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ENVIRONMENTAL SURVEILLANCE OF THE
PALOS PARK FOREST PRESERVE

by

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ENVIRONMENTAL SURVEILLANCE OF THE PALOS PARK FOREST PRESERVE

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ABSTRACT

This is the second report describing an ongoing environmental surveillance program conducted at the Palos Park Forest Preserve near Chicago, Illinois. The Preserve was a site of a nuclear research laboratory (Site A) from 1943 to 1956 and a radioactive waste burial site (Plot M) from 1944 to 1949. An extensive radiological characterization of the site was conducted from February 1976 to August 1977, and hydrogen-3 (tritium) in the form of water was found to be the only radionuclide that migrated from the nuclear facilities. The results were published in U.S. Department of Energy Report DOE/EV-0005/7. The present report summarizes the earlier findings and gives the detailed results of the work from August 1977 through December 1981.

The vertical and horizontal distribution of tritium within the glacial till was determined from measurements of tritium in soil moisture. Chemical and radiochemical analyses were performed on a number of wells in the area. Tritiated water continued to be the only species that was observed to have migrated from the Plot M area. Migration from the Site A area was not observed. The concentration of tritium at the Red Gate Woods well, 1200 feet downgradient from Plot M, continued to show the seasonal fluctuations of high concentrations in the winter and low concentrations in the summer. Monitoring of the Palos Park area is continuing.

1. INTRODUCTION

This is the second report describing the ongoing radiological surveillance program of the former site of Argonne National Laboratory and its predecessor, the University of Chicago's Metallurgical Laboratory, at the Palos Forest Preserve, Illinois. The initial report¹ presented the results obtained through August 1977. This report presents and discusses the data collected through December 1981. A summary of the first report is given to allow this report to be read and understood independently. Data from the first report are repeated where they are of value in understanding recent results. A companion

and cooperative study of the geohydrology of the site is being conducted by the U.S. Geological Survey (USGS) to aid interpretation of the radiological results.^{2,3}

1.1 HISTORICAL BACKGROUND

In 1943, the U.S. Government leased a 1025-acre plot of land in the Palos Forest Preserve (Fig. 1) from the Cook County Forest Preserve District to serve as a site for nuclear research being carried out as part of the U.S. Army Corps of Engineers' Manhattan District project. An area of only about 20 acres, Site A and Plot M, was actually used; it is illustrated in Figure 2. Equipment and facilities originally located at the University of Chicago, including the first nuclear reactor, designated Chicago Pile One (CP-1), were moved to this site in 1943. Two nuclear reactors, the reassembled CP-1 (renamed CP-2) and the first heavy-water moderated and cooled reactor, CP-3, plus related laboratories and experimental facilities occupied 19 acres at what was known as "Site A". In addition, a radioactive-waste burial ground measuring about 150 feet by 140 feet, designated "Plot M", was located nearby. The first recorded use of the waste burial ground was in early 1944. Although records from that era are incomplete, this burial ground is known to have been used for the disposal of equipment, animal carcasses, clothing, building materials, and other liquid and solid wastes. The bulk of this material is believed to have been contaminated with low levels of radioactivity.

Radioactive waste was originally placed in six-foot-deep trenches in Plot M. Beginning in 1948, waste materials were packaged in steel bins before being put in the burial ground. The disposal of waste material in Plot M ceased in June 1949, and all the steel bins were removed at that time.

In accordance with the terms of the lease, the research and waste-disposal areas were decommissioned in 1956, and the property was returned to the Forest Preserve District. In decommissioning the site, the research reactors were disassembled. The radioactive fuel, heavy water, and other components of both reactors were removed from the site. The containment shell of CP-3 was filled with concrete, tumbled into an excavation, and buried along with debris and rubble from the reactor-dismantling and building-demolition operations.

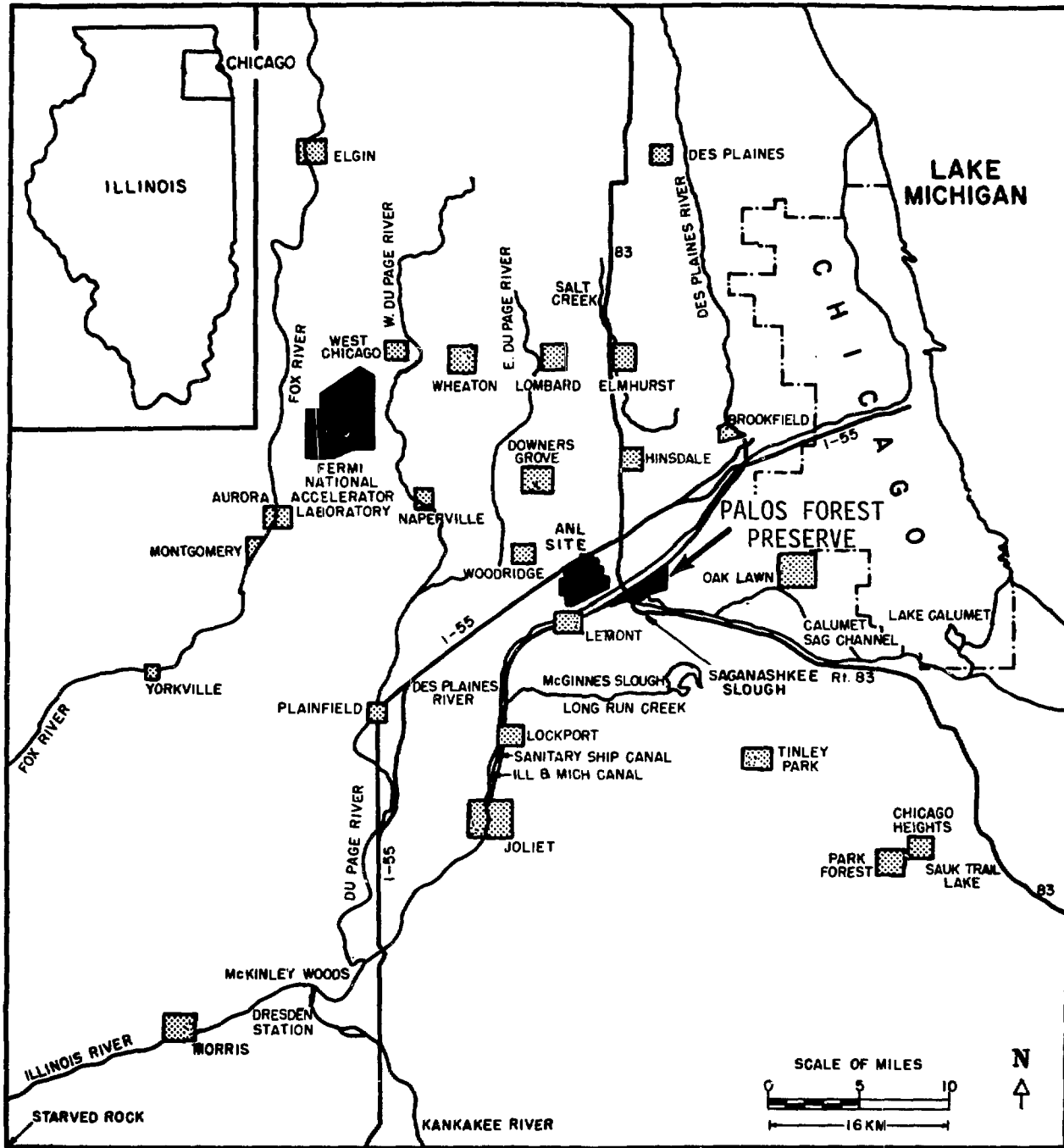


Figure 1. Location of Palos Forest Preserve on Chicago-Area Map.

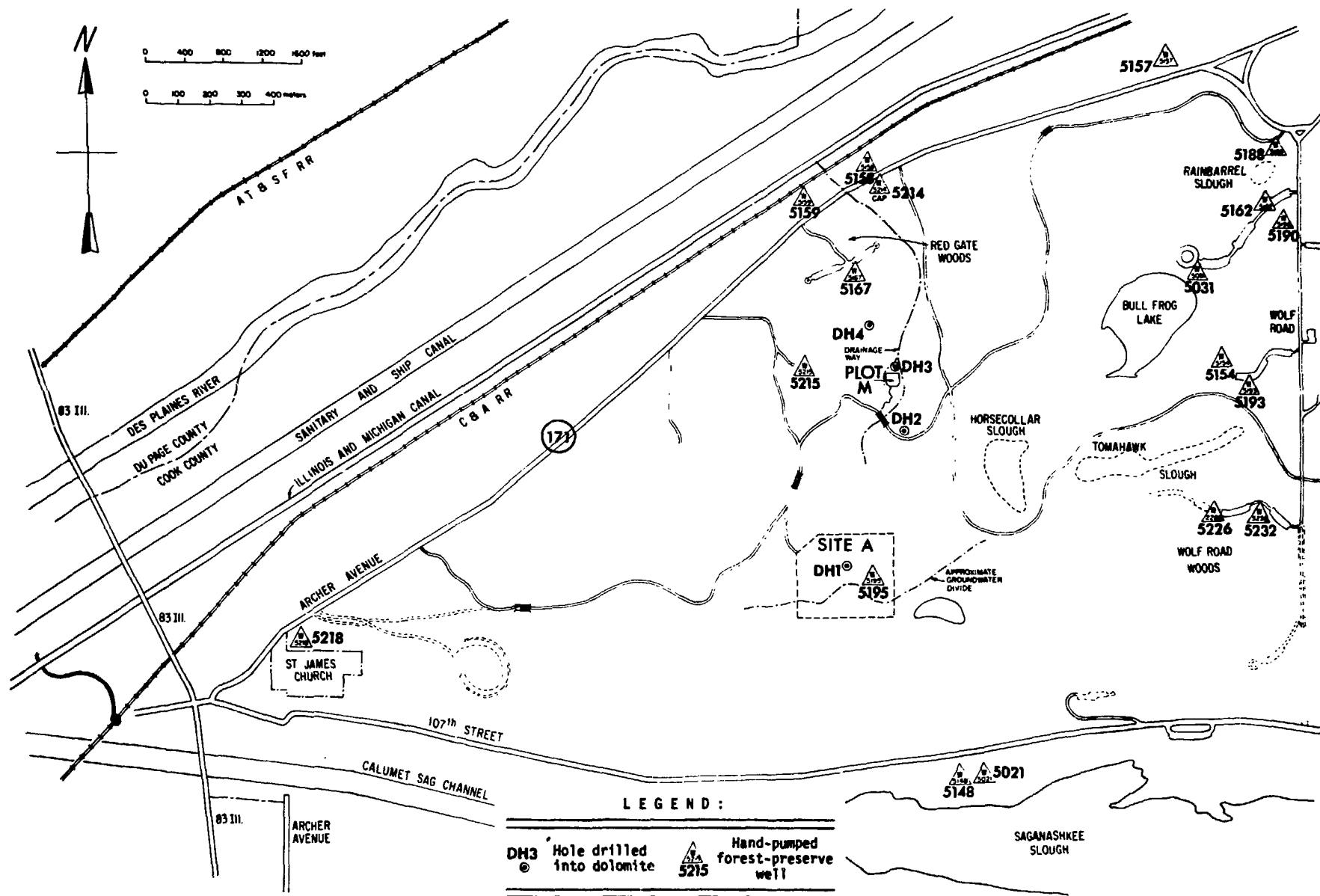


Figure 2. Palos Forest Preserve.

Plot M was decommissioned by digging eight-foot-deep trenches around the perimeter and constructing concrete walls around the plot below grade. A one-foot-thick concrete pad was then poured over the top, creating an inverted concrete box over the burial plot. The plot was then covered with two feet of soil and seeded. By the summer of 1956, decommissioning of both areas was complete, and the reactor site and burial plot were surveyed with state-of-the-art portable survey equipment. No detectable surface contamination was found.

The subsurface of the area consists of unconsolidated glacial drift (or till) underlain by Niagaran dolomite. The maximum thickness of the drift is about 165 feet at the Site A location. The surface slopes downhill north and south of Site A until the dolomite bedrock is reached at the Illinois and Michigan Canal to the north and the Calumet Sag Channel to the south. The drift contains discontinuous sand lenses and is hard, coarse textured, and clay and silt rich. The depth to bedrock at Plot M is about 130 feet. The dolomite dips slightly to the southeast and averages 195 feet in thickness.

1.2 ENVIRONMENTAL MONITORING

A limited environmental monitoring program was begun in the vicinity of Plot M at the Palos site in 1954. Surface water, bottom sediment in streams, and soil were sampled and analyzed for nonvolatile alpha and beta activity. In 1963, sensitive radiochemical analyses showed slightly elevated levels of uranium that resulted from operations formerly carried out at the site. No evidence was seen of movement of radioactive materials from the buried waste or of significant environmental contamination.

In November 1973, the environmental monitoring program was expanded to include measurements of tritiated water in some of the hand-pumped picnic wells in the forest preserve. By 1974, data had been accumulated to show conclusively that low levels of tritium (as tritiated water) were present in three forest-preserve wells near Plot M. Funding was requested and provided early in 1976 to conduct an extensive radiological survey of the Site A/Plot M area as part of a nation-wide Energy Research and Development Administration program to resurvey former Manhattan District sites. The survey was designed to

characterize the radiological environment in the area, with special emphasis on the immediate vicinity of Plot M. The study was planned to identify the reasons for the elevated tritiated-water content in the three picnic wells, and to establish if other radionuclides buried in Plot M or remaining at Site A have migrated from their original locations.

The survey was divided into four principal parts:

1. Radiochemical analyses of water from all existing wells in the area,
2. Radiochemical analyses of soil borings at Site A and Plot M and of surface-soil and vegetation samples from the entire Site A area,
3. Drilling of several additional wells to measure radioactivity in ground water near Site A and Plot M and to provide hydrological information, and
4. Study of the geohydrology of the area to determine the rate and direction of ground-water flow in the forest preserve.

A knowledge of the underground hydrology of the area was essential to explain past, and predict future, migration of radionuclides from Plot M and/or Site A. The Water Resources Division of the USGS (initially the Madison, WI office and now the Champaign, IL office) conducted the hydrological studies.

A principal purpose of the survey was to obtain information to determine if corrective action would be required to assure that any radioactive materials remaining at Site A/Plot M would not cause a health hazard in the future.

1.3 SUMMARY OF RADIOLOGICAL SURVEY RESULTS AND CONCLUSIONS THROUGH 1977

The first group of subsurface-soil samples were collected from March 1976 to April 1977. During this period, 16 boreholes (BH 1-10, 12-13, and 20-23 in Fig. 3) were dug at various locations around and through Plot M. Four boreholes were drilled around the buried reactor shield at Site A, and two were dug at locations away from the Palos Forest Preserve to serve as controls. The soil borings were analyzed for tritiated water, uranium, plutonium, strontium-90,

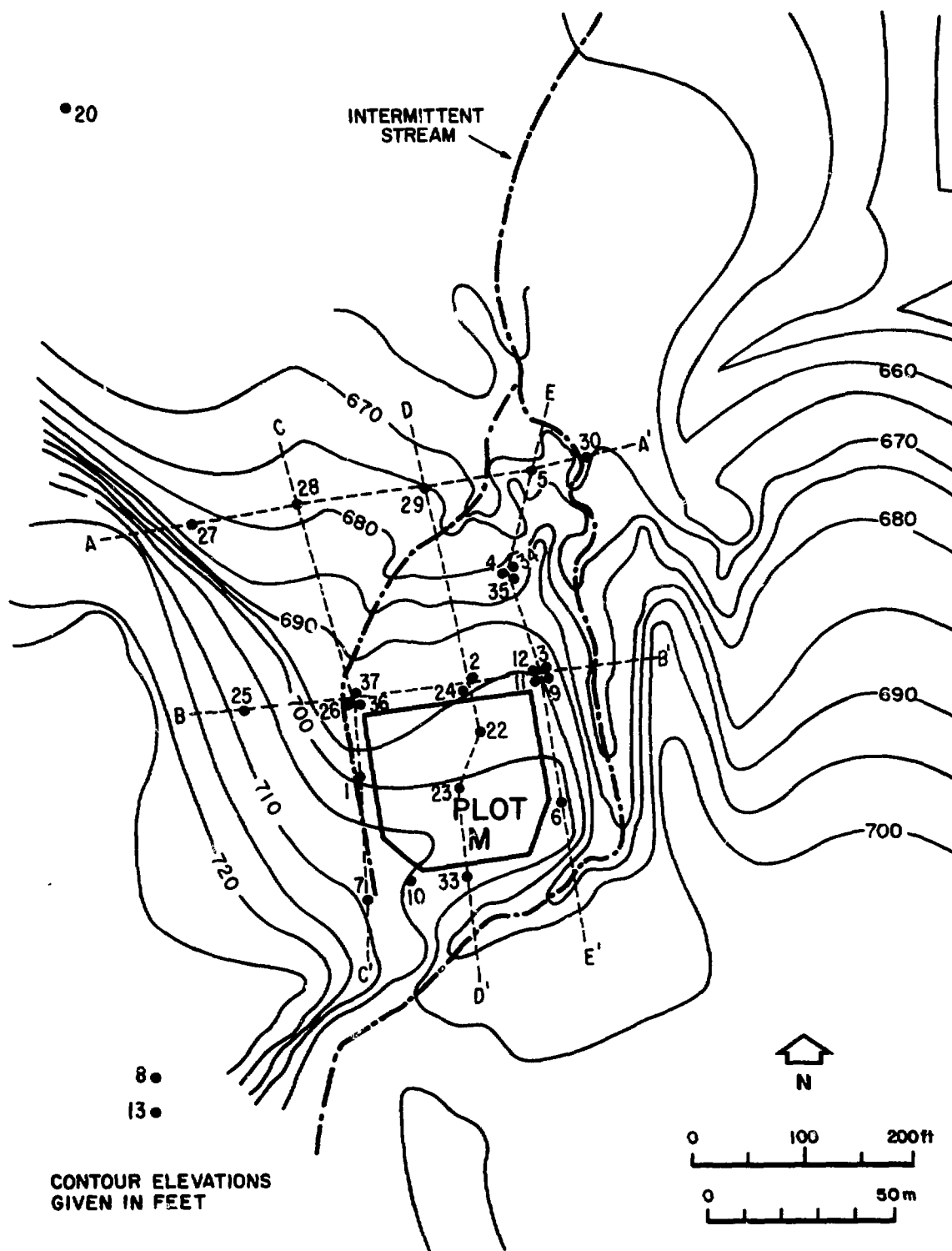


Figure 3. Map of Plot M Burial Site Showing Topography, Intermittent Streams, Borehole Locations, and Lines of Cross-Sections A-A' through E-E'.

and gamma-ray emitters. The results showed that tritium observed in the picnic wells originated in Plot M and that this was the only radioactive nuclide moving from the plot. Because the tritium is present in the form of water, it moves at essentially the same rate as normal ground water.

