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

U.S. Nuclear
Regulatory
Commission

RADIOLOGICAL SURVEY

OF

SHEFFIELD BROOK

WAYNE, NEW JERSEY

P. W. FRAME

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

FINAL REPORT

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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 acquired by the Davison Chemical Division of W.R. Grace and Co. in 1957; thorium ore processing activities continued until July 1971 when the plant was permanently closed. In 1974, Applied Health Physics Inc. decontaminated the buildings and the property was released by the Nuclear Regulatory Commission (NRC) for unrestricted use in January 1975. The buildings are currently under lease to, and occupied by, Electro-Nucleonics, Inc.

Solid wastes containing low (less than approximately 5%) concentrations of thorium were disposed of by on-site shallow land burial. These wastes included thorium-containing residues and slightly contaminated debris. Detailed records of quantities and compositions of waste and their exact burial locations were destroyed in a fire at the facility May 1977. Potentially contaminated liquid wastes were discharged into a small drainage stream 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. The State of New Jersey was represented at this survey and requested, through the U.S. Environmental Protection Agency, an aerial radiological survey of the site. In May 1981, the aerial survey was conducted by EG & G. This aerial survey identified elevated radiation levels

on the W.R. Grace site and west of the site, along Sheffield Brook.[1] The NRC performed confirmatory measurements along the brook in November 1981 and noted radiation levels up to 200 μR/h and elevated concentrations of thorium in bank soil and stream sediment.[2]

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. Supplemental measurements and sampling were performed during the period of August 8-15, 1982. This report presents the findings of those surveys.

A glossary of technical and nuclear terms and schematic representations of the naturally-occurring thorium and uranium radioactive decay series have been provided in Appendices A and B, respectively, to aid the reader in interpreting this report.

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 on the west bank of the Pompton River and the W.R. Grace property and Wayne are located east of the river. The site occupies approximately 2.6 hectares most of which is 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 and heavy brush and weeds grow along a small drainage stream. The land generally slopes toward the west and northwest.

Figure 2 shows the location of Sheffield Brook and associated drainage streams. A small drainage stream enters the W.R. Grace

site near its southeast corner. This stream flows north, then west, and prior to leaving the property, enters a conduit. This conduit carries the water into a tank where it is mixed with the overflow from an on-site artesian well. The water then flows under the company's north parking lot to Black Oak Ridge Road where it combines with two storm sewer lines. It resurfaces approximately 150 m west of Black Oak Ridge Road, along the southern edge of Pompton Plains Cross Road. From this point, it flows southwesterly in a straight channel for approximately 100 m. There it joins with Sheffield Brook, another storm drainage stream originating about 100 m southwest of the W.R. Grace property. (Sheffield Brook was initially the overflow from Sheffield Pond, which was located just north of the brook's present origin. This pond was filled in approximately 10-20 years ago.)

The combined flow of Sheffield Brook and the W.R. Grace drainage stream continues in the straight ditch channel for another 100 m then turns west and continues in that direction until it passes under Farmingdale Road. 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.

East of Farmingdale Road, along the straight channel portion of the W.R. Grace drainage stream and Sheffield Brook, the land is relatively level. There are, however, small mounds of soil scattered along the banks in this area, apparently from periodic dredging of the ditch. Dense brush on both sides of the bank make access to this section of the stream and brook difficult. Beyond about 5 m from the ditch the land becomes open field containing scattered trees and tall grass. After the straight channel section, the brook flows from east to west and the bank on the south side of the brook becomes steeper, rising sharply for approximately 5 m. These banks are covered by brush and trees. North of the brook in this section the land is primarily low, soggy, open field, subject to periodic flooding. Along the portion of the brook west of Farmingdale Road the east bank is overgrown with brush and trees,

while the western bank is comparatively accessible from the park property. An aerial photograph of the Sheffield Brook area is provided as Figure 3.

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. Exposure rate measurements at 1 m above the surface for selected points along Sheffield Brook and associated streams.

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

3. Monitoring of gamma radiation levels at the surface along Sheffield Brook and associated streams.

4. Collection of surface soil and subsurface soil from along Sheffield Brook, associated streams, and adjacent properties.

5. Collection of sediment samples along Sheffield Brook, its associated streams, and from the storm sewer system between W.R. Grace and Sheffield Brook.

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

7. Collection of vegetation samples along the brook.

8. Sampling and measurements at off-site locations to provide baseline and background data for comparison.

Measurement of Direct Radiation

The brook was divided into 50 m intervals between the Pompton River and the juncture with the small drainage stream. Fifty meter intervals were also established along the drainage stream from the juncture to the point of emergence at Pompton Plains Cross Road. At each of these intervals, exposure rates at 1 m above the surface were systematically measured at the edges of the brook and at 5 and 10 m from the edges. Measurements were also taken where the brook entered or exited conduits. NaI(Tl) scintillation ratemeters, field-calibrated using a pressurized ionization chamber, were used to measure exposure rates.

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-penetrating radiations the measurements were made with the probes in both the open- and closed-shield configurations.

Three 50 m intervals were established along Sheffield Brook, upstream from its juncture with the drainage ditch from the W.R. Grace site. Exposure and dose rates were measured at 1 m and 1 cm, respectively, above the surface at these intervals along the stream bank.

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

Soil Sampling

At 50 m intervals along the W.R. Grace drainage stream and Sheffield Brook, surface (0-5 cm) soil samples were collected from both banks and at 5 or 10 m (alternating) from the water's edge. Sampling at these intervals was also extended to 100 m from the stream in the area east of Farmingdale Road. Surface samples were also collected from the banks at 50 m intervals along the upper section of Sheffield Brook and from one of the drainage streams west of Farmingdale Road. Subsurface (30 cm, 60 cm, and 90 cm) samples were collected at about 20% of these 50 m interval locations where surface samples were obtained. Additional subsurface and/or surface soil samples were collected at locations where direct measurements identified elevated radiation levels, and on other properties in the vicinity of the Sheffield Brook site. Soil sampling locations are indicated in Figures 4, 5, and 6.

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.

Sediment Sampling

Two sediment samples were collected at each of the 50 m intervals along Sheffield Brook and the W.R. Grace drainage stream. Samples were obtained using a garden trowel and traversing the bottom of the stream from its center toward the edge. Thus a sample was collected for each side of the stream at each interval. Sediment samples were collected at four locations in Sheffield Brook upstream of the

juncture with the W.R. Grace drainage ditch and at four locations in the Pompton River - two upstream and two downstream of the juncture with Sheffield Brook. Samples were also obtained at five locations in the storm sewer system servicing the W.R. Grace site. Locations of these sediment samples are indicated on figures 6, 7, 8, and 9.

Water Sampling

Surface water samples were collected from the drainage ditch on the W.R. Grace property and at four locations along Sheffield Brook. Samples were also collected from the Pompton River both 100 m and 500 m upstream and downstream of the juncture with Sheffield Brook. Samples of water were obtained from five locations in the storm drain system feeding Sheffield Brook. Two samples of surface water and seven well water samples were obtained from the vicinity of Sheffield Brook and from local residents.

Locations of these water samples are indicated on Figures 6 and 9.

Due to questionably high gross alpha and gross beta concentrations measured in sample 6 from 100 m downstream on the Pompton River, this location was resampled.

Vegetation Sampling

On the original visit to the site, April 26 - May 1, 1982, vegetation samples were collected at five locations in the vicinity of Sheffield Brook (see Figure 6). These samples were analyzed without prior washing. Additional samples were collected from four of these locations as well as three new locations during the second visit to the site, August 8-15. These samples were washed before analysis to remove any surface contamination.

Baseline and Background Measurements

Five soil samples, two water samples, and two vegetation samples were collected at locations 0.3 to 10 km from the W.R. Grace and Sheffield Brook sites. Direct background radiation levels were measured at the locations of the soil samples. Figure 10 indicates the locations of these baseline samples and background measurements.

Equipment and Analytical Procedures

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

RESULTS

Background Radiation and Baseline Concentrations

Background exposure rates in the Wayne-Pompton Plains, NJ, area ranged from 6-12 μR/h; surface beta-gamma dose rates ranged from 10 to 24 μrad/h.

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

Direct Radiation Levels

Exposure Rates at 1 Meter Above the Surface

Exposure rates measured systematically at 1 m above the ground at the edge of the stream/brook ranged from 8 μR/h to 170 μR/h, averaging 51 μR/h. At 5 m from the edge the exposure rates ranged from 9 μR/h to 270 μR/h, averaging 58 μR/h; at 10 m the range was from 8 μR/h to

250 µR/h, with an average value of 38 µR/h. Levels had decreased to approximately background at greater than 25 m from the stream/brook. These 1 m exposure rates are presented on Figures 11 and 12.

Beta-Gamma Surface Dose Rates

Surface beta-gamma dose rates ranged between 10 and 600 µrad/h (see Figures 13 and 14). Differences between the open- and closed-shield measurements were less than 20%, indicating a relatively small contribution from beta and low-energy photon radiations.

Surface Walkover Survey

Surface exposure rates measured during the walkover scan of Sheffield Brook and associated drainage streams ranged from 6 µR/h (background) to 420 µR/h. These exposure levels are presented graphically on Figures 15 and 16. Higher levels were noted in two general areas. One was a narrow strip, approximately 10 m wide and 150 m long, centered near the juncture of the drainage ditch with Sheffield Brook. This region of elevated radiation levels extended on either side of the straight channel portion of the drainage stream and brook for most of its length. Highest levels were mainly near small mounds of earth along the bank, believed to be material from dredging of the channel. Maximum contact radiation levels measured in this area were 420 µR/h and 365 µR/h, both associated with mounds of earth. The other generally elevated area was centered approximately 100 m east of Farmingdale Road on the north side of Sheffield Brook. This elevated region is approximately 150-200 m long and 20-40 m wide. It is in a flat low area, subject to flooding. The maximum surface level measured in this area was 405 µR/h.

Surface radiation levels were considerably lower along the portion of the brook west of Farmingdale Road. Only one area, immediately west of the footpath and about 15 m south of the park access road, had contact levels above 100 µR/h. The maximum level measured here was 270 µR/h at a small localized point. The slope of

the banks at this location is quite prominent, and it is therefore unlikely that the thorium contamination is attributable to direct deposition from the brook, even under flooding conditions.

Of the small drainage streams feeding Sheffield Brook, only the one north of the brook between Farmingdale Road and the footpath, had notably elevated exposure levels. The highest level along this stream, 120 μR/h, was noted in a small area approximately 5 m north of the brook.

Minor discrepancies between the surface exposure rate and dose rate levels are probably the result of slight differences in the distances of the detectors from the surface during measurements.

Radionuclide Concentrations in Soil Samples

Radionuclide concentrations in surface and subsurface soils collected along Sheffield Brook and the associated drainage streams are presented in Table 2. Elevated levels of radium-228 and thorium-228 are present in surface soil over the entire length of the W.R. Grace drainage stream and Sheffield Brook following its juncture with this drainage stream. Another drainage stream adjacent to the township park also has elevated radionuclide concentrations in the bank soils. Following the pattern of the direct radiation levels, elevated concentrations in the soil were more frequent east of Farmingdale Road. In general there is a pattern of decreasing radionuclide concentrations with distance from the W.R. Grace property and from the edge of the brook. Exceptions to this pattern were areas of small mounds of dredging debris and at several other locations. For example, samples 131 and 135, collected close to the Pompton River, both contained radium-228 and thorium-228 concentrations exceeding 100 pCi/g. The maximum radium-228 and thorium-228 concentrations measured in surface soil were 734 and 722 pCi/g, respectively, at sample location 105. Samples obtained along the portion of Sheffield Brook upstream of the juncture with the drainage stream from the W.R. Grace property, and along the Pompton River, did

not contain radionuclide concentrations significantly different from the baseline levels.

Concentrations in subsurface soils obtained along the brook and drainage streams generally decreased with depths below 30 cm. Only two samples, from locations 112 and 113, contained significant radionuclide concentrations at the 90 cm depth; levels of radium-228 and thorium-228 at these locations exceeded 100 pCi/g. Elevated radionuclide concentrations below a 30 cm depth were often associated with the mounds of dredged material.

Surface soil at locations 130 and 153, from the area of the park soccer field having slightly elevated direct exposure levels, contained the following levels of radium-228 and thorium-228 respectively: 9.08 and 41.4 pCi/g, radium-228, and, 5.56 and 324 pCi/g, thorium-228. The sample taken from a depth of 30 cm at location 130 contained a radium-228 concentration of 24.1 pCi/g and a thorium-228 concentration of 21.8 pCi/g. The surface soil sample from location 154, an area of the soccer field with direct exposure levels comparable to the background levels, contained radionuclide levels in the range of the baseline samples. Samples 142 and 143, from the John Baum property on the southeast corner of Farmingdale and Pompton Plains Cross Roads, also had radionuclide concentrations in the range of the baseline samples.

Table 3 lists the concentrations of radionuclides measured in soil from the Kuehm and Baum properties north of Pompton Plains Cross Road. All of the samples from the Kuehm farm and all but one from the Baum property had concentrations comparable to the baseline levels. The exception, surface soil from location 160 on the Baum property, contained a radium-228 concentration of 112 pCi/g and a thorium-228 concentration of 113 pCi/g. This location was an isolated spot determined by a walkover survey to have direct radiation levels considerably above those characteristic of the remainder of the property. The location of this small elevated area was such that it was not accessible for subsurface sampling.

The average ratio of radium-228 and thorium-228 concentrations, measured in soils by gamma spectrometry is near 1. Alpha spectroscopy on three soil samples indicates an average thorium-232 to thorium-228 ratio of approximately 1.1. These ratios confirm that the thorium decay series is essentially in secular equilibrium. This equilibrium state allows the use of the radium-228 level as representative of the thorium-232 concentration present.

Elevated concentrations of uranium-238 and radium-226 were also measured in samples containing high concentrations of thorium. The source of these radionuclides is the natural uranium, which was present in the monazite sand - the major raw material for the Rare Earths, Inc., and W.R. Grace operations. The maximum radium-226 level, 46.8 pCi/g, was measured in sample 105. Radium-226 concentrations were generally less than 5% of the total thorium (thorium-232 plus thorium-228) levels in the soil samples. Radon-222, a radioactive noble gas, is produced by the decay of radium-226. This radon and its daughter products may be a large contributor to radiation doses from soils containing radium-226. The soils along Sheffield Brook, however, contain much higher concentrations of thorium than radium-226. Radiation contributed by radon-222 will, therefore, be much less than the levels of direct gamma radiation. For this reason radon and radon daughter concentrations in air were not measured as part of this survey. The maximum uranium-238 concentration was 247 pCi/g, measured in sample 44. When high enough to be detected, the uranium-238 concentrations in soil were typically 10-35% of the total thorium levels.

Radionuclide Concentrations in Sediment Samples

Radionuclide concentrations in sediment samples are presented in Table 4. Although no consistent pattern in the distribution of elevated levels in sediment was observed, concentrations were generally higher along the W.R. Grace drainage stream and the portion

of Sheffield Brook between the juncture with the drainage stream and Farmingdale Road. Elevated sediment levels were also frequently associated with sudden changes in flow rate due to severe bends, constrictions, expansions, or obstacles in the stream bed. The maximum concentrations of radium-228 and thorium-228 (61.0 and 53.9 pCi/g respectively) were measured at sample location 16. At locations 8 and 9, where the drainage stream joins Sheffield Brook, the radionuclide concentrations are considerably lower. Physical or chemical conditions may be inhibiting the deposition in or enhancing the clearance of radionuclides from the sediment at that location. West of Farmingdale Road the maximum thorium concentrations were noted at locations 24 and 31.

Levels in sediment from Sheffield Brook upstream of its juncture with the W.R. Grace drainage stream were in the range of baseline soil samples. Samples collected from the Pompton River upstream and downstream of Sheffield Brook were also in this baseline range; however, the downstream concentrations were slightly higher than those in upstream samples.

Sediment from the storm sewer system also contained thorium contamination. The maximum levels, 15.1 pCi/g of radium-228 and 14.9 pCi/g of thorium-228, were measured in sample location 45, the first sample collected in the drainage system after it leaves the site.

Radium-226 concentrations in sediment did not exceed 5 pCi/g. Where elevated levels were measured, they were generally less than 5% of the thorium concentrations. As with the soil samples, the uranium-238 levels in sediment were consistently lower than the thorium concentrations. Sediment from location 20 had the highest uranium-238 concentration, 20.1 pCi/g.

Water Samples

Radionuclide concentrations measured in water samples are presented in Table 5 and 6. Table 5 includes samples from Sheffield Brook, the associated drainage streams, and the Pompton River. Samples from residential wells in the Wayne area and other sources of surface water are presented in Table 6.

The maximum gross alpha concentration, 29 pCi/l (with the exception of 39 pCi/l originally measured in sample 6), was measured in sample 8, from the drainage stream on the W.R. Grace property. Samples 9 and 10 from the storm sewer also had elevated gross alpha concentrations. Samples 8 and 13 (also from the storm sewer system) contained elevated radium-228 levels. Other specific radionuclides were not measured at significant levels in samples from the storm drainage system.

