Prepared by
Oak Ridge Associated
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Prepared for
Division of Fuel
Cycle and
Material Safety

U.S. Nuclear
Regulatory
Commission

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RADIOLOGICAL SURVEY OF SHEFFIELD BROOK WAYNE, NEW JERSEY

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Radiological Site Assessment Program
Manpower Education, Research, and Training Division

DRAFT

PRELIMINARY REPORT

July 1982

THIS IS A DRAFT OF A PRELIMINARY REPORT BY OAK RIDGE ASSOCIATED UNIVERSITIES ON THE FIRST PORTION OF ITS RADIOLOGICAL SURVEYS IN THE WAYNE, NEW JERSEY AREA. IT WAS SUBMITTED TO THE NUCLEAR REGULATORY COMMISSION STAFF FOR REVIEW AND COMMENT. IT IS EXPECTED THAT THERE WILL BE SOME CHANGES PRIOR TO PUBLICATION OF THE FINAL VERSION OF THIS REPORT.

NOTICE

Analyses of samples and interpretation of data from this survey have not been completed. However, this preliminary report of survey findings has been prepared because of current interest in the radiological conditions of Sheffield Brook and the adjacent areas. Additional results will be incorporated into a final report as they become available. It is not anticipated that these additional results will substantially alter the evaluation of radiological conditions as presented here.

RADIOLOGICAL SURVEY
OF
SHEFFIELD BROOK
Wayne, New Jersey

Prepared for

Division of Fuel Cycle and Material Safety
U.S. Nuclear Regulatory Commission

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INTRODUCTION

In 1948, Rare Earths, Inc., of Wayne, New Jersey, began processing monazite sand to extract thorium and rare earths. The facility was aquired by the Davison Chemical Division of W.R. Grace in 1957; thorium ore processing activities continued until July 1967. The plant was permanently closed in April 1971. In 1974, Applied Health Physics Inc. decontaminated the site and the property was released by the Nuclear Regulatory Commission (NRC) for unrestricted use in January 1975. The buildings are currently occupied by Electro-Nucleonics Inc., under a long-term lease.

Solid wastes containing low (less than approximately 5%) concentrations of thorium were disposed of by on-site shallow land burial, in accordance with the regulations in effect at that time.[1] Although detailed records of quantities and compositions of waste are not available, W.R. Grace has estimated that approximately 9×10^4 kg of thorium-containing residues and slightly contaminated debris have been buried on the property. Potentially contaminated liquid wastes were monitored to assure that radionuclide concentrations were within the regulatory limits for release before they were discharged into a small drainage ditch that flows through the site.

In January 1981, as part of a review of formerly licensed facilities, the Nuclear Regulatory Commission measured direct radiation levels and radionuclide concentrations in soil on the W.R. Grace property. The results of these measurements indicated that exposure rates and soil contamination levels exceeded the present criteria for unrestricted use of the site. At the request of the State of New Jersey and the U.S. Environmental Protection Agency, an aerial radiological survey of the site and adjacent areas was conducted by EG&G in May 1981. This survey identified elevated radiation levels, both on the W.R. Grace site and west of the site, along Sheffield Brook.[2] The NRC performed follow-up measurements along the brook in November 1981 and noted radiation levels up to 200 μrem/h and elevated concentrations of thorium in bank soil and stream sediment.[3]

At the request of the NRC Division of Fuel Cycle and Material Safety, a radiological survey of the Sheffield Brook area was conducted April 26-May 1, 1982 by the Radiological Site Assessement Program of Oak Ridge Associated Universities (ORAU), Oak Ridge, Tennessee. This report presents the preliminary findings of that survey.

SITE DESCRIPTION

The W.R. Grace property is located at 868 Black Oak Ridge Road about 2 km east of Pompton Plains and 3 km north of Wayne, in the northeast corner of New Jersey (Figure 1). Pompton Plains is situated in Passaic County on the west bank of the Pompton River while the W.R. Grace property and Wayne are located in Morris County, east of the river. The site occupies approximately 2.6 hectares most of which are surrounded by a chain link security fence. Two office buildings and a warehouse are the main structures on the site. The eastern and northern sections of the site are wooded with heavy brush and weeds along a small drainage stream. The land generally slopes toward the west and northwest.

The small drainage stream enters the site near the southeast corner of the site. This stream flows north; then turns west. Prior to leaving the property, the stream enters a conduit. This conduit carries the water into a mixing tank where it is combined with the overflow from an on-site artesian well. The water then flows under the facility's north parking lot to Black Oak Ridge Road where it is joined by two storm sewer lines. It resurfaces as Sheffield Brook after running west beneath Pompton Plains Cross Road for approximately 150 m.

From this point, it flows southwest for approximately 200 m in a straight channel or ditch. Dense stands of brush, 5 m deep on both sides of the bank, make access to the stream difficult. Beyond the stands of brush the land becomes open field containing scattered trees and tall grass. Approximately midway along this straight channel, the brook is joined by a small stream originating southwest of the W.R. Grace property from the combined discharges of two storm sewer systems. Small mounds of soil, apparently resulting from periodic dredging of the stream bed, are scattered along the banks this section of the brook.

At the end of the straight channel, Sheffield Brook turns west and continues in that direction until it passes under Farmingdale Road. The bank on the south side of the brook in this area rises sharply for about 5 m and is covered by brush and trees. The land north of the brook consists mostly of low soggy field subject to periodic overflow. West of Farmingdale Road the brook turns south and flows through a public park for approximately 150 m until it empties into the Pompton River. The eastern edge of the brook is overgrown with brush and trees, while the western bank is comparatively accessible from the park property. Figure 2 shows the location of Sheffield Brook and associated drainage streams.

SURVEY PROCEDURES

Objectives

The objectives of this survey were to determine:

1. direct radiation levels along Sheffield Brook, and

2. concentrations of radionuclides in soil, sediment, water, and vegetation from the vicinity of the brook.

Plan

The survey plan included the following activities:

1. Monitoring of gamma radiation levels at the ground surface along the banks of Sheffield Brook and associated streams.

2. Exposure rate measurements at 1 m above the surface for selected points along the brook.

3. Dose rate measurements at 1 cm above the surface for each of the locations at which gamma measurements at 1 m were taken.

4. Collection of surface soil and subsurface soil along Sheffield Brook and associated streams.

5. Collection of sediment samples along Sheffield Brook and its associated streams as well as five locations in the storm sewer system flowing into Sheffield Brook.

6. Collection of water samples from streams, storm sewers and local wells.

7. Collection of vegetation samples along the brook.

8. Collection of samples and measurements at off-site locations to provide baseline data for comparison.

Measurement of Direct Radiation

Using NaI(Tl) gamma scintillation ratemeters, walkover surface scans were performed to approximately 10 m on either side of Sheffield Brook from Pompton Plains Cross Road to the Pompton River. General radiation levels and locations of significantly elevated levels were noted.

The brook was divided into 50 m intervals. At each of these intervals, exposure rates at 1 m above the surface were systematically measured at the edge of the brook and at 5 and 10 m from the edge. Measurements were also performed where the brook entered or exited conduits. These measurements were performed with NaI(Tl) scintillation ratemeters field-calibrated using a pressurized ionization chamber.

Beta-gamma dose rates at 1 cm above the surface were measured at each location where the 1 m gamma exposure rates were measured. These measurements were performed using G-M detectors and scalers. To evaluate contributions from both penetrating and non-pentrating radiations the measurements were made with the probes in both the open- and closed-shield configurations.

Three 50 m intervals were established along the small drainage stream which joins Sheffield Brook about 100 m southeast of Pompton Plains Cross Road. Surface gamma levels were monitored by a walkover scan. Exposure rate and dose rate measurements at 1 m and 1 cm, respectively, above the surface were performed at 50 m intervals along the stream bank.

A walkover surface gamma survey was performed along three small drainage streams that join Sheffield Brook west of Farmingdale Road.

Soil Sampling

Systematic surface (0-5 cm) soil samples were collected from both banks of Sheffield Brook at 50 m intervals and at least one additional surface sample was collected from each bank. These samples alternated between 5 and 10 m from the stream edge. Surface samples were also collected at 50 m intervals along the edge of the stream flowing into Sheffield Brook near Pompton Plain Cross Road, one of the drainage streams west of Farmingdale Road, and at several additional locations along the brook.

Systematic subsurface (30 cm, 60 cm, and 90 cm) samples were collected from 14 of the locations where systematic surface samples were obtained, at 100 m intervals and on alternating sides of the brook. The majority of these sampling locations were 5 or 10 m from the brook edge, however, several were considerably further (up to approximately 100 m) from the brook.

Biased surface and subsurface soil samples were collected from 30 locations indicated by the walkover survey to have elevated radiation levels.

Surface soil samples were collected using a garden trowel from which residual soil was cleaned between samples. Subsurface samples were collected from 15 cm diameter holes drilled with a portable motorized auger. Soil sampling locations are indicated in Figures 3, 4, 5.

Water Sampling

Surface water samples were collected at four locations along Sheffield Brook; the discharge from the W.R. Grace site, 100 m and 500 m upstream and downstream of Sheffield Brook on the Pompton River; and three locations on a small farm on the north side of Pompton Plains Cross Road. Water samples were also collected from five locations in the storm drain system feeding Sheffield Brook. Samples of well water were collected from the farm north of Pompton Plains Cross Road and from five local residents. Locations of these water samples are indicated on Figures 5 and 8.

Vegetation Sampling

Vegetation samples were collected at five locations in the vicinity of Sheffield Brook (see Figure 5). The samples consisted of grass, weeds, and other plants characteristic of the selected location.

Baseline and Background Measurements

Five soil samples, two water samples, and one vegetation sample were collected at locations approximately 0.25 to 10 m from the W.R. Grace and Sheffield Brook sites. Measurements of direct background radiation levels were performed at the locations of the soil samples. Figure 9 indicates the locations of these baseline samples and background measurements.

Equipment and Analytical Procedures

Appendix A contains a list of the major equipment and instrumentation used for this survey. Analytical procedures are described in detail in Appendix B.

RESULTS

Background Radiation and Baseline Concentrations

Background exposure rates in the Wayne-Pompton Plains, New Jersey, area ranged from 6 to 12 μR/h; surface beta-gamma dose rates ranged from 16 to 38 μrad/h.

Baseline radionuclide concentrations in soil, water, and vegetation are presented in Table 1. The concentrations in these samples are typical of those normally encountered in such media.

Direct Radiation Levels

Surface Survey

Surface exposure rates measured during the walkover scan ranged from 6 μR/h (background) to 423 μR/h. The highest levels were noted in two general areas. The first was a strip, approximately 5 m wide and 200 m long on either side of Sheffield Brook, from Pompton Plains Cross Road to the end of the straight channel. Along this portion of the brook, elevated radiation levels were often associated with small piles of earth believed to be the result of dredging the stream. The two highest levels noted in this region, 423 μR/h and 365 μR/h, were associated with such piles. The other area was on the north side of Sheffield Brook, approximately 100 m east of Farmingdale Road. Exposure rates up to 423 μR/h were measured in the latter region.

The surface radiation levels along the brook were considerably lower west of Farmingdale Road. Only one sizable area along this section of the brook had elevated exposure levels. This was the area just south of the park access road and west of the footpath. Exposure rates in the area, up to 269 μR/h, resulted from a localized area of contamination. The slope of the land at this location is such that contamination here is not easily attributable to deposition from the brook.

Of the small streams feeding Sheffield Brook, only the one north of the brook, between Farmingdale Road and the footpath, showed notably elevated exposure levels. The highest level along this stream, 115 μR/h, was noted in a small area approximately 5 m north of the brook.

Figures 10 and 11 present the results of the surface scan in graphic form.

Exposure Rates at 1 Meter

Exposure rates measured systematically at 1 m above the ground at the edge of the brook ranged from 8 μR/h to 173 μR/h, averaging 51 μR/h. At 5 m from the brook the exposure rates ranged from 9 μR/h to 269 μR/h, averaging 58 μR/h; at 10 m from the brook the range was from 8 μR/h to 250 μR/h, with an average value of 38 μR/h. The pattern of these 1 m exposure rates was very similar to the pattern of the surface exposure levels noted by the walkover scan. These 1 m exposure rates are presented on Figures 12 and 13.

Beta-Gamma Surface Dose Rates

The surface beta-gamma dose rates along Sheffield Brook are presented in Figures 14 and 15, and ranged between 16 to 948 µrad/h. The levels showed a close correlation with the exposure rates at 1 m measured at the same locations. The absence of any significant difference between the open and closed-shield configurations indicated a negligible beta and low energy x-ray contribution.

Radionuclide Concentrations in Soil Samples

Radionuclide concentrations in surface and subsurface soils are presented in Tables 2 and 3. Elevated surface levels of Ra-228 and Th-228, representatives of natural thorium, are present over the entire length of Sheffield Brook and along one small associated drainage stream, adjacent to the township park. As with the direct radiation levels, elevated soil concentrations occurred more frequently along the portion of Sheffield Brook east of Farmingdale Road. The maximum Ra-228 and Th-228 concentrations in surface soil were 734 and 722 pCi/g, respectively, at sample location 105. The general pattern is a decrease in radionuclide concentration with distance from the W.R. Grace property and from the edge of the brook. However, there are exceptions to this pattern e.g. samples 131 and 135 collected comparatively close to the Pompton River both of which have Ra-228 and Th-228 concentrations above 100 pCi/g. Samples obtained along the storm drainage stream that joins Sheffield Brook south of Pompton Plains Cross Road and along the Pompton River were not significantly different from baseline levels.

Subsurface soil concentrations generally decreased with depth, although there were several locations where the concentrations were slightly higher at 30 or 60 cm deep. Samples 112 and 113 from a depth of 90 cm contained Ra-228 and Th-228 concentrations exceeding 100 pCi/g. Concentrations in other samples from this depth were considerably lower, most being in the range of baseline levels.

Elevated concentrations of Ra-226 were also measured in samples containing high concentrations of thorium. The maximum Ra-226 level, 46.8 pCi/g, was found in sample 105. Ra-226 concentrations were generally 5-10% of the thorium levels in the elevated soil samples.

There was good correlation between the results of the direct radiation surveys and the soil sample results. Locations of soil samples which exceed 5 pCi/g of Ra-228 (representative of the Th-232 level) are indicated on Figures 16 and 17.

Radionuclide Concentrations in Sediment Samples

Radionuclide concentrations in sediment samples are presented in Table 4. Concentrations in these samples follow the general pattern of the bank soil samples, being higher along that portion of the brook between Pompton Plains Cross Road and Farmingdale Road. The maximum concentrations of Ra-228 and Th-228 (61.0 and 53.9 pCi/g respectively) were measured at sample location 16. At locations 8 and 9, where the small stream flows into Sheffield Brook, the radionuclide concentrations show a dramatic decrease. Physical or chemical conditions may be inhibiting the deposition or enhancing the clearance of radionuclides in the sediment at that location.

Levels in sediment from the small stream entering Sheffield Brook south of Pompton Plains Cross Road were in the range of baseline soil samples. Levels in samples collected from the Pompton River upstream of Sheffield Brook were also in the range of baseline soil. Pompton River sediment samples downstream of the brook were slightly higher than the upstream samples, but they also were within the baseline range. No consistent pattern in the distribution of elevated sediment levels was identified. However, west of Farmingdale Road the maximum thorium concentrations were noted at locations 24 and 31, which are both areas where the brook flow suddenly changes due to bends or constrictions.

