3.3 Cross Section CC

Cross section CC is approximately 500 ft south of BB and shows the valley much developed in breadth and that its deepest measured point is 118 ft beneath the surface of the swamp.

West of the section, 500 ft beyond borehole B.33, the valley outcrops in a bedrock ridge at 50 ft above swamp level. Eastwards its rise is more gradual with outcrops of bedrock, thinly veneered with sandy till, at 200 ft north of borehole B. 32.

A deposit of silt blankets the valley and varies in thickness from 38 ft in the deepest region to 6 ft at the shallow end to the east. Its surface is therefore a very subdued replica of the valley.

The deltaic grey sands overlying this silt extend to the surface and contain one major band of varved silt and clay between 2 1/2 ft and 4 ft thick. This lies about 35 ft beneath the surface and acts as an impermeable barrier between the sands above and those beneath. This layer is an extension of the varved clay and silt formations overlying the glacial till in cross sections AA and BB. The lower sands are generally finer, have a higher silt content and are less permeable than those in the upper region which may be classified broadly as laminated fine sands. Narrow bands or lenses of silty loam are embedded in this upper region and have been found in borehole T. 119a and in a series of shallow boreholes sunk close to borehole B. 33 Fig. 16 shows an undisturbed sample of sand containing a 1 1/4 in. band of silty loam.

At the western end of the cross section beyond the swamp, boreholes B. 32 and B. 36 span the site of the first tritium experiment. Direct measurements of ground water velocity had been made here by W.F. Merritt[7]. It was