Outside the immediate area of Plot M, tritiated-water concentrations in the soil borings were at a maximum at about 10 to 30 feet below the land surface. Beneath the plot, peaks in the tritium concentrations were found at about 40 and 65 feet below the surface.

Tritium (as water) was detected at elevated levels in the intermittent streams that drain the Plot M area, but could not be detected in the Illinois and Michigan Canal, the Sanitary and Ship Canal, the Des Plaines River, or nearby ponds.

Three hand-pumped forest-preserve picnic wells were found to have tritium attributable to Plot M. The highest levels were found in water from the well in Red Gate Woods (well 5167 in Fig. 2), where the results ranged from 0.25 to 14 nanocuries per liter (nCi/L). The annual average has been about 7 nCi/L, whereas normal concentrations in water from the same aquifer ranged from 0.05 to 0.20 nCi/L.

Tritiated-water concentrations in the Red Gate Woods well showed a seasonal fluctuation; they were highest in the winter and lowest in the summer. The well opposite the entrance to Red Gate Woods and downgradient from the Red Gate Woods well (well 5159 in Fig. 2) also showed a seasonal pattern, but about four to six months out of phase with the Red Gate Woods well. This cyclic pattern was not apparent in any other wells. The pattern was attributed to the movement of tritiated water from the Plot M area, to the dolomite aquifer, and then to the wells, principally by spring rains when they recharge the ground-water supply. A well about 900 feet northeast of well 5159 (well 5158 in Fig. 2) also contained elevated tritium concentrations in some samples, but concentrations in both these wells were lower than those in the Red Gate Woods well. All the private-residence wells in the area had normal tritium concentrations.

The relative radiological hazard of these tritium levels can be evaluated by comparing them to the U.S. Environmental Protection Agency's limit for tritium in community public drinking-water supplies, 20 nCi/L. Water containing tritium at this concentration will produce a radiation dose of 4 mrem/yr to an individual if it is consumed at a rate of two liters per day, the average daily intake of drinking water. If an individual consumed one liter of water each day containing the average tritium concentration in the well at Red Gate Woods, 7 nCi/L, the resulting radiation dose would be 0.7 mrem/yr. Because no individual is known to use this well as a sole source of drinking water, even this low level of exposure is extremely unlikely to occur.

Tritium was also detected in surface- and subsurface-soil samples collected in the vicinity of the buried CP-3 reactor shell at Site A. These levels were lower than the Plot M samples and represent little contribution to the tritium content of the ground water. No plutonium, strontium-90, or gamma-ray emitters (except those that are naturally occurring) were detected in the subsurface samples; uranium was present in normal amounts.

Some surface-soil samples at Site A contained strontium-90 and cesium-137 in excess of fallout levels. A few samples also contained small amounts of cobalt-60, antimony-125, and europium-155. Such results represent evidence of activities carried out at the site during research operations, but these radionuclides are present at levels that do not present a health hazard. Measurements with thermoluminescent dosimeters have shown that there is no detectable external radiation dose from the radioactive materials remaining at Site A or Plot M.

The principal conclusion of the survey was that there is no present danger to the health and safety of the public posed by the radioactive materials buried at Site A and Plot M. Removal of these buried materials would not reduce the tritium levels in the ground water because the tritium has moved out of the plot down to the bedrock. There was no evidence that radionuclides other than tritium are leaving the site. Consequently, recommendations of the study were that the site remain undisturbed and that radiological monitoring be continued and, in some areas, expanded to develop additional information on the ground-water dynamics and radiological condition in the area.

2. CURRENT STUDIES

2.1 PLOT M

2.1.1 Subsurface Soil

Because the initial subsurface investigations established that Plot M was the source of the tritiated water in the picnic wells, the principal objective of the current studies was to determine the extent of tritium migration from Plot M. Since 1977, 15 additional holes have been bored to expand the knowledge of the areal and vertical extent of subsurface tritium migration in the glacial drift around Plot M. They are BH 11, 24-30, and 33-37 (shown in Fig. 3), and BH 31 and BH 32 next to wells 5159 and 5167, respectively (see Fig. 2). From the boreholes drilled in 1976 and 1977, soil samples were collected to a maximum depth of 40 feet (except BH 22 and BH 23). The boreholes drilled since 1977 ranged in depth from 65 to 130 feet.

The boreholes, in addition to providing soil and water for radionuclide analyses, provide geologic and hydrologic data to define the lithologic and stratigraphic characteristics of the drift, locate the approximate position of the water table, and determine the hydraulic-head distribution of the saturated zone in the drift. The geology and hydrology of the glacial drift is described in reports prepared by the USGS.^{2,3}

For reference purposes, the glacial drift overlying the bedrock in the area beneath the Plot M site has been divided into units based on vertical variations in lithostratigraphic features (such as color and grain-size distribution).³ They are referred to as Units 1 through 7, from the land surface downward, and are identified in Table 1 along with a general description of the geologic properties within each one.

The location, drilling date, and soil-moisture tritium results of these boreholes are given in Appendix A, Tables A.1 through A.13 (soil samples were not collected from BH 34 and BH 37). The new cores, together with the pre-1978 cores, provide a monitoring grid delineated by two east-west lines, sections A-A'

Table 1. General Description of the Glacial Drift at the Plot M Site

Unit	Approx Depth (ft)	Approx Thickness (ft)	Description
1	16	16	Yellow-brown silty clay containing pebbles, stones, wide variety of mineral and rock fragments, oxidized fractures, discontinuous sand layers
2	33	16	Alternating sequence of brown and gray-brown clayey silts containing pebbles, stones, and rocks, mostly dolomite and black shale grains, discontinuous sand and gravel layers
3	50	16	Alternating sequence of brown and gray-brown clayey silts containing pebbles and stones, mostly dolomite and black shale grains, relatively low density, easy to drill and sample
4	65	16	Alternating sequence of gray and gray-brown silts, few or no pebbles and stones, very dry and hard, relatively high density, difficult to drill and sample
5	80	16	Gray and light gray silt and sand, no pebbles, dry, stiff, brittle, extremely hard, difficult to drill and sample
6	100	16	Gray-brown gravelly sandy silts, moist; all grains are dolomite
7	115	16-23	Dark brown, gravelly, clayey silt containing pebbles and stones, moist; encountered only in BH 36

and B-B', and three north-south lines, sections C-C', D-D', and E-E', as shown in Figure 3.

Tritium concentrations measured in soil moisture from collected borehole samples are illustrated in cross sections E-E', B-B', A-A', and D-D' in Figures 4, 5, 6, and 7, respectively. Concentration levels are indicated in units of nanocuries per liter of water, and lines of equal concentration indicate

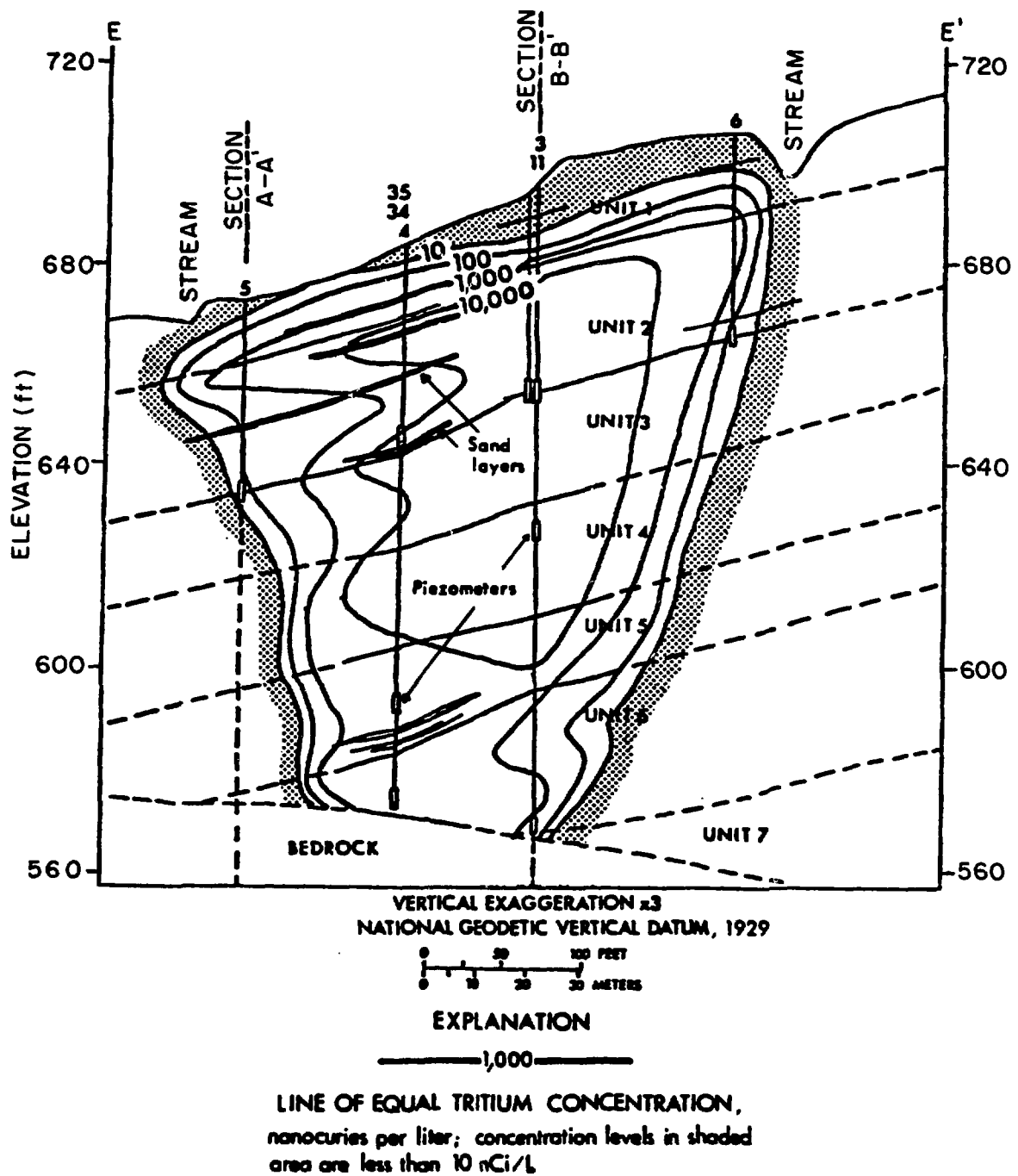


Figure 4. The Extent of Tritium Migration and Levels of Concentration in Soil Moisture Collected from Borehole Samples of the Drift, Cross-Section E-E'.

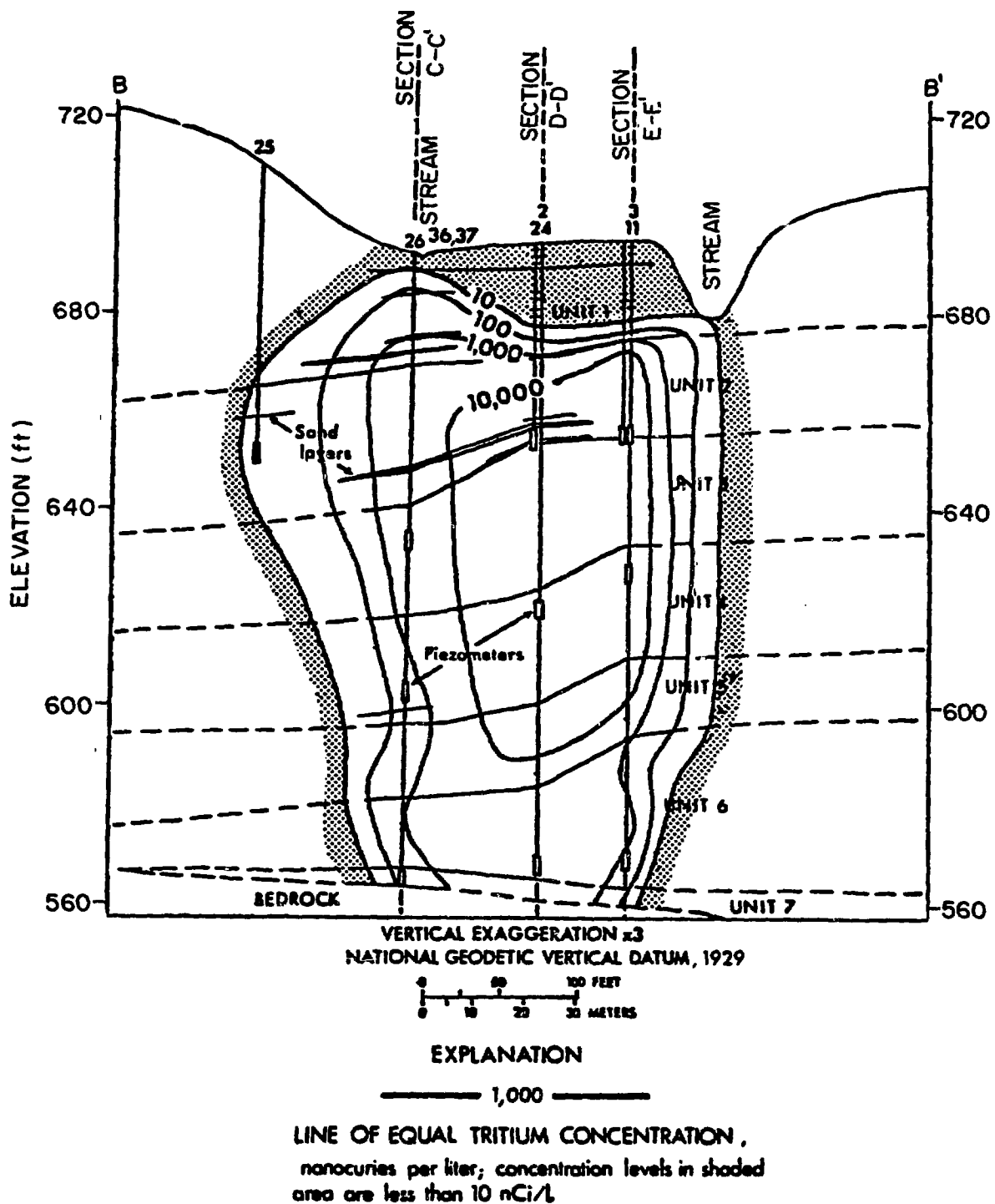


Figure 5. The Extent of Tritium Migration and Levels of Concentration in Soil Moisture Collected from Borehole Samples of the Drift, Cross-Section B-B'.