Radium 226 concentrations in sediment did not exceed 5 pCi/g. Where elevated levels were noted they were generally less than 10% of the thorium concentrations.

Water Samples

Gross alpha levels measured in the water samples are presented in Table 5. These levels ranged from <0.7 pCi/l to 39 pCi/l. Gross alpha concentrations exceeding the 15 pCi/l guideline[4] for drinking water, established by the Environmental Protection Agency (EPA), were noted in three samples. Two of these (samples 8 and 9 — 29 and 19 pCi/l respectively) were collected from the storm sewer system close to the W.R. Grace Property. Sample 6, containing 39 pCi/l, was collected from the Pompton River approximately 100 m downstream from its confluence with Sheffield Brook. A duplicate sample is being collected from the latter location for analysis since this level is highly inconsistent with the others in Sheffield Brook and Pompton River.

Additional analyses for specific radionuclides in these water samples are being performed.

Vegetation Samples

Radionuclide concentrations in the vegetation samples are presented in Table 6. Levels in sample 2 may be considered typical of those normally encountered in vegetation. Elevated concentrations of thorium were noted in all other samples, the highest levels being in samples 3 and 4 from areas having elevated exposure rates and high concentrations of radionuclides in the soil.

Additional radionuclide analyses are being performed on these samples.

SUMMARY

At the request of the Nuclear Regulatory Commission, the ORAU Radiological Site Assessment Program conducted a radiological survey of Sheffield Brook and adjacent properties in Wayne, New Jersey. The findings of this survey indicate the presence of thorium contaminated soil and sediment along this brook. The thorium contamination apparently originated on the W.R. Grace property located near the intersection of Black Oak Ridge Road and Pompton Plains Cross Road. Thorium bearing ores were processed at this site from 1948 to 1971. Some wastes from these operations still remain on the property. It is believed that small quantities of thorium have entered the brook via the storm drainage and waste treatment discharges over an extended time period to be deposited along the streambed and banks. Periodic dredging along the eastern portion of the brook has deposited additional thorium contaminated sediments on the bank.

Direct radiation levels and radionuclide concentrations in the soil and sediment at many locations along Sheffield Brook exceed the guidelines proposed by the Nuclear Regulatory Commission for unrestricted land use. These guidelines, summarized in Appendix C, recommend maximum exposure rates of 10 μR/h above background and average natural thorium concentrations, i.e. Th-232 plus Th-228 in equilibrium with daughter products, of 10 pCi/g. It is estimated that 5000-10,000 cubic meters of soil must be removed from along Sheffield Brook to satisfy those guidelines.

The survey findings also show that the thorium contamination is generally limited to a narrow strip, approximately 10 m maximum on either side of the brook and that the contamination is primarily - although not completely - in the surface soil. Low concentrations noted in the surface streams and well water from this area indicate low leachability of the radionuclides.

While Ra-226 was also detected in elevated concentrations the levels are considerably less (5-10%) than the thorium concentrations. Since the recommended soil concentration guidelines for Th-232, Th-228, and Ra-226 are the same, thorium is the major radioactive material of concern on this site.

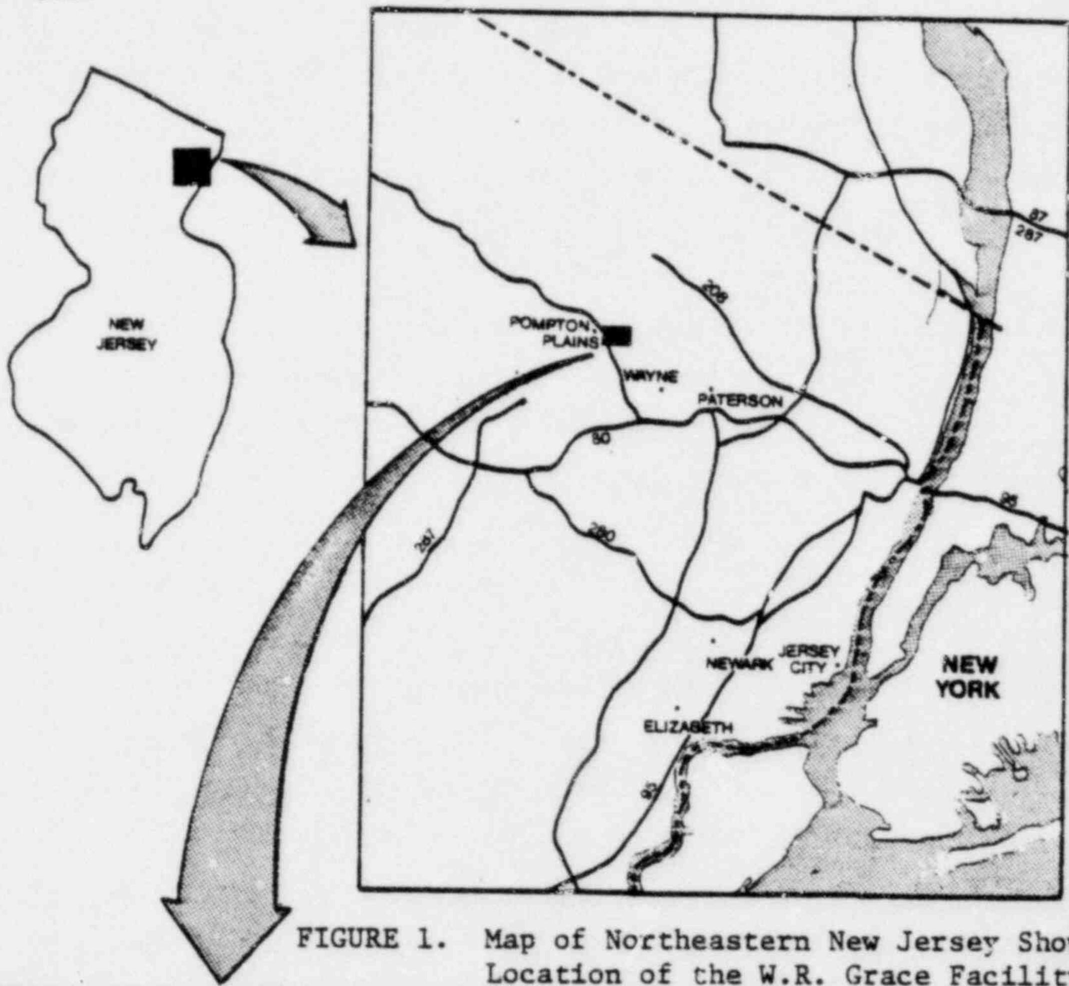

FIGURE 1. Map of Northeastern New Jersey Showing the Location of the W.R. Grace Facility.

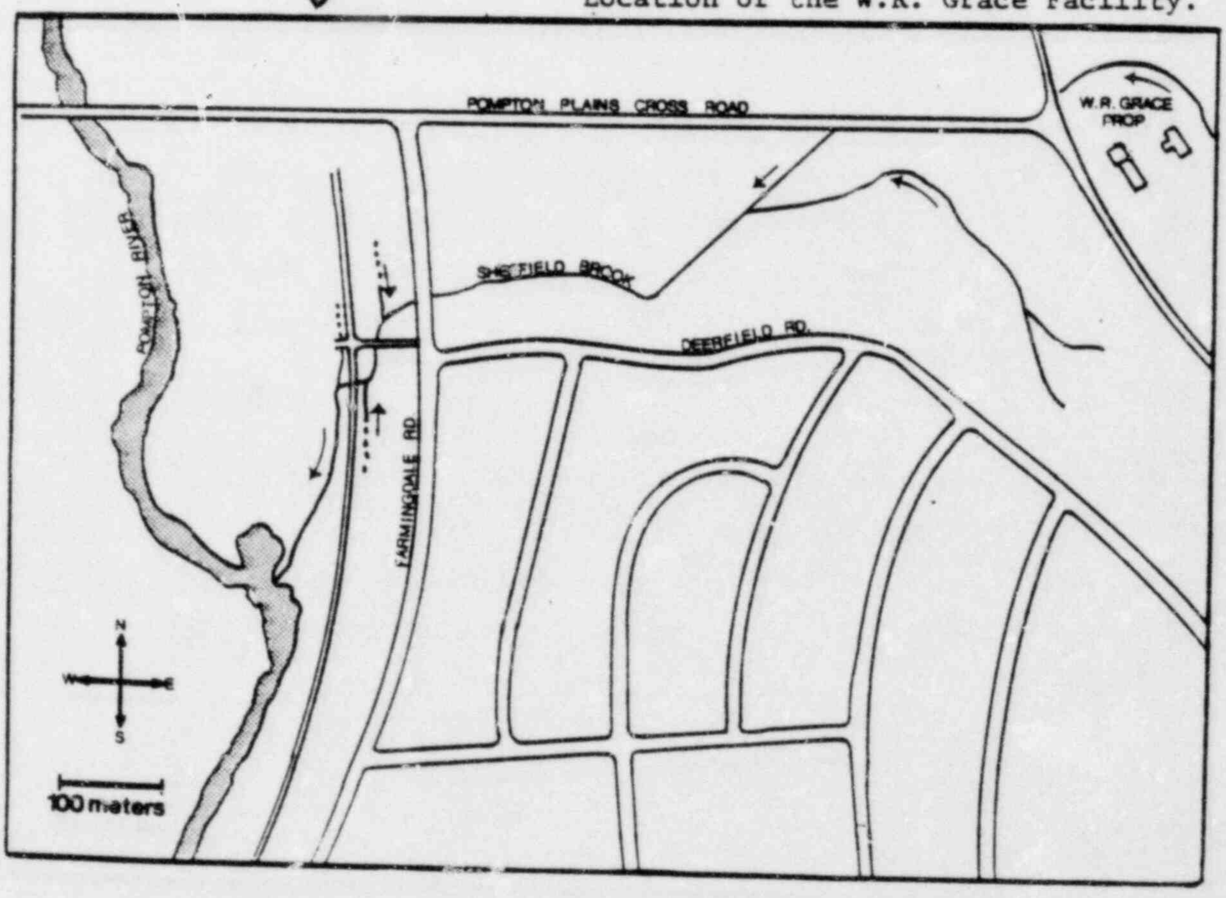

FIGURE 2. Portion of Wayne, New Jersey, Indicating the Locations of the W.R. Grace Property, Sheffield Brook and Associated Streams.

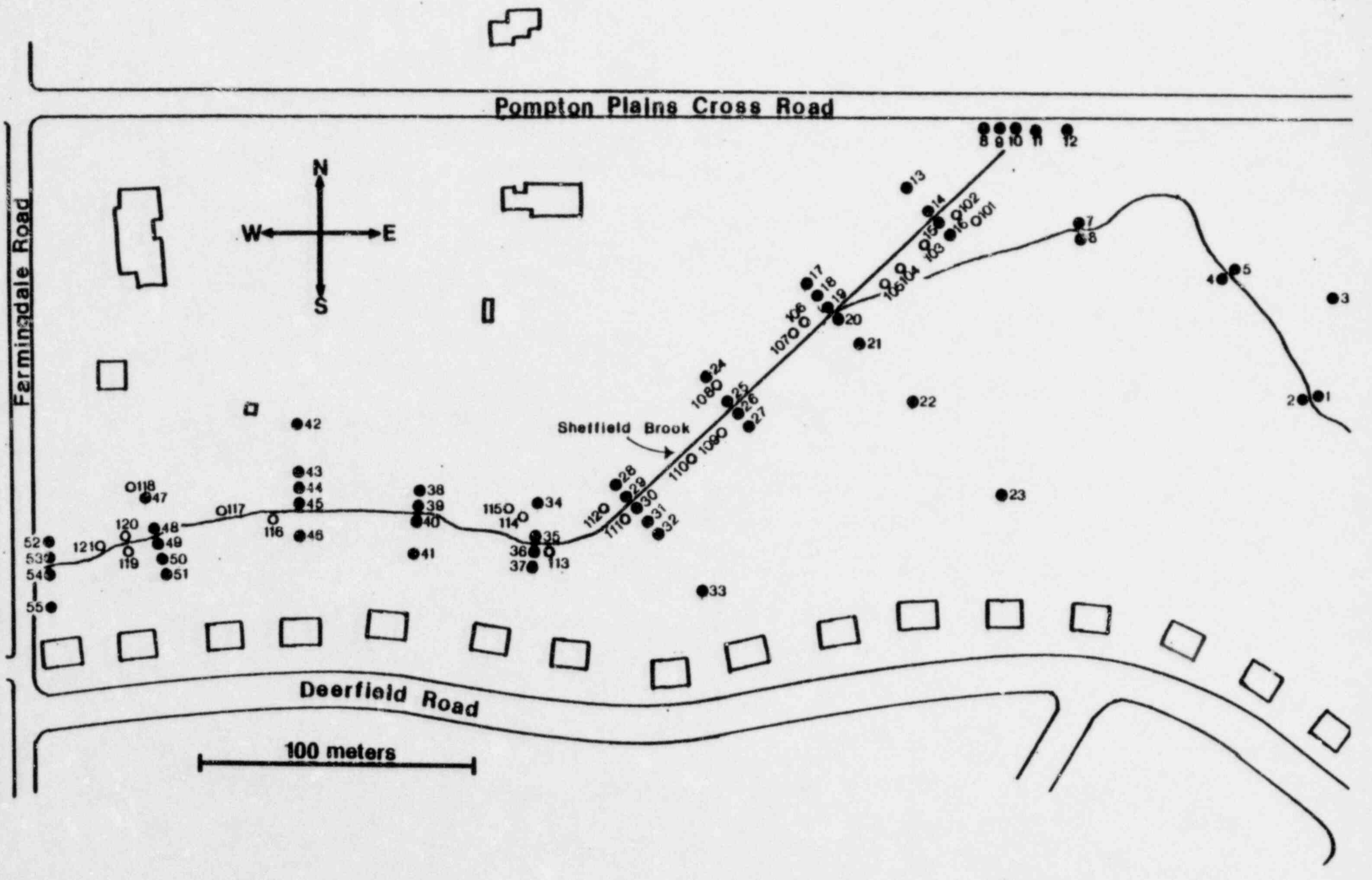

FIGURE 3. Map of Sheffield Brook, East of Farmingdale Road, Indicating Locations of Soil Samples.