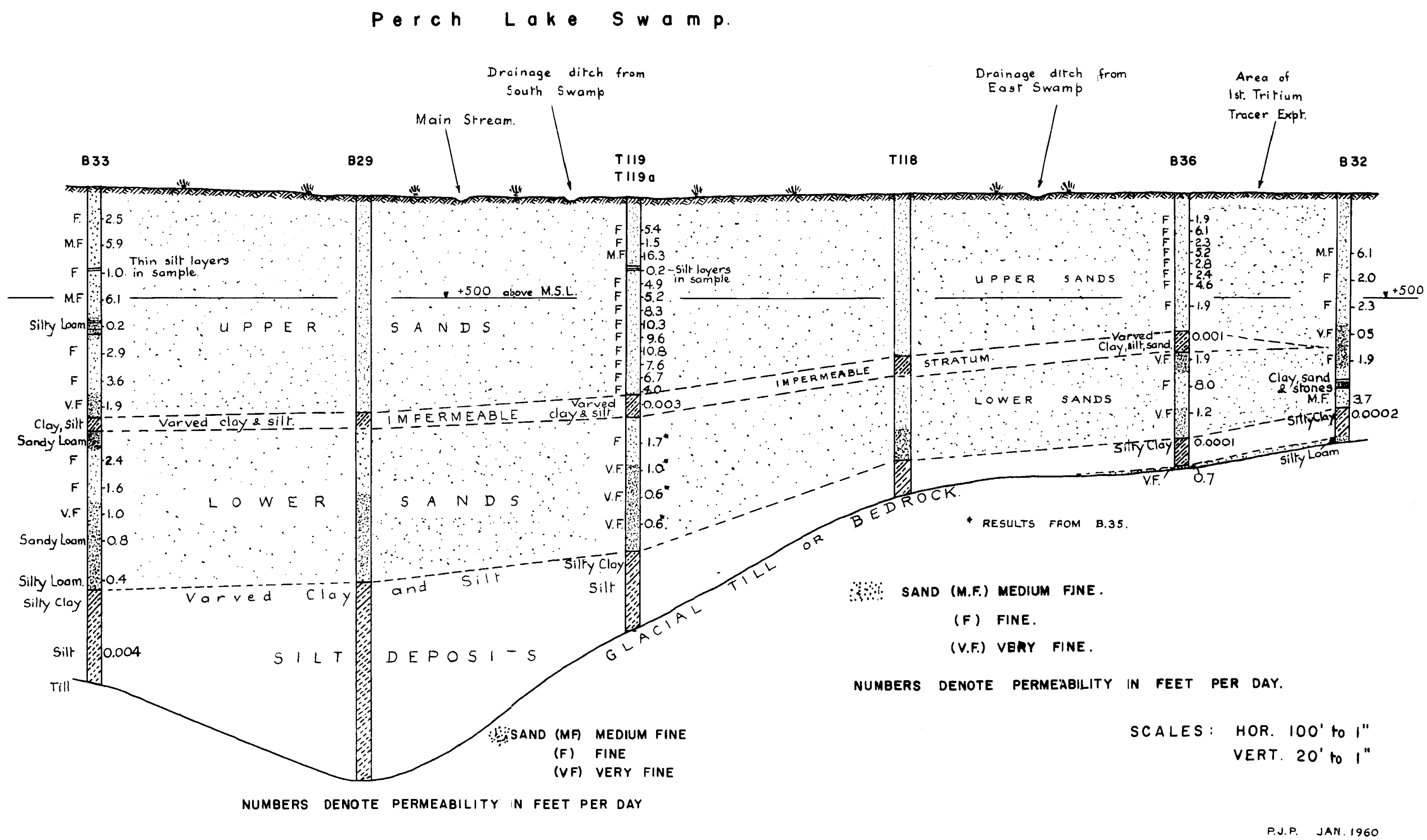


Figure 13: Cross section CC. Through Perch Lake Swamp 500 ft south of Power Line.