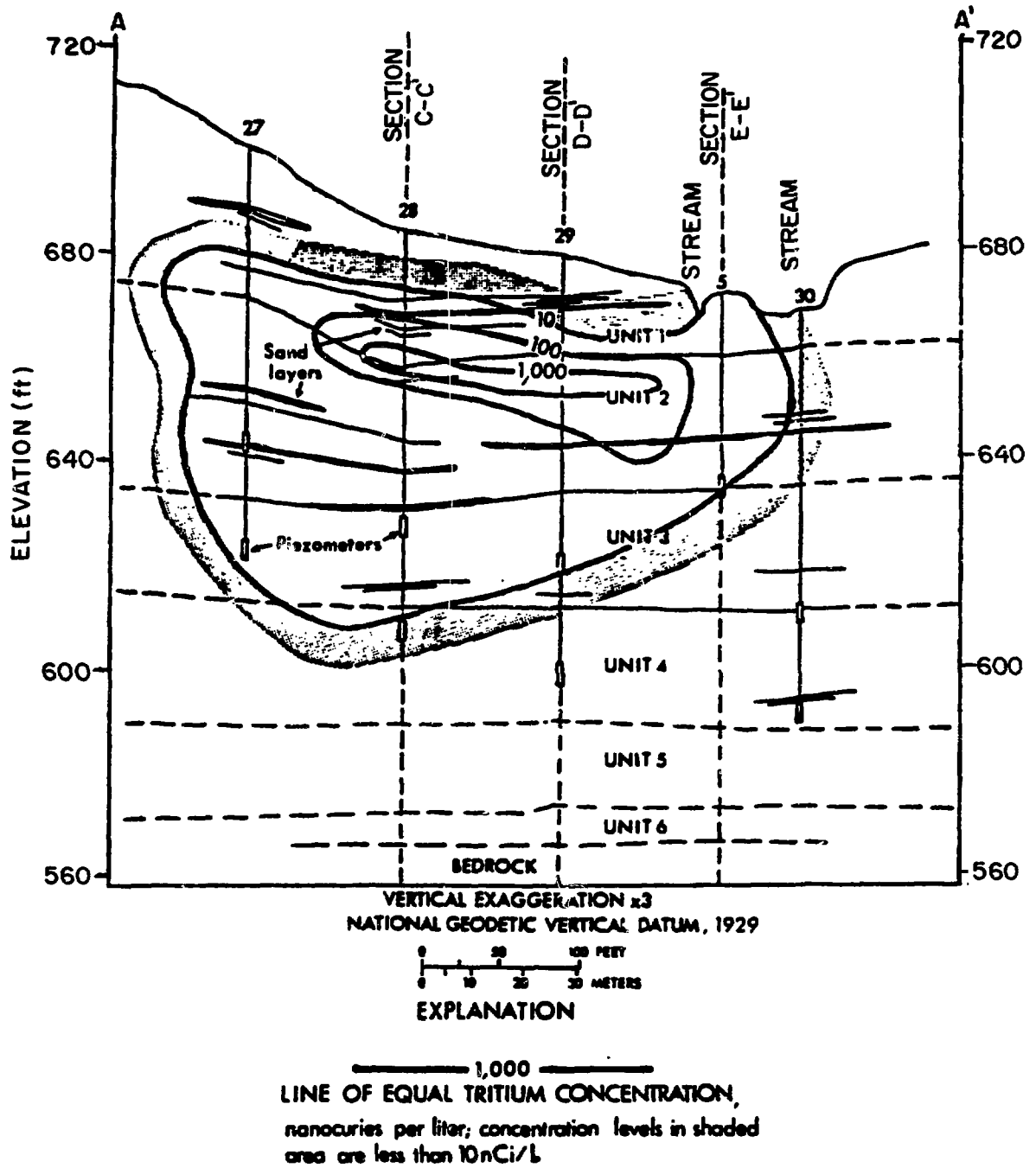


Figure 6. The Extent of Tritium Migration and Levels of Concentration in Soil Moisture Collected from Borehole Samples of the Drift, Cross-Section A-A'.

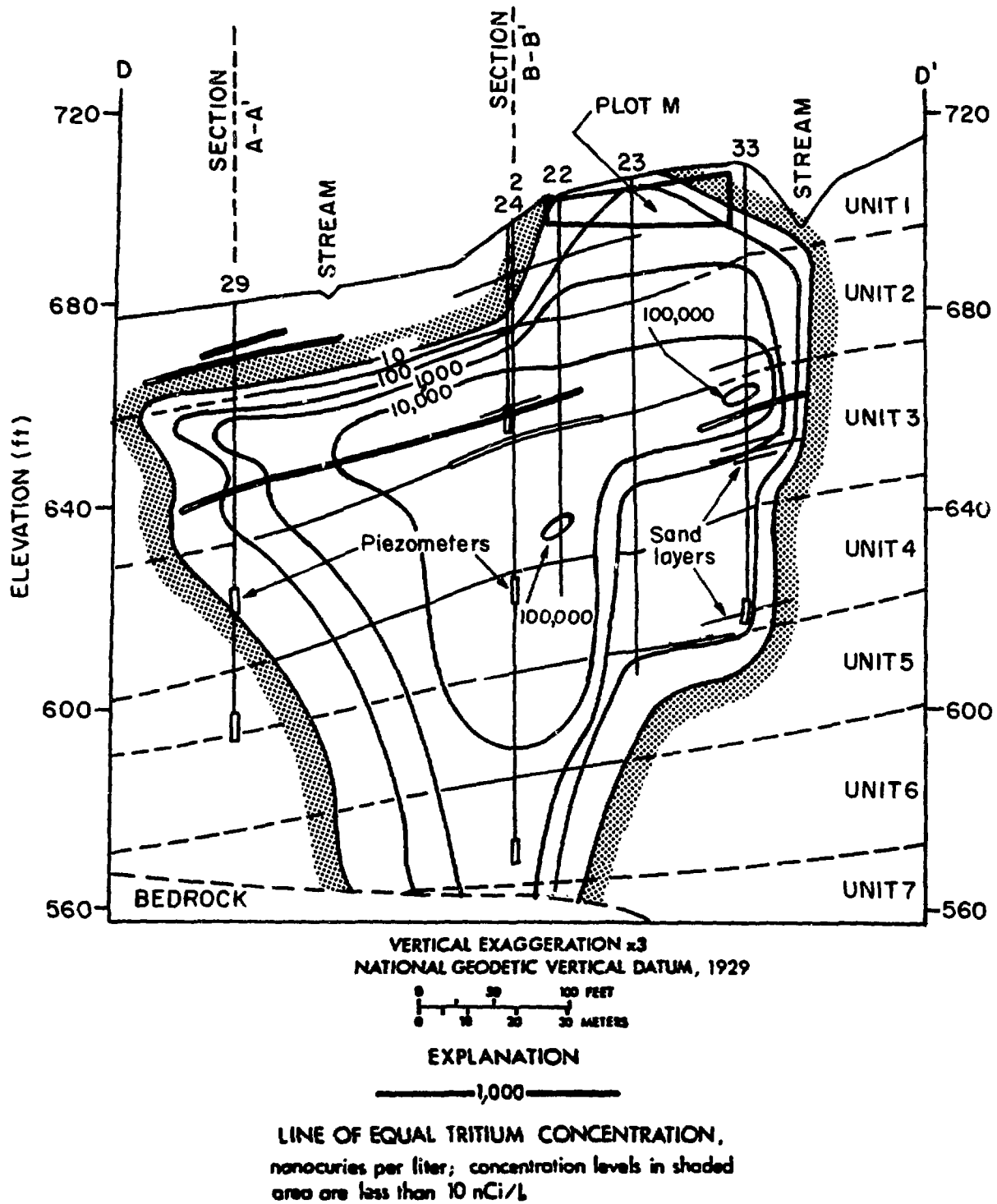


Figure 7. The Extent of Tritium Migration and Levels of Concentration in Soil Moisture Collected from Borehole Samples of the Drift, Cross-Section D-D'.

exponential changes in tritium-concentration levels. In most areas, the lines of equal concentration are based on data derived from continuously collected core samples. The volume of the drift in which concentration levels exceed 10 nCi/L is referred to as the tritium plume.

The north-south cross section E-E', which is just east of the plot, shows the maximum lateral and vertical extent of the tritium plume (Fig. 4). The plume extends laterally from the stream south of the site to the area north of BH 5, and vertically from the middle of Unit 1 to bedrock. The plume narrows downward, decreasing in width from about 295 feet in Unit 1 to less than 165 feet at the bedrock surface. Soil moisture from BH 11 had the highest tritium-concentration levels in section E-E', exceeding 10,000 nCi/L, from 20 to 80 feet below the land surface. The shape of the plume indicates that the principal direction of tritium migration in section E-E' is vertically downward. The northward extensions, which are visible in the isoconcentration lines at various depths, correspond with sand and/or gravel layers in the drift. Tritiated water moves horizontally within these hydraulically highly conductive geologic layers.

Section B-B', just north of the plot, illustrates the east-west extent of the tritium plume (Fig. 5). Tritium has migrated deeper into the drift than it has laterally, as was demonstrated along cross section E-E'. The zone of highest concentration levels, exceeding 10,000 nCi/L, is confined to an area between the stream on the east and BH 26 on the west. BH 11 had the highest concentration level in this cross section, 94,000 nCi/L at a depth of 65 feet. The geologic data show that the sand layers cause the tritium plume to spread horizontally. Lower levels of tritium concentrations in soil moisture east and west of the site are due in part to the absence of hydraulically conductive sand layers in these areas.

Cross section A-A' (Fig. 6) is near the leading, northern edge of the tritium plume. The cross-sectional area of the plume is small compared to the area of the plume close to, and immediately north of, Plot M (section B-B'). Also, tritium concentrations are significantly lower because the distance from the plot is greater. The east-west width of the plume in section A-A' is 360 feet, which is about the same as that in section B-B'. However, the

plume is considerably thinner (from top to bottom) and the highest tritium-concentration levels, exceeding 1000 nCi/L, are located in a small, thin zone near the surface. This zone contains numerous sand layers in Unit 1 near BH 28 and BH 29. Tritium concentrations diminish to the east at BH 30 and to the west at BH 27.

Section D-D' passes through the burial plot (Fig. 7). Soil boring 33, drilled in June 1980 adjacent to the south edge of the burial plot, had a maximum tritium concentration of 270,000 nCi/L at 45 feet below the land surface. This was the highest concentration measured in any of the vertical core samples. High concentrations here can be attributed to numerous sand lenses that cross BH 33 and extend into the soil directly beneath Plot M (Fig. 7). Although the direction of the bulk ground-water flow through Plot M is to the north, there is a small flow component to the southeast toward the stream south of the plot, which would carry ground water from the south end of the plot through BH 33. The more concentrated centers of the plume (greater than 10,000 nCi/L) have not reached the bedrock.

2.1.2 Surface Water

Tritiated-water measurements were made on samples from 13 locations in the streams draining Plot M. The surface drainage around Plot M is principally by an intermittent stream that travels south to north along the east side of the plot. A small swale drains the west side of the plot and joins the main stream north and downhill of the plot, as shown in Figure 8. The stream continues north until it empties into the Illinois and Michigan Canal about 800 yards north-northwest of Plot M. It is only after heavy precipitation, normally in the spring, that the flow reaches the canal. Under lighter rains, the water usually infiltrates into the coarse gravel bed in the vicinity of Red Gate Woods, and during much of the year the entire stream bed is dry.

The general trend of the tritiated-water concentration in 1976 and 1977 was to increase as water moved from upstream to below the Plot M area, and then to decrease downstream of Plot M as a result of dilution by other waters from overland, subsurface, and ground-water flows.¹ The same general trend is illustrated by tritiated-water concentrations in samples collected from 1977

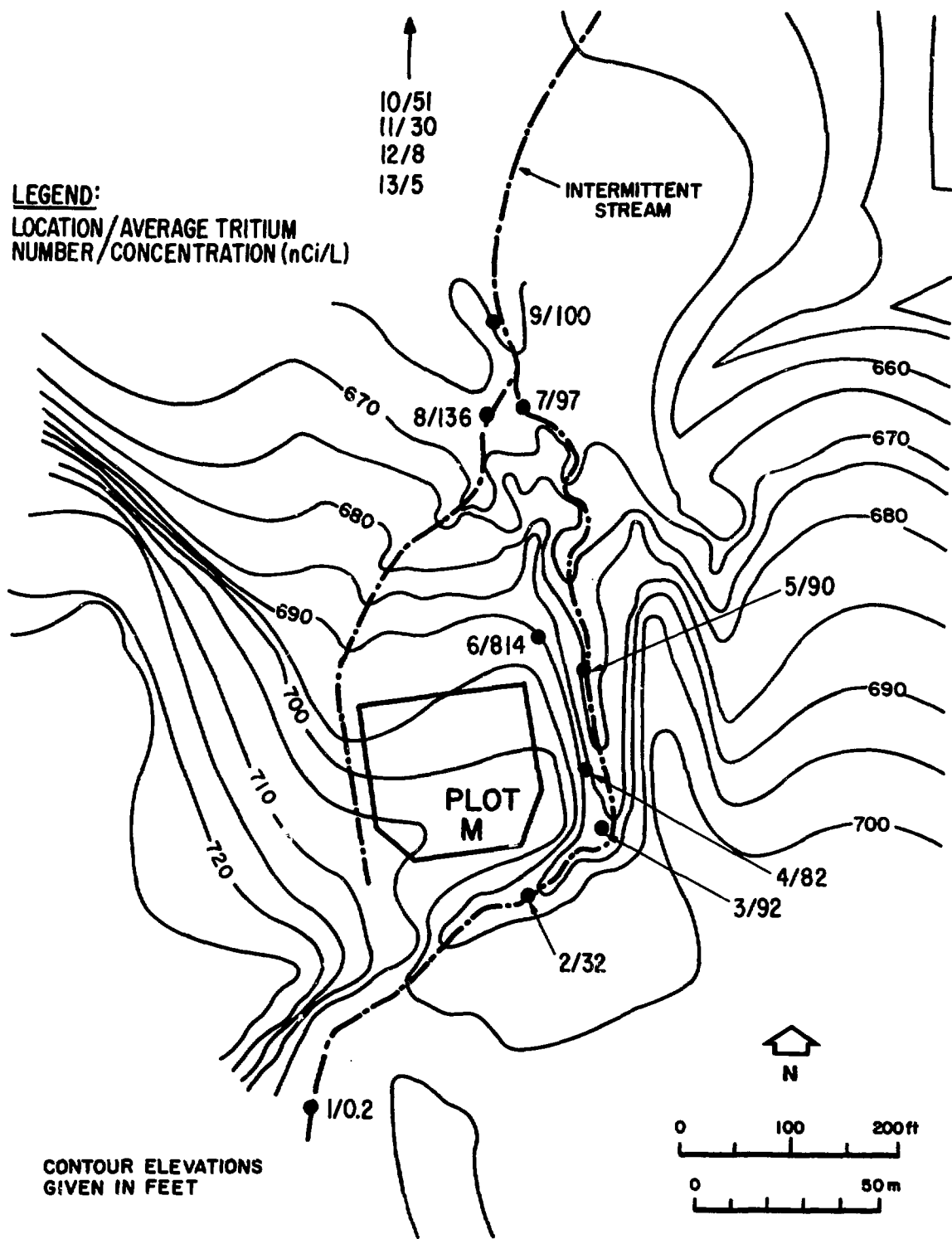


Figure 8. Average Tritiated-Water Concentrations at Surface-Water Sampling Locations near Plot M, 1976-81.

through 1981. All surface-water measurements are presented in Appendix A, Table A.14. The average tritium concentration in samples collected at each location is indicated in Figure 8. All the samples, except that collected at location 6, were taken from the stream itself. Location 6 is a low-volume seep at the base of the Plot M hill; the water from this seep flows into the intermittent streambed northeast of the plot.

Concentrations at locations 3, 4, and 5 are nearly identical, inasmuch as these locations are all east of the plot and probably receive the same amount of dilution from water flows over the adjacent land surfaces. The tritium concentrations in water at location 6, the seep, are at least eight times greater than those in water at any of the stream-sampling sites. Because the seep is directly northeast of the burial site and does not receive nearly as much dilution as the locations in the streambed, the water here is primarily ground water that has passed through Plot M. Thus, the tritium levels at location 6 are expected to be greater than in the streambed itself.

The highest tritium concentration in the stream (not including the seep or swale) was at location 9, where the average was 100 nCi/L. This sampling location is at the confluence of the streams draining the plot, which results in higher concentrations due to the joining of flows from both streams. For all sampling locations, variations in tritiated-water concentrations showed the same pattern from 1976 through 1981. The data from the surface-water studies do not indicate a definite change over the past five years in the amount of tritium present at any location.

2.1.3 Surface Soil

A soil sample was collected on September 6, 1979 from the seep just northeast of Plot M (location 6 in Fig. 8) to determine if any radionuclides other than tritium were leaving the plot at this point. For comparison purposes, a control sample was obtained upstream from the plot at location 1 (Fig. 8). Five 2-inch deep cores were composited as one sample at each location. The samples were analyzed for strontium-90, cesium-137, radium-226, thorium, uranium, and plutonium, and the soil moisture was analyzed for tritium. The results of these analyses are presented in Table 2.