With the exception of samples 2 and 6, surface water from the remainder of the brook and drainage system, contained levels in the range of the baseline water samples. Because of the unusually high alpha level of 39 pCi/l originally determined for sample 6, instrument malfunction or sample cross-contamination was suspected. This location was resampled and the results indicate an alpha concentration in the baseline range. The reason for the elevated gross alpha level in sample 2 is unexplained. Sample 2 contained a relatively high (compared to other samples) concentration of thorium-230; the reason for this is also unknown. Specific radionuclides in other samples from the surface drainage system are comparable to baseline levels.

Of the other water samples collected from the Wayne area, significant gross alpha concentrations were only measured in samples 20 and 21 (6.8 pCi/l and 12 pCi/l respectively). The unexpectedly high gross alpha concentration measured in sample 21, as well as its gross beta concentration of 60 pCi/l, raised the possibility of an analytical problem similar to that encountered with sample 6. Two

separate reanalyses of sample 21 were performed and both indicated gross alpha and beta concentrations in the range of the baseline levels. Sample 16 from one of the farm wells contained a radium-228 level of 3.07 pCi/l. All other radionuclide concentrations in these water samples were comparable to the baseline levels.

Vegetation Samples

Table 7 presents the results of vegetation sample analysis. With the exception of sample 2, elevated concentrations of radium-228 and thorium-228 were measured in the unwashed vegetation from the vicinity of the brook. The highest levels, 12.8 pCi/g of radium-228 and 10.1 pCi/g of thorium-228, occurred in sample 3; sample 4 contained 6.96 pCi/g and 4.11 pCi/g of radium-228 and thorium-228, respectively. These two samples were from regions of high surface soil levels. Washed samples from these same locations had much lower concentrations, indicating that the activity measured in the unwashed samples is primarily due to external surface contamination. Sample 2 and vegetation samples 6, 7, and 8 from the nearby farm had radionuclide levels comparable to those of the baseline samples.

Comparison of Results with Guidelines

Guidelines for levels of radiation and radioactive materials in the environment are established by federal regulatory agencies such as the Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA). These guidelines are usually based on conservative factors of land use and occupancy, potential intake by inhalation and ingestion, biological retention times, relative hazard of the radionuclide and potentially exposed population groups. Such guidelines are, therefore, for highly restrictive situations that may not be representative of the actual conditions at a specific site. For this reason these federal guidelines are often used as target criteria with site specific limits established on a case-by-case basis.

The Nuclear Regulatory Commission's Standards for Protection Against Radiation (10CFR20.105) limits the annual radiation dose to an individual in the general population to 500 millirem.[3] Assuming continual exposure, i.e. 168 h/wk, this is equivalent to an average exposure rate of approximately 60 μR/h. There are numerous locations along Sheffield Brook and the drainage streams which exceed this level; however, these locations are not in areas of continual occupancy.

Guidelines for concentrations of radionuclides in soil have not been specifically developed for the Sheffield Brook site. The NRC Branch Technical Position on storage and disposal of uranium and thorium wastes provides an example of soil concentration limits which have been proposed for other sites[5]. In this document, the most restrictive level for both natural thorium (i.e. thorium-232 plus thorium-228 with daughters in equilibrium) and natural uranium (uranium-238 plus uranium-234 with daughters, including radium-226, in equilibrium) in soil is 10 pCi/g. Guideline levels for these radionuclides in soils at the Sheffield Brook site may be higher than that value. The following volumes of soil exceeding various concentration levels of thorium have been estimated for the property in the vicinity of Sheffield Brook:

Thorium Concentration Limit (pCi/g)	Soil Volume (m^3)
10	13,000
20	11,000
50	5,000

There are no established criteria for acceptable levels of radioactivity in ground water; however, the EPA has established the following levels for radioactive contaminants in community drinking water systems[6]:

Combined radium-226 and radium-228	5 pCi/l
Gross alpha (including radium-226 but excluding radon and uranium)	15 pCi/l
Gross beta	50 pCi/l

A water sample obtained from the W.R. Grace property and one from the storm sewer exceeded the gross alpha limit. All other samples were below the gross alpha and gross beta limits. None of the samples exceeded 5 pCi/l of combined radium-226 and radium-228. It should be noted that although these EPA levels have been used for comparison purposes, they are intended only for control of larger drinking water systems and are not applicable to surface drainage water or residential wells.

Most of the activity associated with the vegetation collected from the vicinity near the brook appears to be the result of surface contamination rather than radionuclides assimilated by the plants. After washing, radionuclide concentrations in the plants were low, most samples were in the range of baseline levels. Vegetation from the nearby farm also had radionuclide concentrations in the baseline range.

An evaluation of the current radiation exposures at this site is presented in Appendix E.

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 survey findings indicate thorium contamination of soils and streambed sediments in certain areas along this brook and the associated drainage streams. Smaller quantities of radionuclides from the natural uranium decay series, e.g. uranium-235, uranium-238, and radium-226 are also present.

The contamination apparently originated on the 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 by Rare Earths, Inc., and, later, W.R. Grace and Co., the present owner of the property. It is believed that some of the wastes from these operations entered the drainage system via liquid effluent discharges and storm runoff over an extended time period. This drainage system flowed off-site in a storm sewer line beneath Pompton Plains Cross Road. The flow surfaced about 150 m west of the facility to enter a drainage ditch into which Sheffield Brook subsequently flowed. The contaminants were deposited along the streambed and banks of the drainage ditch and portions of Sheffield Brook. Periodic dredging and occasional flooding of the brook have resulted in a spread of the contamination beyond the original areas of deposition. Several locations of soil contamination also are suggestive of prior earth-moving and grading activities and use of contaminated soils for "fill."

The contamination is concentrated in the immediate area of the drainage stream from the W.R. Grace property and portions of the brook. [illegible] primarily limited to the upper 30-60 cm of soil. Low radionuclide [illegible]ncentrations in surface water, well water, and vegetation from the area confirms the low solubility of the material. It would therefore appear that the primary mode of exposure in the vicinity of the contaminated properties is external gamma radiation.

The levels of direct radiation and radionuclide concentrations in soil and sediment at many locations along Sheffield Brook and the associated drainage streams exceed target criteria proposed by the NRC for uncontrolled use by the general public. These criteria were developed by the NRC using highly restrictive assumptions. These assumptions may or may not be applicable to the Sheffield Brook property.

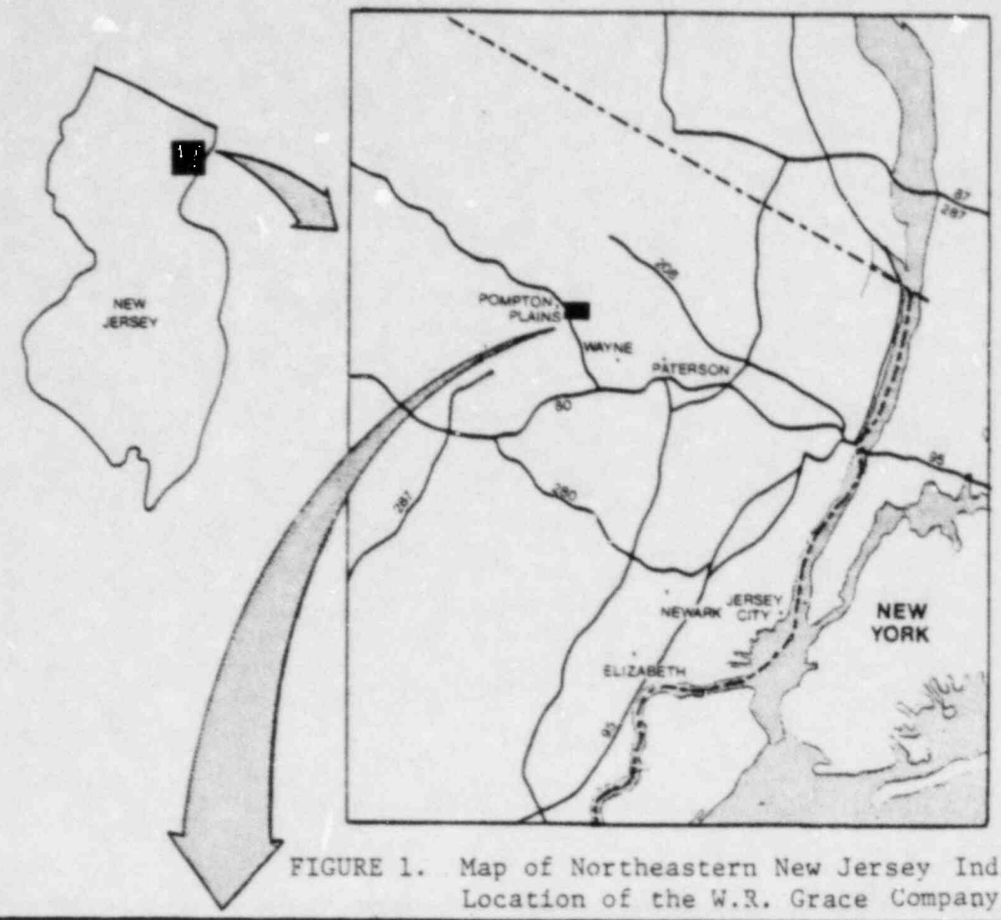

FIGURE 1. Map of Northeastern New Jersey Indicating the Location of the W.R. Grace Company.

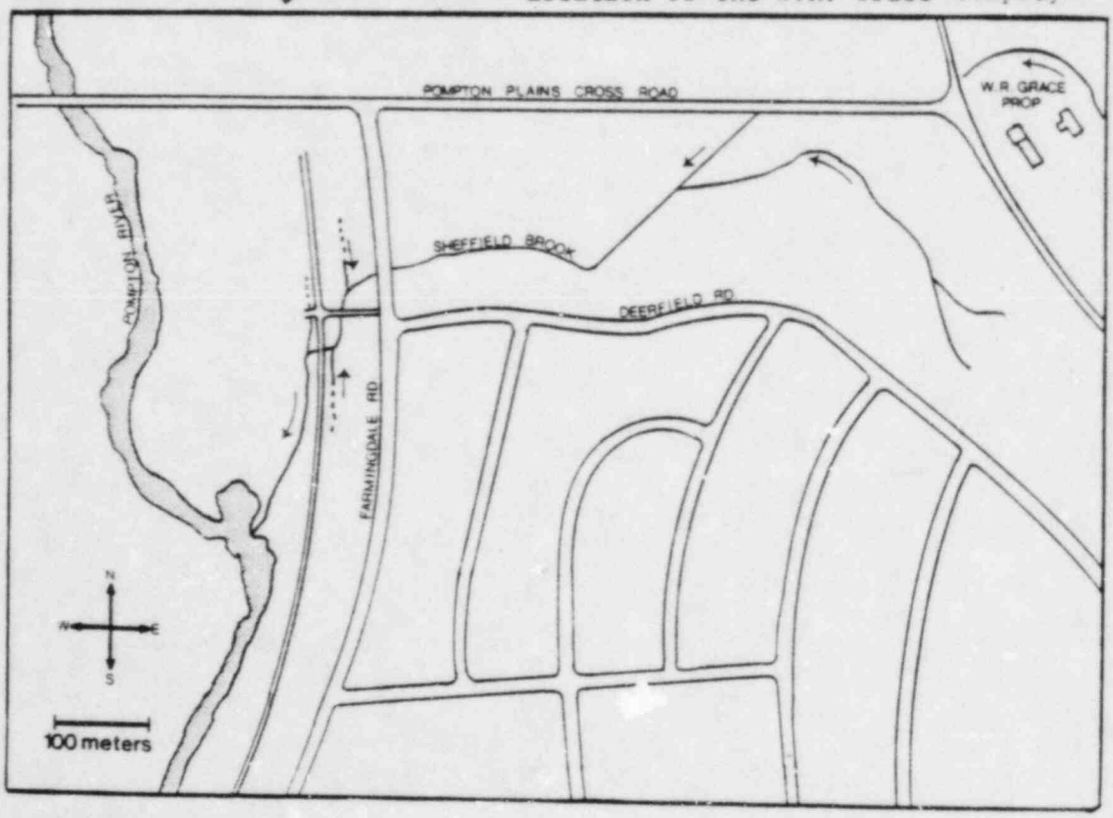

FIGURE 2. Portion of Wayne, NJ, Indicating the Location W.R. Grace Property, Sheffield Brook and Associated Streams.

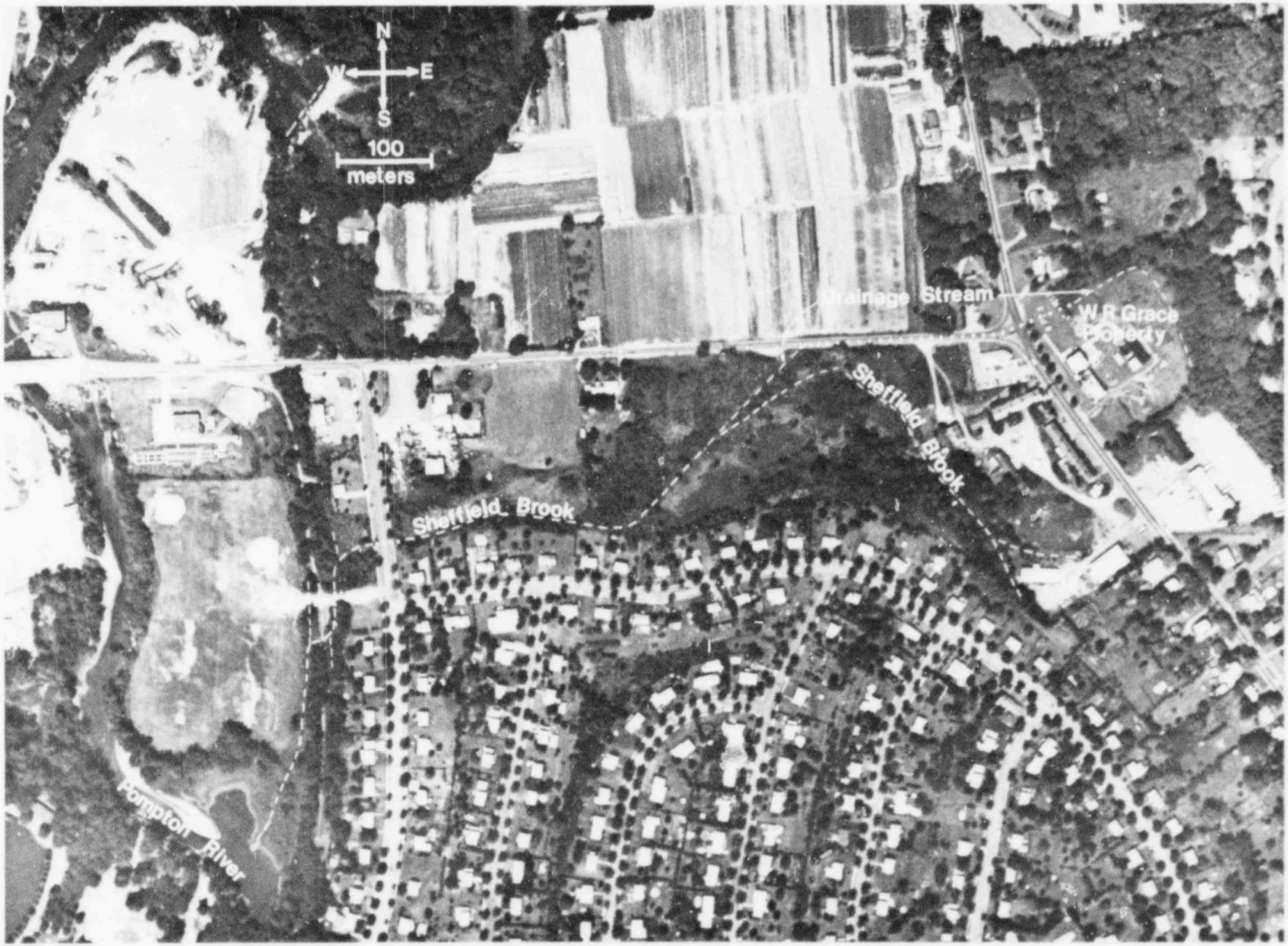

FIGURE 3. Aerial Photograph of Portion of Wayne, NJ, Indicating the Locations of the W.R. Grace Property, Sheffield Brook, and Associated Streams.