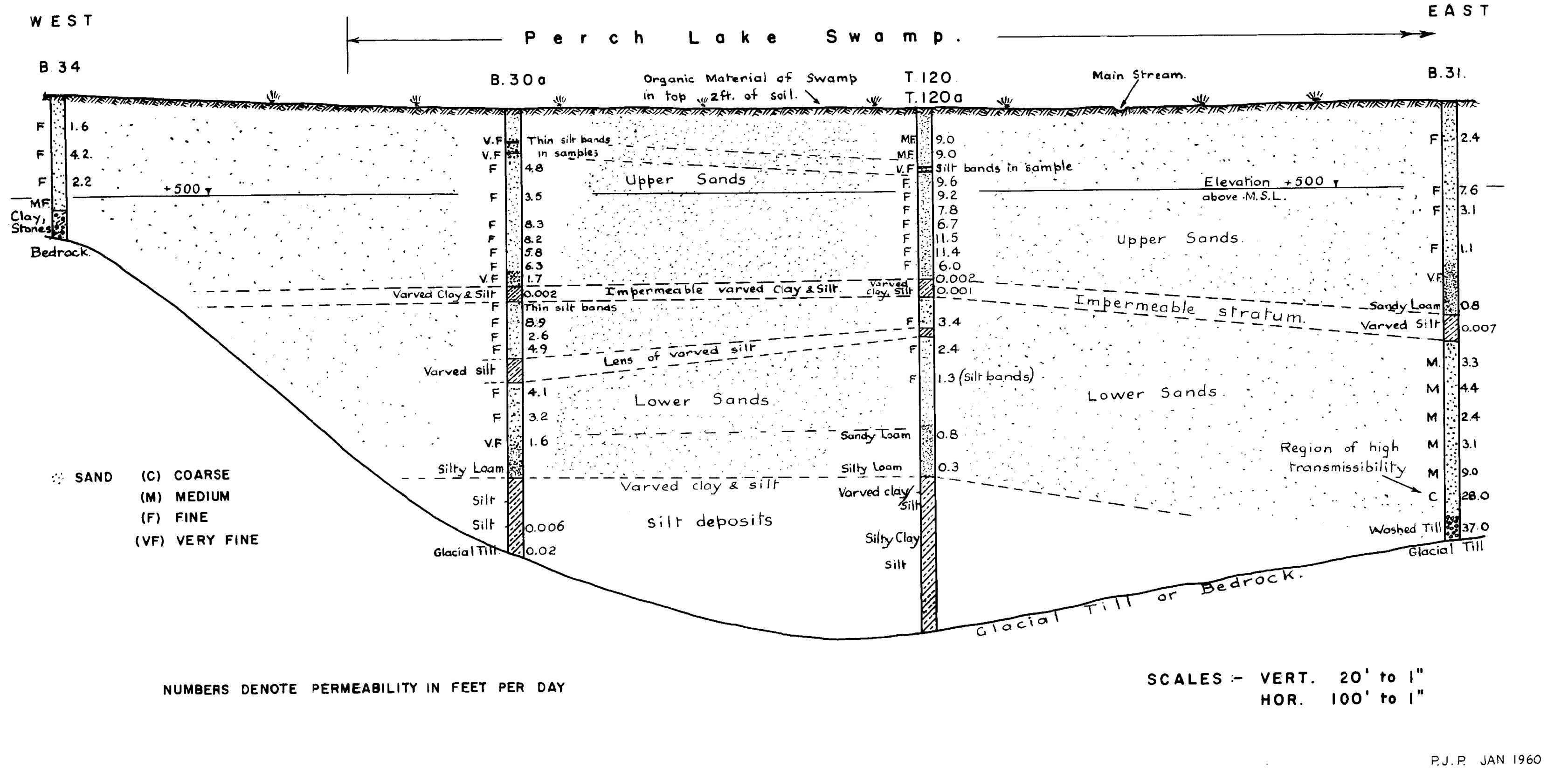


Figure 14: Cross section DD. Through Perch Lake Swamp 1100 ft south of Power Line.

therefore desirable to examine this soil in great detail to try to relate the calculated ground-water velocities from soil samples with those measured *in situ*. Sampling was conducted at intervals of 2 ft in borehole B. 36. All the samples down to 25 ft were grouped as fine sands but showed large variations in their permeability factors. A comparison of the calculated and measured ground-water velocities is given in Table III, page 44.

3.3.4 Extra Boreholes

Boreholes B. 37 and B. 38 were holes drilled onto the rising glacial till to the north and east of borehole B. 32. Glacial till was struck between 9 and 11 ft down and was found to be covered with silt at least 2 ft thick in each hole. Sand overlaid this and continued to the surface. Boreholes with an 'a' suffix to their number indicate that these have been resampled at closer intervals than in the original drillings. B. 36 was the first borehole to demonstrate that sampling at 5-ft intervals can conceal large local variations in permeability.

3.3.5 Cross Section DD

Cross section DD is a further 600 ft south of CC. It shows the valley to have developed further in breadth to extend under the eastern leg of Perch Lake Swamp beyond this cross section. The bedrock ridge has closed in from the west and the steep west side of the valley is located between boreholes B. 34 and B. 30a.

The bed of the valley has risen 20 ft from its greatest depth in Section CC but is still covered with silt over this deepest region. At borehole T. 120 the silt layer extends between depths of 67 ft and 95 ft (28 ft thick) but as the bed rises gradually to the east this silt disappears, and at borehole B. 31, 450 ft away, it is replaced by coarse and medium sand.

The main sand deposits vary between 60 and 80 ft thick and are again separated into two by the varved clay strata which extend through from the previous section. The upper sands with their occasional thin silt bands are not changed from section CC, but the lower sands have an additional lens of varved silt lying 8 ft beneath the clay barrier. This is probably 500 ft wide and its thickness varies between zero and 4 ft. The lower sands at borehole B. 31 are different from those encountered in any of the previous cross-sections. They are consistently coarser and better sorted, i.e. more uniform in grain size.

If these sands are continuous to the south or south-east they provide a path of high transmissibility for the ground water contained beneath the dividing clay layer. A sample of washed till, collected from a depth of 80 ft beneath this sand, had a high permeability factor. Eighteen inches below this point the normal unwashed till was found but the sample was not large enough to determine the permeability factor.

3.3.6 Additional boreholes

Borehole B.44 was sunk between section DD and Perch Lake. The results show that the submerged valley stops before Perch Lake is reached and that it is really an elongated depression. In drawing 3 the contours of the till or bedrock are plotted. The axis of the depression is not parallel with that of Perch Lake Swamp. It skirts the north-east of Perch Lake. Borehole B.45 (see drawing 3) was sited close to Perch Creek where it leaves Perch Lake. At this point a sandy till has risen to within five feet of the surface and is overlain by silt with only a thin cover of organic material.

At borehole B.46, 43 ft of sand overlies a bedrock or till depression beneath the eastern shore of Perch Lake. Layers of varved clay and silt occur close to the surface and 30 ft down.

Borehole B.49 was sited south of Perch Lake to investigate a swamp between two bedrock outcrops. Glacial till was found immediately beneath the surface.

3.4 Summary of cross sections

Perch Lake Swamp may be considered as two thick deposits of grey sand separated from each other by an impermeable horizontal clay barrier.