Table 2. Radionuclide Concentrations in Plot M
Surface-Soil Samples, September 6, 1979
(pCi/g)

Radionuclide	Location† ¹	
	6 (Seep)	1
Hydrogen-3	10.9 ± 0.14† ²	0.038 ± 0.036
Strontium-90	0.26 ± 0.06	0.20 ± 0.04
Cesium-137	1.07 ± 0.07	0.72 ± 0.06
Radium-226	1.44 ± 0.11	1.45 ± 0.12
Thorium-228	0.52 ± 0.05	0.47 ± 0.02
Thorium-230	0.67 ± 0.06	0.65 ± 0.02
Thorium-232	0.44 ± 0.05	0.38 ± 0.02
Uranium	1.22 ± 0.12	0.94 ± 0.12
Plutonium-238	0.0020 ± 0.0003	0.0010 ± 0.0002
Plutonium-239,240	0.040 ± 0.002	0.019 ± 0.001

†¹ See Figure 8.

†² Uncertainties in radioactivity measurements given in this and other tables are statistical counting errors at the 95% confidence level.

Cesium-137 concentrations were within the concentration range due to fallout, which was about 0.5 to 1.2 pCi/g. Fallout concentrations of strontium-90 were about 0.1 to 0.2 pCi/g; the strontium-90 values at the two surface-soil sites were near this range. The plutonium concentrations were similar to those in surface soil from fallout, which were about 0.020 to 0.040 pCi/g for plutonium-239,240 and about 0.0005 to 0.002 pCi/g for plutonium-238. Thus, tritium is the only nuclide present in the seep soil that can be attributed to Plot M.

2.2 SURFACE SOIL AT SITE A

During the fall of 1976, 104 surface-soil samples were collected at Site A. The locations are depicted in Figure 9. The results of the analysis of the samples indicated that small amounts of radionuclides from Site A operations remained at random locations, as shown in Figure 10 and as discussed

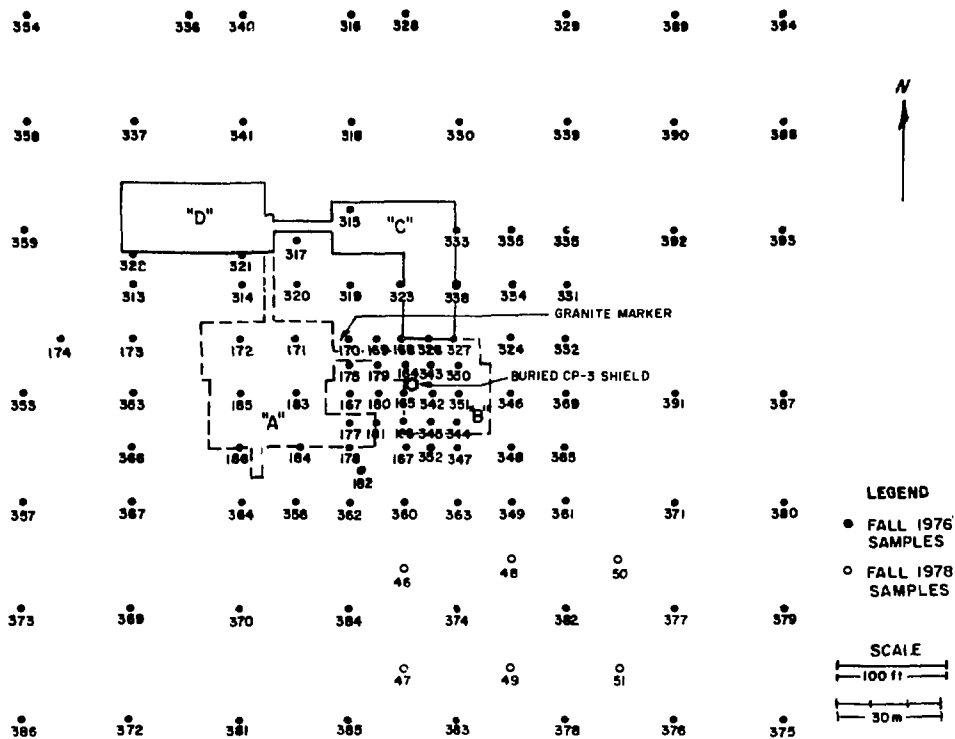


Figure 9. Locations of Surface-Soil Samples Collected at Site A, with Sample-Identification Numbers.

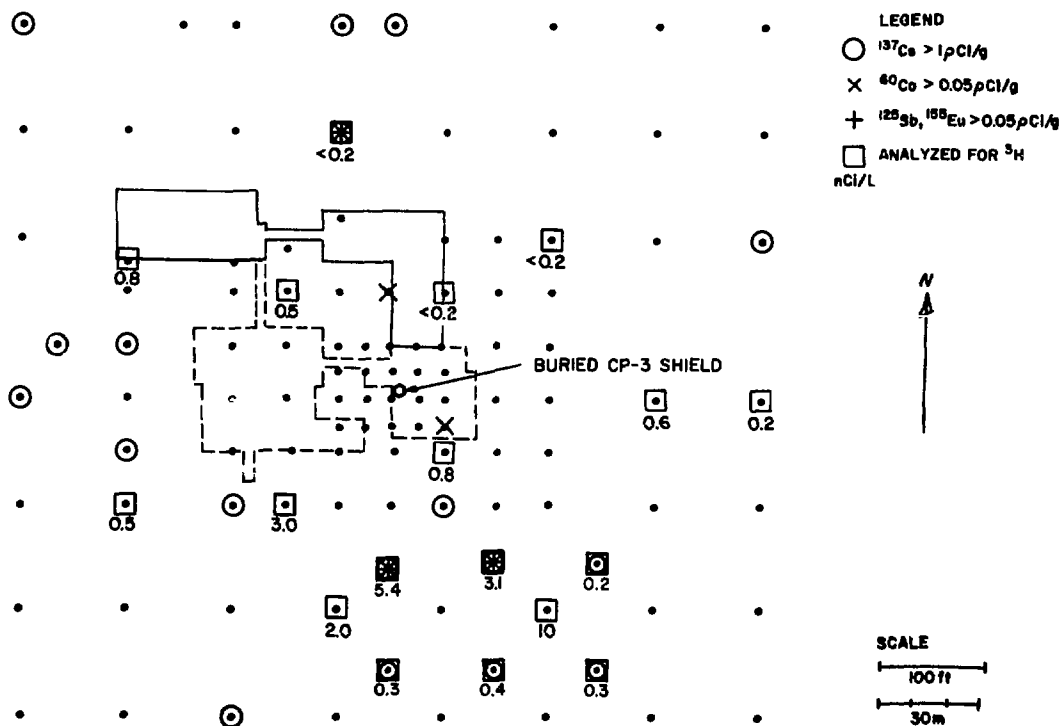


Figure 10. Radionuclides Detected in Surface Soil at Site A.

in Section 1.3. The soil moisture of twelve of these samples was analyzed for tritiated water and, although no definite pattern of tritium distribution in surface soil could be established, the three highest concentrations were from samples collected on the south side of the site.

In September 1978, six more soil samples were obtained just south of Site A, sample numbers 78S46 through 78S51 (Fig. 9). These cores were analyzed by gamma-ray spectrometry, and the moisture was analyzed for tritium. The results are shown in Table 3. Two samples, 78S46 and 78S48, had detectable concentrations of cobalt-60 and antimony-125, and concentrations of cesium-137 in excess of fallout levels. The same two samples had the highest tritium concentrations, 5.37 nCi/L and 3.12 nCi/L, respectively, an order of magnitude greater than tritium levels in the other four samples. The other samples had cesium-137 concentrations, due to fallout, in the range of 0.5 to 1.2 pCi/g. The cerium-144 is from recent fallout.

These sampling results show that small amounts of radionuclides from Site A operations persist in the surface soil south of the buried CP-3 shield. It appears that surface contamination diminishes beyond about 250 feet south of the buried shield. The maximum concentrations of all radionuclides found in 78S46 and 78S48 are of the same order of magnitude as those observed in the 1976 soil samples.

2.3 WELL WATER

2.3.1 Tritiated-Water Analyses

After tritiated water was first detected in the Red Gate Woods picnic well in November 1973, periodic sampling was begun in this and four nearby wells and continues to the present time. The wells sampled (Fig. 2) are:

1. Well 5167, the Red Gate Woods well, located about 400 yards north-northwest of Plot M;
2. Well 5159, located opposite the entrance to Red Gate Woods, 700 yards north-northwest of Plot M, and in line with well 5167;

Table 3. Radionuclide Concentrations in Site A Surface-Soil Samples, September 26, 1978

Sample Number	Location with Respect to the SW Corner of Lab C† ¹	³ H Concentration (nCi/L)	Concentration (pCi/g)				
			³ H	⁶⁰ Co	¹²⁵ Sb	¹³⁷ Cs	¹⁴⁴ Ce
78S46	210 feet south	5.37 ± 0.12	0.833 ± 0.018	0.1 ± 0.1	0.1 ± 0.1	2.5 ± 0.6	0.2 ± 0.1
78S47	300 feet south	0.26 ± 0.07	0.054 ± 0.014	< 0.1	< 0.1	1.0 ± 0.3	< 0.1
78S48	200 feet south & 100 feet east	3.12 ± 0.10	0.393 ± 0.013	0.2 ± 0.1	0.1 ± 0.1	2.8 ± 0.7	< 0.1
78S49	300 feet south & 100 feet east	0.35 ± 0.07	0.054 ± 0.011	< 0.1	< 0.1	0.8 ± 0.3	< 0.1
78S50	200 feet south & 200 feet east	0.21 ± 0.06	0.038 ± 0.012	< 0.1	< 0.1	0.9 ± 0.3	0.2 ± 0.1
78S51	300 feet south & 200 feet east	0.27 ± 0.06	0.056 ± 0.014	< 0.1	< 0.1	1.1 ± 0.3	< 0.1

†¹ See Figure 9.

3. Well 5158, located about 300 yards northeast of the entrance to Red Gate Woods and 850 yards north of Plot M;
4. Well 5157, at 95th and Archer, located 1500 yards north-northeast of Plot M; and
5. Well 5215, which was used at the guard post on the entrance road to Site A, located about 400 yards west-northwest of Plot M.

All these wells are hand pumped and are available for public use. Well 5167, the Red Gate Woods well, is used most often by the public because of its location.

Monthly average tritium concentrations in these five wells from 1973 through 1981 are presented in Appendix A, Table A.15. Tritium concentrations in well 5167 ranged from 0.25 to 14 nCi/L, and continued to fluctuate seasonally, as described in Section 1.3. The graph of tritiated-water concentration vs. sampling date (1974-81) for the Red Gate Woods well, in Figure 11, shows that concentrations reach lows during summer months, increase during fall months, and reach peak values in winter.

Concentrations in well 5159 have continued to fluctuate also, but about four to six months out of phase with those in well 5167. This trend was noted in the data collected earlier and has been substantiated by data collected through 1981. Figure 11 also shows the variation of tritium concentrations in the well opposite the entrance to Red Gate Woods from 1974 to 1981. Annual average tritiated-water concentrations in wells 5167 and 5159, and percent changes from year to year, are presented in Table 4.

Tritium concentrations in well 5158 have varied from 0.7 nCi/L (maximum in May 1974) to 0.07 nCi/L. Since 1978, the results have usually been less than 0.2 nCi/L. Concentrations less than this value, the detection limit for the standard measurement method used, were measured by electrolytic enrichment of the tritium prior to liquid-scintillation counting. In some years, this well has shown small peaks, usually in the spring or early summer, but the variations are not as consistent or pronounced as in the two wells closer to Plot M.

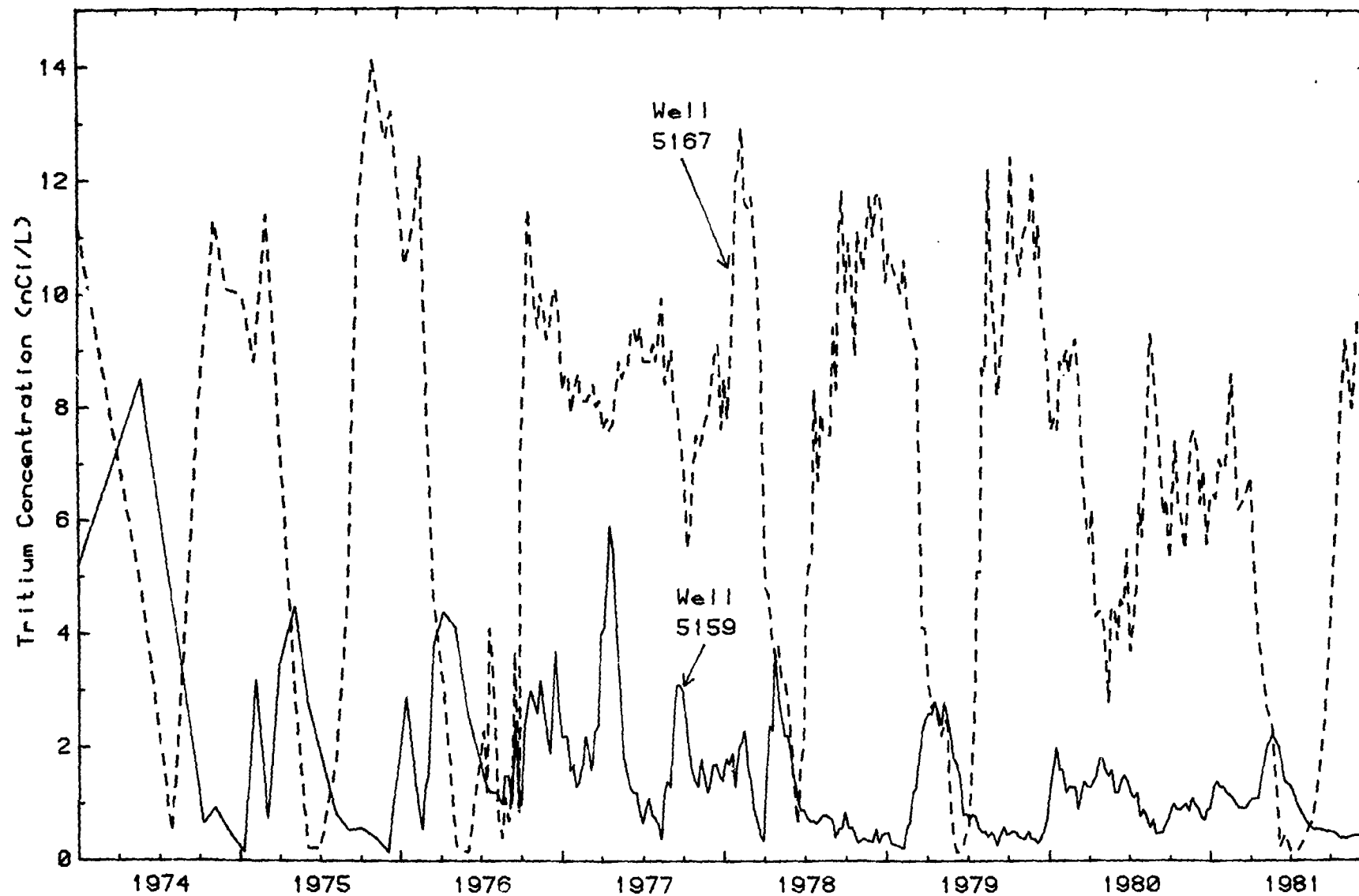


Figure 11. Tritium Concentration in the Red Gate Woods Well (5167) and the Well Opposite the Entrance to Red Gate Woods (5159), 1974-81.

Table 4. Annual Average Concentrations of Tritiated Water in the Red Gate Woods Well (5167) and the Well Opposite the Entrance to Red Gate Woods (5159), 1974-81

Year	Well 5167		Well 5159	
	Measured	Decay Corrected	Measured	Decay Corrected
<u>Concentration (nCi/L):</u>				
1974	7.0	7.0	(4.8)	(4.8)
1975	6.6	7.0	1.7	1.8
1976	6.1	6.8	1.9	2.1
1977	8.2	10.2	2.1	2.5
1978	7.5	9.4	1.3	1.6
1979	7.1	9.4	0.96	1.3
1980	7.0	9.8	1.02	1.4
1981	4.3	6.3	1.06	1.6
<u>Change (%):</u>				
1974-75	-6	0	-	-
1975-76	-8	-3	+12	+17
1976-77	+34	+50	+11	+19
1977-78	-9	-8	-38	-36
1978-79	-5	0	-26	-19
1979-80	-1	+4	+6	+8
1980-81	-39	-36	+4	+14

Concentrations in wells 5157 and 5215 have shown little or no temporal variation. In the former, the concentration has ranged from 0.1 to 0.68 nCi/L since sampling was initiated in 1973. In the latter, tritium concentrations are usually 0.01 to 0.05 nCi/L; the maximum value has been 0.3 nCi/L.