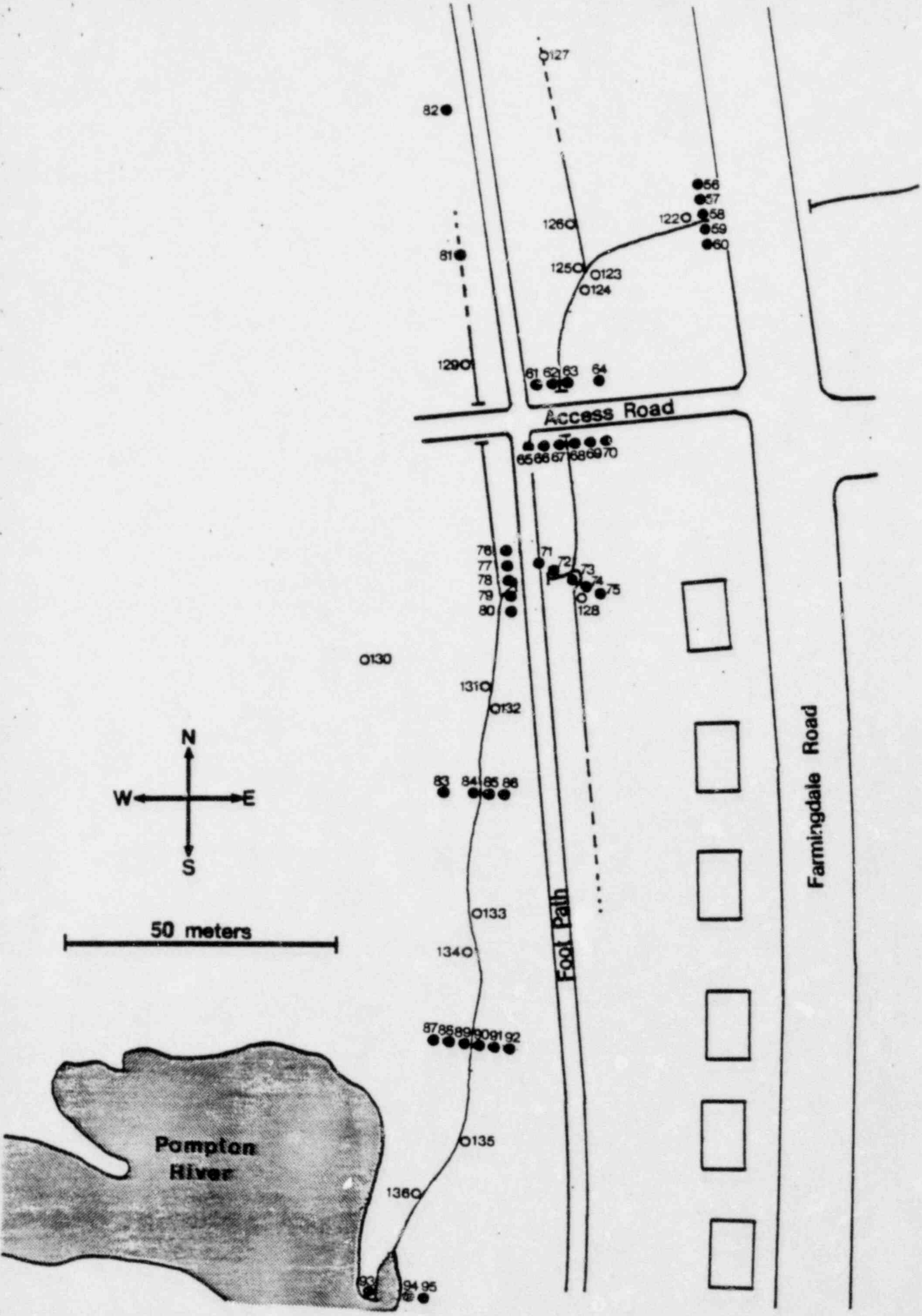

FIGURE 4. Map of Sheffield Brook, West of Farmingdale Road, Indicating Locations of Soil Samples.

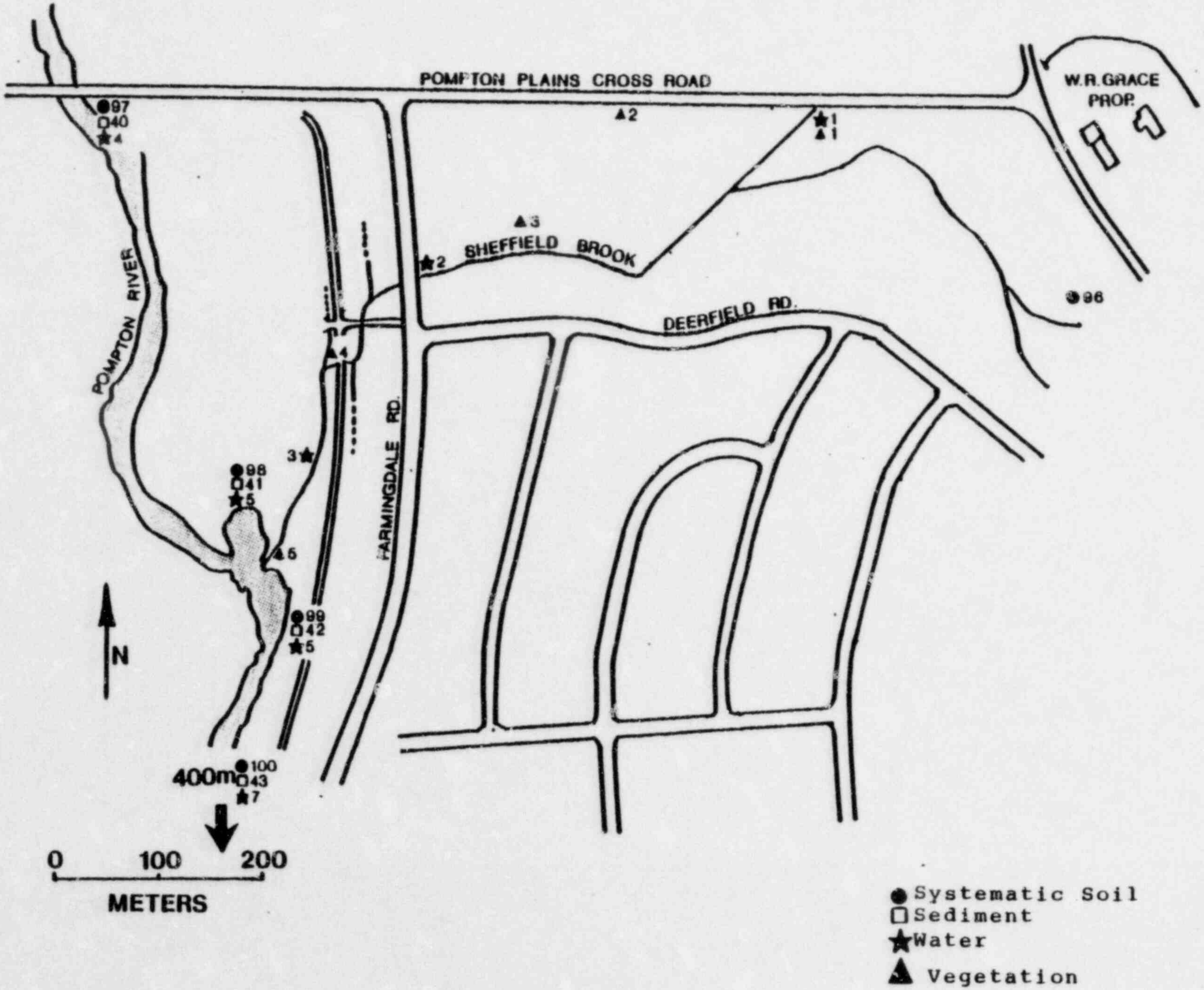

FIGURE 5. Map of Sheffield Brook and Vicinity Indicating Locations of Soil, Sediment, Water, and Vegetation Samples.

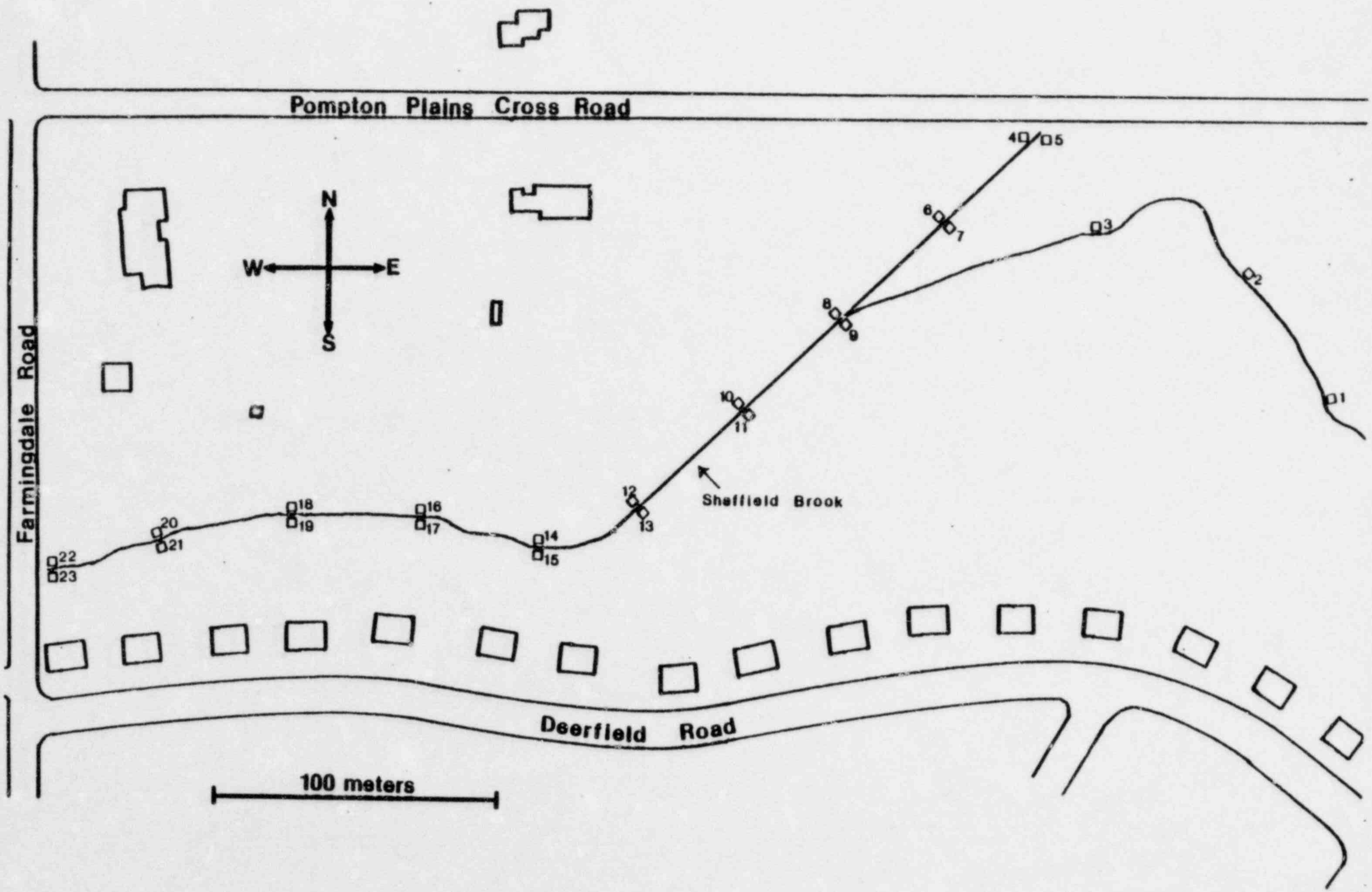

FIGURE 6. Map of Sheffield Brook, East of Farmingdale Road, Indicating Locations of Sediment Samples.

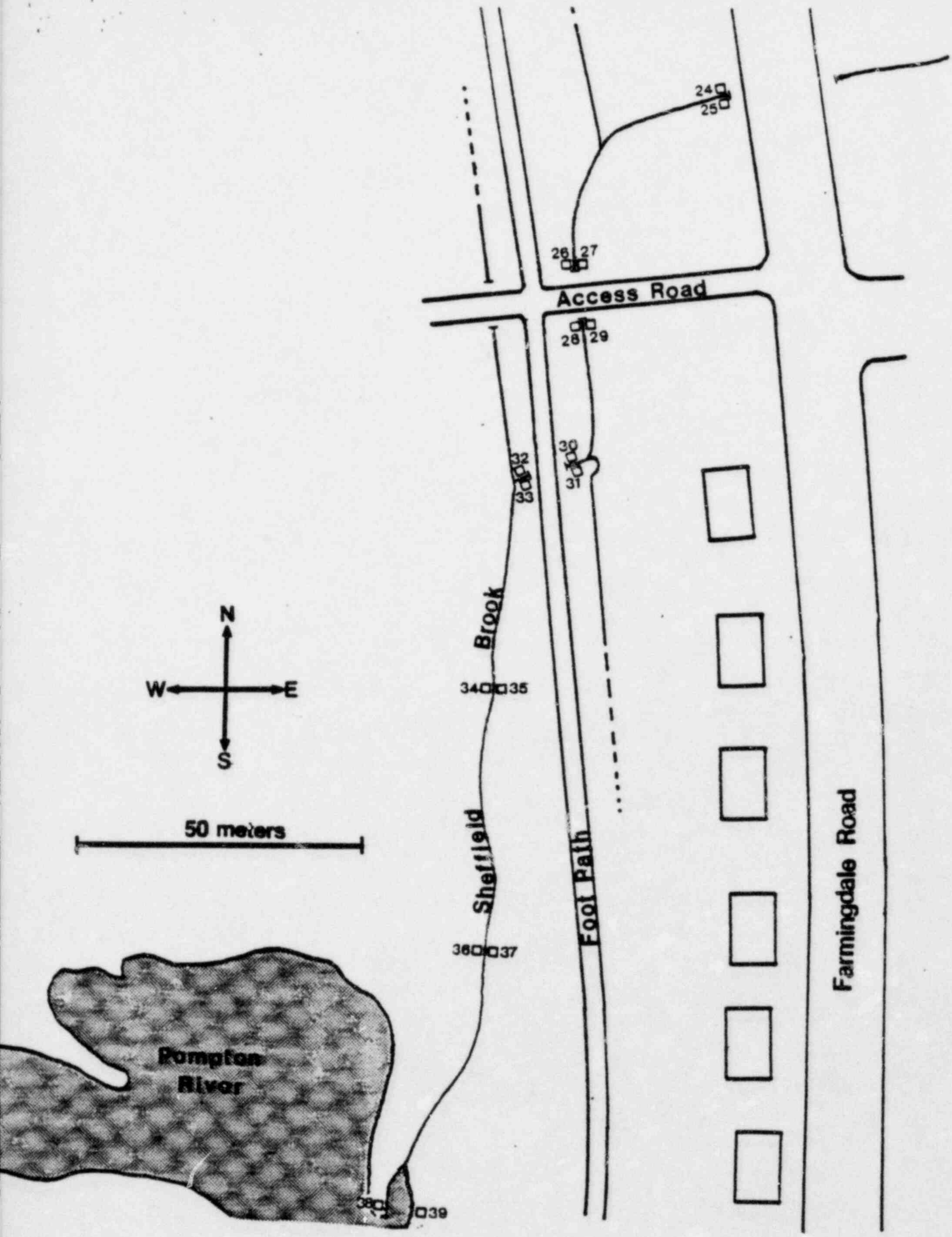

FIGURE 7. Map of Sheffield Brook, West of Farmingdale Road, Indicating Locations of Sediment Samples.