3.4.1 Upper Sands

The upper sands extend north of Perch Lake Swamp into the South Swamp where they represent the entire sand deposits. Ground water will flow in this upper aquifer according to the water-table contours of drawing 1.

3.4.2 Lower Sands

The lower sands are contained beneath the clay barrier and generally above silt deposits overlying glacial till. They do not extend north of the power line and there is a separate water table controlling this ground water flow.

A few deep wells penetrating this region indicate a widespread small artesian head but there are insufficient details to delineate the lower water table accurately.

The clay layers in the varves are generally between 1/16 in. and 1/8 in. thick and consist of a soft reddish-brown plastic clay containing over 60% clay-size particles. An example of clay and silt varves is shown in figure 15.

The silt lining is light grey and densely packed, with the upper layers slightly varved. The clay content decreases with depth, changing from silty clay to silty clay loam to silt. Approximately 0.2% of these materials are colloids.

3.4.3 Longitudinal Section

A longitudinal section through South and Perch Lake Swamps has been drawn along the estimated path of ground

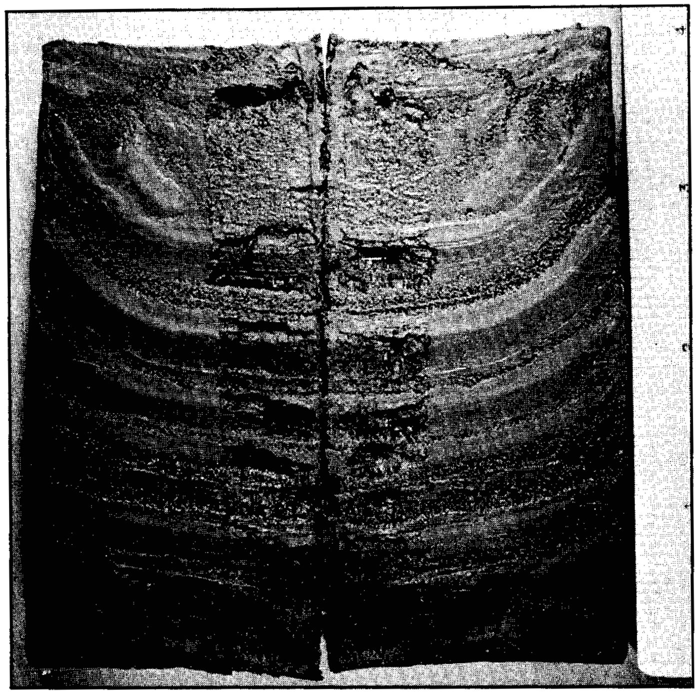


Figure 15: Sample of varved clay and silt from borehole B. 30.
(Depth 33ft 6in.)

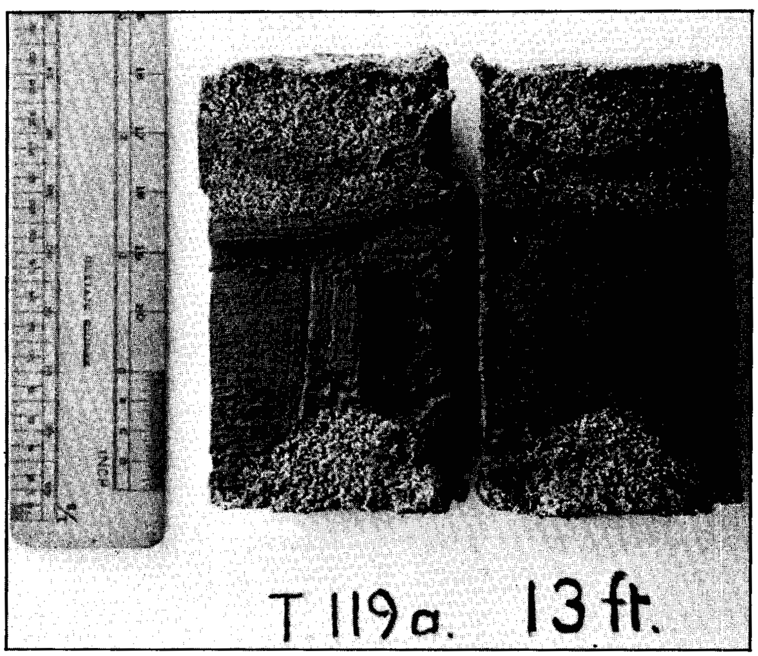


Figure 16: Silt band $1\frac{1}{2}$ in. thick embedded in sand deposits.