Ten other forest-preserve wells (5188, 5190, 5162, 5031, 5193, 5154, 5232, 5226, 5021, and 5148) and the St. James Church well (5218) were sampled five times between 1976 and 1981 and tested for tritium. The locations are shown in Figure 2. All the results were less than the detection limit of 0.2 nCi/L.

Four deep wells, designated DH 1 to DH 4, were drilled and cased into the dolomite aquifer in the fall of 1976. The locations are shown in Figure 2. Construction data are given in Appendix A, Table A.16. Samples were collected monthly and analyzed for tritiated water, and the results are presented in Appendix A, Table A.17. There is no detectable seasonal variation in tritium content in these deep wells. However, most results from DH 1, DH 2, and DH 4 were less than the detection limit, thus making it difficult to discern variations.

There are sufficient data from DH 3 to see how tritium concentrations vary at this location, which is about 100 feet north of and downgradient from Plot M. Figure 12 illustrates how tritium levels have generally declined in DH 3 water from 1976 to the present time. No other trend in tritium variation is discernible; specifically, no seasonal fluctuation is apparent. The decline in tritium concentrations in DH 3 bedrock water since 1976 may be due to steady

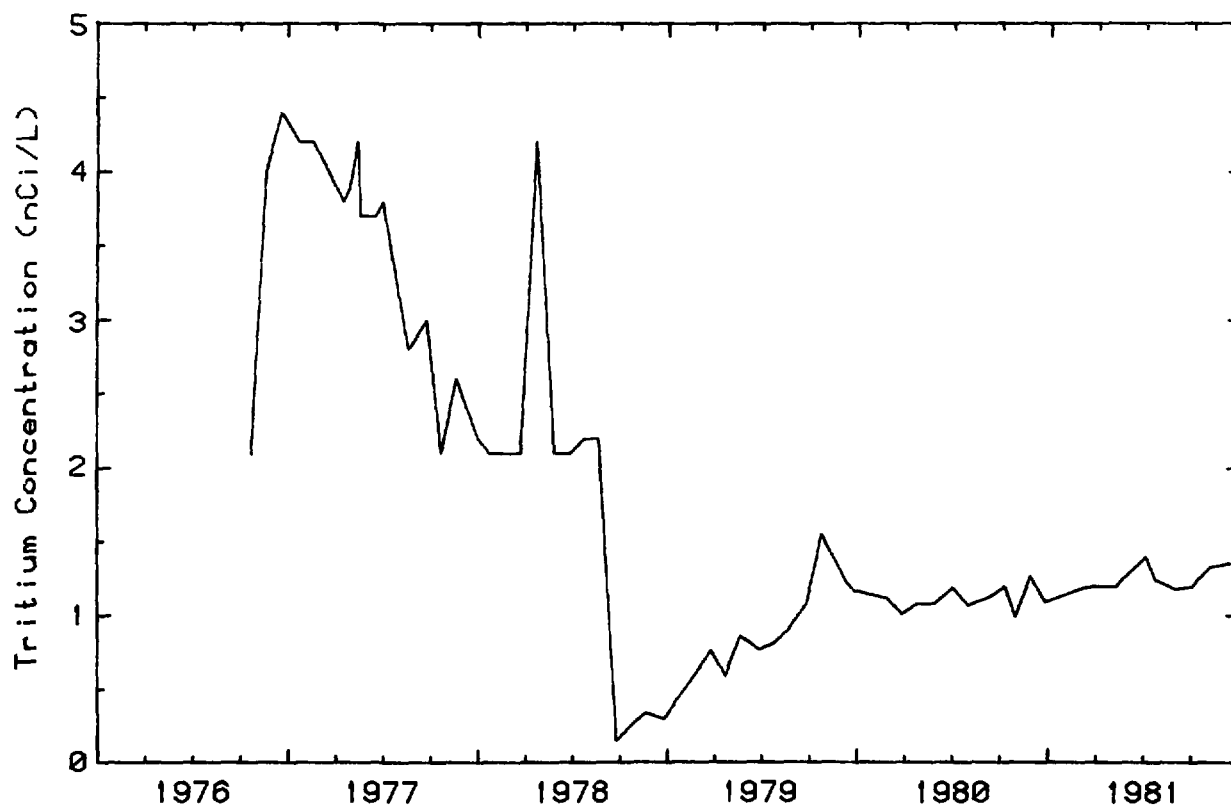


Figure 12. Tritium in Water from DH 3, 1976-81.

replenishment of ground water after a drought in 1976. Hydrographs of water levels in bedrock wells DH 1 to DH 4 show responses to spring recharge and summer recession (Fig. 13). The average water level ranges from 160 feet below the surface at DH 1 to 90 feet below the surface at DH 4. Therefore, it is surprising that no corresponding seasonal changes in tritium levels occur.

Tritium concentrations in DH 3 and DH 4 are about seven to ten times lower than values found in the Red Gate Woods well water. This is surprising because these two deep holes are not only downgradient from Plot M, but are closer to the source of tritium than is the Red Gate Woods well. In contrast, the concentrations in well 5159, opposite the entrance to Red Gate Woods, are comparable to those found in DH 3. The range of tritium concentrations in DH 3 over the five-year period from 1976 to 1981 is < 0.2 to 4.4 nCi/L, and in well 5159 it is < 0.2 to 5.9 nCi/L. The Red Gate Woods well (5167) had a range of tritium values of < 0.2 to 12.9 nCi/L over the same period.

The Red Gate Woods well water consistently exhibits higher tritium concentrations than water from neighboring wells or deep holes. Also, borehole samples near Red Gate Woods have much lower concentrations of tritiated water in the soil than does water from this well. The borehole anomaly can be explained by the fact that the leading edge of the tritium plume has not migrated through the drift as far north as the Red Gate Woods well, but enters the dolomite near Plot M. The pathways of ground-water movement in the dolomite are not known. It appears that tritiated water in the aquifer beneath Plot M travels a route that does not directly include the localities of DH 3 or DH 4, but does include the Red Gate Woods well.

The dolomite is known to be highly fractured and to contain many clay-filled solution cavities.² The position and size of these fractures and cavities may determine the pathways of tritiated water through the dolomite. Further studies will be made of the dolomite structure to gain a better understanding of tritium-migration pathways to Red Gate Woods, as is discussed in Section 3.

From the boreholes that are described in Section 2.1.1, standing-water samples were periodically removed and analyzed for tritium. The annual average

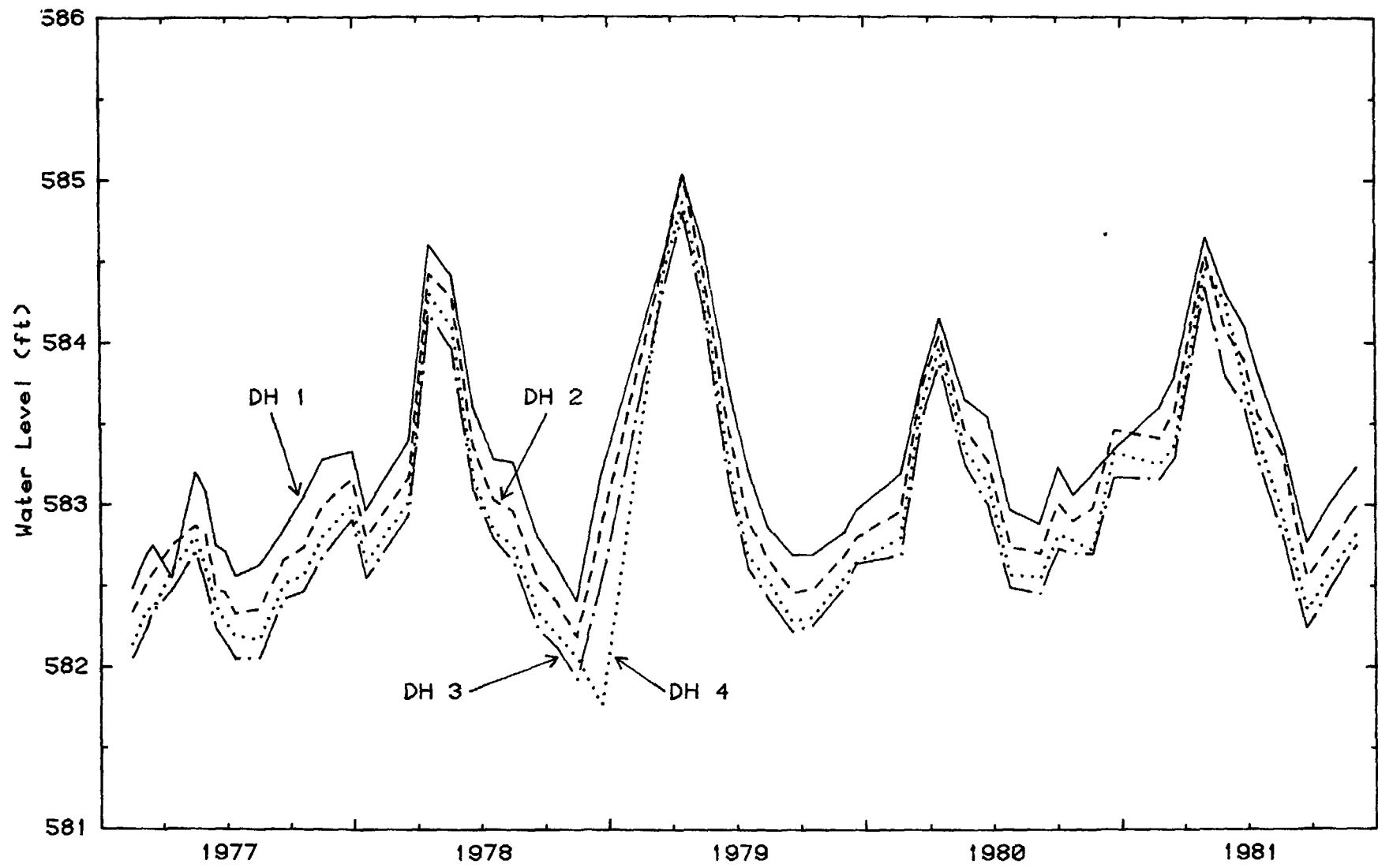


Figure 13. Water-Level Variation in Bedrock Wells at Site A/Plot M, 1977-81.

concentrations of tritium from 1977 to 1981 for several of the boreholes are presented in Table 5. The borehole locations are indicated in Figure 3.

2.3.2 Packer Tests

Packer tests were performed at DH 4 and at the Red Gate Woods well to obtain information on the radioactivity concentrations and water capacities at various depths in the dolomite aquifer. Inflatable packers were placed at known levels in the well to isolate and obtain water from specific depths.

The first packer test was conducted at DH 4 in September 1979. The well was pumped at four depth zones and samples were collected at half-hour intervals for tritium analyses. The data are shown in Table 6. Within Zone 1, 109 to 141 feet below the land surface, the tritium content increased during the first hour of pumping and then leveled off. In Zone 2 (142 to 172 feet) tritium levels increased slightly with pumping for about 2.5 hours and then began decreasing. In Zone 3 (193 to 223 feet) and Zone 4 (224 to 280 feet) the tritium concentrations remained less than 0.2 nCi/L after four hours of pumping. The greatest amount of tritium was found within Zone 1, the uppermost zone in this dolomite well. However, all concentrations were 1.4 nCi/L or less.

A second packer test was conducted at DH 4 in August 1980. The results are shown in Table 7. At most depths, tritium levels decreased with the time of pumping. The exceptions to this are at pump depths of 123 feet and 210 feet, where, although decreases were seen after 15 minutes, concentrations increased after 30 minutes of pumping. The maximum tritium concentration was 1.1 nCi/L at a depth of 134 feet. All other tritium analyses of samples from this packer test yielded concentrations less than 0.30 nCi/L. The packer tests at DH 4 suggest that either there are no appreciable amounts of tritium in the dolomite aquifer surrounding DH 4 or there are impermeable barriers between nearby tritiated-water flows and DH 4.

The packer test at the Red Gate Woods well was performed in August 1980. Water samples were collected at six pumping depths. The results are presented

Table 5. Annual Average Tritium Concentrations in Borehole Water Samples (nCi/L)

Borehole Number† ¹	Year (parentetical entries indicate the number of samples collected)				
	1977	1978	1979	1980	1981
1	(6) 478	(10) 454	(10) 761	(10) 1640	(7) 3070
2	(18) 6430	(10) 2190	(10) 955	(10) 1310	(7) 1180
3	(17) 2730	(8) 2920	(10) 3160	(11) 3390	(8) 3490
4	(18) 3310	(11) 2030	(10) 1760	(11) 1140	(7) 855
5	(19) 87	(11) 38	(10) 19	(11) 26	(7) 46
6	(12) 799	(10) 690	(10) 369	(11) 673	(7) 196
7	-	(4) 3.7	(2) 3.2	-	-
8	(15) 0.40	(11) 0.26	(10) 0.24	(11) 0.32	(2) 0.22
9	(5) 1.1×10^4	(10) 2.1×10^4	(10) 5.2×10^4	(11) 1.9×10^4	(7) 1.3×10^4
10	-	(9) 1.1×10^5	(10) 8.5×10^4	(11) 6.5×10^4	(7) 4.3×10^4
11 (39 ft)	-	(10) 5590	(10) 5190	(11) 5760	(7) 4640
11 (124 ft)	-	(10) 18.5	(10) 41.4	(11) 13.8	(7) 29.5
14	-	(10) 0.5	(9) 4.0	(11) 2.6	(2) 0.17
20	-	(1) 0.21	(2) 0.23	(9) 0.32	(2) 0.45
24 (126 ft)	-	(7) 1.6×10^4	(9) 1980	(11) 1340	(7) 875
26 (60 ft)	-	-	(3) 490	(9) 1340	(7) 1560
28 (60 ft)	-	-	-	(10) 305	(7) 291
35	-	-	-	(6) 6640	(7) 1.0×10^4
36	-	-	-	(6) 89	(7) 196

†¹ See Figure 3.

Table 6. Tritiated-Water Content of Packer-Test Water in DH 4,
September 12, 1979
(nCi/L)

Elapsed Pumping Time (hours)	Zone			
	1 (109-141 ft)	2 (142-172 ft)	3 (193-223 ft)	4 (224-280 ft)
0	0.29 ± 0.09	0.33 ± 0.10	< 0.2	0.24 ± 0.10
0.5	0.29 ± 0.09	0.22 ± 0.09	< 0.2	< 0.2
1.0	1.02 ± 0.10	0.39 ± 0.09	< 0.2	< 0.2
1.5	0.85 ± 0.10	0.28 ± 0.09	< 0.2	< 0.2
2.0	1.40 ± 0.11	0.53 ± 0.09	< 0.2	< 0.2
2.5	1.16 ± 0.11	0.62 ± 0.09	< 0.2	0.34 ± 0.10
3.0	1.19 ± 0.11	0.43 ± 0.09	< 0.2	< 0.2
3.5	1.00 ± 0.10	0.36 ± 0.09	< 0.2	< 0.2
4.0	1.06 ± 0.10	0.29 ± 0.10	< 0.2	-
4.5	1.14 ± 0.11	0.23 ± 0.10	< 0.2	-
5.0	1.12 ± 0.11	-	-	-

in Table 8. At every pump location, tritium concentrations decreased during the 30-minute pumping time; the decrease was more pronounced at greater depths. It appears from these tests that water closer to the top of the bedrock not only contains higher levels of tritium than water deeper into bedrock, but also that the areal extent of tritiated water in the vicinity of Red Gate Woods is greater in the upper portion of the dolomite and decreases as depth increases. This conclusion is based on the observation that, at lesser depths, water drawn in from around the well over the 30-minute pumping time caused no significant decrease in tritium concentration. That is, the water around the periphery of the well at these depths (less than 120 ft) has a tritium concentration similar to that of the standing water in the well. However, at greater depths, tritiated-water content decreased rapidly with pumping time, suggesting that surrounding water at these levels is less contaminated and, therefore, dilutes the tritiated water that is in the well before pumping begins.

Table 7. Tritiated-Water Content of Packer-Test Water
in DH 4, August 26, 1980

Straddle Number	Depth (ft)			Time of Day	Tritium Concentration (nCi/L)
	Upper Packer	Lower Packer	Pump		
1	107.5	118.3	112.0	1000	0.22 ± 0.12
				1027	0.20 ± 0.12
2	118.3	129.2	122.8	1047	0.16 ± 0.12
				1101	0.15 ± 0.12
				1116	0.27 ± 0.12
3	129.2	140.0	133.7	1121	1.12 ± 0.13
				1136	0.29 ± 0.12
				1151	0.29 ± 0.12
5	151.1	161.9	155.6	1510	0.26 ± 0.12
				1525	0.10 ± 0.12
				1540	0.04 ± 0.11
6	161.9	172.7	166.5	1605	0.14 ± 0.12
9	194.3	205.1	198.8	1645	0.16 ± 0.12
				1700	0.05 ± 0.12
				1715	0.08 ± 0.12
10	205.1	215.9	209.6	1725	0.13 ± 0.12
				1740	0.05 ± 0.12
				1755	0.18 ± 0.12
11	215.9	226.7	220.4	1800	0.18 ± 0.12
				1815	0.17 ± 0.12
				1830	0.08 ± 0.12

2.3.3 Other Radiochemical Analyses

Several wells in the study area were sampled and analyzed for other radionuclides that may have been buried at Plot M. The uranium results, given in Appendix A, Table A.18, show uranium present in measurable quantities; however, these concentrations are within the normal range for wells in the area. Analyses of well-water samples for other radionuclides assumed buried in Plot M (App. A, Table A.19) show tritium to be the only nonnatural radionuclide present.

