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Material Safety

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Commission

RADIOLOGICAL ASSESSMENT OF BALLOD ASSOCIATES PROPERTY (STI CHEMICAL COMPANY) MOOD, NEW JERSEY

L. W. COLE

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

FINAL REPORT

July 30, 1981

RADIOLOGICAL ASSESSMENT OF BALLOD AND ASSOCIATES PROPERTY (STEPAN CHEMICAL COMPANY) MAYWOOD, NEW JERSEY

Leslie W. Cole, Jim Berger, Phyllis Cotton,
Robert Gosslee, Jonathan Sowell, Clayton Weaver

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Oak Ridge, Tennessee 37830

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RADIOLOGICAL ASSESSMENT OF BALLOD AND ASSOCIATES PROPERTY (STEPAN CHEMICAL COMPANY) MAYWOOD, NEW JERSEY

INTRODUCTION

Ballod Associates property is approximately 2.8 hectares and projects into a residential area in Maywood, New Jersey. The eastern boundary is New Jersey State Highway 17 which is also the boundary between the towns Rochelle Park and Maywood, New Jersey; the northern boundary is the New York Susquehanna and Western Railroad. A railroad spur to Stepan Chemical Company crosses the northeast corner. The terrain is generally level, interspersed with shallow ditches and slight mounds. An underground stream passes through the area in an east to west direction coming to the surface about 200 meters west of the site, and eventually flowing into the Saddle River. Ground cover is primarily 5 to 15 cm high weeds with some weeds up to two meters tall and young to mature trees on the northern and northwestern section. Private residences border the property on the south and west. The location and layout of the site are shown on Figures 1 and 2.

During World War I Maywood Chemical Company of Maywood, New Jersey began processing thorium ores to extract thorium as a raw material for use in gas lantern mantels and other rare earth metals for various uses. The company continued this processing into the mid-1950's. The processed wastes from the operations, some of which contained low concentrations of thorium, were pumped to the lower lying areas to the west of the processing facilities, the property now belonging to Ballod Associates. Earthen dikes were constructed to control the distribution of the wastes. The approximate location of two of these dikes is indicated on Figure 2. The dike along the south edge was constructed to divide the area into what was known as the "north dike" area and the "south dike" area. The smaller dike in the northeast corner was a containment dike for a major waste pile. Waste from both dike areas has been partially removed.

A number of alterations in the general appearance of this area have been made over the years. New Jersey State Highway 17 was constructed through the Maywood Chemical Company property in the early 1930's, effectively dividing the disposal area from the remainder of the property. Several road underpasses were constructed apparently to allow continued use of the disposal site.

Maywood Chemical Company was purchased by Stepan Chemical Company in 1959. In 1966 and 1967, wastes were removed from the south dike area and a radiological survey of the property was performed in September 1968 by the Atomic Energy Commission. Based on the findings of that survey, clearance was granted for release

of the property for unrestricted use. At the time of the survey there was unawareness of the waste material existing in the northeast corner. Late in 1968 this property was sold by Stepan Chemical Company to Mr. A. Baresi. The current owners, Ballod Associates, acquired the site from Mr. Baresi several years ago. Over the past few years the property has been used primarily for unauthorized trash disposal by local residents. The local youth also find it a convenient playground.

Elevated radiation levels on the property, particularly in the northeast corner, were brought to the attention of the Nuclear Regulatory Commission (NRC) in late 1980. This information prompted the NRC to request a comprehensive survey to assess the radiological conditions on the property.

RADIOLOGICAL SURVEY PLAN

This survey was performed to provide information regarding the radiological status and to locate and quantify thorium deposits which may remain on the property as a result of operations conducted by Maywood Chemical Company. The survey was performed by five members of the Radiological Site Assessment Program of Oak Ridge Associated Universities during the period February 9, 1981 through February 13, 1981. Assistance was provided by a representative from the Region I Office of the NRC. The survey included the following measurements:

1. External gamma radiation and beta-gamma radiation levels at the surface and at one meter above the surface at 15.25 meter intervals over the entire property.

2. Surface gamma radiation levels at 3 meter intervals in two small areas - generally those areas enclosed by the two dikes described above.

3. Subsurface gamma radiation levels at 30 centimeter intervals in 38 boreholes.

4. Concentrations of Th-232 and daughters, Ra-226, U-235, U-238, and K-40 in surface soil samples at 53 locations.

5. Concentrations of Th-232 and daughters, Ra-226, U-235, U-238, and K-40 in 86 subsurface soil samples taken in 38 boreholes.

6. Concentrations of Th-232 and daughters, Ra-226, U-235, and U-238, in 14 water samples taken from the boreholes, one sample of standing surface water, and one sample taken from the outfall of the underground stream, approximately 200 meters west of the site.