water between A disposal area and Perch Lake (Drawing 1) and is shown in Fig. 17. Borehole B.41 at the northern end of the section shows the depths at which strontium-90 has been found in soil samples. It is believed that because of the stratified nature of the sands the flow of ground water is parallel to the layers rather than horizontal. The presence of thin silt bands in Boreholes T.119a and T.120a at depths of 13 1/2 ft and 11 ft respectively indicates that the horizons of flow would be approximately parallel to the ground surface. (Fig. 16)

3.4.4 Depth of principal flow of ground water

The permeability figures plotted for the five boreholes show that within the mass southward movement of ground water in the upper sands there should be two streams where there are high pore velocities. The most important one begins at a depth of 11 ft in Borehole B.41, where the soil is already contaminated with strontium-90. This passes beneath the swamp and intersects Perch Lake, probably at a depth of less than 10 ft.

The second stream remains between 20 and 23 ft beneath ground level and ends beneath the bed of Perch Lake.

3.5 Ground Water Seepage Rates

3.5.1 Pore velocities in soil samples

Results from resistivity tests on sand samples

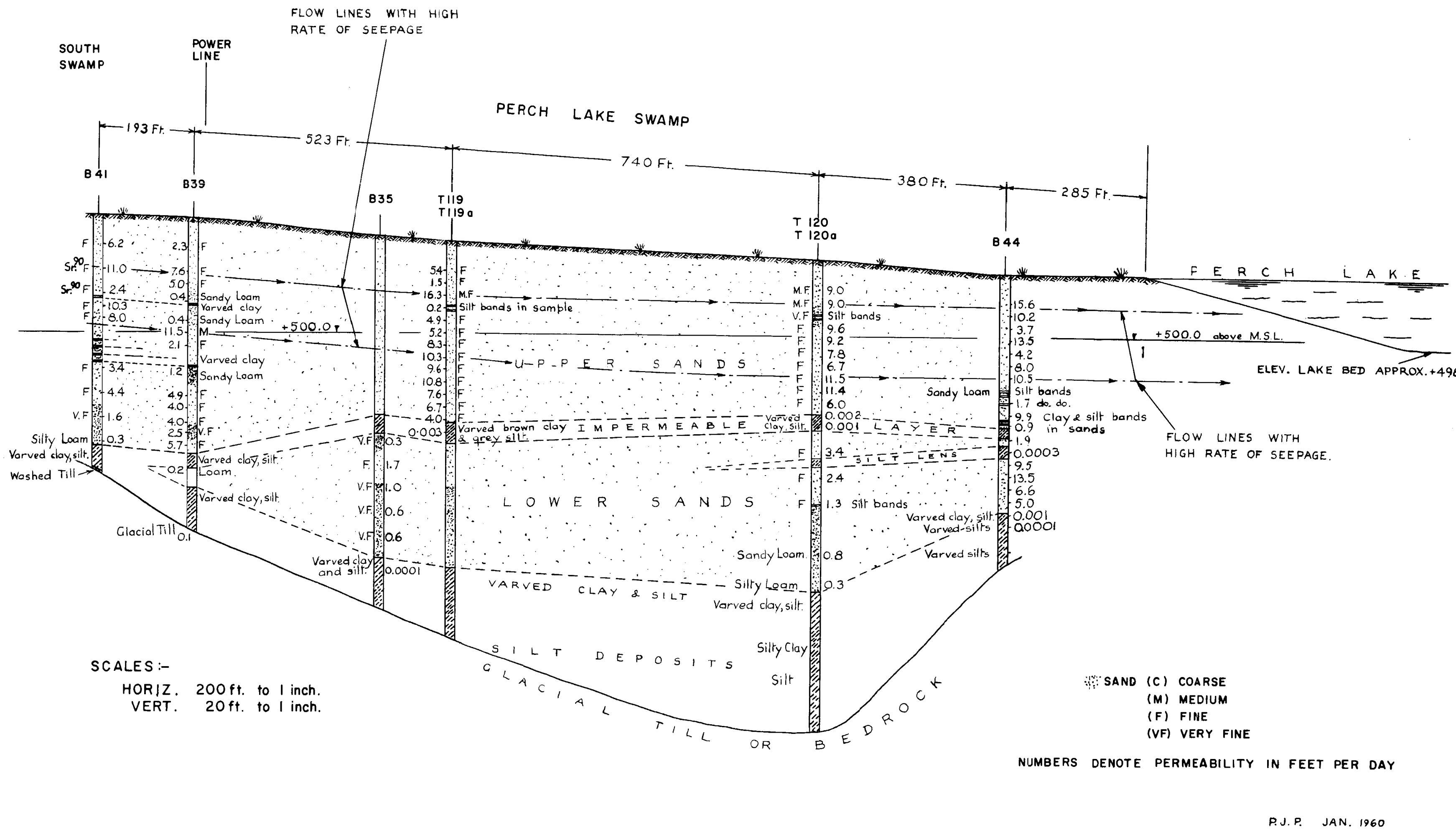


Figure 17: Longitudinal section YY through Perch Lake Swamp.

selected from boreholes on the predicted flow line, show that the ratio

$$\frac{\text{Max. pore velocity through sample}}{\text{Mean pore velocity through sample}} = 1.6$$

The sands tested had permeability factors varying from 4.2 to 13.5 ft/day.

3.5.2 Predicted seepage rates at sites of tracer experiments

The estimated rates of ground water flow at the sites of the tritium tracer tests were calculated from soil samples collected from the appropriate depths and are shown in Table III.

Table III

Comparison of measured and predicted ground water velocities

	Site 1	Site 2
Permeability factor of soil sample (ft/day)	6.1	15.0
Porosity (%)	37.25	38.10
Hydraulic gradient	$\frac{1}{130}$	$\frac{1}{108}$
Maximum pore velocity estimated from soil samples (ft/day)	$1.6\left(\frac{6.1 \times 100}{130 \times 37.25}\right)$ = 0.20	$1.6\left(\frac{15.0 \times 100}{108 \times 38.10}\right)$ = 0.583
Velocity of tritium tracer measured in situ (ft/day)	= 0.375	= 1.0
Ratio $\frac{\text{actual velocity}}{\text{predicted velocity}}$	= 1.87	= 1.72