Table 8. Tritiated-Water Analyses of Packer Tests of the Red Gate Woods Well (5167), August 27, 1980

Straddle Number	Depth (ft)			Time of Day	Tritium Concentration (nCi/L)
	Upper Packer	Lower Packer	Pump		
1	84.7	95.5	89.2	1421	8.27 ± 0.20
				1436	7.83 ± 0.19
				1451	8.06 ± 0.19
2	95.5	105.3	100	1458	8.89 ± 0.21
				1513	7.50 ± 0.20
				1528	6.88 ± 0.19
3	105.3	116.1	109.8	1531	6.55 ± 0.19
				1546	6.90 ± 0.19
				1600	6.36 ± 0.19
4	116.1	126.9	120.6	1610	7.39 ± 0.20
				1625	6.53 ± 0.19
				1640	6.21 ± 0.19
5	126.9	137.7	131.4	1644	6.94 ± 0.19
				1659	3.25 ± 0.16
				1714	1.93 ± 0.14
6	137.7	147	142.2	1740	3.98 ± 0.17

During the 1979 packer tests at DH 4, a representative sample from each depth zone, collected after several hours of pumping, was analyzed for a number of radionuclides in addition to tritium. The results are given in Table 9. They indicate that only tritium and uranium were present in measurable quantities. The uranium content was normal. The tritium concentration was greatest in the uppermost zone, 109 to 141 feet below the land surface, and decreased with increasing depth.

2.3.4 Specific-Ion Analyses

The explanation given in the previous report¹ for the seasonal variation of tritium concentrations at the Red Gate Woods well was that recharge by spring rains and increased movement of ground water moved additional tritium from the vicinity of the plot. A second possibility is that spring rains and

Table 9. Specific Radiochemical Analyses of DH 4 Water Samples, Fall 1979

Sample Location	Sample Depth (ft)	Sample Date	Radionuclide (pCi/L)						
			⁹⁰ Sr	⁹⁹ Tc	U (natural)	²³⁷ Np	²³⁸ Pu	²³⁹ Pu	³ H
Zone 1	109-141	9/12/79	< 0.25	< 0.5	2.48 ± 0.16	< 0.001	< 0.001	< 0.001	1190 ± 110
Zone 2	142-172	9/12/79	< 0.25	< 0.5	1.93 ± 0.27	< 0.001	< 0.001	< 0.001	616 ± 90
Zone 3	193-223	9/13/79	< 0.25	< 0.5	1.67 ± 0.17	< 0.001	< 0.001	< 0.001	< 100
Zone 4	224-280	9/13/79	< 0.25	< 0.5	2.77 ± 0.25	< 0.001	< 0.001	< 0.001	342 ± 96

snowmelt locally infiltrate the Red Gate Woods well and dilute the water in it, thus reducing the tritium concentration. If this occurs, then the concentration of other constituents in the well water could also show seasonal fluctuations, because ground water and infiltrating precipitation should contain different concentrations of some constituents.

To test the latter possibility, well-water samples collected from 1979 to 1981 were analyzed for fluoride, chloride, nitrate-nitrogen, and potassium. Ion-selective electrodes were used for direct concentration determinations. The wells tested in this portion of the study were the same ones sampled for tritiated water, as discussed in Section 2.3.1: wells 5167, 5159, 5158, 5157, and 5215. The average concentrations, standard errors, and minimum and maximum concentrations of the various ions are given in Appendix A, Tables A.20, A.21, and A.22, for three of the wells. Of the ionic constituents analyzed, only potassium demonstrated a seasonal variation in concentration. Potassium concentrations, at the Red Gate Woods well only, demonstrated a seasonal fluctuation that is remarkably similar to tritium variations at the same location, as is shown in Figure 14. The data are as yet insufficient to determine if both tritium and potassium vary for the same reasons. To judge better the usefulness of the results, concentrations of these ions in precipitation must be known.

Analyses of other nonradioactive elements were performed on samples of water from the Red Gate Woods well in 1979 and 1980. These results are presented in Appendix A, Table A.23.

2.4 SUMMARY AND CONCLUSIONS

Radionuclide analyses of moisture extracted from borehole samples show that tritium has migrated from the burial trenches at Plot M into the drift. The tritium plume, defined to be the contaminated zone in the drift in which tritium-concentration levels exceed 10 nCi/L, has migrated horizontally northward at least 165 feet and vertically 130 feet down to the dolomite-bedrock surface. Tritium-concentration levels in borehole samples collected just above bedrock are greater than 1000 nCi/L.

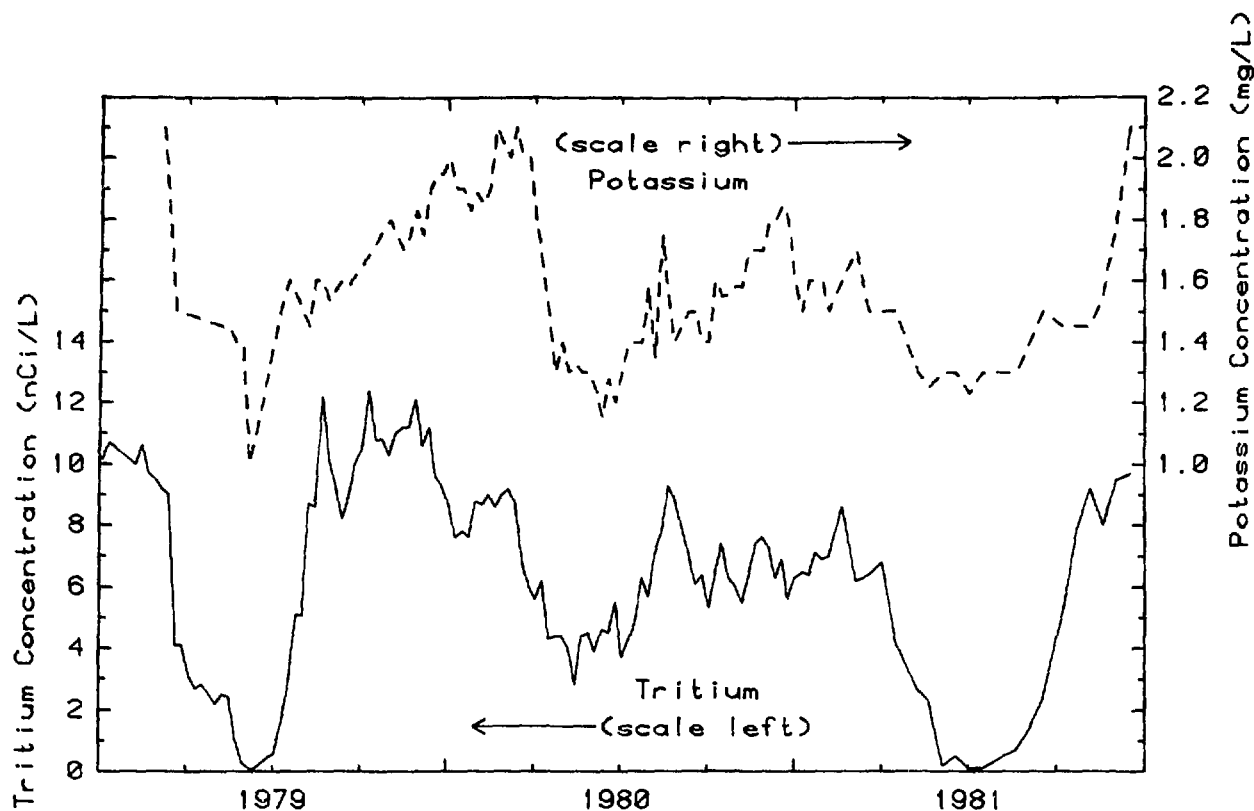


Figure 14. Tritium and Potassium Concentrations in the Red Gate Woods Well (5167), 1979-81.

Several small zones or lobes of relatively high tritium concentration protrude northward from the plume. These lobes correspond with sand layers in Units 1 and 2, which aid infiltration and cause tritiated water to spread throughout a larger volume of drift than expected, enlarging the horizontal extent of the plume.

The underlying dolomite bedrock is highly permeable, contributing to a significant vertical total head gradient in the saturated zone of the drift. Thus, the primary direction of ground-water flow is downward. The diameter of the tritium plume decreases with depth, and the elongate shape of the plume supports the data that indicate that tritiated water moves primarily downward in the drift.

The plume intersects the underlying bedrock surface. Its leading edge reached the dolomite below Plot M prior to 1973 (at the time tritium was first

discovered in the Red Gate Woods well). That is, tritiated water traveled 130 feet vertically through the drift below Plot M in no more than about 25 years (ca. 1948-73). Therefore, tritiated water moves vertically in the drift beneath Plot M at a rate of at least five feet per year.

The highest tritium concentration is still about 70 feet above bedrock, or 60 feet below the burial site, but should continue to move deeper through the drift as a result of infiltration and the significant vertical total head gradient in the saturated zone of the drift. As the plume moves downward, higher concentrations of tritium are reaching the bedrock surface. This explains why tritium levels in the Red Gate Woods well have not appreciably declined since 1973, even though 25% of the tritium present in 1973 has decayed (the half-life of tritium is 12.4 years). The data clearly show that the tritiated water in the Red Gate Woods well has migrated there through the dolomite aquifer, because tritium does not move horizontally through the drift from Plot M to Red Gate Woods. The seasonal fluctuations of tritium concentrations in water at this well, then, are a rough measure of the relative amount of tritium annually entering the dolomite from the drift below Plot M.

The concentration pattern of the plume indicates that the burial site is probably no longer releasing tritium to the drift. However, tritiated water will continue to move into the bedrock, causing elevated tritium levels in dolomite wells, until the entire plume has moved completely through the drift beneath Plot M. The concentration levels in the drift and dolomite, and the life of the plume, will be limited by radioactive decay and the velocity of water movement through the till.

The estimated total volume of the tritium plume is 8.79 million ft³, which is equivalent to a cubical volume of 206 feet on a side. If the average total porosity of the drift is conservatively estimated to be 30%, then the total volume of pore space occupied by tritiated water is 2.64 million ft³. Based on an average tritium concentration of 10,000 nCi/L, the estimated inventory of tritiated water under Plot M is about 800 Ci. This estimate is considered reliable within a factor of about ten.

The Site A area has small spots of surface contamination at random locations. Two of the six surface-soil samples collected in September 1978 south

of Site A contained cobalt-60 and antimony-125 in detectable concentrations, and cesium-137 concentrations slightly above fallout levels. Tritium was also present in these two samples, but at levels less than 10 nCi/L.

The Plot M burial site continues to show no evidence of releasing radioactivity to the surrounding environment that could endanger the health or safety of the public visiting the site, or anyone living in the vicinity.

3. FUTURE STUDIES

The extent of tritium migration from Plot M through the surrounding drift has been quite adequately determined from studies conducted to date. However, the pathways of tritiated-water movement within the bedrock are not known. Four dolomite wells, DH 1 to DH 4, were constructed in 1976. The monitoring of these wells has provided hydrologic data showing that water levels in the bedrock respond to spring recharge, summer recession, and annual precipitation variations. Tritium analyses of water samples from DH 1 to DH 4, as well as from the five hand-pumped forest-preserve wells (in Red Gate Woods, opposite the entrance to Red Gate Woods, 300 yards east of the entrance to Red Gate Woods, at 95th and Archer, and at the guard post), have provided information concerning tritium concentrations at each of these locations. However, the data do not provide information required to delineate the paths of tritiated-water movement within the bedrock.

The prime objective of the next portion of the radiological survey of Site A/Plot M is to determine the rate and direction of tritiated-water movement in the bedrock and to identify fractures, cavities, and other anomalies in the bedrock. It will be necessary to construct additional dolomite wells. The locations of these wells will be based on the tritium concentrations in existing bedrock wells, and on geologic and hydrologic information regarding the dolomite layer.

In addition, future endeavors will include drilling through the Plot M cap and the buried wastes to the drift directly beneath the plot. This task was undertaken initially in 1977 (BH 22 and BH 23). Further sampling beneath

Plot M will result in a more complete understanding of the movement of the tritium plume and verify calculations made concerning the rate of movement, present location, and shape of the plume. Samples taken from beneath the plot will also be analyzed for strontium, uranium, plutonium, and gamma-ray emitters.

Monitoring of the bedrock wells, water in the boreholes, and surface waters will continue for tritium analyses, water-level measurements, and occasional analyses for other radionuclides.

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Table A.1. Borehole 11 (9/7/77)
 (Northeast corner of Plot M,
 next to Borehole 3)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
77S87	0-1.5	16.4	1.74	0.29
77S88	5-6.5	13.2	3.38	0.45
77S89	10-11.5	13.1	17.6	2.31
77S90	15-16.5	12.5	7,340	918
77S91	20-21.5	11.6	18,600	2,160
77S92	25-26.5	7.8	22,200	1,730
77S93	30-31.5	11.3	21,200	2,400
77S94	35-36.5	12.1	22,600	2,730
77S95	40-41.5	11.7	14,500	1,340
77S96	45-46.5	13.2	35,500	4,680
77S97	50-51.5	12.4	29,500	3,650
77S98	55-56.5	12.4	16,000	1,980
77S99	60-61.5	13.4	77,600	10,400
77S100	65-66.5	11.7	93,800	11,000
77S101	70-71.5	13.6	56,400	6,600
77S102	75-76.5	13.6	41,100	5,590
77S103	80-81.5	12.9	24,000	3,090
77S104	85-86.5	14.6	9,410	1,370
77S105	90-91.5	17.5	10,400	1,820
77S106	95-96.5	17.7	790	140
77S107	100-101	14.1	564	79.5
77S108	105-106.5	16.6	670	111
77S109	110-111.5	8.2	1,190	97.3
77S110	115-116.5	10.5	1,900	200
77S111	120-121.5	8.7	1,060	92.3
77S112	125-126.5	14.1	440	62.0

Table A.2. Borehole 24 (5/1/78)
(Next to Borehole 2, 85 ft
north of the center
of Plot M)

Sample Number	Depth (ft)	³ H Concentration (nCi/L)
78S1	5-7	1.32
78S2	10-12	6.63
78S3	15-17	5.70
78S4	20-22	1,810
78S5	25-27	7,780
78S6	30-31.5	8,810
78S7	35-36.5	36,100
78S8	40-41.5	50,500
78S9	45-46.5	50,300
78S10	50-51.5	18,500
78S11	55-56.5	19,000
78S12	60-61.5	21,200
78S13	65-66.5	42,300
78S14	70-71.5	43,200
78S15	75-76.5	47,500
78S16	80-81.5	56,900
78S17	85-86.5	54,600
78S18	90-91.5	30,300
78S19	95-96.5	30,300
78S20	100-101.5	10,800
78S21	105.5-106.5	11,700
78S22	110-111.5	1,920
78S23	115-116.5	1,320
78S24	120-121.5	4,400
78S25	125-126.5	2,880

Table A.3. Borehole 25 (10/5/79)
(110 ft west of Borehole 26
and 180 ft south of
Borehole 27)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S245	19.5-21	14.9	0.39	0.058
79S246	24.5-26	12.4	0.44	0.055
79S247	29.5-31	9.1	0.59	0.054
79S248	34.5-36	8.9	0.87	0.078
79S249	39.5-41	10.2	5.93	0.607
79S250	44.5-46	11.5	11.3	1.30
79S251	49.5-51	12.3	8.38	1.03
79S252	54.5-56	12.9	20.0	2.60
79S253	59.5-61	10.7	50.4	5.42

Table A.4. Borehole 26 (10/9/79)
(30 ft northwest of the north-
west corner of Plot M)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S254	0-1.5	15.4	7.29	1.12
79S258	6-7.5	12.9	103	13.3
79S262	12-13.5	12.8	388	49.7
79S266	18-19.5	12.2	1360	165
79S270	24-25.5	12.4	2800	346
79S272	27-28.5	10.4	9060	947
79S274	30-31.5	11.5	8780	1010
79S276	33-34.5	11.2	7890	886
79S278	36-37.5	9.5	5560	530
79S282	42-43.5	10.1	2850	287
79S286	48-49.5	11.7	2170	255
79S290	54-55.5	11.8	2060	244
79S293	58.5-60	12.5	2260	284