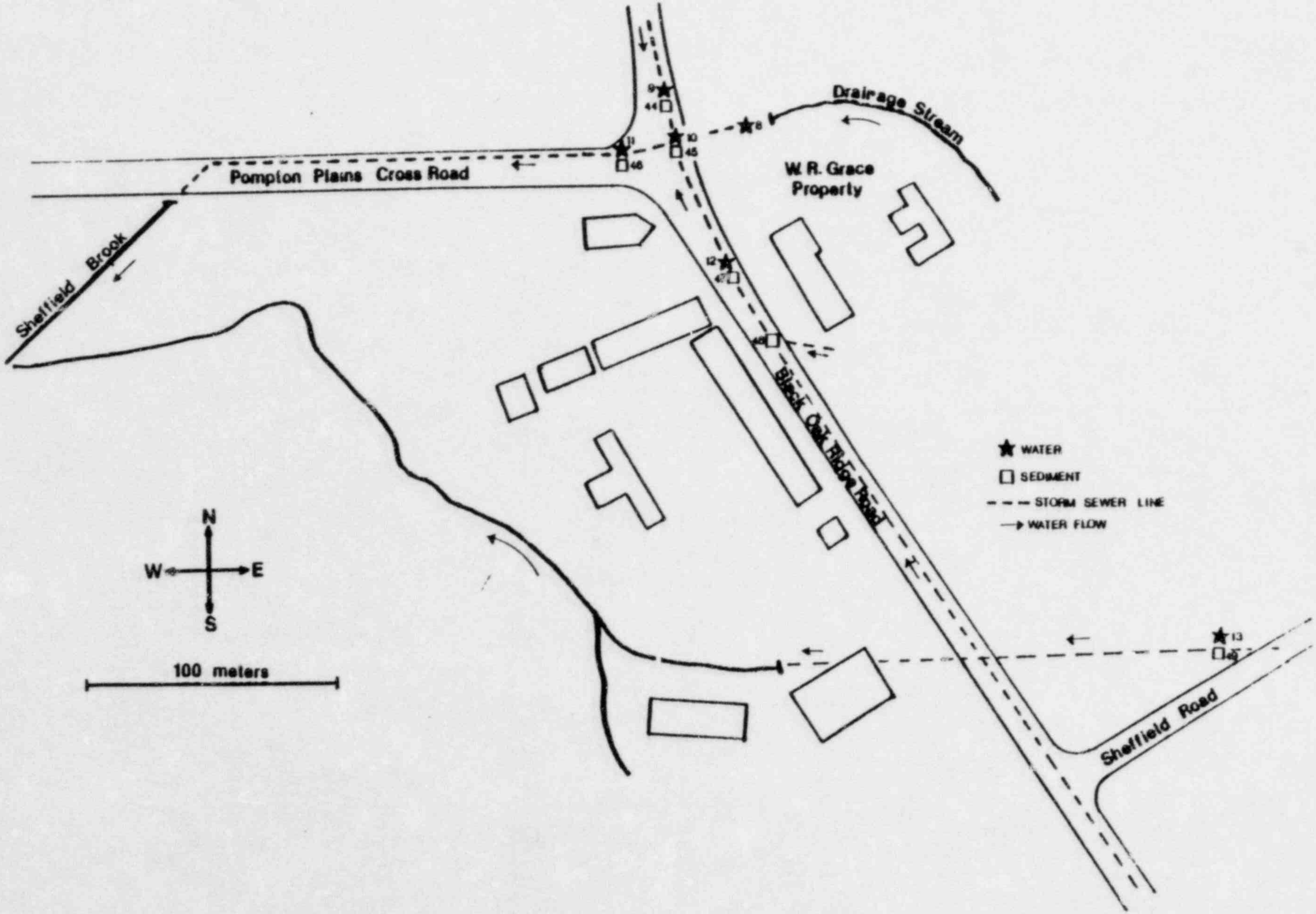

FIGURE 8. Plan View of Storm Sewer System Feeding Sheffield Brook, Indicating Locations of Sediment and Water Samples.

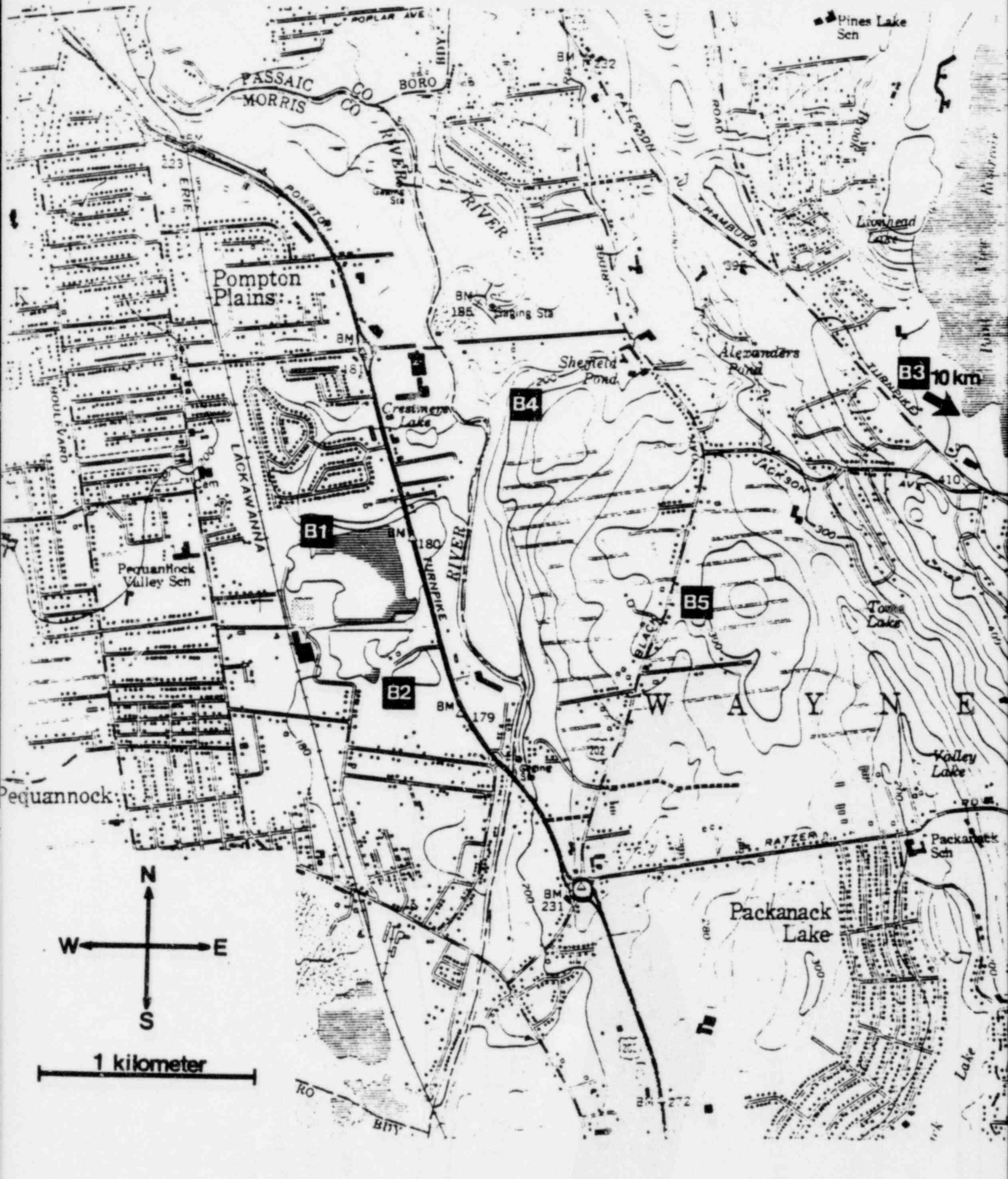

FIGURE 9. Locations of Background Measurements and Baseline Samples in the Wayne-Pompton Plains Area.

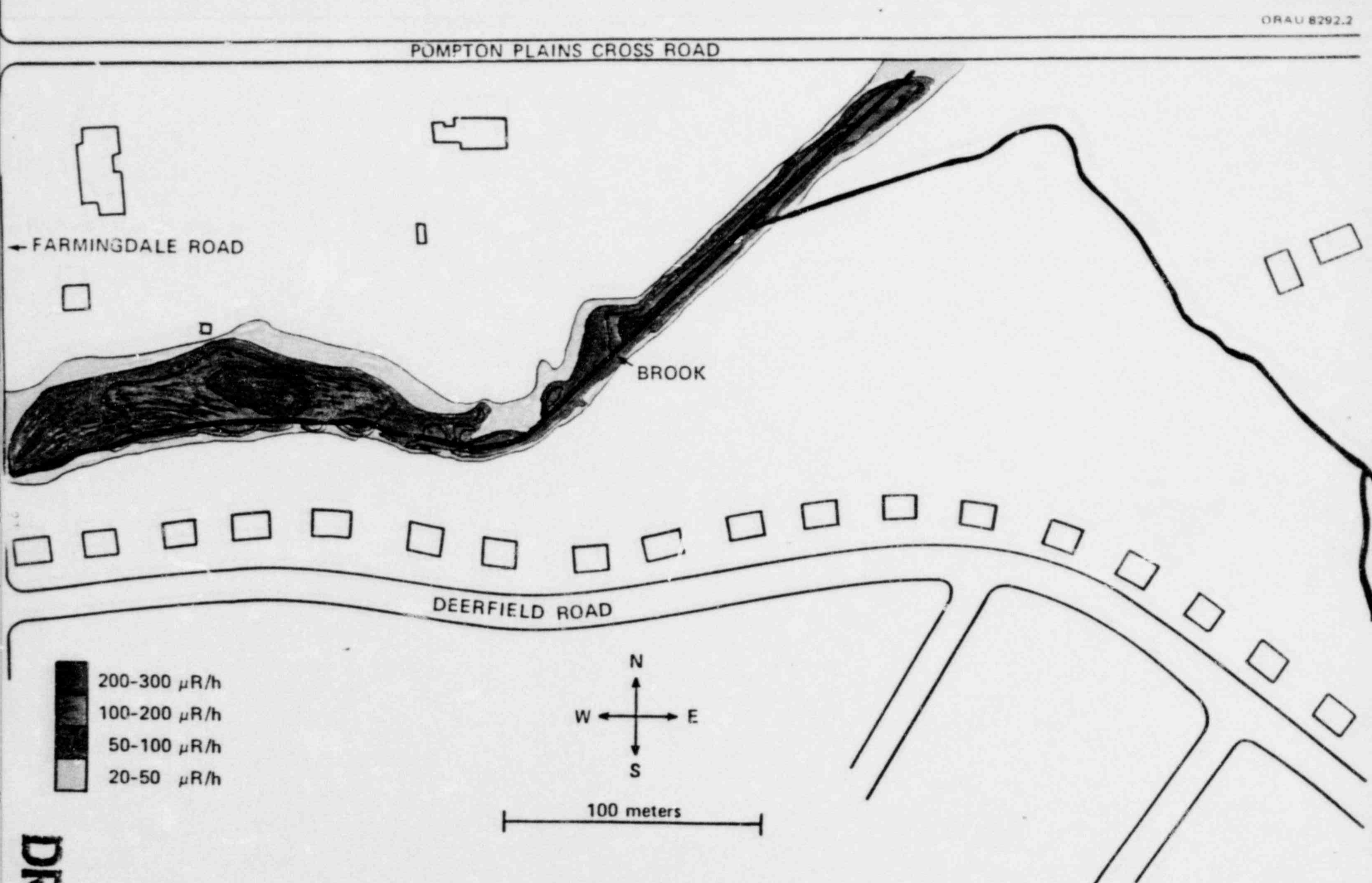

FIGURE 10. Surface Exposure Rates (μR/h) Along Sheffield Brook East of Farmingdale Road.

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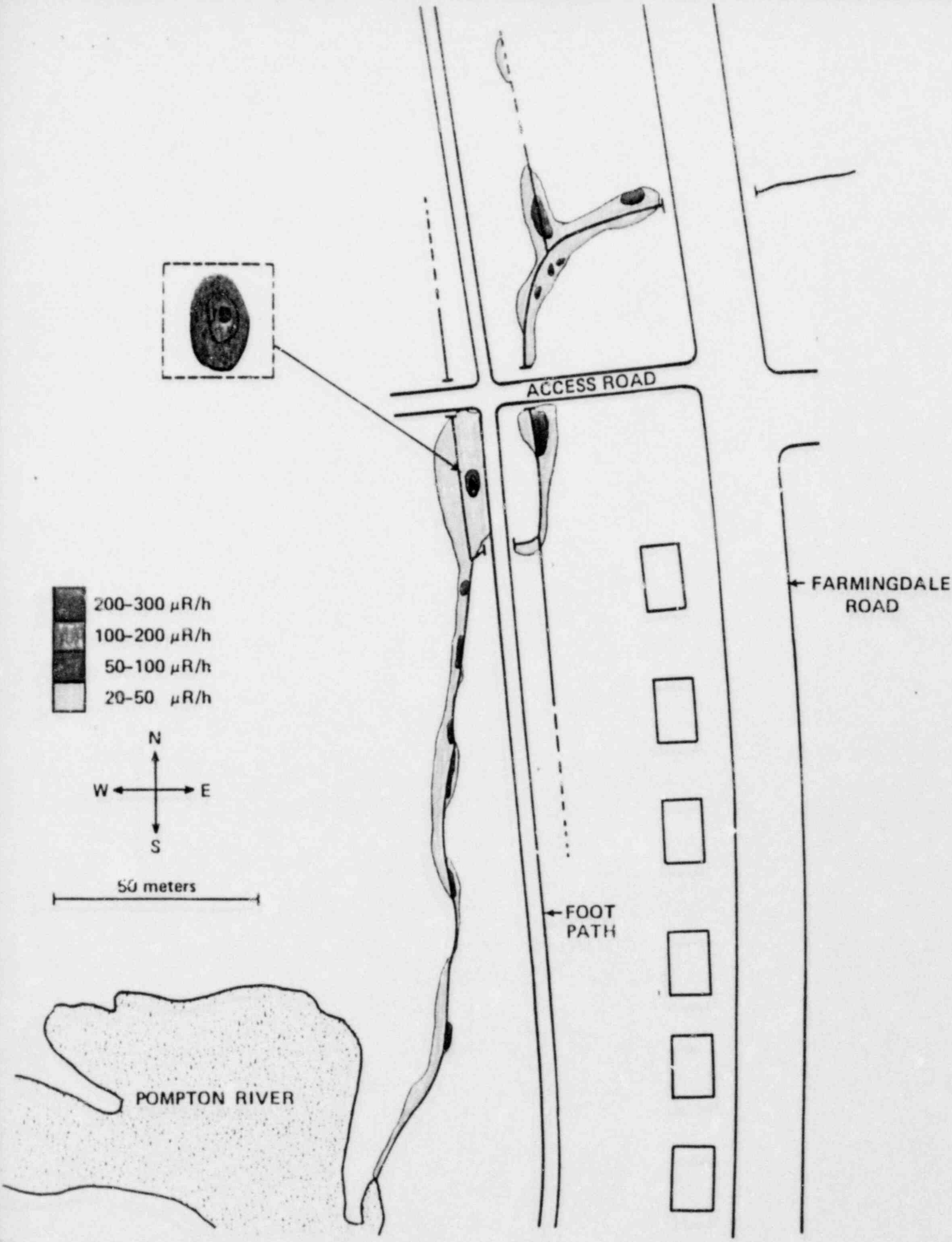

FIGURE 11. Surface Exposure Rates (μR/h) Along Sheffield Brook West of Farmingdale Road.