The difference between the true and the predicted velocities is attributed to the difference between the horizontal field permeability parallel to the layers of soil and the vertical tested permeability across them.

A correction factor of 1.8 based on the results of these two tests is used to estimate the ground water velocities along the predicted path in Perch Lake Swamp.

3.5.3 Seepage rates through Perch Lake Swamp

Tables 4 and 5 record the permeability and porosity results obtained from soil samples collected on the anticipated flow line, starting at a depth of 11 feet in borehole B.41. The maximum pore velocities are calculated for each position using the two factors previously described. These values are calculated for a theoretical 1-in-1 hydraulic gradient. The mean of these values between adjacent boreholes, combined with the actual hydraulic gradient is used to calculate the flow time between the boreholes. Table 4 shows that 13 1/2 years is the expected time to be taken for ground water to seep from section AA to Perch Lake. The results for the lower (21 ft) stream are tabulated in Table 5, showing the transit time to be 16 years. These estimated times cover the passage of water to points below the shoreline of Perch Lake. It is probable, however, that a large delay will occur as the water seeps through the soil/water boundary

BOREHOLE	SAMPLE DEPTH	SAMPLE ELEVATION ft above M.S.L.	ELEVATION OF WATER TABLE ft.	PERMEABILITY K cu.ft / ft^2 / day	POROSITY N %	ESTIMATED MAXIMUM PORE VELOCITIES WITH A HYDRAULIC GRADIENT $\frac{1}{1}$ $V = 1.8\left[\frac{1.6 \times K \times 100}{N}\right]$: AT BOREHOLE V. [ft /day]	MEAN VELOCITY BETWEEN BOREHOLES V_m [ft /day]	HYDRAULIC GRADIENT i	FIELD VELOCITY $V_m \times i$ [ft./day]	DISTANCE BETWEEN BOREHOLES [ft.]	TIME TAKEN FOR GROUND WATER TO FLOW BETWEEN BORE HOLES: DAYS	YEARS
B 41	11'-0"	513	523.4	11.0	37.6	84.2						
							71.6	$\frac{1}{112}$	0.64	193	302	0.83
B 39	11'-0"	512	521.7	7.6	37.1	59.0						
							90.0	$\frac{1}{154}$	0.585	523	894	2.45
T119a	11'-0"	507.5	518.3	16.3	38.8	121						
							97.1	$\frac{1}{185}$	0.525	740	1410	3.86
T120a	8'-6"	506.5	514.3	9.0	35.4	73.2						
							93.6	$\frac{1}{345}$	0.27	380	1400	3.84
B 44	6'-0"	506.5	513.2	15.6	39.5	114						
							114 (say)	$\frac{1}{380}$	0.30	285	950	2.60
PERCH LAKE	—	—	512.4	—	—	—						