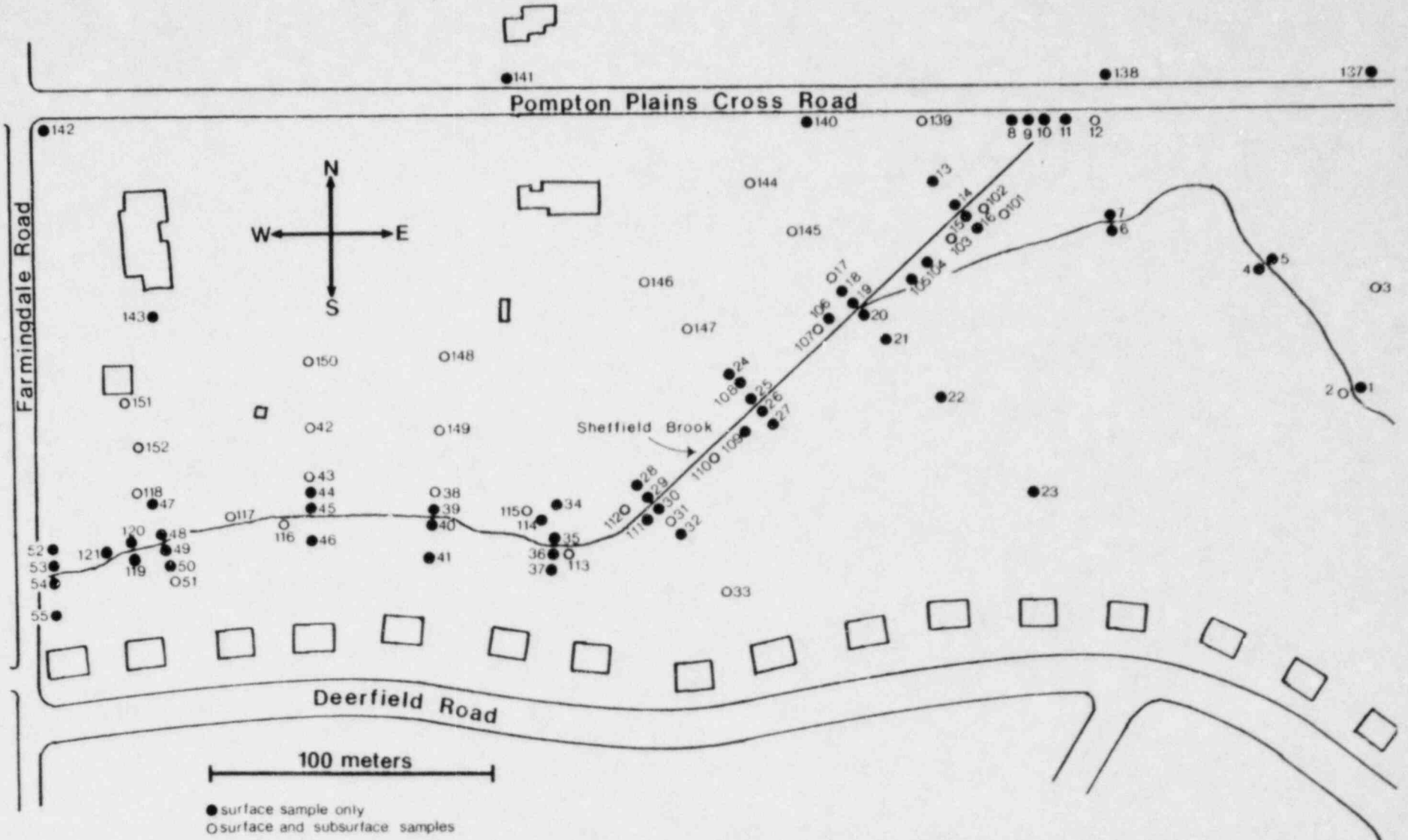

FIGURE 4. Map of Sheffield Brook, East of Farmingdale Road, Indicating Locations of Soil Samples.

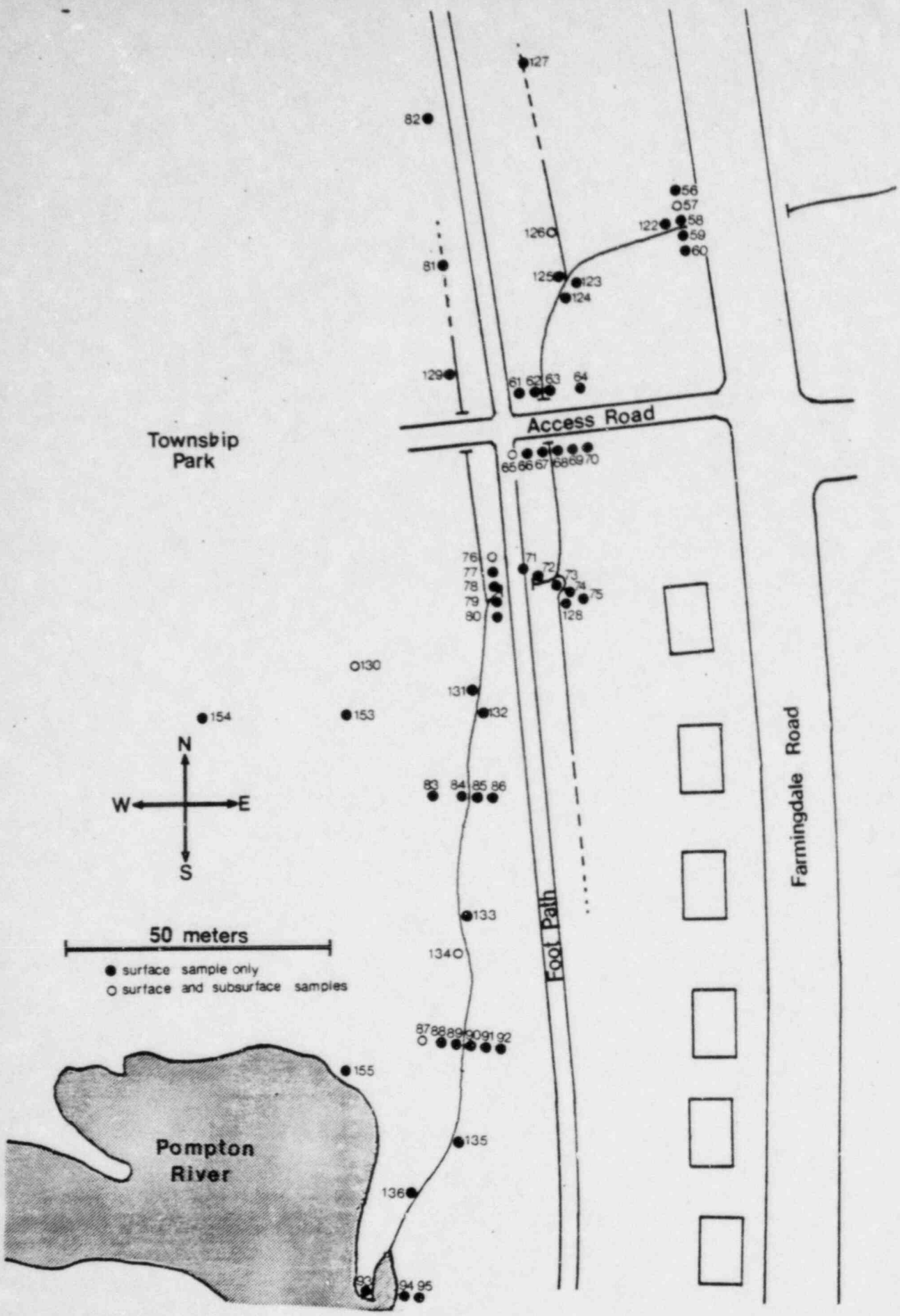

FIGURE 5. Map of Sheffield Brook, West of Farmingdale Road, Indicating Locations of Soil Samples.

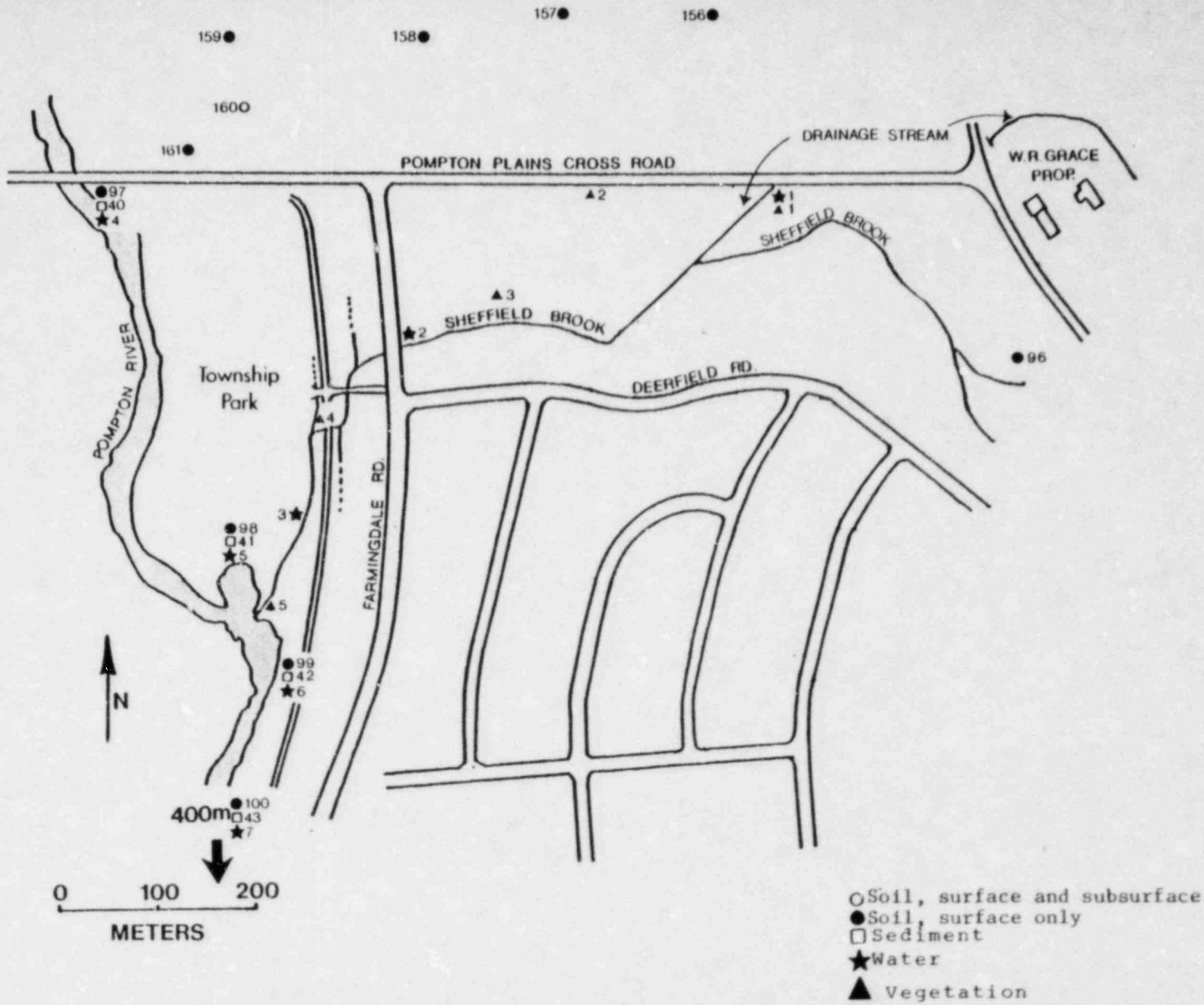

FIGURE 6. Map of Sheffield Brook and Vicinity Indicating Locations of Soil, Sediment, Water, and Vegetation Samples.

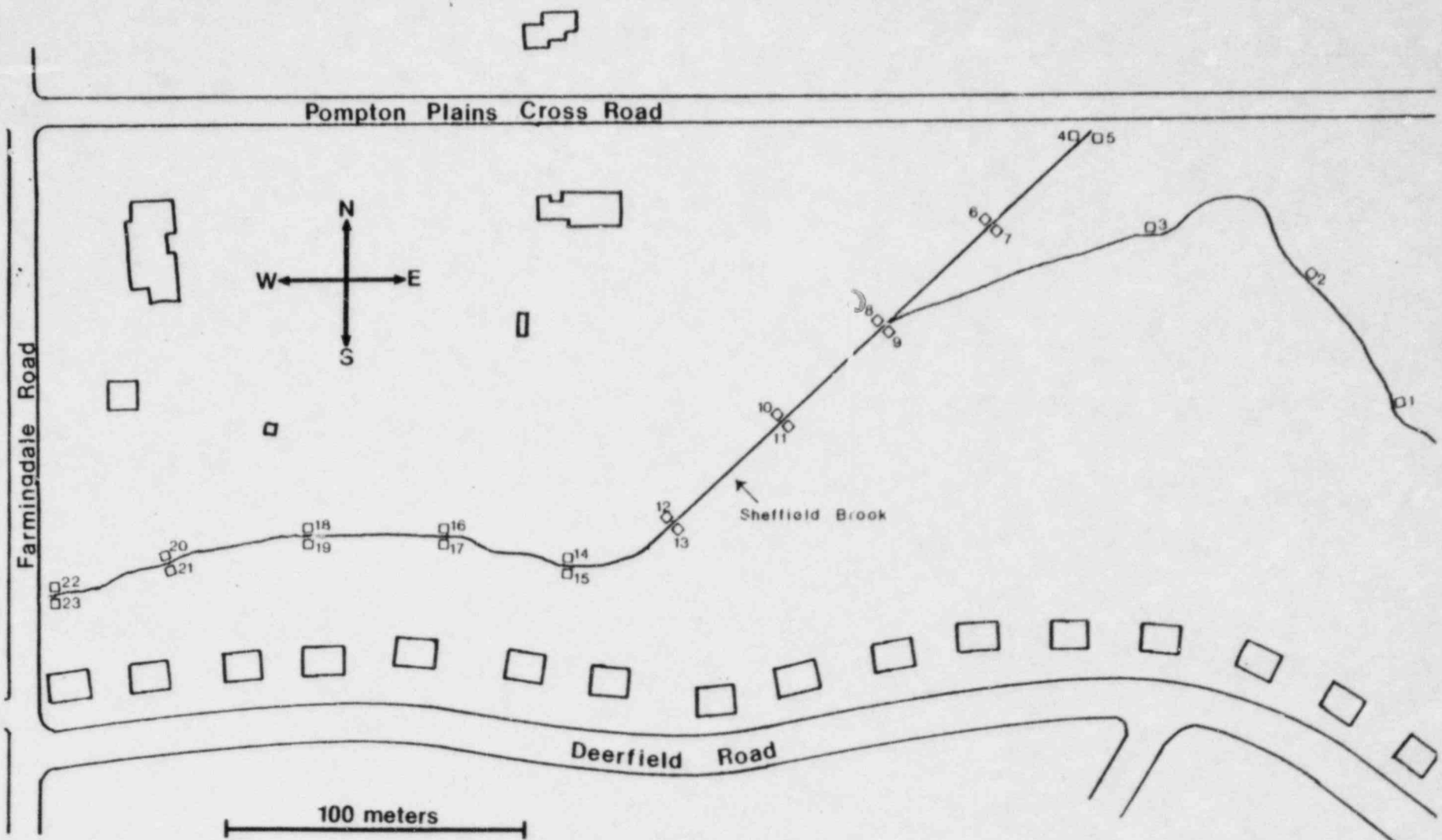

FIGURE 7. Map of Sheffield Brook, East of Farmingdale Road, Indicating Locations of Sediment Samples.