7. Concentrations of Th-232 and daughters, Ra-226, U-235, U-238, and K-40 in one sediment sample taken at the underground stream outfall, west of the site.

8. Concentrations of Th-232 and daughters, Ra-226, U-235, U-238, and K-40 in 11 vegetation samples.

9. Baseline concentrations of radionuclides in six surface soil and four water samples obtained in the Bergen County area, approximately 5-8 km from the survey site.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of External Gamma Radiation and Beta-Gamma Radiation Levels

A 30.5* meter grid system was established on the property to provide survey and sampling location reference points (Figure 3). Gamma radiation levels were measured at the surface and one meter above the surface at 15.25 meter intervals over the grid system, using gamma scintillation ratemeters. Beta-gamma and gamma radiation levels at one centimeter above the surface were determined using energy-compensated Geiger Mueller (G-M) ratemeters in the shield-open and shield-closed configurations respectively.

This systematic survey identified two small areas having radiation levels significantly higher than the remainder of the site. In these areas, surface contact measurements were made at approximately three meter intervals using the gamma scintillation ratemeter.

Measurements of Gamma Radiation in the Boreholes

To sample and measure subsurface radionuclide deposits, boreholes were drilled to the depth of the standing water or below the lower level of the waste fill in 38 locations on the property (see Figure 4). Most of the holes were drilled with a six or eight inch hollow stemmed auger. In those areas where high subsurface concentrations of radionuclides were suspected, based on the surface radiation measurements, a hand-operated bucket auger was used. Surface debris and subsurface obstructions dictated the locations of the boreholes in some cases. At several of the borehole locations the surface had been disturbed by bulldozing to facilitate access by the grid surveyors and drilling equipment.

A collimated NaI(Tl) gamma scintillation probe was lowered into each borehole and gamma radiation measurements made at 30 centimeter intervals. In holes where the gamma radiation levels were notably high, measurements were made at 15 centimeter intervals.

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* *Grid established was actually 100 ft.*

Soil Sampling

Surface (to 5 cm) soil samples were collected at 53 locations on the property and one sediment sample was taken approximately 200 meters west of the site at the outfall of the underground stream. Locations of these samples are indicated on Figure 5.

Subsurface soil samples were obtained at random depths from boreholes providing no significant radiation levels. In those boreholes indicating elevated radiation levels, samples were taken at depths corresponding to the elevated levels. Except in the hand dug holes, samples were scraped from the hole wall with a specially constructed sampler. The side of the hole was initially scraped to lessen the possibility that the sample might contain soil from other depths, transferred by the drilling operation. In the hand-augered holes, samples were taken with the bucket auger.

Water Sampling

Water samples (one liter) were collected from 14 of the boreholes drilled during the survey, from one surface puddle, and from the stream outfall approximately 200 meters west of the site. The actual locations are indicated on Figure 6. The soft soil made collection of the water samples difficult due to frequent "cave-ins" of the boreholes upon removal of the auger. Some samples were taken through the auger stem; however, this method also was only partially successful due to the nature of the soil.

Vegetation Sampling

Vegetation samples were collected at 11 locations on the property, as indicated on Figure 7. These samples consisted of grass, weeds, and other plants characteristic of the selected location. Most of the sampled vegetation was dry since it was mid-winter.

Sample Analysis and Interpretation of Data

Samples were analyzed for Th-232 and daughters, U-238, U-235, Ra-226, and K-40. Appendix A contains a description of the equipment used in this survey and a discussion of the analytical procedures.

RESULTS OF SURVEY MEASUREMENTS

External Radiation Measurements

Results of external gamma radiation measurements are presented in Figures 8 and 9. The maximum surface level observed was 3.6 mR/h. in the northeast corner of the property, enclosed by the containment dike. In the area of the south dike the highest surface gamma radiation level was 0.68 mR/h. Radiation levels at 1 meter above the surface at these same locations were 1.6 mR/h and

0.40 mR/h respectively. In the northwestern and southwestern portions of the site, gamma radiation levels were less than 10 μR/h, corresponding to the normal background in this area. Levels of beta-gamma radiation, at 1 cm above the surface did not differ significantly from the gamma levels.

Borehole Radiation Measurements

Borehole measurements indicated elevated subsurface radiation levels which correlated generally with levels of radionuclides determined in the subsurface soil. Varying ratios of radium, uranium, and K-40 however, prevented quantitative soil analysis by the borehole logging technique alone. Analysis by gamma spectrometry was therefore used to determine the subsurface soil concentrations (refer to the following section).

Radionuclide Concentrations in Soil Samples

The radionuclide concentrations in the surface soil samples are listed in Table 1. Concentrations up to approximately 2500 pCi/gm of Th-232 *, 50 pCi/gm of Ra-226 and 250 pCi/gm of U-238 were found in the northeast corner. Additional scattered areas of surface soil containing in excess of 5 pCi/gm of Th-232 and/or Ra-226 were noted near the south dike area, and at two isolated locations where small quantities of waste had apparently been dumped (see Figure 10). Other surface soil concentrations are comparable to the levels of radionuclides in baseline samples. (Refer to section on background samples.)