TOTAL = 13.58 yrs.

Table 4

Seepage rates for the upper (11-ft) stream between section AA and Perch Lake.

BOREHOLE	SAMPLE DEPTH	SAMPLE ELEVATION ft above M.S.L.	ELEVATION OF WATER TABLE ft.	PERMEABILITY K cu. ft / ft^2/day	POROSITY N %	ESTIMATED MAXIMUM PORE VELOCITIES WITH A HYDRAULIC GRADIENT $\frac{1}{i}$ $V = 1.8\left[\frac{1.6 \times K \times 100}{N}\right]$ Ft./day: AT BOREHOLE	MEAN VELOCITY Vm BETWEEN BOREHOLES	HYDRAULIC GRADIENT i	FIELD VELOCITY Vm x i [ft./day]	DISTANCE BETWEEN BOREHOLES [ft]	TIME TAKEN FOR GROUND WATER TO FLOW BETWEEN BORE HOLES: DAYS	YEARS
B 41	21'-0"	503	523.4	8.0	36.5	63.1						
							81.1	$\frac{1}{112}$	0.724	193	267	0.73
B 39	23'-6"	500	521.7	11.5	33.4	99.2						
							88.0	$\frac{1}{154}$	0.572	523	915	2.51
T119a	23'-6"	495	518.3	10.3	38.6	76.9						
							80.7	$\frac{1}{185}$	0.436	740	1700	4.66
T120a	23'-6"	492	514.3	11.5	39.2	84.5						
							82.9	$\frac{1}{354}$	0.234	380	1625	4.45
B 44	21'-0"	492	513.2	10.5	37.2	81.3						
							81.3 (say)	$\frac{1}{380}$	0.214	1285	1333	3.66
PERCH LAKE	—	—	512.4	—	—							

TOTAL = 16.01 yrs.

Table 5

Seepage rates for the lower (21-ft) stream between section AA and Perch Lake.