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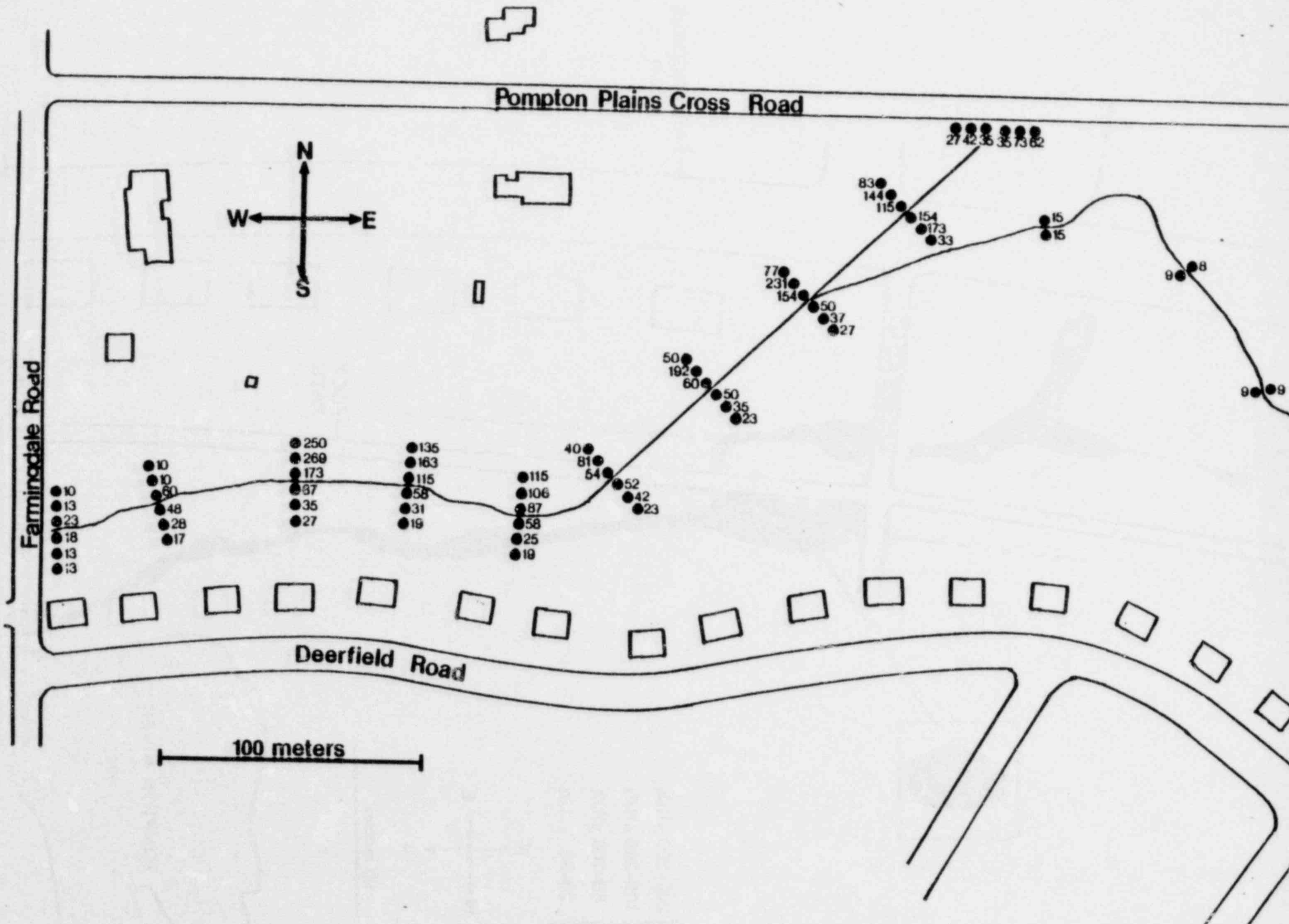

FIGURE 12. Exposure Rates (μR/h) at 1 m Above the Surface Along
Sheffield Brook

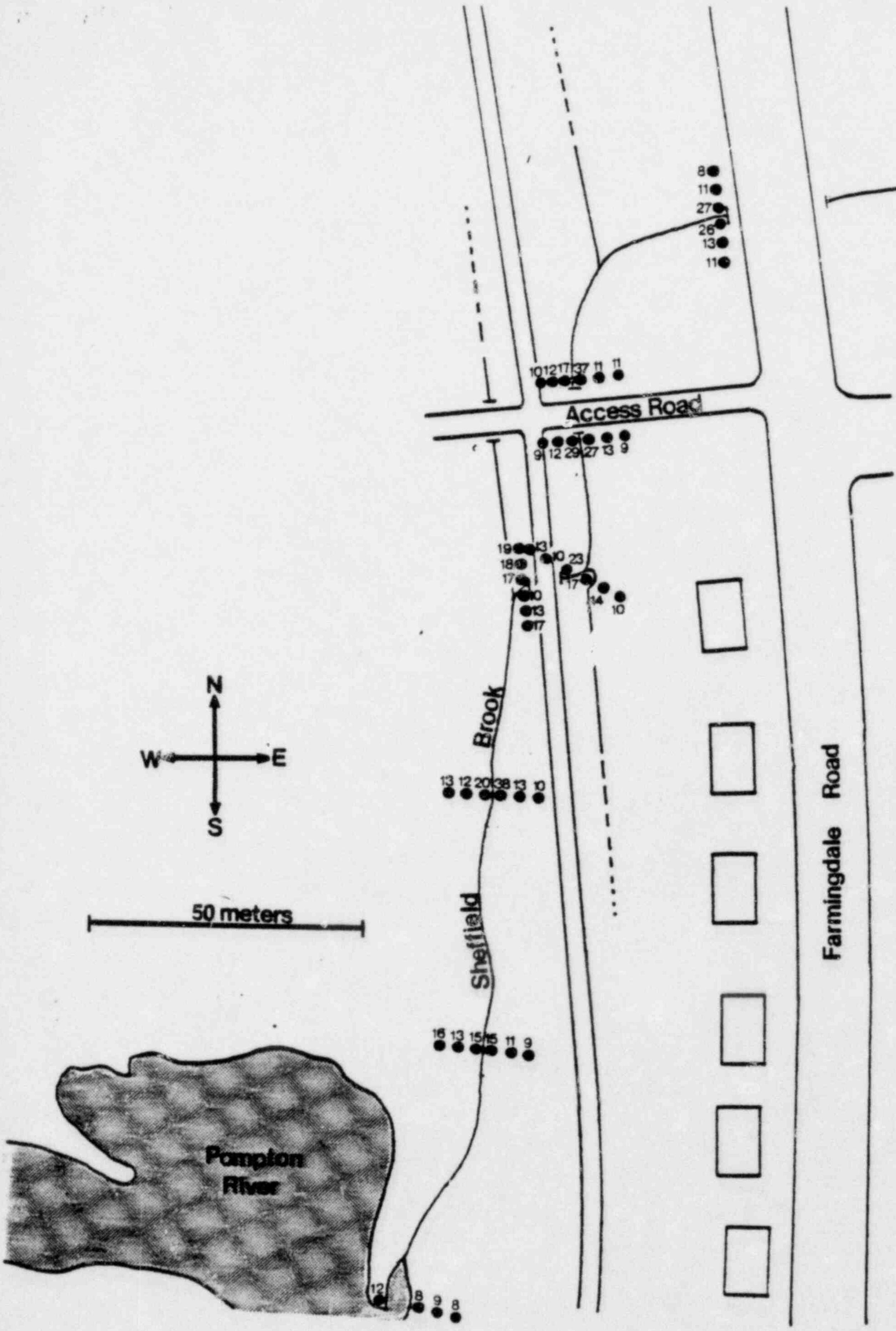

FIGURE 13. Exposure Rates ($\mu R/h$) at 1 m Above the Surface Along Sheffield Brook, West of Farmingdale Road.

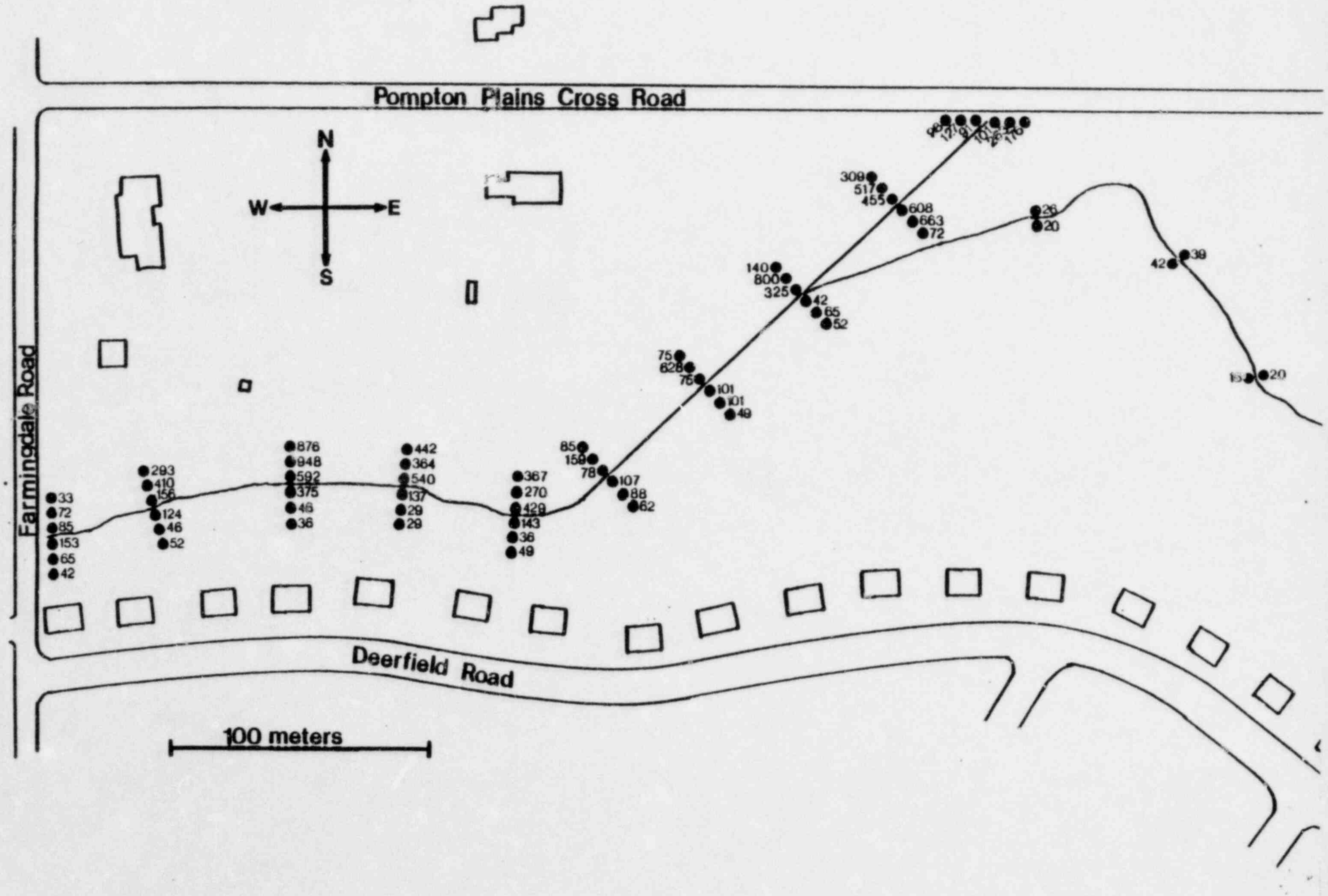

FIGURE 14. Surface Beta-Gamma Dose Rates (μrad/h) Along Sheffield Brook, East of Farmingdale Road.

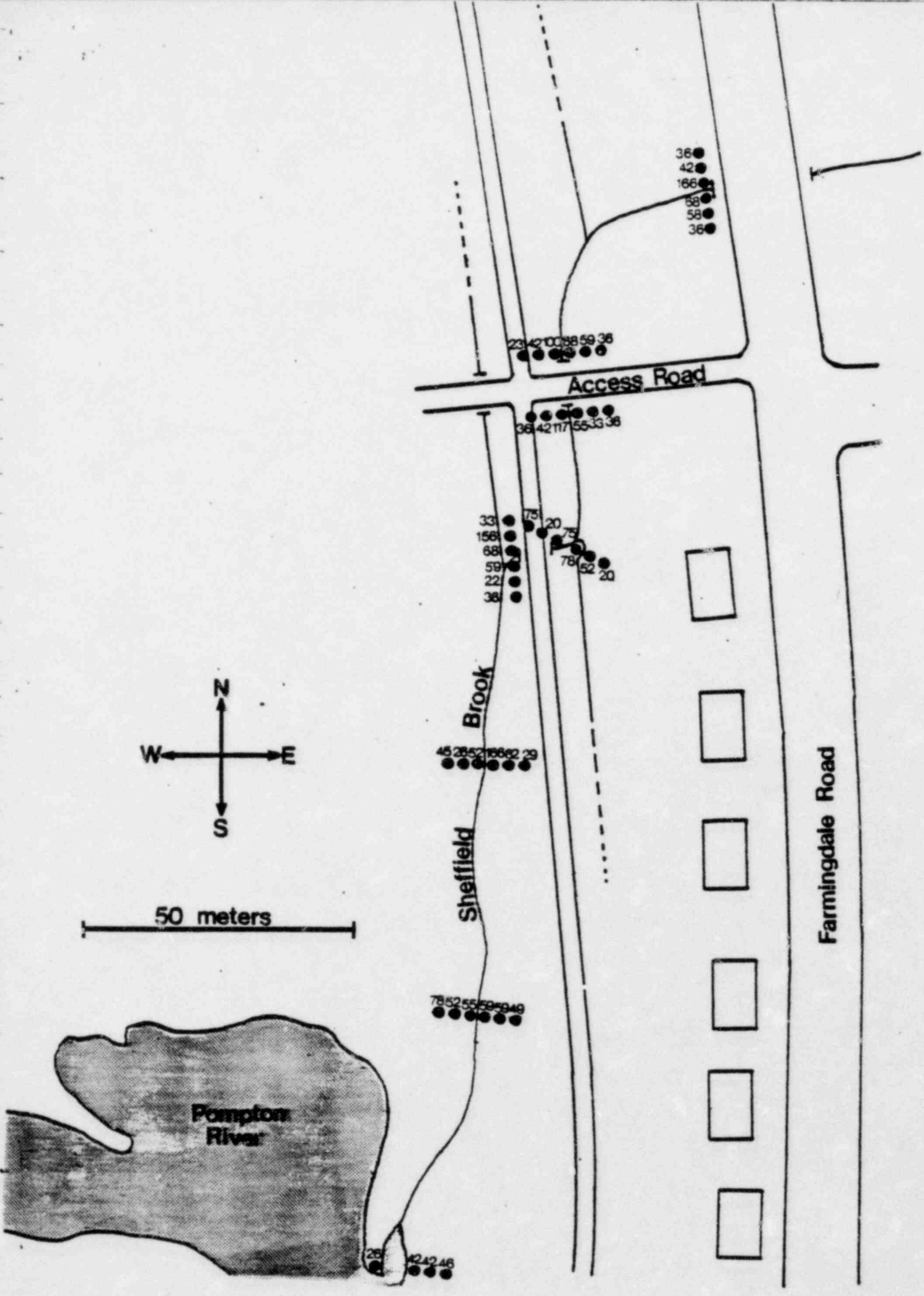

FIGURE 15. Surface Beta-Gamma Dose Rates (μrad/h) Along Sheffield Brook, West of Farmingdale Road.