Table A.5. Borehole 27 (9/27/79)
(100 ft west of Borehole 28
and 200 ft northwest of
the northwest corner
of Plot M)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S140	2-3.5	14.4	0.28	0.040
79S144	8-9.5	11.9	0.26	0.031
79S147	12.5-14	11.2	0.24	0.027
79S151	18.5-20	12.2	0.54	0.067
79S155	24.5-26	9.8	38.0	3.75
79S160	32-33.5	11.6	46.9	5.46
79S163	36.5-38	13.2	25.6	3.40
79S165	39.5-41	12.0	17.6	2.10
79S167	42.5-44	11.9	4.60	0.546
79S169	45.5-47	11.8	3.33	0.397
79S171	48.5-50	13.4	41.5	5.55
79S175	54.5-56	12.3	14.4	1.77
79S179	60.5-62	12.4	0.84	0.104

Table A.6. Borehole 28 (10/3/79)
(215 ft north-northwest of the
northwest corner of Plot M)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S35	0-1.5	18.9	0.30	0.057
79S39	6-7.5	14.9	0.50	0.074
79S43	12-13.5	12.6	25.8	3.25
79S45	15-16.5	11.0	927	102
79S47	18-19.5	12.3	2110	260
79S49	21-22.5	15.4	856	132
79S51	24-25.5	9.6	118	11.4
79S55	30-31.5	10.0	10.3	1.03
79S59	36-37.5	10.4	5.45	0.568
79S63	42-43.5	11.6	40.5	4.70
79S67	48-49.5	12.3	19.0	2.32
79S71	54-55.5	11.1	8.16	0.907
79S75	60-61.5	12.0	15.2	1.83
79S79	66-67.5	23.9	194	46.3
79S83	72-73.5	11.6	7.66	0.891

Table A.7. Borehole 29 (9/25/79)
(270 ft north-northwest of the
center of Plot M and 100 ft
west of Borehole 5)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S87	1.5-3	15.9	0.58	0.093
79S91	7.5-9	15.0	74.2	11.1
79S95	13.5-15	12.1	317	38.2
79S100	21-22.5	13.8	263	36.3
79S103	25.5-27	11.7	84.9	9.93
79S107	31.5-33	11.6	55.1	6.42
79S111	37.5-39	10.9	56.8	6.22
79S115	43.5-45	12.1	9.78	1.18
79S119	49.5-51	13.0	12.4	1.61
79S123	55.5-57	12.2	9.24	1.13
79S127	61.5-63	14.5	5.93	0.86
79S131	67.5-69	11.8	1.72	0.202
79S135	73.5-75	11.6	5.27	0.612

Table A.8. Borehole 30 (10/9/79)
(215 ft north-northeast of the
northeast corner of Plot M
and 50 ft east of
Borehole 5)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
79S193	1.5-3	11.0	34.1	3.74
79S196	6-7.5	10.7	44.1	4.71
79S200	12-13.5	9.1	36.3	3.30
79S205	19.5-21	9.3	34.2	3.17
79S208	24-25.5	11.2	9.12	1.02
79S212	30-31.5	12.1	0.20	0.024
79S217	37.5-39	11.5	0.19	0.021
79S220	42-43.5	13.4	< 0.10	< 0.01
79S224	48-49.5	11.7	0.11	0.013
79S228	54-55.5	12.5	< 0.10	< 0.01
79S233	61.5-63	11.1	< 0.10	< 0.01
79S236	66-67.5	11.5	0.23	0.027
79S240	72-73.5	12.9	< 0.10	< 0.01
79S244	78-79.5	16.0	< 0.10	< 0.01

Table A.9. Borehole 31 (6/11/80)
(Next to well opposite
the entrance to Red
Gate Woods)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
80S1	2-3.5	12.2	0.18	0.022
80S5	9.5-11	7.2	0.43	0.031
80S9	15.5-17	5.1	0.70	0.036
80S13	21.5-23	11.0	0.31	0.034
80S17	27.5-29	5.1	0.66	0.034
80S21	33.5-35	11.8	0.36	0.043
80S25	39.5-41	15.3	0.89	0.136
80S26	41-42.5	12.0	0.88	0.105
80S27	42.5-44	9.1	0.82	0.075
80S28	44-45.5	10.7	1.94	0.269
80S29	45.5-47	11.7	3.12	0.363
80S30	47-47.3	13.3	3.34	0.443

Table A.10. Borehole 32 (6/11/80)
(Next to Red Gate Woods well)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
80S31	0-1.5	23.6	0.17	0.040
80S35	6-7.5	13.7	0.28	0.038
80S39	12-13.5	12.9	0.41	0.054
80S43	18-19.5	11.4	0.55	0.062
80S46	22.5-24	13.3	0.34	0.046
80S50	30-31.5	14.3	0.19	0.027
80S54	36-37.5	13.7	< 0.10	< 0.01
80S58	42-43.5	13.3	< 0.10	< 0.01
80S62	48-49.5	4.7	0.17	0.008
80S66	54-55.5	13.9	0.16	0.022
80S70	60-61.5	14.1	0.08	0.011
80S74	66-67.5	18.9	< 0.10	< 0.01
80S78	72-73.5	10.5	0.21	0.022
80S79	73.5-75	11.8	0.10	0.012
80S80	75-76.5	10.8	0.15	0.016
80S81	76.5-78	11.0	0.15	0.017
80S82	78-79.5	10.6	0.18	0.019
80S83	80-81.5	9.7	0.16	0.015
80S84	82-83.5	12.0	0.27	0.033

Table A.11. Borehole 33 (6/11/80)
 (South edge of Plot M, halfway
 between the southeast and
 southwest corners of
 the burial site)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
80S85	0-1.5	21.7	0.99	0.22
80S89	6-7.5	13.5	3.51	0.47
80S93	12-13.5	11.9	75.4	8.97
80S99	21-22.5	10.3	2,600	267
80S103	27-28.5	11.9	6,200	740
80S107	33-34.5	15.8	9,500	1,500
80S111	39-40.5	12.4	88,000	10,900
80S115	45-46.5	11.2	270,000	30,400
80S120	52.5-54	13.3	48,000	6,410
80S124	58.5-60	11.6	2,200	256
80S128	64.5-66	14.1	76.6	10.8
80S132	70.5-72	11.6	1,500	174
80S136	76.5-78	12.5	7,000	872
80S140	82.5-84	13.3	380	50.5
80S144	88.5-90	12.3	13,000	1,600

Table A.12. Borehole 35 (6/23/80)
(Next to Borehole 4)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
80S145	0.5-2	19.9	4.34	0.86
80S150	8-9.5	13.9	330	46.0
80S154	14-15.5	11.7	11,000	1,290
80S158	20-21.5	11.2	17,000	1,900
80S162	26-27.5	12.6	4,100	516
80S166	32-33.5	10.9	540	58.7
80S170	38-39.5	13.2	17,000	2,240
80S174	44-45.5	12.6	20,000	2,510
80S179	51.5-53	12.5	4,400	550
80S183	57.5-59	12.1	60,000	7,280
80S187	63.5-65	14.4	43,000	6,210
80S191	69.5-71	14.8	24,000	3,560
80S195	75.5-77	13.2	3,300	436
80S200	83-84.5	12.0	1,500	180
80S204	89-90.5	14.4	1,900	274
80S208	95-96.5	16.0	2,000	321
80S212	101-102.5	9.6	1,500	144

Table A.13. Borehole 36 (6/30/80)
(Next to Borehole 26)

Sample Number	Depth (ft)	Water Content (%)	³ H Concentration	
			(nCi/L)	(pCi/g)
80S218	4-5.5	18.5	22.2	4.13
80S222	24-25.5	14.1	4900	693
80S226	44-45.5	13.9	2100	292
80S230	60.5-62	14.3	2600	372
80S234	66.5-68	15.1	2600	393
80S238	72.5-74	14.8	4000	591
80S243	80-81.5	12.9	600	77.4
80S247	86-87.5	14.5	120	17.4
80S251	92-93.5	14.2	190	27.0
80S256	99.5-101	16.3	360	58.6
80S259	104-105.5	16.4	120	19.7
80S263	110-111.5	15.8	1500	238
80S267	116-117.5	8.2	430	35.3
80S270	120.5-122	9.2	290	26.8
80S274	126.5-128	13.2	250	33.1

Table A.14. Concentrations of Tritiated Water in Streams Draining Plot M (nCi/L)

Location† ¹	Loca- tion No.† ²	Year† ³							
			1954	1976	1977	1978	1979	1980	1981
Upstream (265 ft SW)	1	Range:	1.8-2.6	-	<0.2-0.49	-	<0.2-0.3	<0.2-<0.2	<0.2-<0.2
		Avg:	2.3	<0.2	0.32	0.29	0.22	<0.2	<0.2
Adjacent (50 ft SE)	2	Range:	13-429	-	-	-	1.2-2.6	0.33-3.8	0.45-8.6
		Avg:	153	0.24	1.5	88	1.9	2.4	3.5
Adjacent (70 ft ESE)	3	Range:	-	-	-	-	69-137	4.1-171	6.2-329
		Avg:	-	8	-	-	103	60	155
Adjacent (40 ft E)	4	Range:	-	-	-	-	60-116	4.4-178	12.8-268
		Avg:	-	13	-	-	88	54	139
Adjacent (50 ft ENE)	5	Range:	48-490	-	14-29	-	58-99	4.4-145	12.8-227
		Avg:	206	31	22	100	78	47	118
Adjacent (seep) (45 ft NE)	6	Range:	-	970-1930	84-1210	486-753	231-301	780-1330	410-711
		Avg:	-	1380	742	622	266	1040	574
Downstream (250 ft N)	7	Range:	-	75-149	-	-	41-77	13-175	28-123
		Avg:	-	112	-	-	59	110	88
Downstream (in swale 250 ft N)	8	Range:	-	-	-	-	102-199	32-227	45-216
		Avg:	-	110	-	-	150	135	137
Downstream (325 ft N)	9	Range:	880-2910	75-128	12-83	17-101	12-87	16-176	29-131
		Avg:	1560	94	43	71	50	114	89
Downstream (650 ft N)	10	Range:	-	-	-	-	28-31	17-68	29-78
		Avg:	-	67	-	79	30	51	52
Downstream (975 ft N)	11	Range:	-	-	-	-	14-17	15-35	20-45
		Avg:	-	38	-	50	16	27	33
Downstream (2000 ft NNW)	12	Range:	-	-	-	-	2.7-3.2	8.4-9.3	-
		Avg:	-	12	-	15	3.0	8.8	-
Downstream (2500 ft NNW at I&M Canal)	13	Range:	-	-	-	-	1.2-1.8	5.6-5.7	-
		Avg:	-	5.1	-	13	1.5	5.6	-

†¹ Direction and distance from Plot M are given in parenthesis.

†² See Figure 8.

†³ If only one sample was collected, the concentration in that sample is reported as the average.

Table A.15. Monthly Average Concentrations of Tritium in Wells near Site A/Plot M, 1973-81 (nCi/L)

Month & Year	Well Number†1†2				
	5167	5159	5158	5157	5215
Nov 73	11.9	1.3	-	-	-
Dec	11.2	5.2	0.24	0.34	-
May 74	4.7	8.5	0.68	0.33	-
Jul	0.49	-	-	-	-
Oct	8.8	0.65	0.43	0.25	-
Nov	11.3	0.92	0.27	< 0.2	-
Dec	10.1	0.54	0.27	< 0.2	-
Jan 75	10.0	< 0.2	0.21	0.24	-
Feb	8.8	3.2	< 0.2	< 0.2	-
Mar	11.4	0.72	< 0.2	0.26	-
Apr	7.8	3.5	< 0.2	< 0.2	-
May	2.8	4.5	0.27	< 0.2	-
Jun	0.23	2.8	0.45	< 0.2	-
Jul	0.21	1.9	0.24	< 0.2	-
Aug	1.8	0.83	0.48	< 0.2	-
Sep	4.7	0.54	0.37	< 0.2	-
Oct	11.5	0.58	0.26	< 0.2	-
Nov	14.1	0.40	< 0.2	< 0.2	-
Dec	12.9 (2)	< 0.2	< 0.2	< 0.2	-
Jan 76	10.5	2.9	< 0.2	< 0.2	-
Feb	11.0 (3)	1.1 (3)	< 0.2	< 0.2	-
Mar	6.3 (2)	2.6 (2)	< 0.2	< 0.2	-
Apr	3.0	4.4	< 0.2	< 0.2	-
May	0.23	4.1	0.24	0.20	-
Jun	< 0.2	2.6	< 0.2	< 0.2	< 0.2
Jul	2.7 (4)	1.3 (4)	0.25	< 0.2	< 0.2
Aug	1.0 (4)	1.2 (4)	< 0.2	0.20	< 0.2
Sep	2.7 (5)	1.4 (5)	< 0.2	< 0.2	0.30
Oct	9.9 (2)	2.7 (3)	-	-	< 0.2
Nov	9.7 (4)	2.7 (4)	< 0.2	< 0.2	< 0.2
Dec	9.6 (5)	2.7 (5)	0.26	< 0.2	< 0.2
Jan 77	8.3 (4)	1.9 (4)	0.24	0.28	0.22
Feb	8.3 (4)	1.6 (4)	-	0.20	< 0.2
Mar	8.2 (5)	2.4 (5)	< 0.2	< 0.2	< 0.2
Apr	7.7 (4)	5.1 (4)	0.35	0.29	< 0.2
May	8.5 (4)	2.6 (4)	< 0.2	0.27	< 0.2
Jun	9.2 (5)	1.0 (5)	< 0.2	0.28	< 0.2
Jul	8.9 (4)	0.89 (4)	< 0.2	< 0.2	< 0.2
Aug	9.0 (5)	0.98 (5)	< 0.2	< 0.2	< 0.2
Sep	8.1 (4)	2.9 (4)	< 0.2	0.26	< 0.2
Oct	6.3 (4)	1.8 (4)	< 0.2	< 0.2	< 0.2
Nov	7.6 (5)	1.4 (5)	< 0.2	0.26	< 0.2
Dec	8.5 (4)	1.6 (4)	0.42	0.68	< 0.2
Jan 78	8.8 (4)	1.7 (4)	< 0.2	< 0.2	< 0.2
Feb	12.2 (4)	2.0 (4)	< 0.2	< 0.2	< 0.2
Mar	10.6 (5)	0.76 (5)	< 0.2	0.23	< 0.2
Apr	4.3 (4)	2.4 (4)	< 0.2	0.36	0.28
May	3.2 (4)	2.4 (4)	0.21	< 0.2	< 0.2
Jun	1.4 (4)	0.96 (3)	< 0.2	< 0.2	< 0.2

Table A.15. Continued

Month & Year	Well Number† ¹ † ²				
	5167	5159	5158	5157	5215
Jul 78	5.8 (4)	0.70 (4)	0.23	< 0.2	< 0.2
Aug	7.4 (4)	0.76 (4)	< 0.2	0.20	< 0.2
Sep	10.1 (4)	0.60 (4)	< 0.2	< 0.2	< 0.2
Oct	10.0 (4)	0.49 (4)	0.23	0.25	< 0.2
Nov	11.0 (4)	0.36 (4)	< 0.2	< 0.2	< 0.2
Dec	11.4 (4)	0.46 (4)	0.29	0.26	< 0.2
Jan 79	10.4 (2)	0.40 (2)	< 0.2	< 0.2	< 0.2
Feb	9.9 (4)	0.68 (4)	< 0.2	< 0.2	< 0.2
Mar	6.6 (4)	2.0 (4)	< 0.2	< 0.2	-
Apr	2.9 (3)	2.6 (4)	< 0.2	< 0.2	< 0.2
May	1.7 (5)	2.3 (5)	< 0.2	< 0.2	< 0.2
Jun	0.2 (4)	1.2 (4)	0.25	< 0.2	< 0.2
Jul	2.6 (4)	0.73 (4)	0.35	< 0.2	< 0.2
Aug	8.9 (5)	0.48 (5)	< 0.2	< 0.2	< 0.2
Sep	9.1 (4)	0.45 (4)	< 0.2	< 0.2	< 0.2
Oct	10.9 (5)	0.47 (5)	0.35	0.40	< 0.2
Nov	11.4 (4)	0.42 (4)	< 0.2	< 0.2	< 0.2
Dec	10.2 (4)	0.51 (4)	< 0.2	< 0.2	< 0.2
Jan 80	8.1 (5)	1.6 (5)	< 0.2	< 0.2	< 0.2
Feb	8.8 (4)	1.3 (4)	< 0.2	< 0.2	< 0.2
Mar	7.6 (4)	1.2 (4)	< 0.2	< 0.2	< 0.2
Apr	5.0 (5)	1.6 (5)	< 0.2	0.22	< 0.2
May	3.9 (4)	1.5 (4)	< 0.2	< 0.2	< 0.2
Jun	4.6 (4)	1.4 (4)	< 0.2	0.24	< 0.2
Jul	4.9 (5)	1.0 (5)	< 0.2	< 0.2	< 0.2
Aug	8.3 (4)	0.64 (4)	< 0.2	< 0.2	< 0.2
Sep	6.5 (3)	0.59 (4)	< 0.2	< 0.2	< 0.2
Oct	6.3 (5)	0.93 (5)	< 0.2	< 0.2	< 0.2
Nov	6.7 (4)	0.99 (4)	< 0.2	0.24	< 0.2
Dec	6.5 (5)	0.85 (5)	< 0.2	< 0.2	< 0.2
Jan 81	6.7 (4)	1.3 (4)	< 0.2	< 0.2	< 0.2
Feb	7.8 (2)	1.2 (2)	< 0.2	< 0.2	< 0.2
Mar	6.3 (2)	0.94 (2)	< 0.2	< 0.2	< 0.2
Apr	5.5 (2)	1.1 (2)	< 0.2	< 0.2	< 0.2
May	2.5 (2)	2.1 (2)	< 0.2	< 0.2	< 0.2
Jun	0.36 (2)	1.7 (2)	< 0.2	< 0.2	< 0.2
Jul	< 0.2 (2)	1.1 (2)	< 0.2	< 0.2	< 0.2
Aug	0.62 (2)	0.61 (2)	< 0.2	< 0.2	< 0.2
Sep	1.9 (2)	0.54 (2)	< 0.2	< 0.2	< 0.2
Oct	6.5 (2)	0.44 (2)	< 0.2	< 0.2	< 0.2
Nov	8.6 (2)	0.42 (2)	< 0.2	< 0.2	< 0.2
Dec	9.6 (2)	0.48 (2)	< 0.2	0.22	< 0.2

†¹ Well location: 5167 - Red Gate Woods
5159 - Opposite the entrance to Red Gate Woods
5158 - 300 yd northeast of the entrance to Red Gate Woods
5157 - 95th & Archer
5215 - Guard post

†² Concentrations are average values for months during which more than one sample was collected. Parenthetical entries indicate the number of samples collected.