Analysis of the borehole soil samples is tabulated in Table 2. Figures 11-13 show the concentration of Th-232 at the various depths in those holes with subsurface concentrations greater than 5 pCi/gm. A number of these same boreholes also have Ra-226 concentrations greater than 5 pCi/gm with several exceeding 100 pCi/gm. The highest concentrations noted are near the surface in the areas of the two dikes, although there are six locations with Th-232 concentrations exceeding 5 pCi/gm at depths of 90 centimeters or more. The vertical profile of subsurface concentrations and comparison of direct measurements with the soil analysis suggests that in several of the hand augered boreholes, cross contamination may have occurred.

Radionuclide Concentrations in Water Samples

The results of water sample analyses, provided in Table 3, indicate that subsurface concentrations of Ra-226, Th-232, U-235, and U-238 are within the 10CFR20 limits. Samples of surface water and water from the underground stream are also within the acceptable limits for these radionuclides.

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* *Analysis of various Th-232 daughter products indicated this decay series is present in approximate secular equilibrium.*

Radionuclide Concentrations in Vegetation Samples

The results of vegetation sample analyses are presented in Table 4. Those samples obtained from the northeast corner of the property contained higher levels (to 18 pCi/gm) of Th-232 than those from the rest of the property. Elevated levels (to 2.2 pCi/gm) of Ra-226 were also observed in several samples taken from areas of high soil concentrations.

BACKGROUND RADIONUCLIDE LEVELS IN THE BERGEN COUNTY AREA

Background surface soil samples were obtained from six locations, approximately 5-8 kilometers from the site. Background water samples were collected from the Saddle, Passaic, and Hackensack Rivers and from the City of Maywood water supply. Locations of these samples are indicated in Figure 14. The analytical results for the background soil and water samples are presented in Table 5 and 6. Thorium-232, radium-226, and uranium-238 concentrations in soil were in the ranges of 0.58 to 1.1, 0.42 to 0.87, and < 2.3 to pCi/gm respectively. Water concentrations of Th-232 and U-238 were below the minimum detection limits of the procedures, and Ra-226 concentrations in unrestricted background water samples were up to 5% of the permissible concentration of 9×10^{-11} μCi/ml, which is the detection limit of 3×10^{-8} μCi/ml. 0.3% of the permissible levels are generally consistent with ranges of background geologic formations throughout those typical of similar this is a slightly higher level United States. One exception to uranium in the soil.

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* *Title 10, Code of Federal Regulations, Part 20, Appendix B, Table II, Column 2.*

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of Ms. Myu Campbell, NRC Region I for her invaluable assistance during the survey and her patience during the analysis of the data. The efforts and assistance of the remaining members of the Radiological Site Assessment personnel are also appreciated, particularly, Cathy Riemke and Chris Kuechle who performed many of the sample preparations and calculations and Judy Mattina who typed the many drafts of the report before it was completed.

APPENDIX A

Sampling Techniques, Equipment Description and Analytical Procedures

Gamma Scintillation Measurements

Surface Measurements

Measurements of gamma radiation levels were performed using a Victoreen Thyac III Model 490 portable ratemeter with a Victoreen Model 489-5 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. Count rates (c/m) were converted to exposure levels (μR/hr) using a factor of 715 c/m = 1 μR/hr. This factor was determined by comparing the response of the scintillation detector with that of the Eberline PRS-1 survey meter with an energy-compensated G-M probe to gamma photons measured on the site. Both the ratemeters were calibrated with Ra-226 of known activity.

Borehole Gamma Radiation Measurements

Borehole gamma radiation measurements were made with an Eberline Model PRS-1 portable ratemeter and a Victoreen Model 489-5 gamma scintillation probe. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the shield in the area nearest the scintillation detector. The probe was lowered into each hole using a tripod holder with a small winch. One minute measurements were routinely performed at 30 cm intervals in all holes and at 15 cm intervals in boreholes where elevated radiation levels were noted.

The borehole logging probe was calibrated with thorium spiked sand. It was determined that the thorium concentration could be determined from the following relationship:

$$Th = 0.0074\ (C-265)$$

Where Th is the activity of thorium in pCi/gm and C is the observed response of the detector in counts per minute.

This relationship held closely in the survey of Ballod Associates Property where concentrations of uranium, radium, or K-40 were low. Presence of these radionuclides in varying ratios however, restricted the use of this technique in all cases.