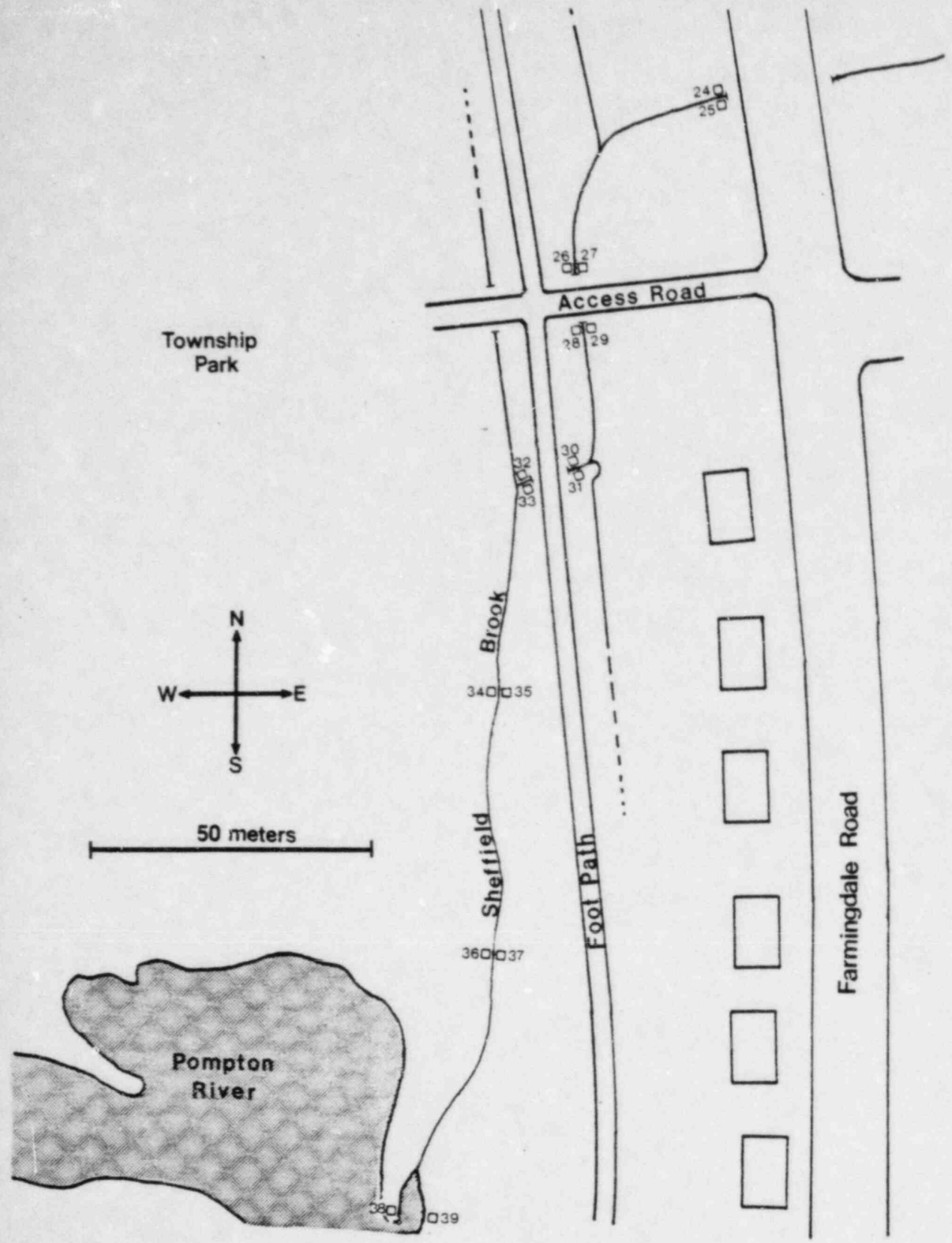

FIGURE 8. Map of Sheffield Brook, West of Farmingdale Road, Indicating Locations of Sediment Samples.

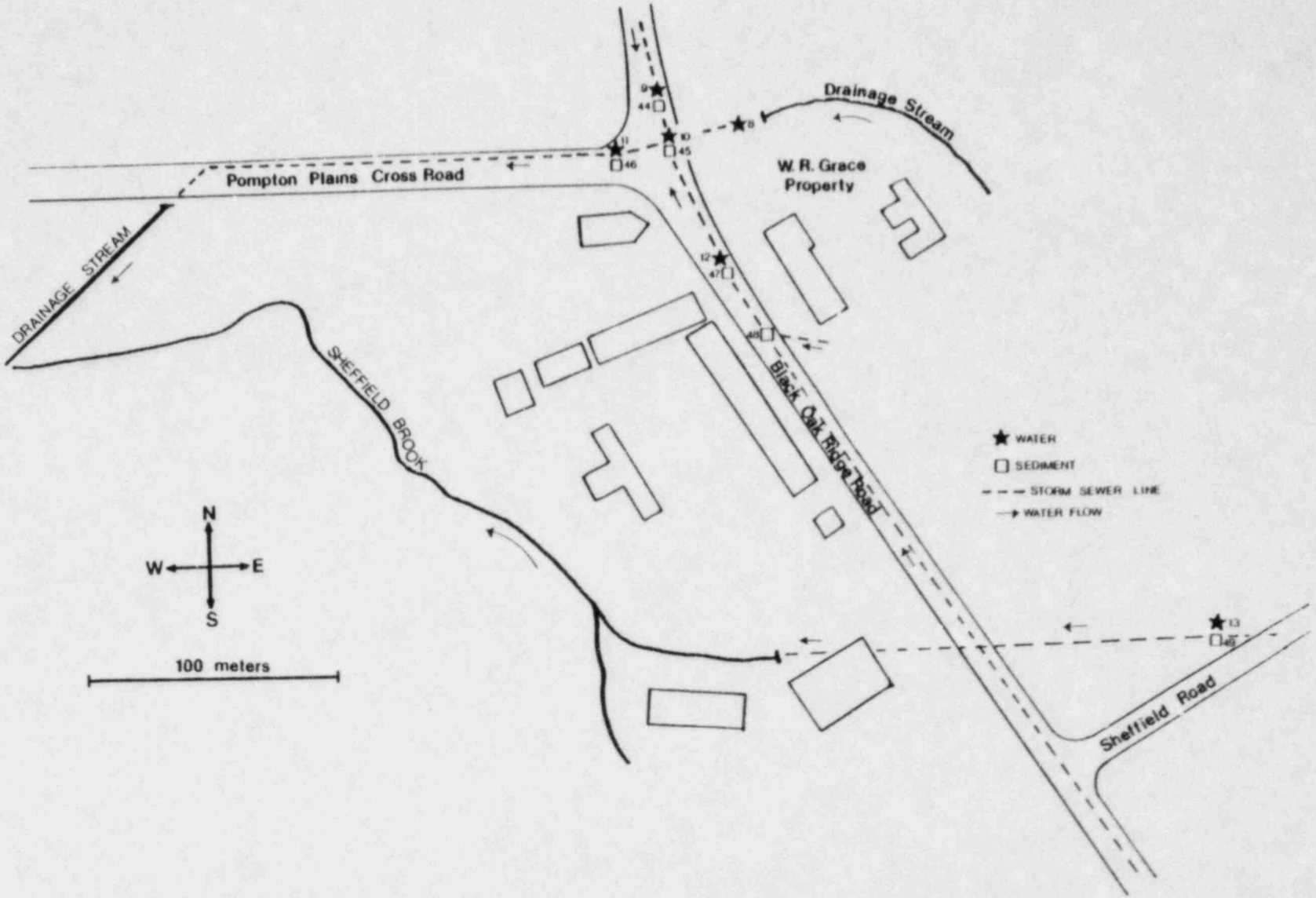

FIGURE 9. Plan View of Storm Sewer System Feeding Sheffield Brook, Indicating Locations of Sediment and Water Samples.

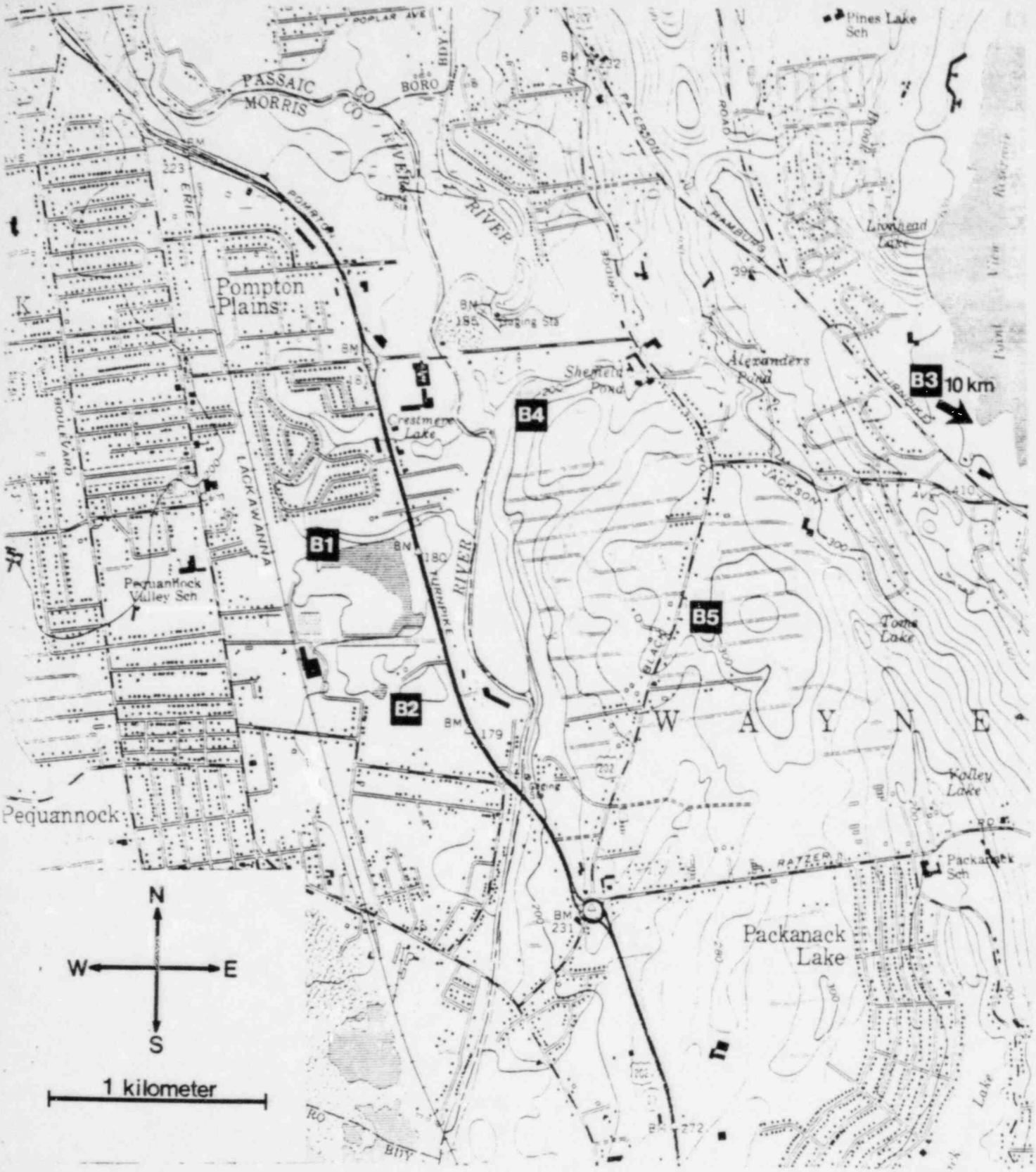

FIGURE 10. Locations of Background Measurements and Baseline Samples in the Wayne-Pompton Plains Area.

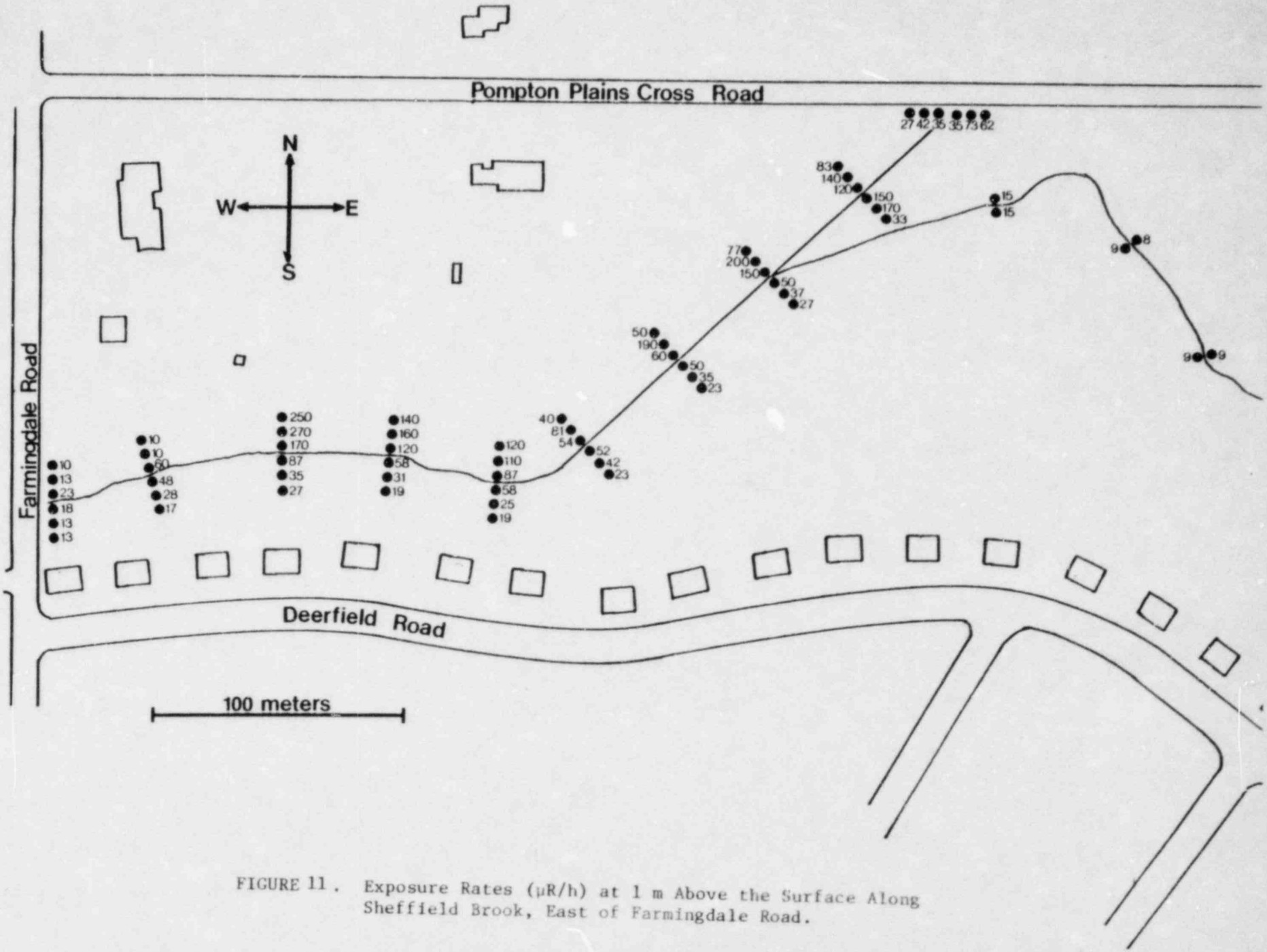

FIGURE 11. Exposure Rates (μR/h) at 1 m Above the Surface Along Sheffield Brook, East of Farmingdale Road.

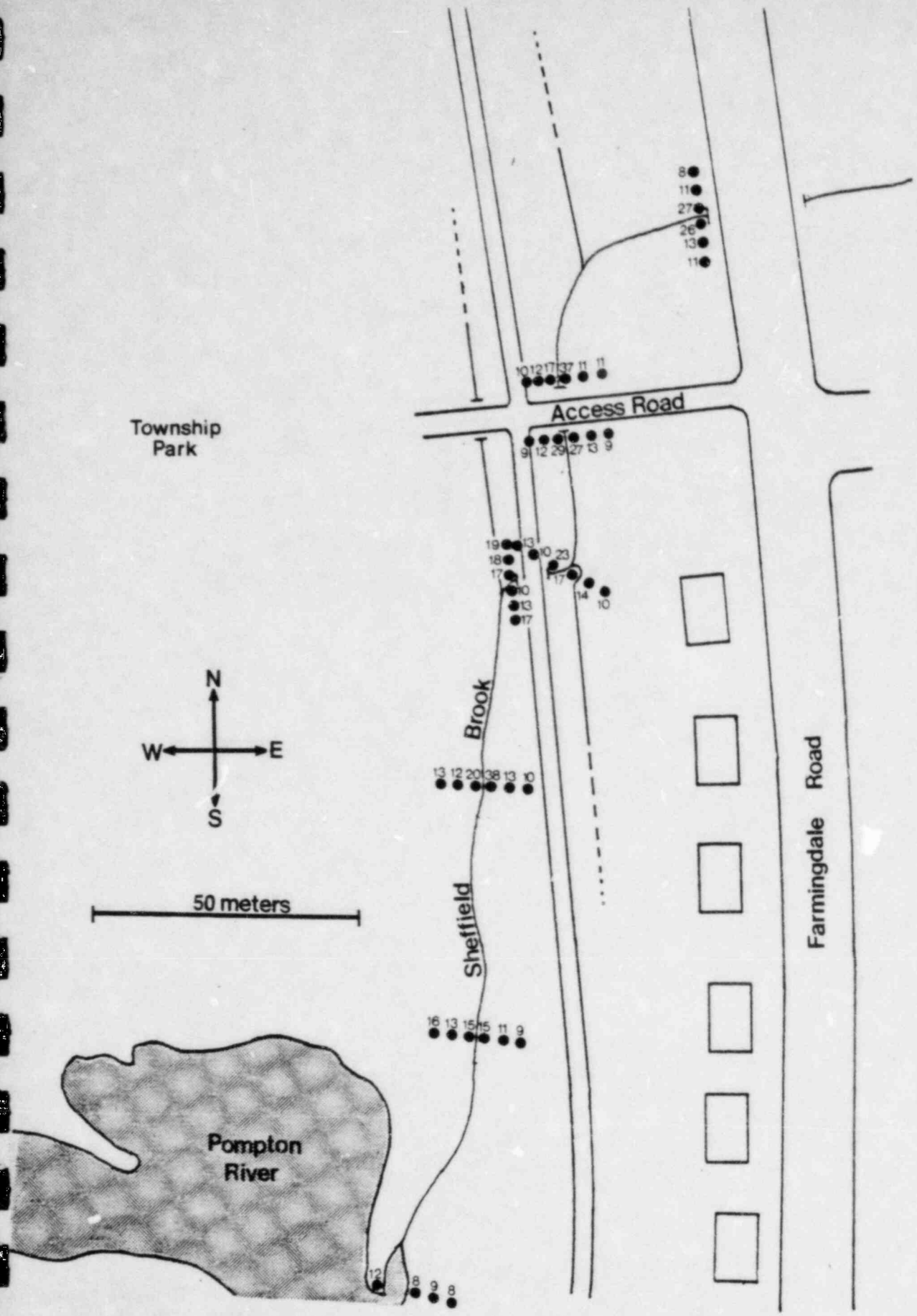

FIGURE 12. Exposure Rates (μR/h) at 1 m Above the Surface Along Sheffield Brook, West of Farmingdale Rd.