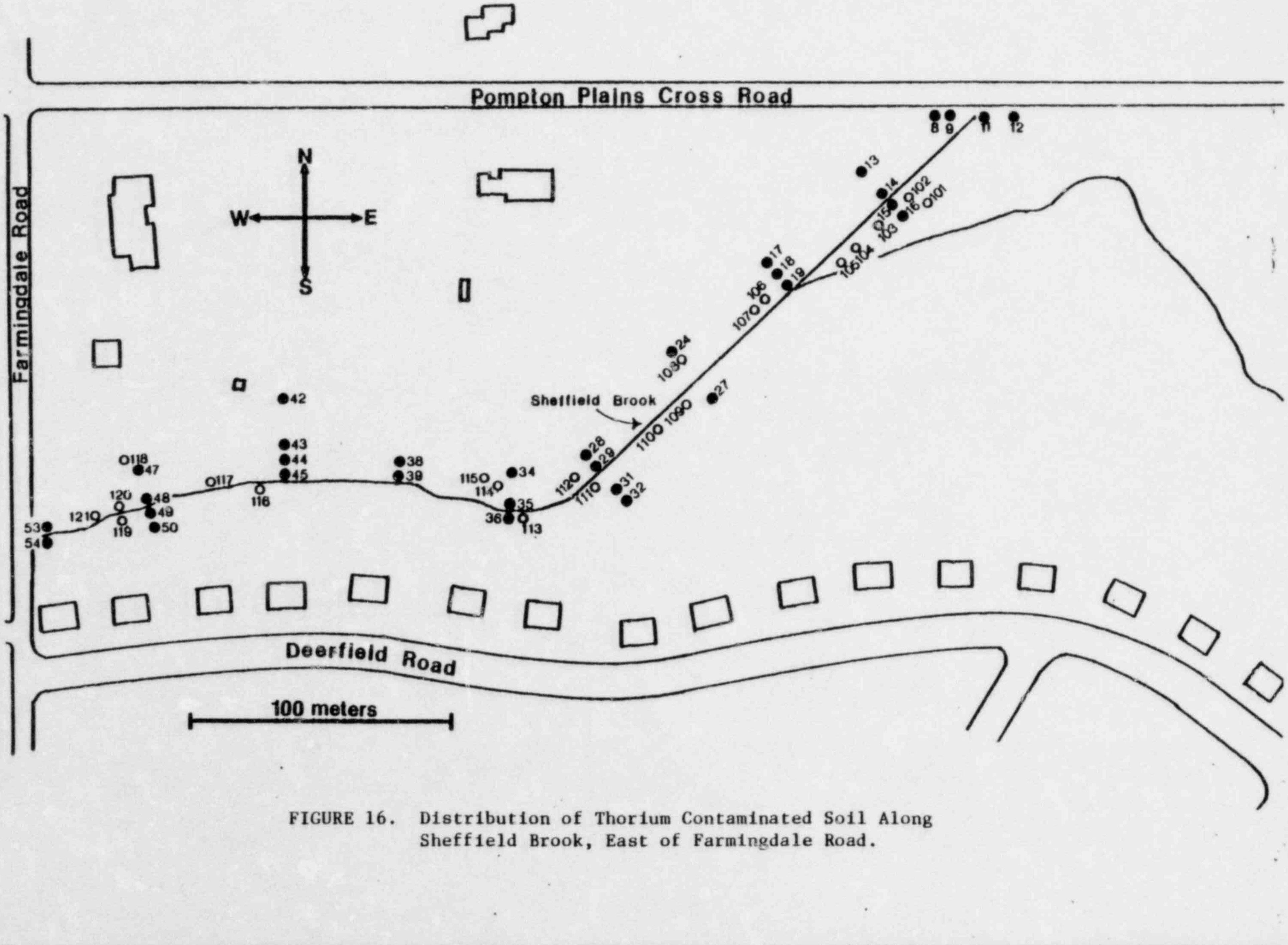

FIGURE 16. Distribution of Thorium Contaminated Soil Along Sheffield Brook, East of Farmingdale Road.

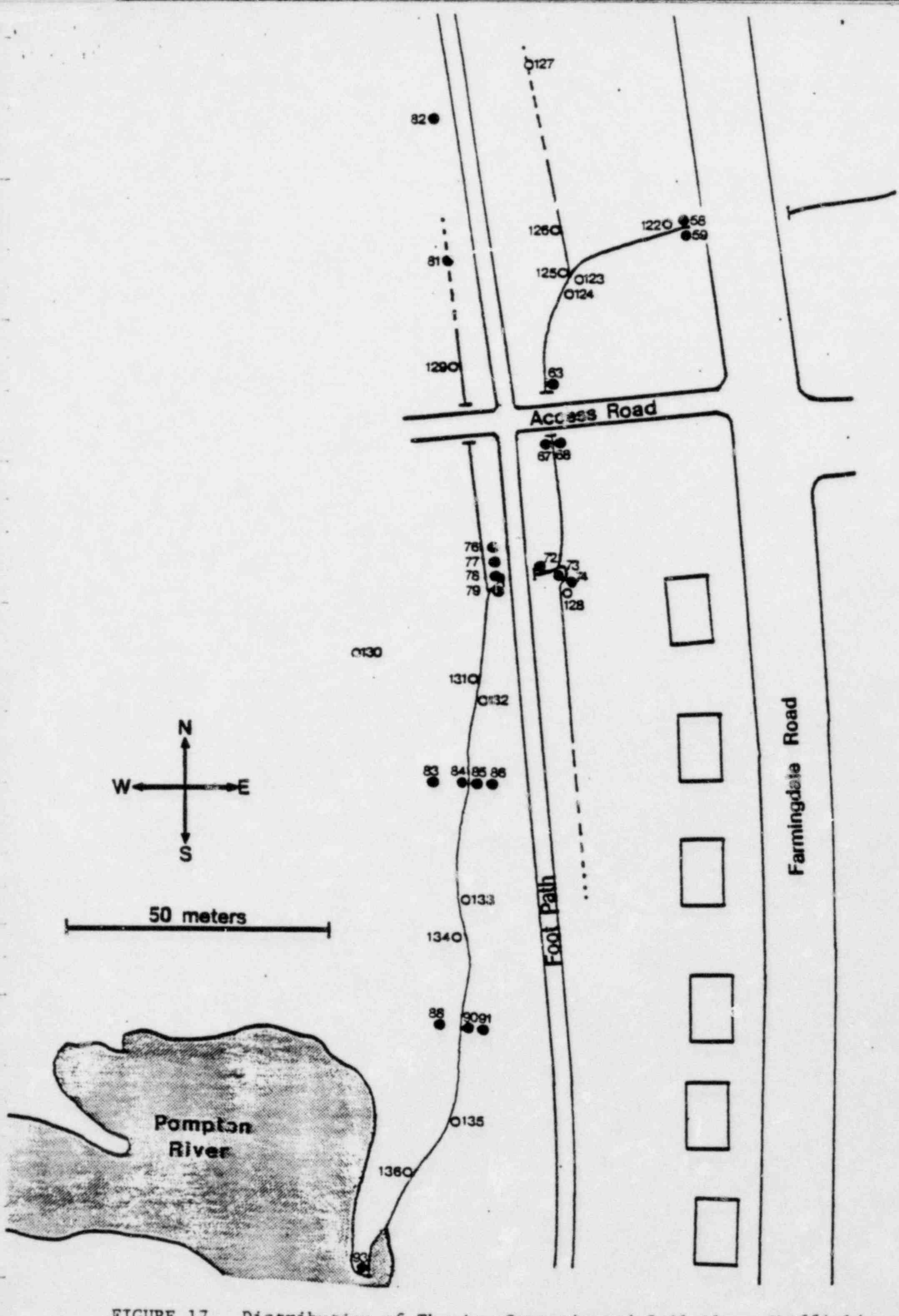

FIGURE 17. Distribution of Thorium Contaminated Soil Along Sheffield Brook, West of Farmingdale Road.

TABLE 1

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL, VEGETATION, AND WATER SAMPLES

Sample Location	Depth (cm)	Radionuclide Concentrations (pCi/g)*		
		Ra-228[b]	Th-228	Ra-226
Soil[a]				
B1 - P.V. Park	Surface	0.51 ± 0.23[c]	0.58 ± 0.27	0.47 ± 0.15
	30	0.72 ± 0.22	0.80 ± 0.21	0.47 ± 0.22
	60	0.69 ± 0.21	0.69 ± 0.21	0.49 ± 0.13
	90	0.45 ± 0.33	0.54 ± 0.17	0.50 ± 0.16
B2 - McDonald Park	Surface	0.69 ± 0.25	0.56 ± 0.23	0.45 ± 0.17
	30	1.00 ± 0.25	0.71 ± 0.30	0.58 ± 0.20
	60	0.56 ± 0.23	0.59 ± 0.18	0.37 ± 0.12
	90	0.72 ± 0.24	0.66 ± 0.21	0.40 ± 0.19
B3 - Orth Ave.	Surface	1.36 ± 0.33	1.60 ± 0.31	1.13 ± 0.26
	30	1.17 ± 0.23	1.39 ± 0.19	1.34 ± 0.17
	60	1.18 ± 0.24	1.31 ± 0.19	1.11 ± 0.17
B4 - Farmingdale Rd.	Surface	0.92 ± 0.32	1.00 ± 0.26	1.12 ± 0.25
	30	1.00 ± 0.29	1.21 ± 0.28	1.05 ± 0.21
B5 - Black Oak Ridge Rd.	Surface	0.85 ± 0.30	0.70 ± 0.21	0.85 ± 0.20
	30	0.91 ± 0.29	0.73 ± 0.22	0.65 ± 0.18
Range		0.45 to 1.36	0.54 to 1.60	0.37 to 1.34
Vegetation[d]				
2		0.17 ± 0.23	0.28 ± 0.18	0.36 ± 0.15

TABLE 1 (cont.)

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL, VEGETATION, AND WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations in Water (pCi/l or $x10^{-9}$ μCi/ml)
	Gross Alpha
B1 - P.V. Park	0.95 ± 1.20
B2 - McDonald Park	<2.28
B6 - City Water	<1.56

[a] Refer to Figure 9.
[b] Assumed to be in equilibuium with Th-232.
[c] Error is 2σ based on counting statistics only.
[d] Refer to Figure 5.
* Other analyses not yet completed.

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location[a]	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)[a]		
			Ra-228[b]	Th-228	Ra-226
1	0 (edge)	surface	0.84 ± 0.29[c]	0.85 ± 0.22	0.56 ± 0.17
2	0	surface	0.65 ± 0.29	0.57 ± 0.18	0.45 ± 0.15
		30	0.77 ± 0.24	0.72 ± 0.18	0.63 ± 0.16
		60	0.74 ± 0.23	0.87 ± 0.20	0.66 ± 0.18
3	0	surface	1.01 ± 0.42	0.96 ± 0.36	0.84 ± 0.30
		30	1.09 ± 0.40	1.17 ± 0.41	1.07 ± 0.28
		60	0.87 ± 0.45	0.92 ± 0.33	0.75 ± 0.27
		90	0.71 ± 0.31	0.75 ± 0.29	0.93 ± 0.23
4	0	surface	0.79 ± 0.42	0.87 ± 0.33	0.64 ± 0.27
5	0	surface	0.69 ± 0.23	0.93 ± 0.24	0.62 ± 0.17
6	0	surface	0.86 ± 0.27	0.80 ± 0.26	0.57 ± 0.23
7	0	surface	1.05 ± 0.50	1.00 ± 0.35	0.81 ± 0.28
8	10	surface	30.8 ± 1.2	30.5 ± 1.1	2.41 ± 0.51
9	5	surface	18.4 ± 0.9	17.4 ± 0.8	1.47 ± 0.44
10	0	surface	1.74 ± 0.32	2.18 ± 0.29	0.87 ± 0.22
11	0	surface	10.7 ± 0.7	9.9 ± 0.6	1.05 ± 0.35
12	10	surface	9.80 ± 1.16	9.67 ± 1.03	1.83 ± 0.57
		30	19.5 ± 0.9	18.0 ± 0.8	2.11 ± 0.39
		60	5.16 ± 0.59	4.40 ± 0.43	0.75 ± 0.25
		90	2.14 ± 0.42	2.05 ± 0.31	0.94 ± 0.22
13	10	surface	52.6 ± 1.5	51.5 ± 1.3	4.92 ± 0.68
14	0	surface	71.4 ± 1.7	69.9 ± 1.6	5.34 ± 0.72
15	0	surface	132 ± 2	132 ± 2	11.4 ± 1.1
16	5	surface	116 ± 2	113 ± 2	7.49 ± 0.94
17	10	surface	29.6 ± 1.9	26.9 ± 1.5	1.42 ± 0.68
		30	12.4 ± 0.9	12.2 ± 0.7	1.43 ± 0.34
		60	3.68 ± 0.48	3.51 ± 0.39	1.08 ± 0.30
		90	3.06 ± 0.47	2.62 ± 0.37	0.81 ± 0.22

TABLE 2 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclie Concentrations (pCi/g)		
			Ra-228	Th-228	Ra-226
18	5	surface	153 ± 3	144 ± 3	8.25 ± 1.12
19	0	surface	89.0 ± 2.0	83.1 ± 1.9	5.00 ± 0.90
20	0	surface	4.78 ± 0.53	4.77 ± 0.48	0.81 ± 0.32
21	10	surface	0.84 ± 0.36	0.65 ± 0.24	0.53 ± 0.20
22	50	surface	1.05 ± 0.39	1.47 + 0.47	1.36 ± 0.28
23	100	surface	1.24 ± 0.44	1.36 ± 0.38	0.81 ± 0.32
24	10	surface	5.49 ± 0.57	5.82 ± 0.55	0.59 ± 0.30
25	0	surface	1.64 ± 0.34	2.18 ± 0.31	0.55 ± 0.18
26	0	surface	3.38 ± 0.55	3.69 ± 0.44	0.77 ± 0.25
27	5	surface	13.9 ± 1.1	13.6 ± 1.0	1.74 ± 0.49
28	5	surface	18.7 ± 1.2	18.9 ± 0.9	1.89 ± 0.41
29	0	surface	12.7 ± 0.8	13.2 ± 0.7	1.38 ± 0.36
30	0	surface	4.45 ± 0.53	5.00 ± 0.52	0.78 ± 0.27
31	5	surface	8.94 ± 0.99	8.91 ± 0.92	1.58 ± 0.46
		30	6.76 ± 0.67	5.93 ± 0.59	1.94 ± 0.33
		60	1.29 ± 0.40	1.21 ± 0.25	0.69 ± 0.19
		90	1.53 ± 1.21	1.33 ± 0.29	0.69 ± 0.18
32	10	surface	6.99 ± 1.06	6.95 ± 0.74	1.10 ± 0.40
33	50	surface	4.86 ± 1.18	3.98 ± 1.17	1.23 ± 0.58
		30	0.97 ± 6.39	1.18 ± 0.29	0.94 ± 0.23
		60	1.07 ± 0.29	1.06 ± 0.24	0.85 ± 0.17
		90	0.91 ± 0.25	0.93 ± 0.22	0.76 ± 0.18
34	10	surface	36.9 ± 1.2	32.4 ± 1.2	1.92 ± 0.55
35	0	surface	40.2 ± 1.5	34.4 ± 1.2	2.67 ± 0.60
36	0	surface	18.6 ± 1.1	16.5 ± 0.9	1.29 ± 0.44