Soil Samples

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 ranged from 400 to 600 grams of soil. The beakers were capped but not sealed. Net soil weights were determined and the samples counted for 1800 seconds using a 23% Ge(Li) detector (Princeton Gamma Tech) coupled to a Nuclear Data Model 66 Multichannel Analyzer. The following energy peaks were used for determination of the radionuclides of concern:

Th-232 - 0.907 MeV from Ac-228 (secular equilibrium assumed)
Ra-226 - 0.609 MeV from Bi-214
U-235 - 0.185 MeV
U-238 - 1.001 MeV from Pa-234m
K-40 - 1.460 MeV

The background plus compton continuum was "stripped" by hand calculations from each of the photopeaks of interest, prior to applying appropriate calibration and correction factors.

Initial analysis included determination of Ac-228, Pb-212, and Tl-208 concentrations. Activity ratios of these radionuclides indicated essentially secular equilibrium of the Th-232 series. Therefore the Ac-228 photopeak was used for all gamma spectrum analyses for Th-232.

To evaluate the effect of possible Rn-222 losses on the equilibrium of Bi-214 with Ra-226, two soil samples were sealed in counting beakers. The relative photopeak intensities of various Ra-226 decay products were noted and compared to the relative intensities of capped, but unsealed, samples over a time period necessary for the Bi-214 peak intensity to stabilize. From this comparison it was determined that radon losses resulted in a 20% decrease in the Bi-214 concentration and that this condition reached a steady state in the unsealed sample within approximately three days after sample preparation (drying, grinding, and placing into the beakers). Sufficient time to reach this steady state was therefore allowed between sample preparation and analysis and, a correction for the 20% decrease due to radon loss was applied to all Ra-226 calculations based on the Bi-214 photopeak intensity.

For U-235 analysis, contributions in the 0.185 MeV photopeak area from the 0.186 MeV Ra-226 gamma ray were subtracted. The ratio of the 0.186 MeV to 0.609 MeV peak intensities in a laboratory prepared soil sample containing Ra-226, but no U-235, was determined and this ratio was multiplied by the intensity of the 0.609 MeV photopeak in each of the samples to determine the magnitude of this contribution.

Due to the low abundance of the Pa-234m gamma, the minimum detection limits * for U-238 are relatively high compared to the accepted concentration guidelines and statistical errors (based only on the number of events recorded) are also large. In those samples with high concentrations of uranium, the U-238/U-235 ratio was approximately that of naturally occurring uranium.

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* *The minimum detectable limit as used in this report is based on two times the standard deviation of the instrument background.*

Water Samples

Water samples were filtered using Whatman no. 2 filter paper to remove suspended solids. Each sample was analyzed by gamma spectrometry in a Marinelli beaker in the same manner as the soil samples. Aliquots of each sample were filtered through 0.45 membrane filters, radium separated by precipitation with barium sulfate and then redisolved, and the samples stored to permit radon ingrowth. Analysis for soluble Ra-226 was then performed by the radon emanation technique.

Vegetation Samples

The vegetation samples were ground to uniform size and dried at 120 °C for 24-48 hours. They were then analyzed by gamma spectrometry in Marinelli beakers in the same manner as the soil samples.

Calibration and Quality Assurance

With the exception of the exposure- and dose-rate conversion factors for portable survey gamma and beta-gamma meters, all survey and laboratory instruments were calibrated with NBS-traceable standards. The response of these survey meters was determined by comparison with a portable ionization survey meter, calibrated (±15%) with a sealed Ra-226 needle, certified by Atomic Energy of Canada, Ltd. Quality control procedures on all instruments included daily background and check-source measurements to confirm lack of malfunctions and nonstatistical deviations in equiment.