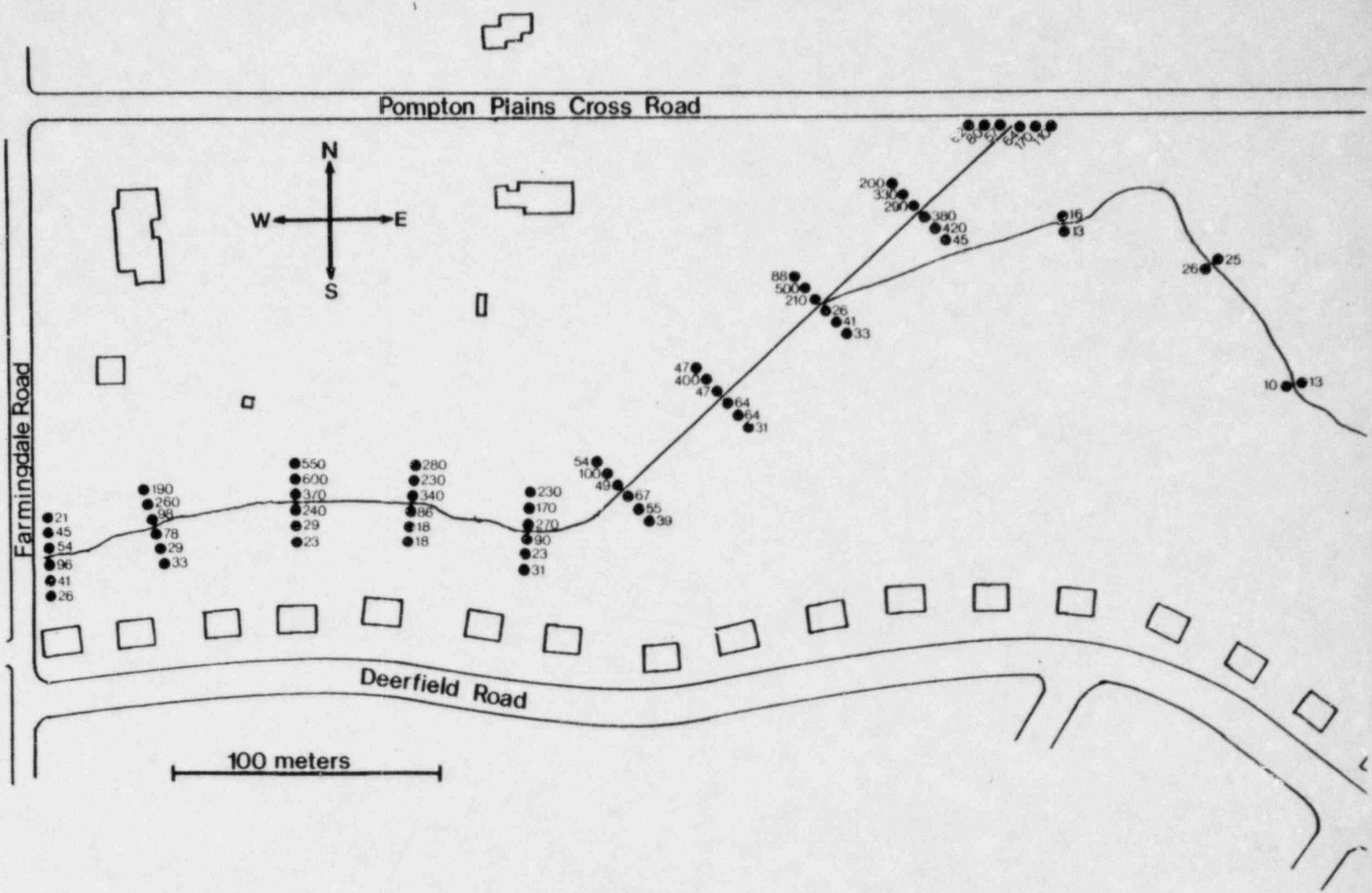

FIGURE 13. Surface Beta-Gamma Dose Rates (μrad/h) Along Sheffield Brook, East of Farmingdale Road.

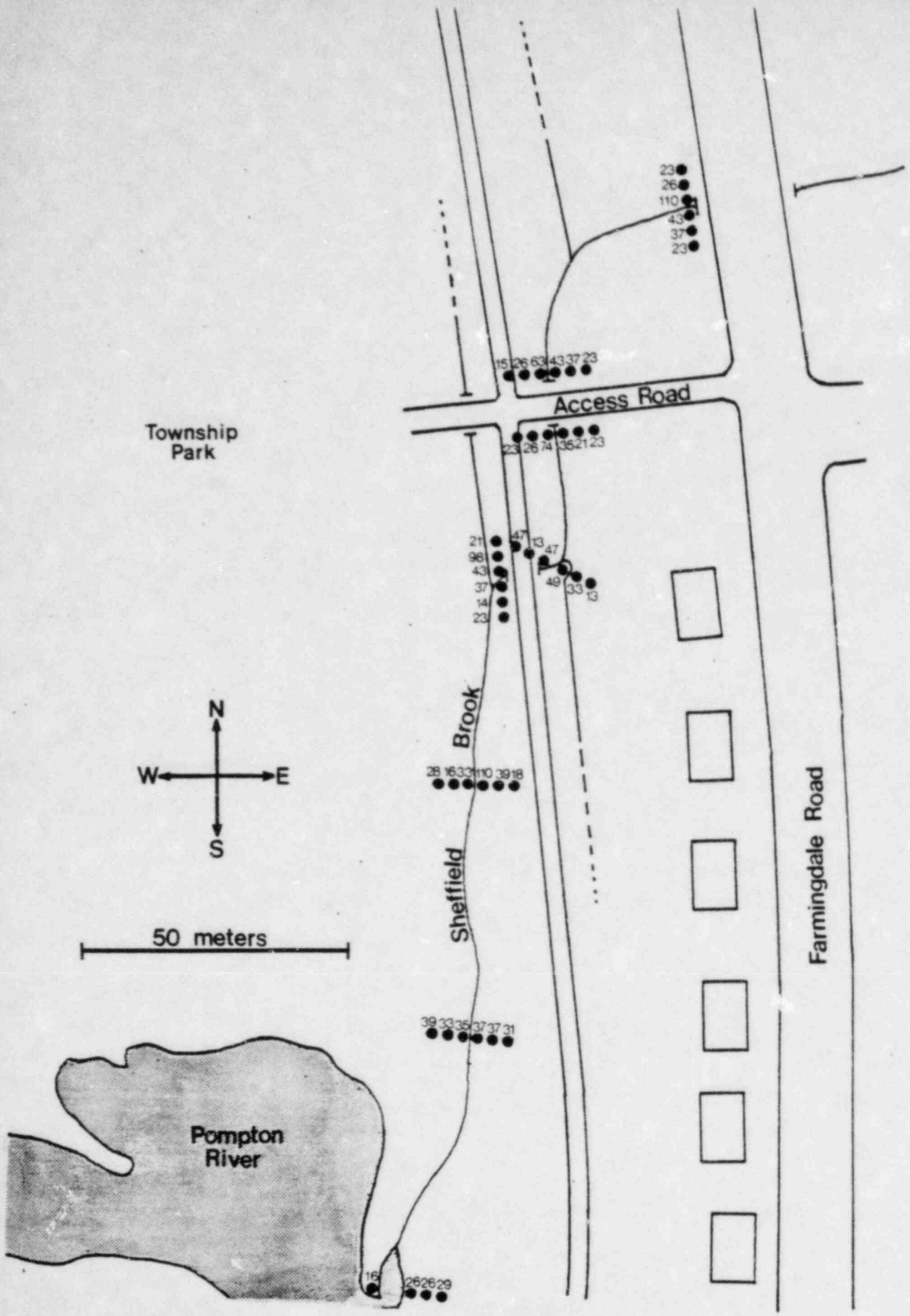

FIGURE 14 . Surface Beta-Gamma Dose Rates (μrad/h) Along Sheffield Brook, West of Farmingdale Road.

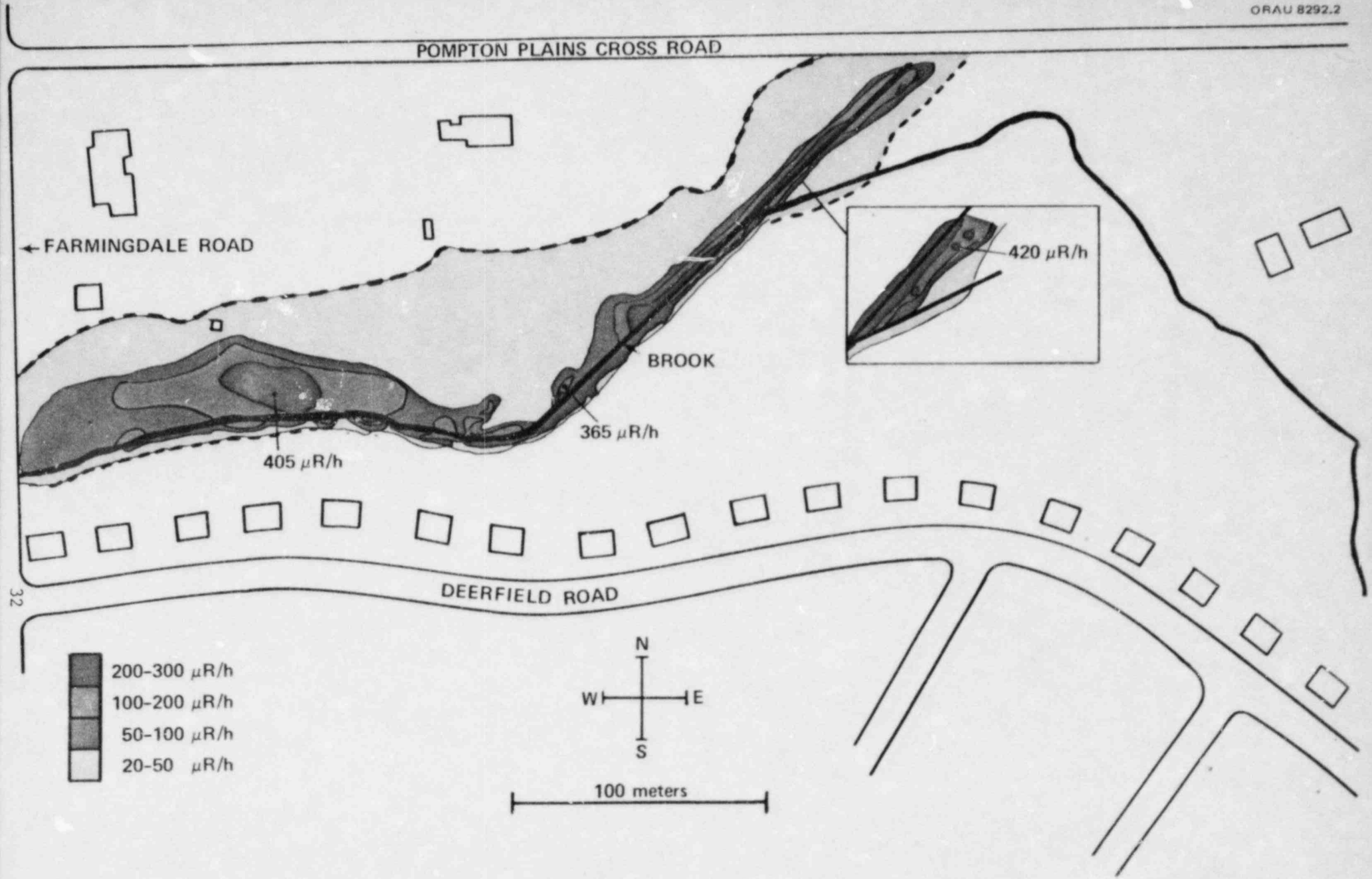

FIGURE 15. Surface Exposure Rates (μR/h) Along Sheffield Brook, East of Farmingdale Road.

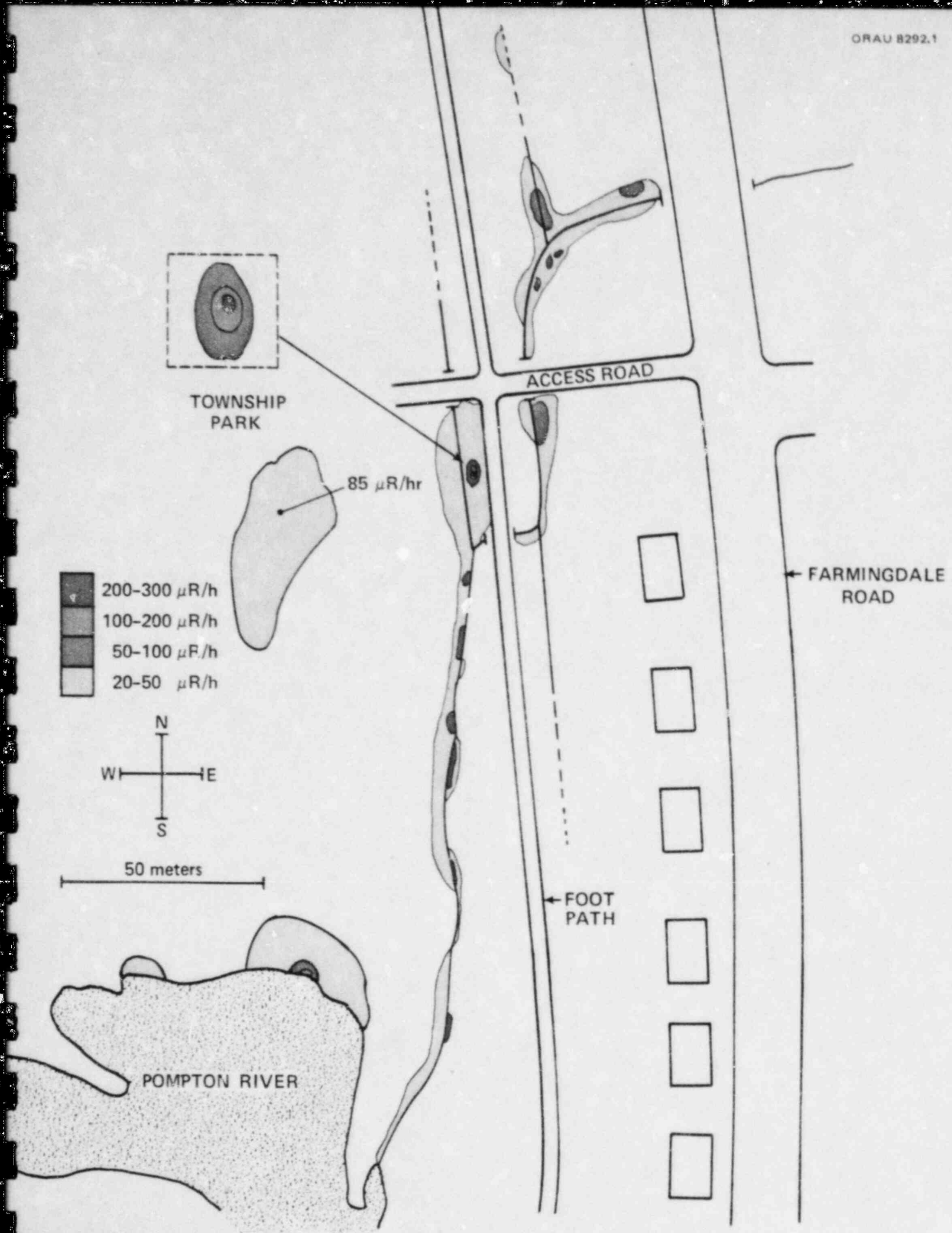

FIGURE 16. Surface Exposure Rates (μR/h) Along Sheffield Brook, West of Farmingdale Road.