TABLE 2 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)		
			Ra-228	Th-228	Ra-226
37	5	surface	1.50 ± 0.41	1.48 ± 0.36	1.00 ± 0.21
38	5	surface	34.4 ± 1.8	27.7 ± 1.3	1.68 ± 0.58
		30	102 ± 2	88.4 ± 2.0	6.38 ± 0.96
		60	17.8 ± 1.1	15.8 ± 0.9	1.83 ± 0.40
		90	5.79 ± 0.88	7.98 ± 0.75	0.64 ± 0.38
39	0	surface	20.8 ± 1.3	19.4 ± 1.0	1.49 ± 0.52
40	0	surface	2.31 ± 0.44	2.43 ± 0.38	0.74 ± 0.22
41	10	surface	1.31 ± 0.30	1.09 ± 0.30	0.94 ± 0.22
42	30	surface	29.5 ± 1.6	29.8 ± 1.4	2.18 ± 0.66
		30	1.22 ± 0.35	1.25 ± 0.27	0.72 ± 0.18
		60	1.03 ± 0.24	0.98 ± 0.22	0.61 ± 0.19
		90	0.79 ± 0.24	0.79 ± 0.18	0.69 ± 0.16
43	10	surface	84.3 ± 2.7	71.7 ± 2.2	2.79 ± 0.90
		30	17.8 ± 1.0	16.1 ± 0.9	1.27 ± 0.42
		60	7.06 ± 0.65	13.6 ± 0.6	0.92 ± 0.28
		90	6.29 ± 0.58	5.49 ± 0.50	0.82 ± 0.25
44	5	surface	573 ± 7	472 ± 5	7.87 ± 2.42
45	0	surface	18.8 ± 1.1	16.7 ± 0.9	1.38 ± 0.47
46	5	surface	1.41 ± 0.33	1.31 ± 0.30	0.86 ± 0.18
47	10	surface	143 ± 3	87.3 ± 2.6	3.40 ± 1.14
48	0	surface	24.8 ± 1.4	23.2 ± 2.4	1.71 ± 0.49
49	0	surface	21.8 ± 1.2	16.5 ± 0.9	1.37 ± 0.48
50	5	surface	5.23 ± 0.56	5.73 ± 0.51	0.95 ± 0.26
51	10	surface	1.04 ± 0.30	1.18 ± 0.26	0.61 ± 0.21
		30	1.05 ± 0.30	1.19 ± 0.26	0.67 ± 0.17
		60	0.90 ± 0.27	0.93 ± 0.24	0.58 ± 0.16
		90	1.47 ± 0.33	1.02 ± 0.25	0.61 ± 0.17
52	5	surface	1.00 ± 0.28	1.16 ± 0.28	0.62 ± 0.19

TABLE 2 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)		
			Ra-228	Th-228	Ra-226
53	0	surface	27.5 ± 1.5	27.4 ± 1.2	2.24 ± 0.52
54	0	surface	30.5 ± 1.5	28.9 ± 1.2	1.62 ± 0.52
55	10	surface	0.93 ± 0.34	0.87 ± 0.32	0.69 ± 0.23
56	10	surface	0.77 ± 0.39	0.96 ± 0.26	0.68 ± 0.24
57	5	surface	0.78 ± 0.21	0.93 ± 0.26	0.70 ± 0.19
		30	1.01 ± 0.28	1.09 ± 0.28	0.67 ± 0.16
		60	0.62 ± 0.25	0.70 ± 0.25	0.65 ± 0.16
		90	1.01 ± 0.30	0.90 ± 0.20	0.56 ± 0.15
58	0	surface	50.1 ± 2.2	48.2 ± 1.8	2.56 ± 0.73
59	0	surface	26.2 ± 1.5	24.3 ± 1.3	1.69 ± 0.60
60	5	surface	1.51 ± 0.37	1.70 ± 0.31	0.87 ± 0.22
61	5	surface	0.86 ± 0.42	1.03 ± 0.27	1.40 ± 0.60
62	0	surface	3.16 ± 0.43	3.01 ± 0.41	0.66 ± 0.29
63	0	surface	45.9 ± 2.1	44.5 ± 1.4	2.60 ± 0.65
64	10	surface	0.97 ± 0.39	0.93 ± 0.25	0.76 ± 0.20
65	10	surface	0.79 ± 0.49	1.04 ± 0.38	0.76 ± 0.24
		30	0.98 ± 0.29	0.92 ± 0.21	0.11 ± 0.14
		60	0.84 ± 0.33	0.99 ± 0.26	0.57 ± 0.25
		90	1.02 ± 0.30	0.94 ± 0.22	0.67 ± 0.17
66	5	surface	0.94 ± 0.29	1.03 ± 0.29	0.74 ± 0.16
67	0	surface	56.0 ± 2.3	43.1 ± 1.8	2.42 ± 0.80
68	0	surface	44.2 ± 2.1	33.1 ± 0.8	2.53 ± 0.74
69	5	surface	0.88 ± 0.40	1.06 ± 0.23	0.64 ± 0.18
70	10	surface	1.20 ± 0.35	0.98 ± 0.28	0.95 ± 0.21
71	5	surface	1.03 ± 0.43	2.56 ± 0.23	0.15 ± 0.19

TABLE 2 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)		
			Ra-228	Th-228	Ra-226
72	0	surface	20.2 ± 1.0	2.27 ± 0.90	1.39 ± 0.48
73	0	surface	18.4 ± 1.3	15.6 ± 1.1	1.20 ± 0.53
74	5	surface	7.23 ± 0.83	5.85 ± 1.21	0.47 ± 0.35
75	10	surface	1.44 ± 0.30	1.59 ± 0.67	0.87 ± 0.48
76	10	surface	150 ± 3	133 ± 3	7.91 ± 1.31
		30	66.2 ± 1.9	58.5 ± 1.6	3.72 ± 0.74
		60	13.5 ± 0.8	13.9 ± 0.66	1.45 ± 0.33
		90	8.17 ± 0.67	8.14 ± 0.60	1.19 ± 0.34
77	5	surface	38.6 ± 1.7	34.7 ± 1.3	2.85 ± 0.64
78	0	surface	12.5 ± 0.9	10.4 ± 0.7	1.22 ± 0.33
79	0	surface	7.01 ± 0.63	5.61 ± 0.57	0.89 ± 0.28
80	5	surface	1.36 ± 0.31	1.35 ± 0.24	0.65 ± 0.18
81	0	surface	5.10 ± 0.74	4.75 ± 0.64	1.01 ± 0.38
82	0	surface	9.96 ± 0.92	10.3 ± 0.8	1.13 ± 0.39
83	10	surface	5.55 ± 0.67	5.75 ± 0.64	0.83 ± 0.34
84	0	surface	6.43 ± 0.67	6.32 ± 0.61	1.23 ± 0.31
85	0	surface	30.6 ± 1.5	31.5 ± 1.4	2.32 ± 0.69
86	5	surface	7.01 ± 0.74	6.68 ± 0.33	1.09 ± 0.34
87	10	surface	1.12 ± 0.51	1.06 ± 0.27	0.88 ± 0.23
		30	1.59 ± 0.39	1.63 ± 0.29	0.89 ± 0.22
		60	0.85 ± 0.24	0.92 ± 0.23	0.57 ± 0.14
		90	0.34 ± 0.20	0.46 ± 0.16	0.51 ± 0.14
88	5	surface	8.57 ± 0.93	7.38 ± 0.71	1.09 ± 0.41
89	0	surface	1.85 ± 0.52	1.47 ± 0.38	1.01 ± 0.25

TABLE 2 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SYSTEMATIC SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)		
			Ra-228	Th-228	Ra-226
90	0	surface	10.6 ± 1.0	10.3 ± 0.8	1.07 ± 0.45
91	5	surface	7.33 ± 0.63	7.57 ± 0.66	1.41 ± 0.38
92	10	surface	4.33 ± 0.67	3.74 ± 0.58	0.83 ± 0.31
93	0	surface	7.61 ± 0.43	6.52 ± 0.65	0.92 ± 0.31
94	0	surface	2.20 ± 0.54	1.74 ± 0.37	1.09 ± 0.26
95	5	surface	3.55 ± 0.66	3.85 ± 0.51	0.76 ± 0.27
96	20	surface	2.76 ± 0.40	2.68 ± 0.33	0.62 ± 0.22
97	0	surface	0.56 ± 0.37	4.36 ± 0.38	0.59 ± 0.21
98	0	surface	0.60 ± 0.34	0.66 + 0.20	0.54 ± 0.16
99	0	surface	1.04 ± 0.36	1.09 ± 0.26	0.72 ± 0.11
100	0	surface	0.71 ± 0.30	0.97 ± 0.24	0.83 ± 0.19

[a] Refer to Figures 3, 4, and 5.

[b] Assumed to be in equilibrium with Th-232.

[c] Error is 2σ based on counting statistics.

* Other analyses not yet completed.

TABLE 3

RADIONUCLIDE CONCENTRATIONS IN BIASED SOIL SAMPLES

Location[a]	Depth (cm)	Radionuclide Concentrations (pCi/g)[a]		
		Ra-228[b]	Th-228	Ra-226
101	Surface	91.4 ± 3.2[c]	86.5 ± 2.6	3.38 ± 1.10
	30	182 ± 4	163 ± 4	9.61 ± 1.63
	60	44 ± 2	41.9 ± 1.9	3.43 ± 0.88
	90	31.2 ± 1.8	27.8 ± 1.5	1.81 ± 0.78
102	Surface	32.4 ± 1.6	32.3 ± 1.4	2.19 ± 0.63
	30	50.2 ± 2.2	44.1 ± 1.8	2.59 ± 0.88
	60	41.2 ± 1.9	41.8 ± 1.6	3.04 ± 0.72
	90	51.3 ± 2.1	50.8 ± 1.9	2.73 ± 0.82
103	Surface	275 ± 6	201 ± 4	13.6 ± 2.3
	30	102 ± 3	98.6 ± 2.9	7.16 ± 1.40
	60	87.8 ± 2.9	64.0 ± 2.2	4.08 ± 1.00
	90	30.9 ± 1.9	29.4 ± 1.6	2.29 ± 0.78
104	Surface	191 ± 5	187 ± 5	9.95 ± 2.18
105	Surface	734 ± 8	722 ± 8	46.8 ± 3.8
106	Surface	235 ± 6	227 + 5	12.6 ± 2.3
107	Surface	307 ± 7	287 ± 6	11.9 ± 2.6
	30	37.9 ± 2.4	35.5 ± 1.8	3.26 ± 0.83
	60	28.9 ± 18.1	28.0 ± 1.5	2.06 ± 0.78
	90	9.93 ± 0.94	10.0 ± 0.7	1.47 ± 0.32
108	Surface	507 ± 8	479 ± 7	28.1 ± 3.4
109	Surface	9.11 ± 1.59	8.34 ± 1.02	1.21 ± 0.58
110	Surface	19.4 ± 1.5	16.9 ± 1.3	1.58 ± 0.64
	30	75.5 ± 4.0	60.4 ± 3.1	5.07 ± 1.52
	60	76.4 ± 3.3	62.6 ± 2.9	3.17 ± 0.99
	90	6.06 ± 0.86	4.44 ± 0.76	0.71 ± 0.42
111	Surface	19.1 ± 2.3	18.0 ± 1.9	1.31 ± 0.94
112	Surface	345 ± 4	310 ± 4	20.9 ± 1.7
	15	247 ± 5	230 ± 5	24.0 ± 2.4
	30	273 ± 5	260 ± 5	18.3 ± 2.3
	60	289 ± 5	261 ± 5	24.0 ± 2.5
	90	151 ± 4	139 ± 3	10.9 ± 1.6

TABLE 3 (cont.)

RADIONUCLIDE CONCENTRATIONS IN BIASED SOIL SAMPLES

Location	Depth (cm)	Radionuclide Concentrations (pCi/g)*		
		Ra-228	Th-228	Ra-226
113	Surface	23.7 ± 1.7	21.7 ± 1.5	1.03 ± 0.65
	30	152 ± 3	144 ± 3	6.88 ± 1.14
	60	57.7 ± 1.6	53.0 ± 1.5	2.71 ± 0.67
	90	136 ± 2	130 ± 2	7.49 ± 1.06
114	Surface	163 ± 2	139 ± 1	3.08 ± 0.93
115	Surface	170 ± 2	152 ± 4	9.46 ± 1.82
	30	20.9 ± 0.9	19.0 ± 0.9	2.11 ± 0.41
	60	7.28 ± 7.60	5.87 ± 0.61	1.24 ± 0.39
116	Surface	163 ± 6	111 ± 5	2.59 ± 1.69
	30	13.3 ± 1.3	13.6 ± 1.1	1.13 ± 0.29
	60	10.2 ± 0.9	6.88 ± 0.13	1.24 ± 0.38
	90	2.97 ± 0.44	2.18 ± 0.39	0.62 ± 0.11
117	Surface	90.8 ± 3.8	79.6 ± 3.2	3.94 ± 0.70
	30	27.2 ± 1.9	24.7 ± 1.4	1.82 ± 0.64
	60	8.11 ± 0.69	6.58 ± 0.57	1.09 ± 0.35
	90	4.84 ± 0.49	4.00 ± 0.43	0.80 ± 2.40
118	Surface	172 ± 5	124 + 4	4.89 ± 1.80
	30	13.4 ± 0.8	10.5 ± 0.6	1.43 ± 0.35
	60	4.17 ± 0.54	3.32 ± 0.41	0.85 ± 0.26
	90	5.65 ± 0.73	5.05 ± 0.62	0.94 ± 0.35
119	Surface	56.1 ± 2.74	43.6 ± 2.0	2.33 + 0.88
120	Surface	45.6 ± 2.9	35.7 ± 2.2	2.66 ± 1.06
121	Surface	10.3 ± 0.8	10.4 ± 0.6	1.19 ± 0.34
122	Surface	57.1 ± 1.7	43.1 ± 1.6	1.92 ± 0.66
123	Surface	13.4 ± 0.8	10.5 ± 6.4	1.43 ± 0.35
124	Surface	31.3 ± 1.8	23.2 ± 1.4	2.23 ± 0.69
125	Surface	68.9 ± 3.0	51.1 ± 2.3	3.19 ± 1.06
126	Surface	126 ± 3	112 ± 2	3.97 ± 0.98
	30	24.8 ± 1.0	22.3 ± 1.1	2.25 ± 0.48
	60	120 ± 4	114 ± 4	3.50 ± 1.48
	90	8.08 ± 0.93	8.14 ± 0.67	1.25 ± 0.42

TABLE 3 (cont.)