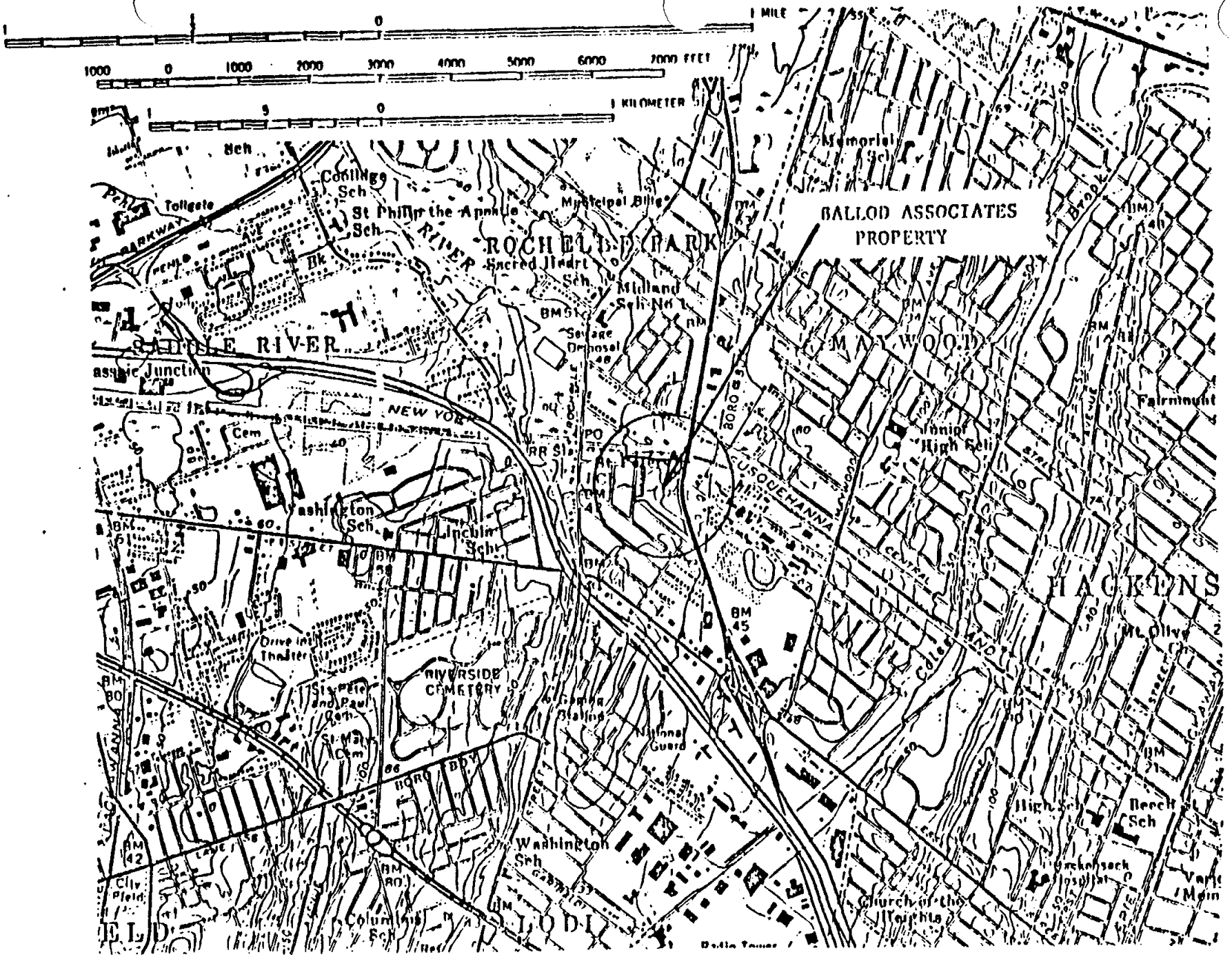


FIGURE 1. Portion of New Jersey indicating location of the Ballod Associates Property.