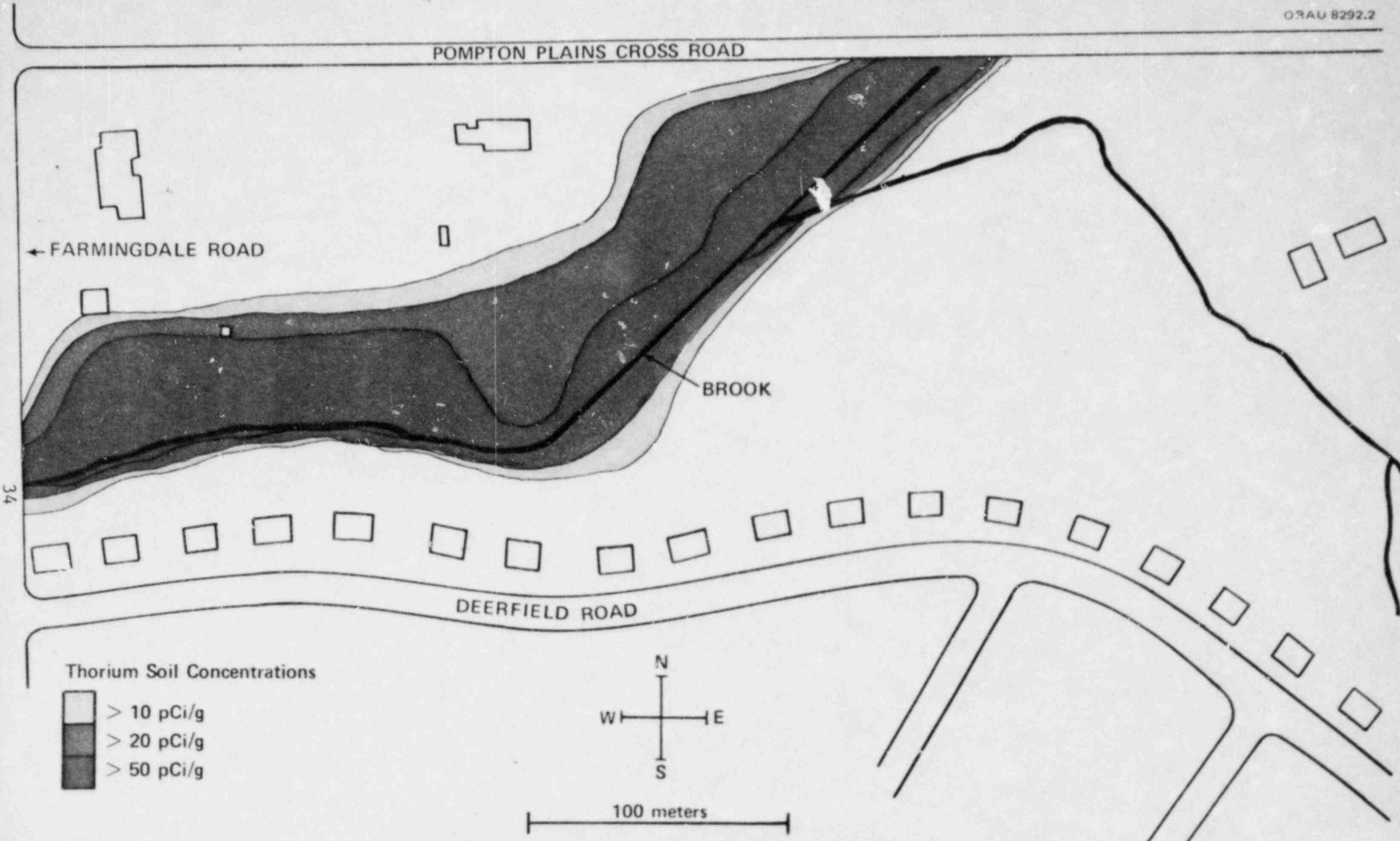

FIGURE 17. Distribution of Thorium Contaminated Soil Along Sheffield Brook, East of Farmingdale Road.

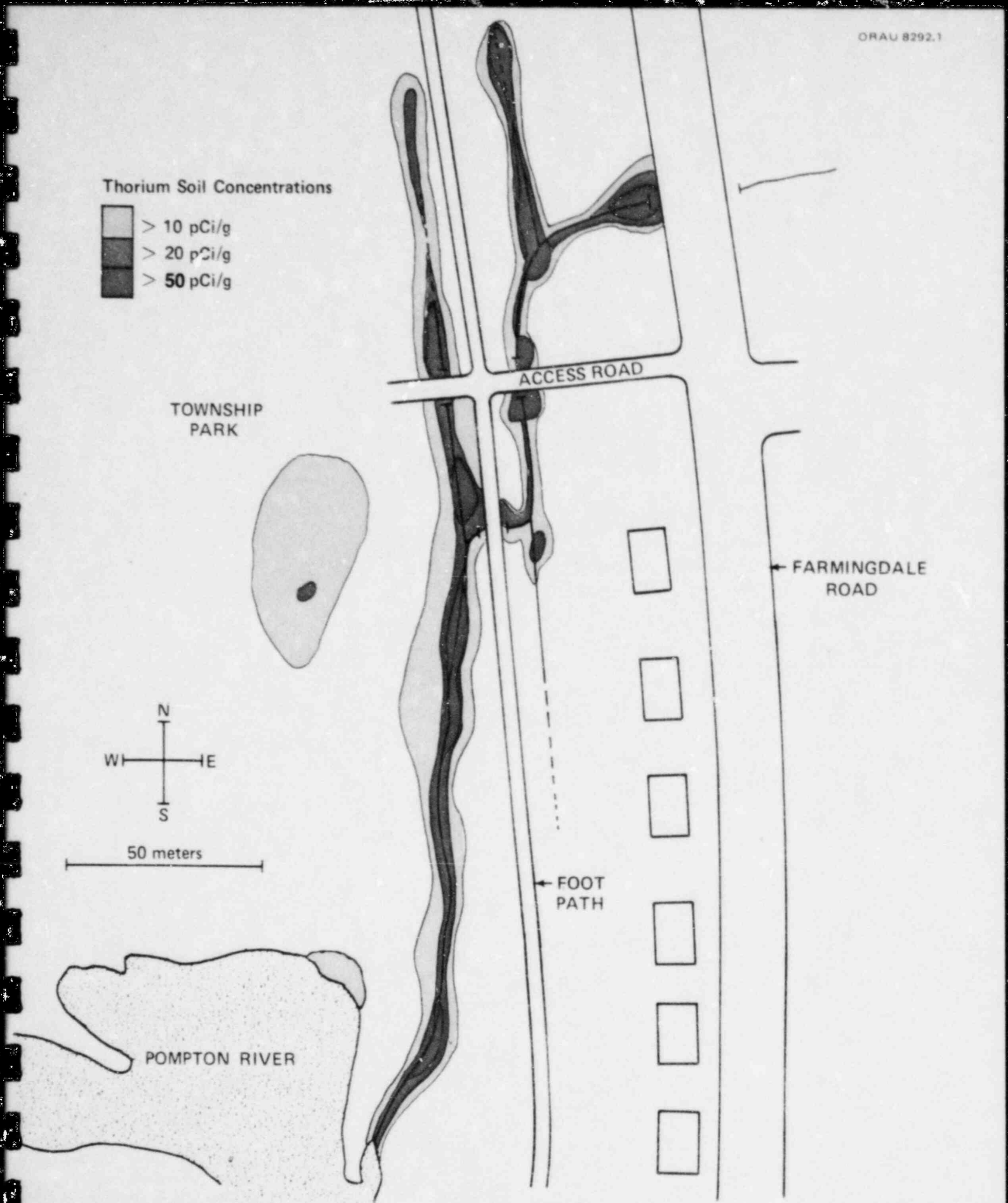

FIGURE 18. Distribution of Thorium Contaminated Soil Along Sheffield Brook, West of Farmingdale Road.

TABLE 1

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL, VEGETATION, AND WATER SAMPLES

Sample Location[a]	Depth (cm)	Radionuclide Concentrations (pCi/g) Ra-228[b]	Th-228	Ra-226	U-238
Soil:					
B1 - P.V. Park	surface	0.51 ± 0.23[c]	0.58 ± 0.27	0.47 ± 0.15	<MDA[d]
	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 - 1.36	0.54 - 1.60	0.37 - 1.34	"
Vegetation:					
B1 - P.V. Park		<0.10	0.29 ± 0.13	<0.06	"
B2 - McDonald Park		0.39 ± 0.18	0.31 ± 0.14	0.21 ± 0.15	"

TABLE 1, cont.

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL,
VEGETATION, AND WATER SAMPLES

Sample Location[a]	Gross Alpha	Gross Beta	Radionuclide Concentrations in Water (pCi/l or x 10^{-9} μCi/ml)							
			Th-228	Th-230	Th-232	Ra-226	Ra-228	U-234	U-235	U-238
B1 P.V. Park	0.95 ± 1.20	<1.3	0.10 ± 0.07	0.07 ± 0.03	<0.05	0.09 ± 0.08	<0.63	0.19 ± 0.03	<0.05	0.13 ± 0.03
B2 McDonald Park	<2.28	<3.6	<0.05	<0.05	<0.05	---[e]	---	0.12 ± 0.03	<0.05	0.09 ± 0.02
B6 City Water	<1.56	<3.7	<1	<1	<1	<0.07	1.12 ± 0.65	<1	<1	<1

[a] Refer to Figure 10.
[b] Assumed to be in equilibrium with Th-232.
[c] Error is 2σ based on counting statistics only.
[d] MDA values generally ranged between 2 to 5 pCi/g.
[e] Dash indicates analysis not performed.

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Location[a]	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228[b]	Th-228	Pa-226	U-238
1	0 (edge)	surface	0.84 ± 0.29[c]	0.85 ± 0.22	0.56 ± 0.17	<MDA[d]
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	11.0 ± 0.4
9	5	surface	18.4 ± 0.9	17.4 ± 0.8	1.47 ± 0.44	11.6 ± 0.4
10	0	surface	1.74 ± 0.32	2.18 ± 0.29	0.87 ± 0.22	<MDA
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	10.3 ± 0.4
		60	5.16 ± 0.59	4.40 ± 0.43	0.75 ± 0.25	2.7 ± 0.3
		90	2.14 ± 0.42	2.05 ± 0.31	0.94 ± 0.22	<MDA
13	10	surface	52.6 ± 1.5	51.5 ± 1.3	4.92 ± 0.68	20.1 ± 0.4
14	0	surface	71.4 ± 1.7	69.9 ± 1.6	5.34 ± 0.72	17.7 ± 0.4
15	0	surface	132 ± 2	132 ± 2	11.4 ± 1.1	27.6 ± 0.5
16	5	surface	116 ± 2	113 ± 2	7.49 ± 0.94	32.9 ± 0.5
17	10	surface	29.6 ± 1.9	26.9 ± 1.5	1.42 ± 0.68	9.42 ± 0.41
		30	12.4 ± 0.9	12.2 ± 0.7	1.43 ± 0.34	<MDA
		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 SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
18	5	surface	153 ± 3	146 ± 3	8.25 ± 1.12	39.1 ± 0.5
19	0	surface	89.0 ± 2.0	83.1 ± 1.9	5.00 ± 0.90	21.5 ± 0.4
20	0	surface	4.78 ± 0.53	4.77 ± 0.48	0.81 ± 0.32	<MDA
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	0.99 ± 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	14.2 ± 0.4
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 SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
37	5	surface	1.50 ± 0.41	1.48 ± 0.36	1.00 ± 0.21	<MDA
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	26.9 ± 0.5
		60	17.8 ± 1.1	15.8 ± 0.9	1.83 ± 0.40	5.92 ± 0.37
		90	5.79 ± 0.88	7.98 ± 0.75	0.64 ± 0.38	<MDA
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	14.2 ± 0.5
		30	1.22 ± 0.35	1.25 ± 0.27	0.72 ± 0.18	<MDA
		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	58.0 ± 0.8
		30	17.8 ± 1.0	16.1 ± 0.9	1.27 ± 0.42	9.41 ± 0.43
		60	7.06 ± 0.65	13.6 ± 0.6	0.92 ± 0.28	5.99 ± 0.38
		90	6.29 ± 0.58	5.49 ± 0.56	0.82 ± 0.25	5.98 ± 0.36
44	5	surface	573 ± 7	472 ± 5	7.87 ± 2.42	247 ± 2
45	0	surface	18.8 ± 1.1	16.7 ± 0.9	1.38 ± 0.47	7.39 ± 0.37
46	5	surface	1.41 ± 0.33	1.31 ± 0.30	0.86 ± 0.18	<MDA
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 SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
53	0	surface	27.5 ± 1.5	27.4 ± 1.2	2.24 ± 0.52	9.73 ± 0.38
54	0	surface	30.5 ± 1.5	28.9 ± 1.2	1.62 ± 0.52	10.9 ± 0.4
55	10	surface	0.93 ± 0.34	0.87 ± 0.32	0.69 ± 0.23	<MDA
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	0.98 ± 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	3.81 ± 0.41	0.66 ± 0.29	"
63	0	surface	45.9 ± 2.1	44.5 ± 1.4	2.60 ± 0.65	23.6 ± 0.5
64	10	surface	0.97 ± 0.39	0.93 ± 0.25	0.76 ± 0.20	<MDA
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	20.0 ± 0.5
68	0	surface	44.2 ± 2.1	33.1 ± 0.8	2.53 ± 0.74	17.1 ± 0.5
69	5	surface	0.88 ± 0.40	1.06 ± 0.23	0.64 ± 0.18	<MDA
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 SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
72	0	surface	20.2 ± 1.0	22.7 ± 0.90	1.39 ± 0.48	11.4 ± 0.4
73	0	surface	18.4 ± 1.3	15.6 ± 1.1	1.20 ± 0.53	6.96 ± 0.39
74	5	surface	7.23 ± 0.83	5.85 ± 1.21	0.47 ± 0.35	<MDA
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	5.99 ± 0.46
83	10	surface	5.55 ± 0.67	5.75 ± 0.64	0.83 ± 0.34	<MDA
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	2.82 ± 0.69	14.6 ± 0.4
86	5	surface	7.01 ± 0.74	6.68 ± 0.33	1.09 ± 0.34	<MDA
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 SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
90	0	surface	10.6 ± 1.0	10.3 ± 0.8	1.07 ± 0.45	<MDA
91	5	surface	7.33 ± 0.83	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 ± 0.49	2.68 ± 0.33	0.62 ± 0.22	"
97	0	surface	5.60 ± 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	"
101	8	surface	91.4 ± 3.2[c]	86.5 ± 2.6	3.38 ± 1.10	24.7 ± 0.5
		30	182 ± 4	163 ± 4	9.61 ± 1.63	<MDA
		60	44 ± 2	41.9 ± 1.9	3.43 ± 0.88	19.7 ± 0.5
		90	31.2 ± 1.8	27.8 ± 1.5	1.81 ± 0.78	11.3 ± 0.4
102	3	surface	32.4 ± 1.6	32.3 ± 1.4	2.19 ± 0.63	24.0 ± 0.4
		30	50.2 ± 2.2	44.1 ± 1.8	2.59 ± 0.88	19.1 ± 0.4
		60	41.2 ± 1.9	37.6 ± 1.6	3.04 ± 0.72	24.4 ± 0.4
		90	51.3 ± 2.1	50.8 ± 1.9	2.73 ± 0.82	23.1 ± 0.4
103	4	surface	275 ± 6	201 ± 4	13.6 ± 2.3	38.6 ± 0.6
		30	102 ± 3	98.6 ± 2.9	7.16 ± 1.40	28.8 ± 0.5
		60	87.8 ± 2.9	64.0 ± 2.2	4.08 ± 1.00	14.8 ± 0.4
		90	30.9 ± 1.9	29.4 ± 1.6	2.29 ± 0.78	12.1 ± 0.4
104	4	surface	191 ± 5	187 ± 5	9.95 ± 2.18	42.9 ± 0.7
105	5	surface	734 ± 8	722 ± 8	46.8 ± 3.8	52.6 ± 0.7

TABLE 2, cont.