RADIONUCLIDE CONCENTRATIONS IN BIASED SOIL SAMPLES

Location	Depth (cm)	Radionuclide Concentrations (pCi/g)		
		Ra-228	Th-228	Ra-226
127	Surface	30.7 ± 2.1	29.2 ± 1.7	2.13 ± 0.83
128	Surface	44.7 ± 2.1	40.9 ± 1.8	2.29 ± 0.82
129	Surface	26.2 ± 1.8	25.6 ± 1.7	1.62 ± 0.78
130	Surface	9.08 ± 0.72	5.56 ± 0.63	0.93 ± 0.27
	30	24.1 ± 1.9	21.8 ± 1.4	1.69 ± 0.69
	60	6.09 ± 0.59	5.58 ± 0.47	0.76 ± 0.32
	90	0.90 ± 0.26	0.75 ± 0.17	0.42 ± 0.16
131	Surface	105 ± 3	90.4 ± 3.1	6.05 ± 1.46
132	Surface	57.3 ± 3.3	50.8 ± 2.4	2.77 ± 1.00
133	Surface	17.9 ± 1.0	15.3 ± 0.8	1.07 ± 0.41
134	Surface	18.6 ± 1.2	17.1 ± 0.9	1.05 ± 0.46
	30	5.25 ± 0.50	4.65 ± 0.43	0.64 ± 0.23
	60	1.79 ± 0.32	1.67 ± 0.25	0.45 ± 0.16
	90	0.54 ± 0.24	0.72 ± 0.17	0.33 ± 0.15
135	Surface	126 ± 2	119 ± 2	4.41 ± 1.02
136	Surface	12.8 ± 1.0	10.3 ± 0.8	1.29 ± 0.39

[a] Refer to Figures 3 and 4.
[b] Assumed to be in equilibrium with Th-232.
[c] Errors are 2σ based on counting statistics only.
* Other analyses not yet completed.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES

Location[a]	Radionuclide Concentrations (pCi/g),		
	Ra-228[b]	Th-228	Ra-226
1	0.54 ± 0.36[c]	0.57 ± 0.12	0.48 ± 0.10
2	0.58 ± 0.25	0.71 ± 0.23	0.36 ± 0.16
3	0.78 ± 0.19	0.67 ± 0.20	0.50 ± 0.14
4	5.38 ± 0.68	4.57 ± 0.52	0.98 ± 0.27
5	5.56 ± 0.57	5.39 ± 0.46	0.95 ± 0.24
6	44.3 ± 2.1	42.7 ± 1.8	3.72 ± 0.90
7	26.7 ± 1.9	24.5 ± 1.6	2.86 ± 0.80
8	0.88 ± 0.26	0.75 ± 0.24	0.55 ± 0.14
9	0.51 ± 0.20	0.46 ± 0.17	0.41 ± 0.13
10	1.21 ± 0.29	0.97 ± 0.23	0.47 ± 0.14
11	1.97 ± 0.30	1.76 ± 0.27	0.69 ± 0.17
12	3.02 ± 0.41	2.80 ± 0.33	0.63 ± 0.21
13	4.60 ± 0.51	4.88 ± 0.37	0.59 ± 0.21
14	26.7 ± 1.6	23.3 ± 1.2	0.93 ± 0.53
15	7.07 ± 0.57	7.04 ± 0.48	0.90 ± 0.31
16	61.0 ± 1.4	53.9 ± 1.3	4.16 ± 0.61
17	4.44 ± 0.41	3.69 ± 0.34	0.58 ± 0.19
18	16.8 ± 1.0	16.4 ± 0.7	1.16 ± 0.34
19	4.56 ± 0.44	3.41 ± 0.35	0.58 ± 0.19
20	32.0 ± 1.31	25.1 ± 1.0	1.99 ± 0.49
21	6.06 ± 0.51	5.75 ± 0.43	0.76 ± 0.21
22	16.4 ± 0.9	17.6 ± 0.8	0.67 ± 0.41
23	9.13 ± 0.63	7.31 ± 0.49	0.70 ± 0.25
24	21.2 ± 1.1	19.5 ± 1.0	1.15 ± 0.43
25	15.5 ± 0.9	14.4 ± 0.8	1.08 ± 0.37
26	7.64 ± 0.58	7.56 ± 0.51	0.92 ± 0.25
27	8.26 ± 0.65	8.48 ± 0.54	0.68 ± 0.20
28	7.56 ± 0.58	7.71 ± 0.54	0.86 ± 0.25
29	5.60 ± 0.49	6.06 ± 0.45	0.68 ± 0.23
30	5.59 ± 0.59	5.69 ± 0.44	0.62 ± 0.24
31	17.5 ± 1.1	17.2 ± 0.89	1.17 ± 0.42
32	8.91 ± 0.68	9.83 ± 0.61	0.98 ± 0.38
33	6.14 ± 0.53	6.26 ± 0.49	0.84 ± 0.24
34	4.07 ± 0.50	3.56 ± 0.39	0.69 ± 0.19
35	3.10 ± 0.41	2.62 ± 0.30	0.51 ± 0.17
36	3.93 ± 0.44	3.47 ± 0.36	0.68 ± 0.20
37	6.18 ± 0.54	6.04 ± 0.48	0.63 ± 0.23
38	9.73 ± 0.77	8.78 ± 0.22	1.00 ± 0.32
39	3.58 ± 0.50	2.76 ± 0.47	0.93 ± 0.25
40	<0.13	0.44 ± 0.24	0.31 ± 0.19
41	0.55 ± 0.25	0.72 ± 0.20	0.55 ± 0.18
42	1.01 ± 0.28	1.03 ± 0.29	0.60 ± 0.23
43	0.92 ± 0.27	0.87 ± 0.20	0.82 ± 0.19

TABLE 4 (cont.)

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES

Location	Radionuclide Concentrations (pCi/g)		
	Ra-228	Th-228	Ra-226
44	1.23 ± 0.38	1.38 ± 0.28	0.48 ± 0.20
45	15.1 ± 0.80	14.9 ± 0.69	2.00 ± 0.38
46	7.92 ± 0.51	7.62 ± 0.45	1.50 ± 0.24
47	0.97 ± 0.25	1.02 ± 0.23	0.61 ± 0.18
48	0.57 ± 1.92	0.65 ± 0.16	0.48 ± 0.14
49	0.86 ± 0.24	0.83 ± 0.30	0.32 ± 0.17

[a] Refer to Figures 5, 6, 7, and 8.
[b] Assumed to be in equilibrium with Th-232.
[c] Error is 2σ based on counting statistics only.
* Other analyses not yet completed.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/l or x 10^{-9} μCi/ml) Gross Alpha*
1 Sheffield Brook	<2.7
2 Sheffield Brook	6.5 ± 1.7[b]
3 Sheffield Brook	<2.2
4 Pompton River - 500 m upstream	1.1 ± 1.4
5 Pompton River - 100 m upstream	<0.7
6 Pompton River - 100 m downstream	39 ± 9
7 Pompton River - 500 m downstream	0.8 ± 1.1
8 Storm Sewer	29 ± 4
9 Storm Sewer	19 ± 8
10 Storm Sewer	12 ± 6
11 Storm Sewer	<2.8
12 Storm Sewer	1.6 ± 1.3
13 Storm Sewer	<2.3
14 Surface water - Farm	3.5 ± 4.0
15 Surface water - Farm	<2.3
16 Well water - Farm	<1.0
17 Well water - Farm	1.6 ± 1.4
18 Well water - Wendt Lane	<2.2

TABLE 5 (cont.)

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/l or x 10^{-9} $\mu Ci/ml$) Gross Alpha*
19 Well water - Wendt Lane	<2.2
20 Well water - Deerfield Road	6.8 ± 5.8
21 Well water - Farmingdale Road	12 ± 6

[a] Refer to Figures 5 and 8.
[b] Error is 2σ based on counting statistics only.
* Other analyses not yet completed.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN VEGETATION SAMPLES

Location[a]	Radionuclide Concentrations (pCi/g)*		
	Ra-228[b]	Th-228	Ra-226
1	2.04 ± 0.47[c]	0.99 ± 0.21	0.34 ± 0.15
2	0.17 ± 0.23	0.28 ± 0.18	0.36 ± 0.15
3	12.8 ± 0.41	10.1 ± 0.32	0.71 ± 0.16
4	6.96 ± 0.36	4.11 ± 0.24	0.44 ± 0.13
5	1.97 ± 0.19	1.83 ± 0.16	0.39 ± 0.10

[a] Refer to Figure 5.
[b] Assumed to be in equilibrium with Th-232.
[c] Error is 2σ based on counting statistics only.
* Other analyses not yet complete.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 20. Standards for Protection Against Radiation, U.S. Government Printing Office, regulations published prior to January, 1981.

2. T.S. Dahlstrom. An Aerial Radiological Survey of the W.R. Grace Property, Wayne Township, New Jersey. EG&G Survey Report, NRC-8113, November 1981.

3. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement. Report #99990001/81-21, January 1981.

4. Title 40, Code of Federal Regulations, Part 141. Interim Primary Drinking Water Regulations. Federal Register, July 1976.

APPENDIX A

MAJOR ANALYTICAL EQUIPMENT

APPENDIX A

Major Analytical Equipment

The display or description of a specific product is not be be construed as an endorsement of that product or its manufacturer by the authors or their employers.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter-Scaler
Model PRS-1
Compensated G-M Probe, Model HP-270
(Eberline Instrument, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
Scintillation Probe, Model 489-55
(Victoreen, Inc., Cleveland, OH)

Pressurized Ionization Chamber (PIC)
Model RSS-111
(Reuter-Stokes, Cleveland, OH)

B. Laboratory Analysis

Ge(Li) Detector
Model LGCC2220SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

Pulse Height Analyzer, ND680
Model 88-0629 with associated computer package
(Nuclear Data, Inc., Schaumburg, IL)

Alpha Spectroscopy System
Tracor Northern 1705
Pulcir PA-1 Alpha Module
(Pulcir, Inc., Oak Ridge, TN)

Low Background Alpha-Beta Counter
Model LB5100-2080
(Tennelec, Inc., Oak Ridge, TN)

APPENDIX B

ANALYTICAL PROCEDURES

APPENDIX B

Analytical Procedures

Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using an Eberline PRM-6 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. Count rates (cpm) were converted to exposure levels (μR/h) using a factor of 520 cpm = 1 μR/h. This factor was determined by comparing the response of the scintillation detector with that of a Reuter Stokes Model RSS-111 pressurized ionization chamber at several locations along Sheffield Brook.

Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal" Model PRS-1 portable ratemeters with Model HP-270 energy compensated G-M probes. Dose rates (μrad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a composite of soil samples from the site. The conversion factor determined was 0.63 cpm = 1 μrad/h.

Soil and Sediment Sample Analysis

Soil samples were dried at 120° C, finely ground, mixed, and a portion placed in a one-liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and typically ranged from 500 to 800 g of soil. Net soil weights were determined and the samples counted using a 23% Ge(Li) detector (Princeton Gamma Tech) coupled to a Nuclear Data model ND-680 pulse height analyzer. The following energy peaks were used for determination of the radionuclides of concern:

Ra-228 - 0.911 MeV from Ac-228

Th-228 - 0.583 MeV from Tl-208

Ra-226 - 0.609 MeV from Bi-214

*U-235 - 0.143 MeV

*U-238 - 1.001 MeV from Pa-234m

Peak identification and concentration calculations were provided by computer analyses.

Several randomly selected samples were analyzed for isotopic thorium by alpha spectroscopy. These analyses indicated equal concentrations of Th-232 and Th-228, confirming that the entire thorium series is in equlibrium in the off-site residues.

Water Samples

Water samples were rough filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by a filtration through 0.45 μm pore size membrane filters. The filters, together with attached solids, were discarded; the filtrate was acidified by the addition of 20 ml of concentrated nitric acid.

Gross Alpha Analysis

Fifty milliliters of each sample was evaporated to dryness and counted on a Tennelec Model LB5100 low background proportional counter.

Gamma Spectrometry

Three and one half liters of each sample was placed in Marinelli beakers and analyzed by Ge(Li) gamma spectrometry using the same techniques as for soil samples.

Analysis not yet complete.

Radium-226/228 Analysis

Samples were analyzed for Ra-226 and 228 using the standard technique EPA 600/4-75-008 (Revised). (Procedures will be described in detail in the final report.)

*Polonium-210 and Lead-210

Radiochemical procedures were used for analysis of Po-210 and Pb-210. (Procedures will be described in detail in the final report.)

*Thorium and Uranium isotopic analysis

Alpha spectrometry analysis for Th-228, Th-232, U-234, U-235, and U-238 was performed by an outside analytical laboratory.

Vegetation Analysis

Gamma Spectrometry

Vegetation samples were air dried, chopped, and mixed. Aliquots were placed in 3.5 l Marinelli beakers and analyzed for identifiable photopeaks in the same manner described above for soil sample analysis.

Calibration and Quality Assurance

Laboratory analytical instruments are calibrated using NBS - traceable standards. Portable survey instruments for exposure rate and dose rate measurements are calibrated by comparison of their responses to those of other instruments having NBS - traceable calibration. Field comparisons or comparisons using samples typical of the area are used to develop these calibrations. Quality control procedures on all instruments included daily background and check-source measurements to confirm lack of malfunctions and nonstatistical deviations in equipment. The ORAU Laboratory participates in the EPA Quality Assurance Program.

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* *Analyses not yet complete.*

APPENDIX C

NRC GUIDELINES FOR CONCENTRATIONS OF THORIUM AND URANIUM IN SOIL

APPENDIX C

NRC Guidelines for Concentrations of Thorium and Uranium in Soil

On October 23, 1981, the Nuclear Regulatory Commission published in the Federal Register a notice of Branch Technical Position "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations." This document establishes guidelines for concentrations of uranium and thorium in soil, that will limit maximum radiation received by the public under various conditons of land usage. These concentrations are as follows:

Material	Maximum Concentrations (pCi/g) for various options*			
	1[a]	2[b]	3[c]	4[d]
Natural Thorium (Th-232 & Th-228) with daughters present and in equilibrium	10	50	—	500
Natural Uranium (U-238 & U-234) with daughters present and in equilibrium	10	—	40	200
Depleted Uranium:				
Soluble	35	100	—	1,000
Insoluble	35	300	—	3,000
Enriched Uranium:				
Soluble	30	100	—	1,000
Insoluble	30	250	—	2,500

[a] Based on EPA cleanup standards which limit radiation to 1 mrad/yr to lung and 3 mrad/yr to bone from ingestion and inhalation and 10 μR/h above background from direct external exposure.

[b] Based on limiting individual doses to 170 mrem/yr.

[c] Based on limiting equivalent exposure to 0.02 working level or less.

[d] Based on limiting individual doses to 500 mrem/yr and in case of natural uranium, limiting exposure to 0.02 working level or less.

Option 1 concentrations permit unrestricted use of the property and is the guideline applicable to surface soils in all areas. Options 2, 3, and 4 apply to buried wastes and assume possible intrusions into the burial sites. The presence of wastes at these concentrations may require restrictions on property use. Regardless of the concentrations in the buried materials, surface soil must meet the Option 1 concentration guidelines.

For the Sheffield Brook area the soils must therefore meet the radionuclide guidelines of 10 pCi/g of natural thorium plus natural uranium.