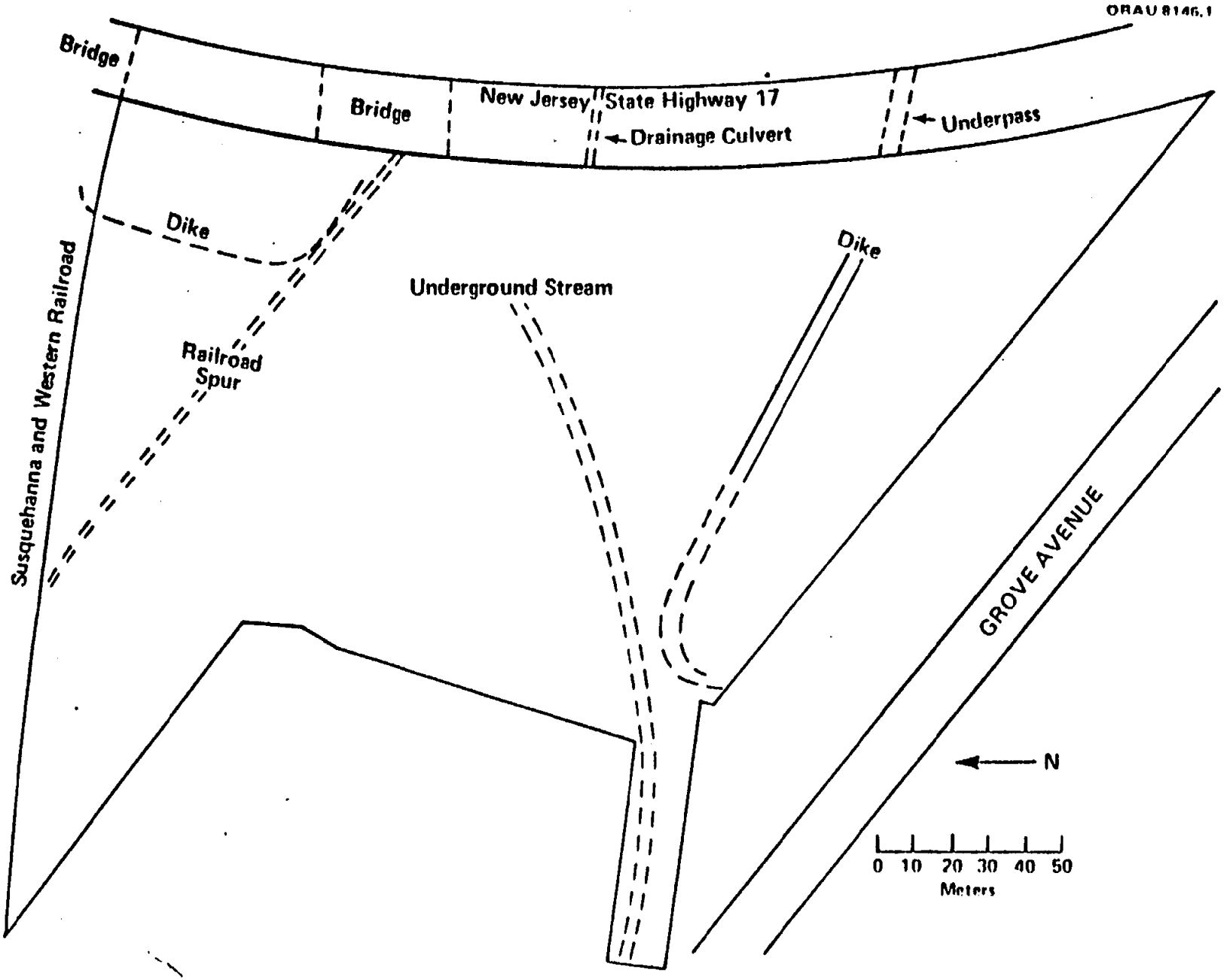
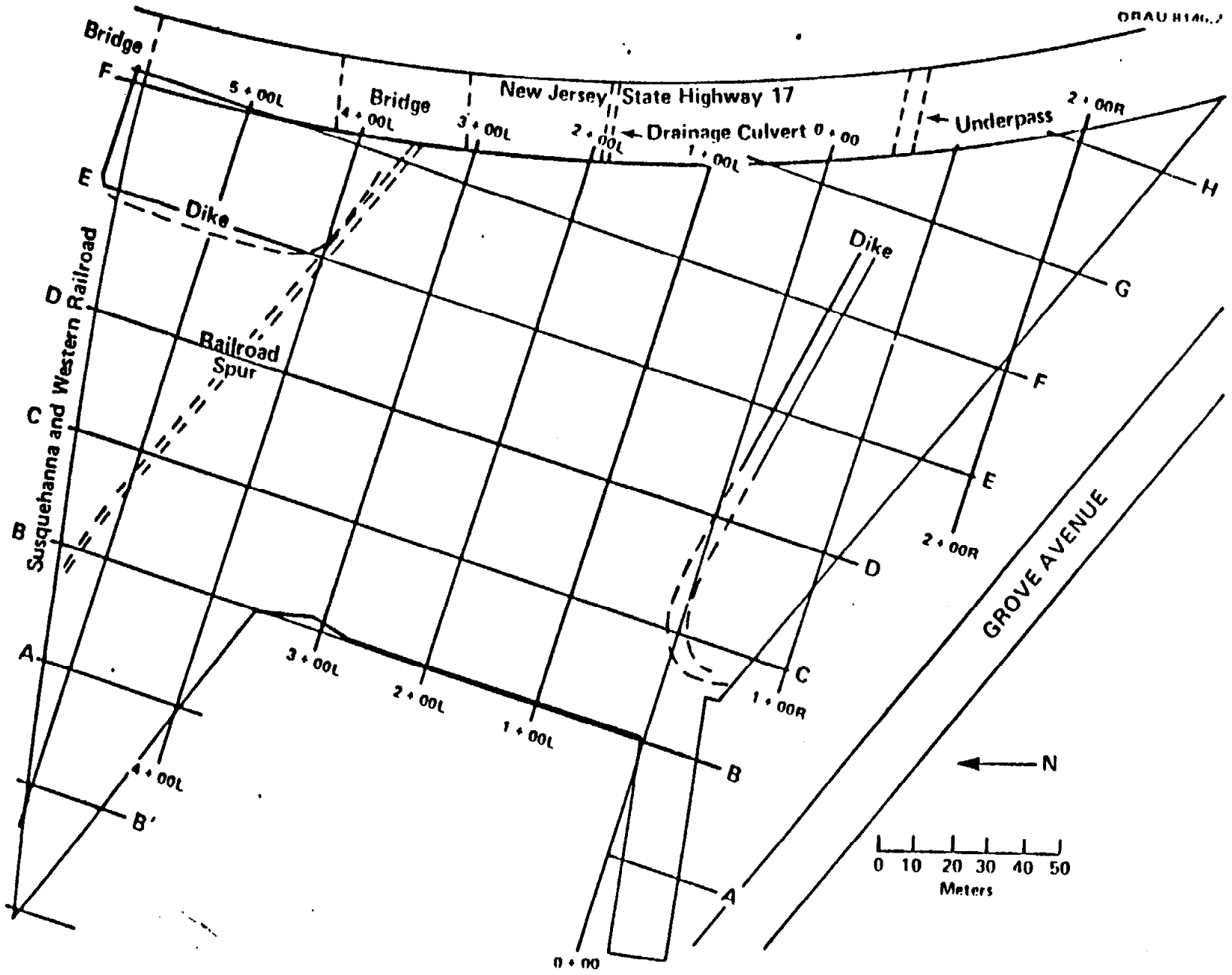