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
106	4	surface	235 ± 6	227 ± 5	12.6 ± 2.3	44.8 ± 0.6
107	4	surface	307 ± 7	287 ± 6	11.9 ± 2.6	65.7 ± 0.8
		30	37.9 ± 2.4	35.5 ± 1.8	3.26 ± 0.83	11.9 ± 0.4
		60	28.9 ± 18.1	28.0 ± 1.5	2.06 ± 0.78	8.6 ± 0.4
		90	9.93 ± 0.94	10.0 ± 0.7	1.47 ± 0.32	3.8 ± 0.4
108	7	surface	507 ± 8	479 ± 7	28.1 ± 3.4	47.1 ± 0.7
109	0	surface	9.11 ± 1.59	8.34 ± 1.02	1.21 ± 0.58	<MDA
110	3	surface	19.4 ± 1.5	16.9 ± 1.3	1.58 ± 0.64	5.29 ± 0.42
		30	75.5 ± 4.0	60.4 ± 3.1	5.07 ± 1.52	17.7 ± 0.5
		60	76.4 ± 3.3	62.6 ± 2.9	3.17 ± 0.99	20.2 ± 0.6
		90	6.06 ± 0.86	4.44 ± 0.76	0.71 ± 0.42	<MDA
111	3	surface	19.1 ± 2.3	18.0 ± 1.9	1.31 ± 0.94	"
112	5	surface	345 ± 4	310 ± 4	20.9 ± 1.7	76.7 ± 0.9
		15	247 ± 5	230 ± 5	24.0 ± 2.4	42.9 ± 0.7
		30	273 ± 5	260 ± 5	18.3 ± 2.3	48.7 ± 0.7
		60	289 ± 5	261 ± 5	24.0 ± 2.5	<MDA
		90	151 ± 4	139 ± 3	10.9 ± 1.6	29.0 ± 0.6
113	0	surface	23.7 ± 1.7	21.7 ± 1.5	1.03 ± 0.65	8.36 ± 0.44
		30	152 ± 3	144 ± 3	6.88 ± 1.14	48.4 ± 0.8
		60	57.7 ± 1.6	53.0 ± 1.5	2.71 ± 0.67	21.0 ± 0.6
		90	136 ± 2	130 ± 2	7.49 ± 1.06	48.6 ± 0.7
114	5	surface	163 ± 2	139 ± 1	3.88 ± 0.93	28.4 ± 0.6
115	5	surface	170 ± 2	152 ± 4	9.46 ± 1.82	76.0 ± 0.9
		30	20.9 ± 0.9	19.0 ± 0.9	2.11 ± 0.41	7.89 ± 0.44
		60	7.28 ± 7.60	5.87 ± 0.61	1.24 ± 0.39	<MDA
116	0.5	surface	163 ± 6	111 ± 5	2.59 ± 1.69	66.0 ± 1.1
		30	13.3 ± 1.3	13.6 ± 1.1	1.13 ± 0.29	8.87 ± 0.45
		60	10.2 ± 0.9	6.88 ± 0.13	1.24 ± 0.38	<MDA
		90	2.97 ± 0.44	2.18 ± 0.39	0.62 ± 0.11	"

TABLE 2, cont.

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
117	0	surface	90.8 ± 3.8	79.6 ± 3.2	3.94 ± 0.70	52.7 ± 0.8
		30	27.2 ± 1.9	24.7 ± 1.4	1.82 ± 0.64	7.29 ± 0.42
		60	8.11 ± 0.69	6.58 ± 0.57	1.09 ± 0.35	<MDA
		90	4.84 ± 0.49	4.00 ± 0.43	0.80 ± 2.40	2.62 ± 0.37
118	15	surface	172 ± 5	124 ± 4	4.89 ± 1.80	88.6 ± 1.0
		30	13.4 ± 0.8	10.5 ± 0.6	1.43 ± 0.35	8.56 ± 0.45
		60	4.17 ± 0.54	3.32 ± 0.41	0.85 ± 0.26	<MDA
		90	5.65 ± 0.73	5.05 ± 0.62	0.94 ± 0.35	3.89 ± 0.38
119	3	surface	56.1 ± 2.74	43.6 ± 2.0	2.33 ± 0.88	25.0 ± 0.7
120	0	surface	45.6 ± 2.9	35.7 ± 2.2	2.66 ± 1.06	19.4 ± 0.5
121	0	surface	10.3 ± 0.8	10.4 ± 0.6	1.19 ± 0.34	<MDA
122	0	surface	57.1 ± 1.7	43.1 ± 1.6	1.92 ± 0.66	35.5 ± 0.6
123	0	surface	13.4 ± 0.8	10.5 ± 6.4	1.43 ± 0.35	12.2 ± 0.5
124	2	surface	31.3 ± 1.8	23.2 ± 1.4	2.23 ± 0.69	14.8 ± 0.5
125	0	surface	68.9 ± 3.0	51.1 ± 2.3	3.19 ± 1.06	36.2 ± 0.6
126	15	surface	126 ± 3	112 ± 2	3.97 ± 0.98	70.7 ± 0.8
		30	24.8 ± 1.0	22.3 ± 1.1	2.25 ± 0.48	<MDA
		60	120 ± 4	114 ± 4	3.50 ± 1.48	56.9 ± 0.7
		90	8.08 ± 0.93	8.14 ± 0.67	1.25 ± 0.42	4.59 ± 0.42
127	75	surface	30.7 ± 2.1	29.2 ± 1.7	2.13 ± 0.83	16.6 ± 0.5
128	3	surface	44.7 ± 2.1	40.9 ± 1.8	2.29 ± 0.82	23.5 ± 0.7
129	0	surface	26.2 ± 1.8	25.6 ± 1.7	1.62 ± 0.78	13.8 ± 0.5
130	25	surface	9.08 ± 0.72	5.56 ± 0.63	0.93 ± 0.27	<MDA
		30	24.1 ± 1.9	21.8 ± 1.4	1.69 ± 0.69	13.6 ± 0.5
		60	6.09 ± 0.59	5.58 ± 0.47	0.76 ± 0.32	3.17 ± 0.38
		90	0.90 ± 0.26	0.75 ± 0.17	0.42 ± 0.16	<MDA
131	0	surface	105 ± 3	90.4 ± 3.1	6.05 ± 1.46	21.3 ± 0.5
132	0	surface	57.3 ± 3.3	50.8 ± 2.4	2.77 ± 1.00	14.2 ± 0.5

TABLE 2, cont.

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
133	0	surface	17.9 ± 1.0	15.3 ± 0.8	1.07 ± 0.41	10.5 ± 0.4
134	0	surface	18.6 ± 1.3	17.1 ± 0.9	1.05 ± 0.46	6.33 ± 0.38
		30	5.25 ± 0.50	4.65 ± 0.43	0.64 ± 0.23	2.41 ± 0.37
		60	1.79 ± 0.32	1.67 ± 0.25	0.45 ± 0.16	<MDA
		90	0.54 ± 0.24	0.72 ± 0.17	0.33 ± 0.15	"
135	0	surface	126 ± 2	119 ± 2	4.41 ± 1.02	27.5 ± 0.6
136	0	surface	12.8 ± 1.0	10.3 ± 0.8	1.29 ± 0.39	7.45 ± 0.41
137	100	surface	1.01 ± 0.24	1.06 ± 0.22	0.77 ± 0.15	<MDA
138	20	surface	1.07 ± 0.29	1.07 ± 0.23	0.57 ± 0.18	"
139	30	surface	1.18 ± 0.32	1.06 ± 0.27	0.57 ± 0.20	"
		50	2.22 ± 0.37	1.76 ± 0.31	0.76 ± 0.22	"
		100	1.54 ± 0.37	1.33 ± 0.30	0.64 ± 0.24	"
140	60	surface	0.80 ± 0.27	0.84 ± 0.22	0.61 ± 0.16	"
141	150	surface	0.80 ± 0.30	1.04 ± 0.24	0.78 ± 0.19	"
142	150	surface	0.62 ± 0.31	0.75 ± 0.27	0.60 ± 0.22	"
143	125	surface	0.80 ± 0.28	0.85 ± 0.22	0.55 ± 0.21	0.63 ± 0.30
144	60	surface	10.9 ± 1.0	8.52 ± 0.67	1.33 ± 0.34	<MDA
		50	11.0 ± 0.9	8.28 ± 0.63	1.03 ± 0.34	"
		100	3.56 ± 0.42	2.30 ± 0.32	0.81 ± 0.21	"
145	30	surface	12.3 ± 0.96	9.72 ± 0.75	1.03 ± 0.41	"
		50	1.86 ± 0.34	1.44 ± 0.14	0.73 ± 0.22	"
		100	2.67 ± 0.48	1.98 ± 0.35	0.78 ± 0.31	"
146	60	50	1.08 ± 0.32	0.98 ± 0.20	0.70 ± 0.15	"
		100	0.98 ± 0.28	0.92 ± 0.23	0.73 ± 0.20	"
147	30	surface	13.6 ± 0.96	9.09 ± 0.79	1.09 ± 0.35	6.51 ± 0.40
		50	4.44 ± 0.44	2.82 ± 0.41	0.49 ± 0.21	<MDA
		100	2.00 ± 0.38	1.28 ± 0.30	0.77 ± 0.24	"

TABLE 2, cont.

RADIONUCLIDE CONCENTRATIONS IN SOIL SAMPLES

Location	Distance from Brook or Stream (m)	Depth (cm)	Radionuclide Concentrations (pCi/g)			
			Ra-228	Th-228	Ra-226	U-238
148	60	surface	1.93 ± 0.37	1.65 ± 0.31	0.62 ± 0.19	"
		50	0.68 ± 0.23	0.85 ± 0.29	0.57 ± 0.14	"
		100	0.74 ± 0.26	0.85 ± 0.21	0.56 ± 0.14	"
149	30	surface	37.0 ± 1.9	33.5 ± 1.7	2.52 ± 0.71	"
		50	1.33 ± 0.40	1.49 ± 0.36	0.66 ± 0.21	"
		100	7.81 ± 0.71	7.57 ± 0.61	0.92 ± 0.30	"
150	60	surface	1.77 ± 0.43	1.62 ± 0.34	0.70 ± 0.20	"
		50	0.94 ± 0.16	0.79 ± 0.25	0.70 ± 0.20	"
151	50	surface	9.89 ± 0.90	8.26 ± 0.72	0.61 ± 0.34	"
		50	0.88 ± 0.29	0.74 ± 0.18	0.49 ± 0.14	"
		100	1.23 ± 0.30	0.96 ± 0.28	0.44 ± 0.22	"
152	30	surface	66.5 ± 0.3	57.5 ± 2.1	3.06 ± 0.93	38.8 ± 0.7
		50	8.41 ± 0.70	6.53 ± 0.64	0.73 ± 0.34	<MDA
		100	2.03 ± 0.45	1.92 ± 0.57	0.53 ± 0.22	"
153	50	surface	41.4 ± 1.6	32.4 ± 1.2	1.49 ± 0.58	18.3 ± 0.5
154	100	surface	0.96 ± 0.29	0.83 ± 0.24	0.62 ± 0.18	<MDA
155	50	surface	9.25 ± 0.89	7.70 ± 0.62	0.92 ± 0.46	"

[a] Refer to Figures 4 and 5.
[b] Assumed to be in equilibrium with Th-232.
[c] Errors are 2σ based on counting statistics only.
[d] MDA values generally ranged between 2 and 5 pCi/g.

TABLE 3

RADIONUCLIDE CONCENTRATIONS IN ADDITIONAL SOIL SAMPLES
FROM THE VICINITY OF SHEFFIELD BROOK

Location[a]	Depth (cm)	Radionuclide Concentrations (pCi/g)			
		Ra-228[b]	Th-228	Ra-226	U-238
156 Kuehm Farm	surface	0.54 ± 0.23[c]	0.65 ± 0.21	0.47 ± 0.17	<MDA
157 Kuehm Farm	surface	0.66 ± 0.22	0.77 ± 0.18	0.60 ± 0.20	"
158 Kuehm Farm	surface	0.75 ± 0.29	0.68 ± 0.26	0.67 ± 0.84	"
159 J. Baum Prop.	surface	0.68 ± 0.26	0.62 ± 0.22	0.63 ± 0.19	"
160 J. Baum Prop.	surface	0.66 ± 0.32	0.78 ± 0.21	0.74 ± 0.17	"
	30	0.70 ± 0.26	0.88 ± 0.20	0.63 ± 0.14	"
	60	1.00 ± 0.26	0.96 ± 0.24	0.57 ± 0.18	"
	90	0.44 ± 0.36	0.61 ± 0.18	0.25 ± 0.15	"
161 J. Baum Prop.	surface	112 ± 4	113 ± 3	10.7 ± 1.5	44.8 ± 0.6

a Refer to Figure 6.
b Assumed to be in equilibrium with Th-232.
c Error is 2σ based on counting statistics.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES

Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-228[b]	Th-228	Ra-226	U-238
1	0.54 ± 0.36[c]	0.57 ± 0.12	0.48 ± 0.10	<MDA[d]
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	4.24 ± 0.38
5	5.56 ± 0.57	5.39 ± 0.46	0.95 ± 0.24	<MDA
6	44.3 ± 2.1	42.7 ± 1.8	3.72 ± 0.90	11.1 ± 0.4
7	26.7 ± 1.9	24.5 ± 1.6	2.86 ± 0.80	10.4 ± 0.5
8	0.88 ± 0.26	0.75 ± 0.24	0.55 ± 0.14	<MDA
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	16.7 ± 0.4
15	7.07 ± 0.57	7.04 ± 0.48	0.90 ± 0.31	<MDA
16	61.0 ± 1.4	53.9 ± 1.3	4.16 ± 0.61	13.0 ± 0.4
17	4.44 ± 0.41	3.69 ± 0.34	0.58 ± 0.19	<MDA
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	1.79 ± 0.30
20	32.0 ± 1.31	25.1 ± 1.0	1.99 ± 0.49	20.1 ± 0.5
21	6.06 ± 0.51	5.75 ± 0.43	0.76 ± 0.21	<MDA
22	16.4 ± 0.9	17.6 ± 0.8	0.67 ± 0.41	7.57 ± 0.37
23	9.13 ± 0.63	7.31 ± 0.49	0.70 ± 0.25	3.24 ± 0.31
24	21.2 ± 1.1	19.5 ± 1.0	1.15 ± 0.43	<MDA
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	6.61 ± 0.35
27	8.26 ± 0.65	8.48 ± 0.54	0.68 ± 0.20	<MDA
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	3.58 ± 0.33
31	17.5 ± 1.1	17.2 ± 0.89	1.17 ± 0.42	<MDA
32	8.91 ± 0.68	9.83 ± 0.61	0.98 ± 0.38	6.02 ± 0.39
33	6.14 ± 0.53	6.26 ± 0.49	0.84 ± 0.24	<MDA
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	U-238
44	1.23 ± 0.38	1.38 ± 0.28	0.48 ± 0.20	<MDA
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 6, 7, 8, and 9.
[b] Assumed to be in equilibrium with Th-232.
[c] Error is 2σ based on counting statistics only.
[d] MDA values generally ranged between 2 and 5 pCi/g.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES

Sample Location[a]	Gross Alpha	Gross Beta	Radionuclide Concentrations (pCi/l or 10^{-9} μCi/ml)							
			Th-228	Th-230	Th-232	Ra-226	Ra-228	U-234	U-235	U-238
Stream, Brook, River										
1 Drainage Stream	4.8 ± 1.8[b]	2.1 ± 1.9	<1.0	<1.0	<1.0	<0.07	<0.63	<1.0	<1.0	1.1 ± 0.8
2 Sheffield Brook	6.5 ± 1.7	2.5 ± 1.9	<1.0	1.7 ± 0.6	<1.0	0.20 ± 0.23	<0.63	<1.0	<1.0	1.1 ± 0.6
3 Sheffield Brook	<2.2	<3.6	<1.0	<1.0	<1.0	---[c]	---	<1.0	<1.0	1.0 ± 0.7
4 Pompton River, 500 m upstream	1.1 ± 1.4	<1.3	0.09 ± 0.07	<0.05	0.10 ± 0.34	0.10 ± 0.10	<0.63	0.10 ± 0.02	<0.05	0.13 ± 0.02
5 Pompton River, 100 m upstream	<0.7	<1.3	<1.0	<1.0	<1.0	<0.07	<0.63	<1.0	<1.0	<1.0
6 Pompton River, 100 m downstream	39 ± 9	877 ± 32	<0.05	0.06 ± 0.03	<0.05	---	---	<0.05	<0.05	0.06 ± 0.02
6[d] Pompton River 100 m downstream	0.9 ± 1.0	1.6 ± 1.6	---	---	---	---	---	---	---	---
7 Pompton River, 500 m downstream	0.8 ± 1.1	2.9 ± 1.9	<1.0	<1.0	<1.0	<0.07	<0.63	<1.0	<1.0	<1.0
Storm Sewer										
8	29 ± 4	10.4 ± 2.3	0.32 ± 0.07	0.08 ± 0.02	0.06 ± 0.02	0.12 ± 0.11	3.25 ± 0.84	0.76 ± 0.04	<0.05	0.79 ± 0.06
9	19 ± 8	8.8 ± 5.3	<0.05	<0.05	<0.05	0.18 ± 0.11	<0.63	0.19 ± 0.03	<0.05	0.11 ± 0.02
10	12 ± 6	4.2 ± 5.7	0.25 ± 0.09	<0.05	<0.05	0.08 ± 0.09	<0.63	1.02 ± 0.07	0.05 ± 0.01	0.98 ± 0.07
11	<2.8	6.6 ± 6.0	0.55 ± 0.08	0.14 ± 0.03	0.06 ± 0.03	0.08 ± 0.07	<0.63	0.52 ± 0.04	<0.05	0.56 ± 0.04
12	1.6 ± 1.3	8.4 ± 2.1	<0.05	<0.05	<0.05	0.25 ± 0.10	<0.63	0.23 ± 0.03	<0.05	0.21 ± 0.03
13	<2.3	<3.7	0.11 ± 0.10	<0.05	0.23 ± 0.11	<0.07	2.16 ± 0.59	0.19 ± 0.06	<0.05	0.34 ± 0.07