Table A.16. Site and Well-Construction Data
of Bedrock Wells near Plot M†¹ (ft)

<u>DH 1</u>	
<u>Completion date:</u> September 17, 1976	
<u>Location:</u> Site A, at the top of the ridge in the Palos Forest Preserve.	
Elevation of land surface	743.0
Elevation of measuring point (top of casing)	744.9
Depth to bedrock from land surface	170.0
Depth to bottom of casing from land surface	175.0
Depth to bottom of borehole from land surface	215.0

<u>DH 2</u>	
<u>Completion date:</u> September 20, 1976	
<u>Location:</u> 525 feet south-southeast of Plot M on the north side of the forest preserve road.	
Elevation of land surface	721.1
Elevation of measuring point (top of casing)	723.1
Depth to bedrock from land surface	154.0
Depth to bottom of casing from land surface	160.0
Depth to bottom of borehole from land surface	201.0

<u>DH 3</u>	
<u>Completion date:</u> September 23, 1976	
<u>Location:</u> 98 feet north-northwest of the northeast corner of Plot M.	
Elevation of land surface	679.4
Elevation of measuring point (top of casing)	681.4
Depth to bedrock from land surface	122.0
Depth to bottom of casing from land surface	128.0
Depth to bottom of borehole from land surface	173.0

<u>DH 4</u>	
<u>Completion date:</u> September 28, 1976	
<u>Location:</u> About 650 feet northwest of Plot M next to the forest preserve road.	
Elevation of land surface	674.7
Elevation of measuring point (top of casing)	676.6
Depth to bedrock from land surface	109.0
Depth to bottom of casing from land surface	116.0
Depth to bottom of borehole from land surface	280.0

†¹ The type of casing of all wells is 5-inch diameter black steel.

Table A.17. Concentrations of Tritium in Water from Bedrock Wells, Site A/Plot M (nCi/L)

Date	DH 1	DH 2	DH 3	DH 4
10/20/76	< 0.2	< 0.2	2.1 ± 0.1	< 0.2
11/17	0.46 ± 0.11	0.35 ± 0.11	4.0 ± 0.1	< 0.2
12/16	0.36 ± 0.11	0.30 ± 0.11	4.4 ± 0.1	0.40 ± 0.11
1/19/77	0.26 ± 0.11	< 0.2	4.2 ± 0.1	< 0.2
2/15	< 0.2	< 0.2	4.2 ± 0.1	0.25 ± 0.11
3/17	0.40 ± 0.11	< 0.2	4.0 ± 0.1	0.26 ± 0.11
4/14	0.42 ± 0.11	0.31 ± 0.11	3.8 ± 0.1	0.21 ± 0.11
4/27	0.31 ± 0.14	0.24 ± 0.13	3.9 ± 0.2	< 0.2
5/11	0.48 ± 0.14	< 0.2	4.2 ± 0.1	0.23 ± 0.11
5/17	0.44 ± 0.11	< 0.2	3.7 ± 0.1	0.38 ± 0.11
6/1	< 0.2	< 0.2	3.7 ± 0.1	< 0.2
6/15	0.22 ± 0.11	< 0.2	3.7 ± 0.1	< 0.2
6/29	< 0.2	< 0.2	3.8 ± 0.1	< 0.2
7/13	< 0.2	< 0.2	3.5 ± 0.1	< 0.2
8/17	< 0.2	< 0.2	2.8 ± 0.1	< 0.2
9/21	< 0.2	0.24 ± 0.11	3.0 ± 0.1	0.29 ± 0.11
10/19	< 0.2	< 0.2	2.1 ± 0.1	< 0.2
11/16	0.55 ± 0.16	1.4 ± 0.1	2.6 ± 0.2	0.44 ± 0.16
12/29	1.5 ± 0.2	< 0.2	2.2 ± 0.2	< 0.2
1/18/78	0.35 ± 0.14	0.76 ± 0.15	2.1 ± 0.2	0.24 ± 0.14
3/20	0.29 ± 0.12	< 0.2	2.1 ± 0.1	< 0.2
4/19	0.21 ± 0.12	< 0.2	4.2 ± 0.2	< 0.2
5/22	< 0.2	< 0.2	2.1 ± 0.1	0.21 ± 0.09
6/21	< 0.2	0.24 ± 0.09	2.1 ± 0.1	0.22 ± 0.09
7/19	0.21 ± 0.09	< 0.2	2.2 ± 0.1	0.24 ± 0.12
8/16	0.21 ± 0.12	0.21 ± 0.09	2.2 ± 0.1	< 0.2
9/20	0.22 ± 0.09	0.20 ± 0.09	< 0.2	< 0.2
10/18	0.29 ± 0.09	0.25 ± 0.09	0.26 ± 0.09	< 0.2
11/15	0.21 ± 0.12	0.25 ± 0.13	0.34 ± 0.13	< 0.2
12/20	0.23 ± 0.13	0.22 ± 0.13	0.30 ± 0.12	< 0.2

Table A.17. Continued

Date	DH 1	DH 2	DH 3	DH 4
3/21/79	0.23 ± 0.12	< 0.2	0.76 ± 0.09	< 0.2
4/18	0.22 ± 0.12	< 0.2	0.59 ± 0.13	< 0.2
5/16	< 0.2	< 0.2	0.86 ± 0.10	1.0 ± 0.10
6/21	< 0.2	< 0.2	0.77 ± 0.13	< 0.2
7/18	< 0.2	< 0.2	0.81 ± 0.10	< 0.2
8/15	< 0.2	< 0.2	0.90 ± 0.10	< 0.2
9/19	0.21 ± 0.13	0.40 ± 0.13	1.08 ± 0.14	0.27 ± 0.13
10/17	< 0.2	< 0.2	1.55 ± 0.10	0.22 ± 0.09
12/4	0.25 ± 0.09	0.25 ± 0.12	1.23 ± 0.10	< 0.2
12/19	< 0.2	0.29 ± 0.12	1.17 ± 0.13	< 0.2
2/20/80	< 0.2	0.24 ± 0.09	1.12 ± 0.10	< 0.2
3/19	< 0.2	0.23 ± 0.12	1.01 ± 0.14	< 0.2
4/17	< 0.2	< 0.2	1.08 ± 0.10	< 0.2
5/21	0.24 ± 0.08	< 0.2	1.08 ± 0.10	< 0.2
6/24	0.39 ± 0.09	0.42 ± 0.09	1.19 ± 0.10	< 0.2
7/24	0.24 ± 0.08	0.42 ± 0.11	1.07 ± 0.12	< 0.2
9/5	< 0.2	0.24 ± 0.09	1.13 ± 0.10	< 0.2
10/2	0.32 ± 0.09	0.40 ± 0.09	1.20 ± 0.10	0.24 ± 0.08
10/23	0.25 ± 0.08	0.21 ± 0.08	0.99 ± 0.10	0.20 ± 0.08
11/20	0.25 ± 0.09	0.55 ± 0.10	1.27 ± 0.11	< 0.2
12/18	< 0.2	0.31 ± 0.11	1.09 ± 0.13	0.33 ± 0.16
2/20/81	< 0.2	< 0.2	1.18 ± 0.10	0.35 ± 0.09
3/18	< 0.2	0.22 ± 0.09	1.20 ± 0.10	< 0.2
5/1	0.28 ± 0.10	0.23 ± 0.10	1.20 ± 0.11	< 0.2
5/27	0.25 ± 0.09	-	-	< 0.2
6/26	0.30 ± 0.11	< 0.2	1.40 ± 0.12	< 0.2
7/16	< 0.2	< 0.2	1.24 ± 0.12	< 0.2
8/20	< 0.2	< 0.2	1.18 ± 0.11	< 0.2
9/23	0.25 ± 0.10	< 0.2	1.20 ± 0.11	< 0.2
10/27	< 0.2	< 0.2	1.33 ± 0.12	< 0.2
12/3	0.25 ± 0.10	0.22 ± 0.10	1.36 ± 0.12	< 0.2

Table A.18. Uranium Concentrations in Site A/Plot M Well-Water Samples (pCi/L)

Date	Well Number† ¹												
	5167	5159	5158	5157	5215	5188	5162	5031	5218	5021	5148	5153	5232
7/29/74	0.54	-	-	-	-	-	-	-	-	-	-	-	-
12/16/75† ²	0.58	-	-	-	-	-	-	-	-	-	-	-	-
6/1/76† ²	0.72	-	-	-	-	-	-	-	-	-	-	-	-
5/11/77† ²	1.01	-	-	-	-	-	-	-	-	-	-	-	-
2/1/78	0.83	1.06	1.28	1.65	0.60	-	-	-	-	-	-	-	-
4/14	-	-	-	-	-	-	-	1.87	2.24	0.40	0.02	-	2.01
8/2	1.11	2.20	-	-	-	-	-	-	-	-	-	-	-
11/1	2.01	-	-	-	-	-	-	-	-	-	-	-	-
3/7/79	3.23	2.84	1.98	2.41	-	-	-	-	-	-	-	-	-
5/2	0.65	-	-	-	-	-	-	-	-	-	-	-	-
8/1	0.98	2.33	-	-	-	-	-	-	-	-	-	-	-
11/7† ²	0.61	2.89	-	-	-	-	-	-	-	-	-	-	-
1/23/80	0.08	-	-	-	-	-	-	-	-	-	-	-	-
8/6† ²	0.27	1.81	1.77	1.26	0.06	-	-	-	-	-	-	-	-
2/4/81	0.08	0.59	-	-	-	-	-	-	-	-	-	-	-
4/16† ²	-	-	-	-	-	<0.01	0.03	<0.01	-	-	-	0.10	-
5/20† ²	0.15	-	-	-	-	-	-	-	-	-	-	-	-
8/5	0.26	3.03	0.12	0.61	0.11	-	-	-	-	-	-	-	-

†¹ Well location: 5167 - Red Gate Woods
5159 - Opposite the entrance to Red Gate Woods
5158 - 300 yd northeast of the entrance to Red Gate Woods
5157 - 95th & Archer
5215 - Guard post
5188 - Rainbarrel Slough
5162 - Bull Frog Lake entrance
5031 - Bull Frog Lake
5218 - St. James Church
5021 - Saganashkee Slough, east
5148 - Saganashkee Slough, west
5153 - Maple Lake, south
5232 - Wolf Road Woods

†² Samples were also analyzed for strontium-90; all values were less than 0.25 pCi/L.

Table A.19. Radionuclide Concentrations in Site A/Plot M Well-Water Samples (pCi/L)

Date	Well Number† ¹	Gross α	Gross β	⁹⁰ Sr	²³⁷ Np	²³⁸ Pu	²³⁹ Pu	Other Transuranic Elements
7/29/74	5167	-	-	-	-	-	< 0.0005	-
12/16/75	5167	-	-	< 0.25	-	-	< 0.0005	< 0.001
6/1/76	5167	-	-	< 0.25	-	-	< 0.0005	< 0.001
5/11/77	5167	-	-	< 0.25	-	-	< 0.0005	< 0.001
11/7/79† ²	5167	1.34	4.27	< 0.25	< 0.001	< 0.001	< 0.001	-
11/7/79† ²	5159	2.04	5.96	< 0.25	< 0.001	< 0.001	< 0.001	-
8/6/80	5167	1.04	3.76	< 0.25	< 0.0001	< 0.0001	0.00022	-
8/6/80	5159	2.60	5.55	< 0.25	< 0.0001	< 0.0001	0.00023	-
9/3/80	5157	1.96	15.2	-	< 0.0001	< 0.0001	0.00033	-
9/10/80	5215	0.80	4.61	-	< 0.0001	0.00054	0.00108	-
9/17/80	5158	1.17	7.36	-	< 0.0001	< 0.0001	0.00023	-
9/24/80	5148	1.43	5.24	-	< 0.0001	0.00023	0.00021	-

†¹ Well location: 5167 - Red Gate Woods
5159 - Opposite the entrance to Red Gate Woods
5157 - 95th & Archer
5215 - Guard post
5158 - 300 yd northeast of the entrance to Red Gate Woods
5148 - Saganashkee Slough, west

†² Samples were also analyzed for technetium-99; all values were less than 0.5 pCi/L.

Table A.20. Concentrations of Inorganic Ions in the Red Gate Woods Well (5167), 1979-81

Constituent	Year	Number of Samples	Concentration (mg/L)			
			Avg	Std Dev	Min	Max
Fluoride	1979	37	0.106	0.017	0.043	0.192
	1980	47	0.169	0.013	0.076	0.220
	1981	9	0.163	0.030	0.076	0.192
Chloride	1979	37	11.3	0.952	4.2	19.8
	1980	50	15.5	0.861	9.4	24.0
	1981	17	14.7	1.26	11.4	22.0
NO ₃ -nitrogen	1979	33	0.155	0.011	0.088	0.200
	1980	46	0.072	0.008	0.023	0.140
	1981	20	0.091	0.011	0.054	0.140
Potassium	1979	29	1.60	0.089	1.0	2.1
	1980	52	1.62	0.074	1.15	2.1
	1981	25	1.46	0.061	1.23	1.8

Table A.21. Concentrations of Inorganic Ions in the Well Opposite the Entrance to Red Gate Woods (5159), 1979-81

Constituent	Year	Number of Samples	Concentration (mg/L)			
			Avg	Std Dev	Min	Max
Fluoride	1979	37	0.086	0.016	0.036	0.188
	1980	49	0.146	0.008	0.064	0.192
	1981	8	0.111	0.005	0.104	0.118
Chloride	1979	37	14.2	1.47	2.6	25.0
	1980	51	15.9	0.737	10.8	22.0
	1981	17	14.8	1.31	10.8	22.0
NO ₃ -nitrogen	1979	31	0.202	0.028	0.1	0.42
	1980	48	0.087	0.011	0.04	0.25
	1981	19	0.091	0.012	0.049	0.14
Potassium	1979	28	2.27	0.111	1.68	3.2
	1980	52	2.11	0.058	1.6	2.5
	1981	25	1.97	0.039	1.8	2.1

Table A.22. Concentrations of Inorganic Ions in the Well
300 Yards Northeast of the Entrance to Red Gate
Woods (5158), 1979-81

Constituent	Year	Number of Samples	Concentration (mg/L)			
			Avg	Std Dev	Min	Max
Fluoride	1979	9	0.084	0.031	0.044	0.160
	1980	10	0.165	0.045	0.090	0.280
	1981	4	0.098	0.054	0.072	0.156
Chloride	1979	9	12.4	1.30	8.80	14.8
	1980	10	15.5	1.44	12.4	20.0
	1981	7	15.3	1.17	13.8	17.2
NO ₃ -nitrogen	1979	6	0.155	0.057	0.11	0.25
	1980	10	0.085	0.015	0.048	0.11
	1981	9	0.105	0.022	0.053	0.14
Potassium	1979	6	3.38	0.333	2.7	4.2
	1980	11	3.17	0.211	2.72	3.6
	1981	11	2.97	0.274	1.9	3.3

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