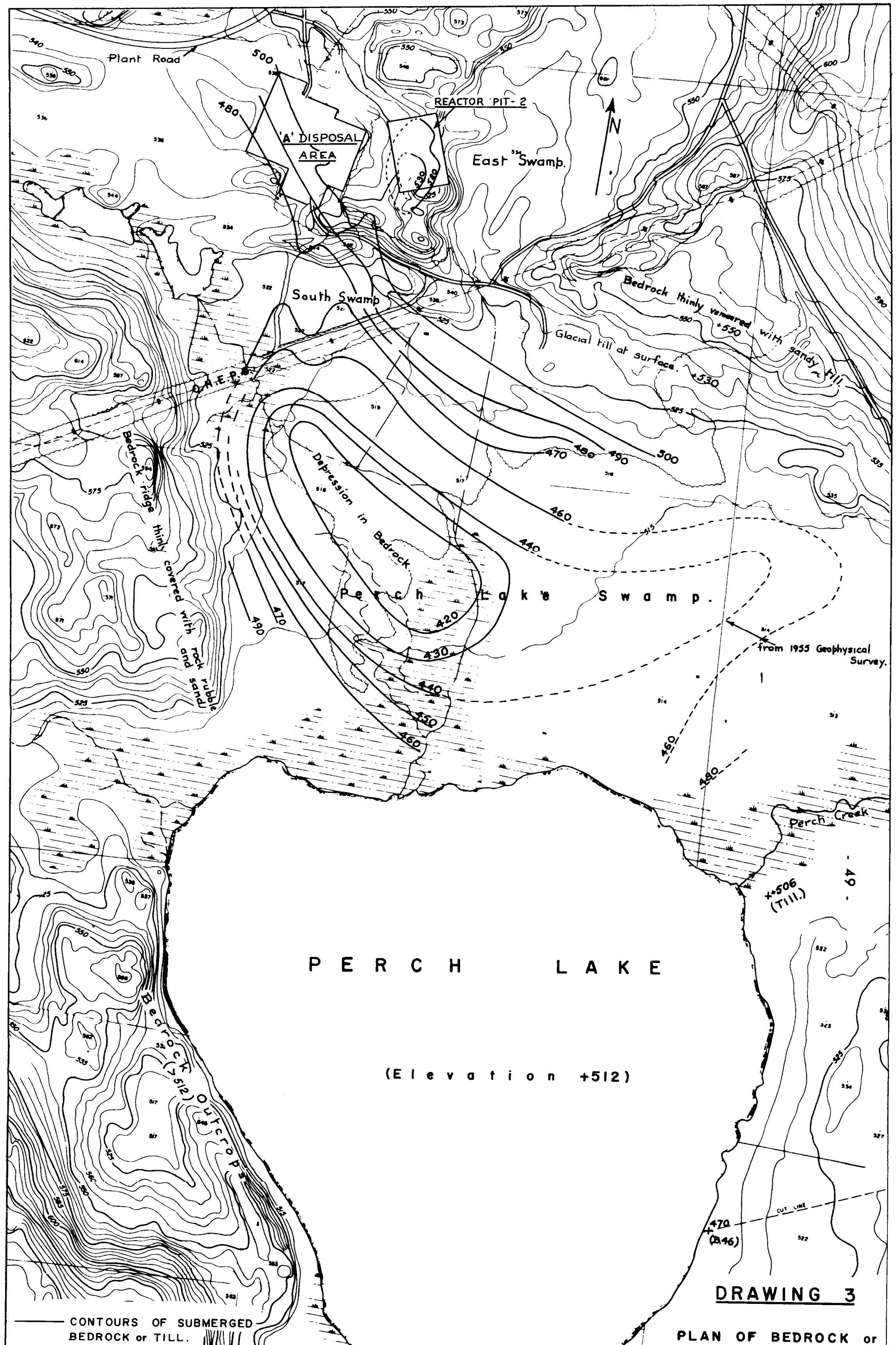
and into Perch Lake. Access difficulties have prevented sampling closer than 285 feet from the Lake (borehole B.44) in Perch Lake Swamp but boreholes B.45 - 47 at the lakeside to the east and south have located silt close to the surface. It is though that silt may be continuous close to the bed of Perch Lake.

3.6 Additional broader conclusions

(a) The original importance attached to a complete mantle of glacial till covering the bedrock basin diminished with the discovery of large deposits of silt and continuous layers of varved clay. Once these were found it was apparent that diamond drilling through the till to prove bedrock was unnecessary.

(b) In the portion of the Perch Lake Basin downstream from and including the A disposal area there is no known path by which radioactive ground water can seep into the fissures of the bedrock basin. The only place where radioactive water is known or expected to come into contact with bedrock is at the outcrop which forms the western boundary of Perch Lake. This is of course principally surface water.

(c) The lowest measured rock formations in the Perch Lake Basin lie not beneath Perch Lake but beneath the swamp to the north of it. In this area the land-locked depression is thickly lined with silt and contains the lower Sands. Ground water is probably stationary in the silt beds and if the clay



DRAWING 3

PLAN OF BEDROCK or GLACIAL TILL in LOWER PERCH LAKE BASIN.

Barrier overlying the lower sands is continuous to the south east beyond the area examined, the lower sands could be regarded as ground water storage. The ion-exchange properties of the clay fractions in the silt beds are probably superior to those of any other local surficial deposits.

4 Future Work

A new type of soil sampler is being used to trace the extent of migration of fission products in the ground water along the predicted path. The object of this program is to locate accurately the front of radioactivity and to measure its velocity through the soil.

5 Acknowledgements

The author wishes to express his appreciation to Dr. N.R. Gadd for his advice and help during the early stages of this investigation. Special thanks are offered to G.G. Gunter for his field work and laboratory testing of samples, and T.R. Johnson whose cooperation on behalf of the B.M. and C. Branch with equipment and labour has enabled this work to proceed without hindrance.

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