[a] Refer to Figures 6 and 9.
[b] Error is 2σ based on counting statistics only.
[c] Dash indicates analysis not performed.
[d] Resampled 7/26/82 due to questionable gross alpha and gross beta concentrations in initial sample.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN ADDITIONAL WATER SAMPLES FROM THE VICINITY OF SHEFFIELD BROOK

Sample location[a]	Radionuclide Concentrations (pCi/l or x 10^{-9} uCi/ml)									
	Gross Alpha	Gross Beta	Th-228	Th-230	Th-232	Ra-226	Ra-228	U-234	U-235	U-238
14 Surface Water Kuehm Farm	3.5 ± 4.0	4.9 ± 5.6[b]	<1	<1	<1	<0.07	<0.63	<1	<1	<1
15 Surface Water Kuehm Farm	<2.3	<3.6	<0.05	<0.05	<0.05	2.17 ± 0.02	<0.63	0.19 ± 0.03	<0.05	0.13 ± 0.03
16 Well Water Kuehm Farm	<2.8	<3.7	<1	<1	<1	<0.07	3.07 ± 2.06	<1	<1	<1
17 Well Water Kuehm Farm	1.6 ± 1.4	<1.3	<1	<1	<1	<0.07	<0.63	<1	<1	<1
18 Well Water Wendt Lane	<2.2	14.7 ± 6.5	<1	<1	<1	<0.07	<0.63	<1	<1	<1
19 Well water Wendt Lane	<2.2	<3.6	<1	<1	<1	<0.07	<0.63	<1	<1	<1
20 Well Water Deerfield Rd.	6.8 ± 5.8	<3.8	<1	<1	<1	<0.07	<0.63	<1	<1	<1
21 Well Water Farmingdale Rd.	12 ± 6	60 ± 10	<1	<1	<1	0.42 ± 0.04	<0.63	<1	<1	<1
21[d] Well Water Farmingdale Rd.	1.3 ± 2.3	<2.3	--	--	--	--	--	--	--	--
21[d] Well Water Farmingdale Rd.	3.7 ± 2.8	3.1 ± 3.5	--	--	--	--	--	--	--	--
22 Well Water Black Oak Ridge Rd.	1.2 ± 1.1	1.3 ± 1.6	--[c]	--	--	--	--	--	--	--

[a] Sample location not indicated in Figures.
[b] Errors are 2σ based on counting statistics only.
[c] Dash indicates analysis not performed.
[d] Reanalyzed due to questionable gross alpha and gross beta concentrations.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN VEGETATION SAMPLES

Location[a]		Radionuclide Concentrations (pCi/g)				
		Ra-228	Th-228	Ra-226	U-235	U-238
1	Unwashed	2.04 ± 0.47[b]	0.99 ± 0.21	0.34 ± 0.15	<MDA[c]	<MDA
	Washed	0.31 ± 0.12	0.09 ± 0.11	0.04 ± 0.06	"	"
2	Unwashed	0.17 ± 0.23	0.28 ± 0.18	0.36 ± 0.15	"	"
3	Unwashed	12.8 ± 0.4	10.1 ± 0.3	0.71 ± 0.16	"	"
	Washed	0.69 ± 0.61	0.15 ± 0.12	0.10 ± 0.10	"	"
4	Unwashed	6.96 ± 0.36	4.11 ± 0.24	0.44 ± 0.13	"	"
	Washed	2.38 ± 2.06	0.28 ± 0.12	0.14 ± 0.19	"	"
5	Unwashed	1.87 ± 0.19	1.83 ± 0.16	0.39 ± 0.10	"	"
	Washed	1.25 ± 0.16	0.89 ± 0.12	0.14 ± 0.07	"	"
6	Washed	0.37 ± 0.13	0.14 ± 0.12	0.08 ± 0.11	"	"
Kuehm Farm:						
	Kale	<0.08	0.21 ± 0.12	0.10 ± 0.09	"	"
	Zucchini	0.25 ± 0.12	0.14 ± 0.08	0.16 ± 0.07	"	"
	Dill	<0.05	<0.03	0.04 ± 0.06	"	"

a Refer to Figure 6.
b Error is 2σ based on counting statistics only.
c MDA = minimum detectable activity
Uranium-235: 0.05 - 0.10 pCi/g
Uranium-238: 1.2 - 2.3 pCi/g

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APPENDIX A

GLOSSARY OF TERMS

Glossary

Activation: The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.

Activity: Radioactivity, the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an unstable nuclide. As a result of this emission, the radioactive material is converted (or decays) into a different nuclide (daughter), which may or may not be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) nuclide is formed.

Aerial survey: A search for sources of radiation by means of sensitive instruments mounted in a helicopter or airplane. Generally, the instrumentation records the intensity, location, and spectral analysis of the radiation.

Alpha particle: A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, and hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, and can be stopped by a sheet of paper.

Background radiation: The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements. It is also called natural radiation. The term may also mean radiation that is unrelated to a specific experiment. Levels vary, depending on location.

Baseline concentration: The concentration of a given substance typically encountered in the area under consideration, i.e. the normal or naturally occurring level.

Beta particle: An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Contamination: Undesired radioactive materials that have been deposited on surfaces, are internally ingrained into structures or equipment, or that have been mixed with another material.

Curie: A special unit of activity. One curie equals 3.7×10^{10} nuclear disintegrations per second. Several fractions of the curie are in common usage:

- Millicurie - one thousandth of a curie. Abbreviated as mCi.
- Microcurie - one millionth of a curie. Abbreviated as μCi.
- Nanocurie - one billionth of a curie. Abbreviated as nCi.
- Picocurie - one trillionth of a curie. Abbreviated as pCi.

Daughter: The product of radioactive decay of a nuclide. (also see Parent).

Decay, radioactive: The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of original radioactive nuclides in a sample. It involves the emission from the nucleus of alpha particles, beta particles, or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.

Decontamination: Those activities employed to reduce the levels of contamination.

Dose: A measure of the quantity of radiation absorbed in a unit mass of a medium. The unit of dose is the rad.

Dose rate: The radiation dose delivered per unit time and measured, for example, in rads per hours.

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

Exposure rate: The radiation exposure per unit time. Measured, for example, in roentgens per hour.

Gamma radiation: High-energy, short-wave length electromagnetic radiation of nuclear origin (radioactive decay). Gamma rays are

the most penetrating of the three common types of radiation.

Half-life: The time in which half the atoms of a particular radioactive sustance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.

Microrad (μrad): A submultiple of the rad, equal to one-millionth of a rad. (see rad).

Microroentgen (μR): A submultiple of the roentgen, equal to one-millionth of a roentgen. (see roentgen).

Millirem (mrem): A submultiple of the rem, equal to one-thousandth of a rem. (see rem).

Natural uranium: Uranium as found in nature, containing 0.7 percent of uranium-235, 99.3 percent of uranium-238. It is also called normal uranium.

Natural thorium: Thorium as found in nature. Natural thorium contains equal activity level of thorium-232 and thorium-228.

Parent: A radionuclide which disintegrates or decays to produce another nuclide which is also radioactive. This second radionuclide is known as the daughter product.

Picocurie (pCi): One-trillionth (10^{-12}) of a curie.

Rad: The unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joules/kilogram of absorbing material.

Radiation: Energetic nuclear particles including neutrons, alpha particles, beta particles, x-rays, and gamma rays (nuclear physics). Also includes electromagnetic waves (radiation) of any origin.

Radioactivity: The property of certain nuclides of spontaneously emitting particles, or gamma radiation. Often shortened to "activity."

Radionuclide: A general term applicable to any radioactive form of the elements, a radioactive nuclide.

Radium (Ra): A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite, and other minerals; the uranium decays to radium in a series

of alpha and beta emissions. By virtue of being an alpha- and gamma-emitter, radium is used as a source of illuminescence and as a radiation source in medicine and radiography. The isotope of radium with an atomic weight of 228 is found in the thorium decay series.

Radon (Rn): The heaviest element of the noble gases, produced as a gaseous emanation from the radioactive decay of radium. Its atomic number is 86. All isotopes are radioactive. Rn-222 is an isotope with a half-life of 3.82 days.

Rare earths: A group of 15 chemically similar metallic elements, including elements 57 through 71 on the Periodic Table of the Elements, also known as the Lanthanide Series.

Rem: The unit of ionizing radiation that produces the same biological damage to man as a unit of absorbed dose (1 roentgen) of high voltage x-rays.

Roentgen (R): A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions.

Secular Equilibrium: The state which prevails when the rate of formation of a radioactive material equals the material's rate of decay. Although, by theory, this condition is never completely achieved, it is essentially established in the thorium decay series as it occurs in nature.

Survey: An evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions.

Thorium (Th): A naturally occurring radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232.

Thorium series: The series (sequence) of nuclides resulting from the radioactive decay of thorium-232. Many man-made nuclides decay into this sequence. The end product of the sequence in nature is lead-208.

Uranium (U): A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natual uranium) and uranium-238 (99.3 percent of natural uranium). Natural uranium also includes a minute amount of uranium-234.

Uranium series: The series (sequence) of nuclides resulting from the radioactive decay of uranium-238. The end product of the series is lead-206.

EXPLANATION OF SYMBOLS AND UNITS

Symbols	Unit	English Equivalents
cm	centimeter (x 10^{-2} meters)	0.394 inches
g	gram	0.032 ounces
h	hour	-----
kg	kilogram (x 10^{3} grams)	2.2 pounds
km	kilometer (x 10^{3} meters)	0.622 miles
l	liter	0.264 gallons
m	meter	3.28 feet
ml	milliliter (x 10^{-3} liters)	0.061 cubic in.
mrem	millirem (x 10^{-3} rem)	-----
pCi	picocurie (x 10^{-12} curies)	-----
Ra	Radium	-----
U	Uranium	-----
Th	Thorium	-----
µCi	microcurie (x 10^{-6} curies)	-----
µrad	microrad (x 10^{-6} rads)	-----
µR	microroentgen (x 10^{-6} roentgens)	-----

APPENDIX B

THORIUM AND URANIUM DECAY SERIES

THORIUM DECAY SERIES

Parent	Half-Life	Major Decay Products	Daughter
Thorium-232	14 billion years	alpha	Radium-228
Radium-228	5.8 years	beta	Actinium-228
Actinium-228	6.13 hours	beta, gamma	Thorium-228
Thorium-228	1.91 years	alpha	Radium-224
Radium-224	3.64 days	alpha	Radon-220
Radon-220	55 seconds	alpha	Polonium-216
Polonium-216	0.15 seconds	alpha	Lead-212
Lead-212	10.6 hour	beta, gamma	Bismuth-212
Bismuth-212	60.6 minutes	alpha (1/3)* beta (2/3)*	Thallium-208 Polonium-212
Thallium-208	3.1 minutes	beta, gamma	Lead-208
Polonium-212	0.0000003 seconds	alpha	Lead-208
Lead-208	stable	none	none

* Two decay modes are possible for Bismuth-212.

URANIUM DECAY SERIES

Parent	Half-life	Major Decay Products	Daughter
Uranium-238	4,500,000,000 yrs.	alpha	Thorium-234
Thorium-234	24 days	beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	beta, gamma	Uranium-234
Uranium-234	250,000 years	alpha	Thorium-230
Thorium-230	80,000 years	alpha	Radium-226
Radium-226	1,600 years	alpha	Radon-222
Radon-222	3.8 days	alpha	Polonium-218
Polonium-218	3 minutes	alpha	Lead-214
Lead-214	27 minutes	beta, gamma	Bismuth-214
Bismuth-214	20 minutes	beta, gamma	Polonium-214
Polonium-214	2/10,000 second	alpha	Lead-210
Lead-210	22 years	beta	Bismuth-210
Bismuth-210	5 days	beta	Polonium-210
Polonium-210	140 days	alpha	Lead-206
Lead-206	stable	none	none

APPENDIX C

MAJOR ANALYTICAL EQUIPMENT

APPENDIX C

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)

25 mg Californium-252 Source with
Flexo-Rabbit Pneumatic Transfer system
(Reactor Experiments, Inc., San Carlos, CA)

Multichannel Analyzer
Model TN-7200
(Tracor Northern, Middleton, WI)

APPENDIX D

ANALYTICAL PROCEDURES

APPENDIX D

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 natural thorium source. The conversion factor determined was 1.0 cpm = 1 μrad/h.

Soil and Sediment Sample Analysis

Soil and sediment samples were sifted to remove rocks (the fraction removed constituted <5% of the total), 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 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 approximately equal concentrations of Th-232 and Th-228, confirming that the thorium series is in equilibrium in the off-site residues.

All soil and sediment samples were analyzed for U-238 and U-235 by gamma spectrometry. Samples with detectable levels of uranium were subsequently analyzed for U-238 by neutron activation. Approximately 19-20 g of soil were irradiated for 15 minutes in a neutron flux of 10^8 n/cm^2/sec. After a one minute wait time, the U-239 peak (74.6 keV) was counted for 10 minutes and the U-238 concentration calculated.

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 and Gross Beta 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.

Radium-226/228 Analysis

Samples were analyzed for Ra-226 and 228 using the standard technique EPA 600/4-75-008 (Revised).

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.

APPENDIX E

EVALUATION OF RADIATION EXPOSURES ALONG SHEFFIELD BROOK WAYNE, NEW JERSEY

Appendix E

Evaluation of Radiation Exposures
Along Sheffield Brook
Wayne, New Jersey

The survey of Sheffield Brook indicates that the streambeds and bank soils of the brook and two drainage streams contain radioactive material in concentrations exceeding the normal background levels. Elevated concentrations of this material are also present on some of the adjacent properties.

The radionuclides present are from the thorium and uranium decay series. These are naturally occurring substances, believed to have been created when the earth was formed, and present today in small quantities throughout our environment. They occur in soil, air, water, food, etc., and are the sources of a portion of the background exposure each person receives daily. Soils in the United States typically have thorium (Th-228 and Th-232) and uranium (U-234 and U-238) levels of 2 pCi/g and 1.2 pCi/g, respectively.[1] Thorium concentrations in igneous rock are typically 2.6 pCi/g.[2] Uranium concentrations in Florida phosphate rock and Tennessee bituminous rock average 80 pCi/g and 30-50 pCi/g respectively. Radiation exposures arising from these radioactive substances in their natural state are not the result of man's activities and, to a large extent, can be controlled only by relocating to regions of lower background levels.

Thorium is the principal radioactive substance present along Sheffield Brook. It is present in its natural form with all daughter products in equilibrium (refer to Appendices A and B). Radionuclides from the uranium decay series are present in lower concentrations than the thorium, e.g. the average concentration of radium-226, one of the decay products in the uranium series, is less than 5% of the thorium levels. Evaluations of various exposure pathways for thorium have determined that the primary pathway is direct exposure to the gamma radiation associated with this decay series.[3,4] Although additional exposures may be received through ingestion of contaminated food or water or through inhalation of airborne radioactive materials, contributions from the pathways are very small compared to that from direct radiation.

The National Council on Radiation Protection and Measurements has recommended a maximum annual whole-body dose equivalent of 500,000 microrem (μrem) per year to an individual in the general population.[5] This is equivalent to a continuous level of approximately 57 microrem per hour (μrem/h). The maximum exposure level measured at one meter above the ground along Sheffield Brook is 270 microroentgens per hour (μR/h); the average exposure level is 49 μR/h. To calculate the annual exposure which might be received it is necessary to first estimate the amount of time that would be spent in the areas where these radiation levels occur. This is referred to as the "occupancy factor"; an occupancy factor of 10% - an average of 16.8 hours per week, 52 weeks per year - was selected for this purpose. It is felt that this is an overestimate of the occupancy time and will therefore lead to a conservative overestimate of the radiation exposure and potential health effects. If an individual were to spend 10% of his or her time in the maximum and average radiation levels at this site, the annual dose equivalent above background would be approximately 201,000 μrem and 31,400 μrem respectively. The latter value, based on the average exposure level, is more likely representative of the radiation an individual might receive at this site. This value can be compared with the annual natural background radiation of approximately 70,000 μrem which residents of the Wayne-Pompton Plains area receive from direct external exposures or the approximately 20,000 μrem per year received from the radionuclides (e.g. K-40) normally present in the human body. Also, for comparison, a typical chest x-ray (according to data from the Department of Health and Human Services) might yield an exposure of about 27,000 μR.

The primary health effect associated with radiation exposure is an increased risk of cancer. In this connection, an individual exposed continually for 70 years to the estimated average dose rate of 31,400 μrem/year would receive a dose of approximately 2.2 rem over the entire period. Based on a lifetime risk estimate of 100 fatal cancers per million people exposed to 1 rem of radiation*, the estimated increased risk of fatal cancers from 2.2 rem of radiation exposure is 0.22 deaths per 1000 total deaths. This may be compared with the cancer death rate in Passaic County, according to the 1977 vital statistics (not age adjusted), of 222.3 cancer deaths per 1000 total deaths.

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* *Calculated from risk estimates provided in the 1980 National Academy of Sciences report, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," and the 1977 report by the U.S. Scientific Committee on Effects of Atomic Radiation.*

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