FIGURE 2. Plan View of Ballod Associates Property.


Bridge
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5 + 00L
Bridge
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New Jersey State Highway 17
2 + 00L
Drainage Culvert 0 + 00
1 + 00L
Underpass
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E
Dike
Dike
G
D
Railroad Spur
F
Susquehanna and Western Railroad
C
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D
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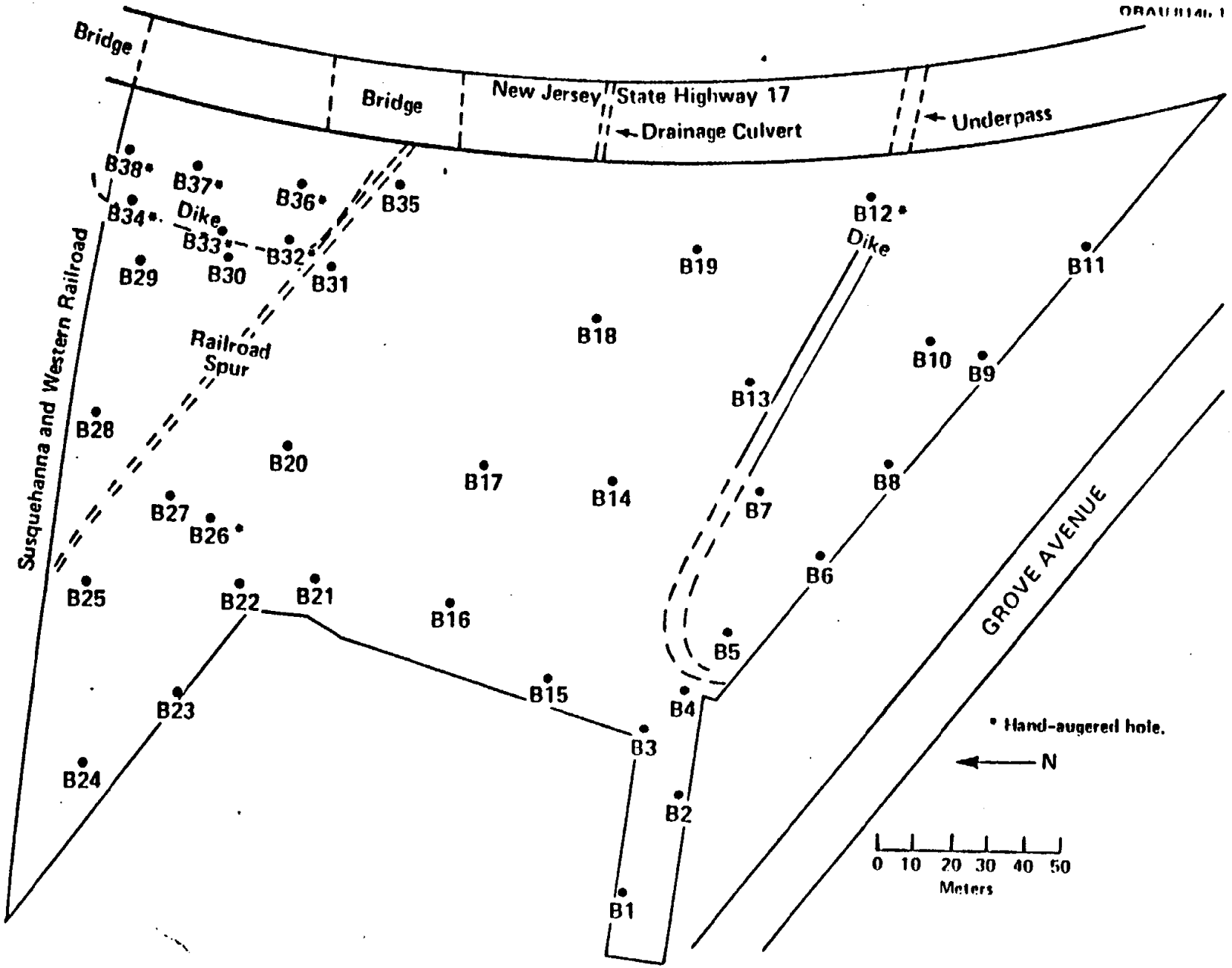
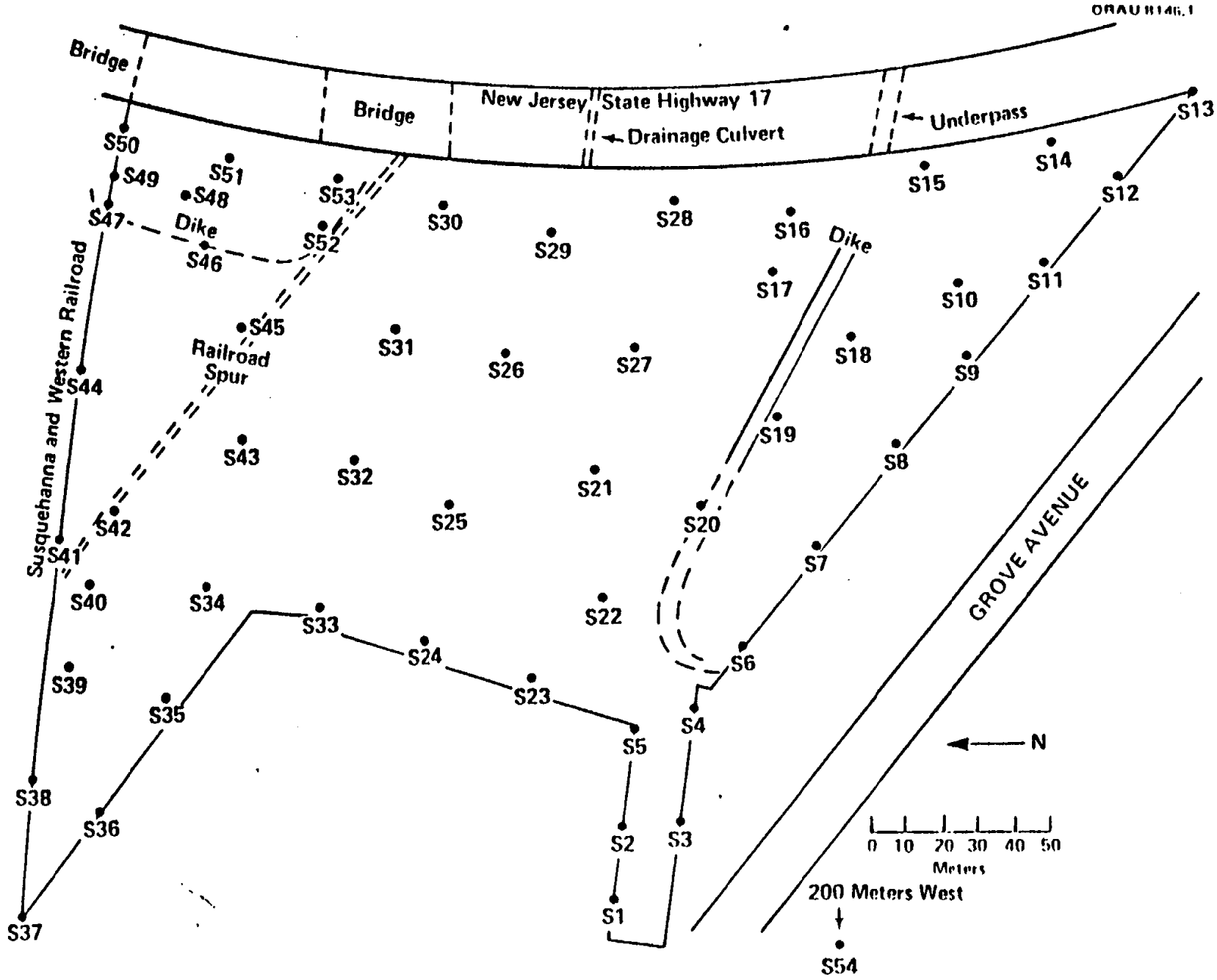


FIGURE 4. Locations of Boreholes and Subsurface Soil Samples.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Bridge
New Jersey State Highway 17
Drainage Culvert
Underpass
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S49
S51
S48
S53
S47
Dike
S52
S46
S30
S29
S28
S16
Dike
S15
S14
S13
S12
S17
S10
S11
S45
S31
S26
S27
S18
S9
Railroad Spur
S44
Susquehanna and Western Railroad
S19
S8
S43
S32
S21
S42
S25
S20
S7
S41
GROVE AVENUE
S40
S34
S33
S24
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S6
S39
S23
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S1
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S54

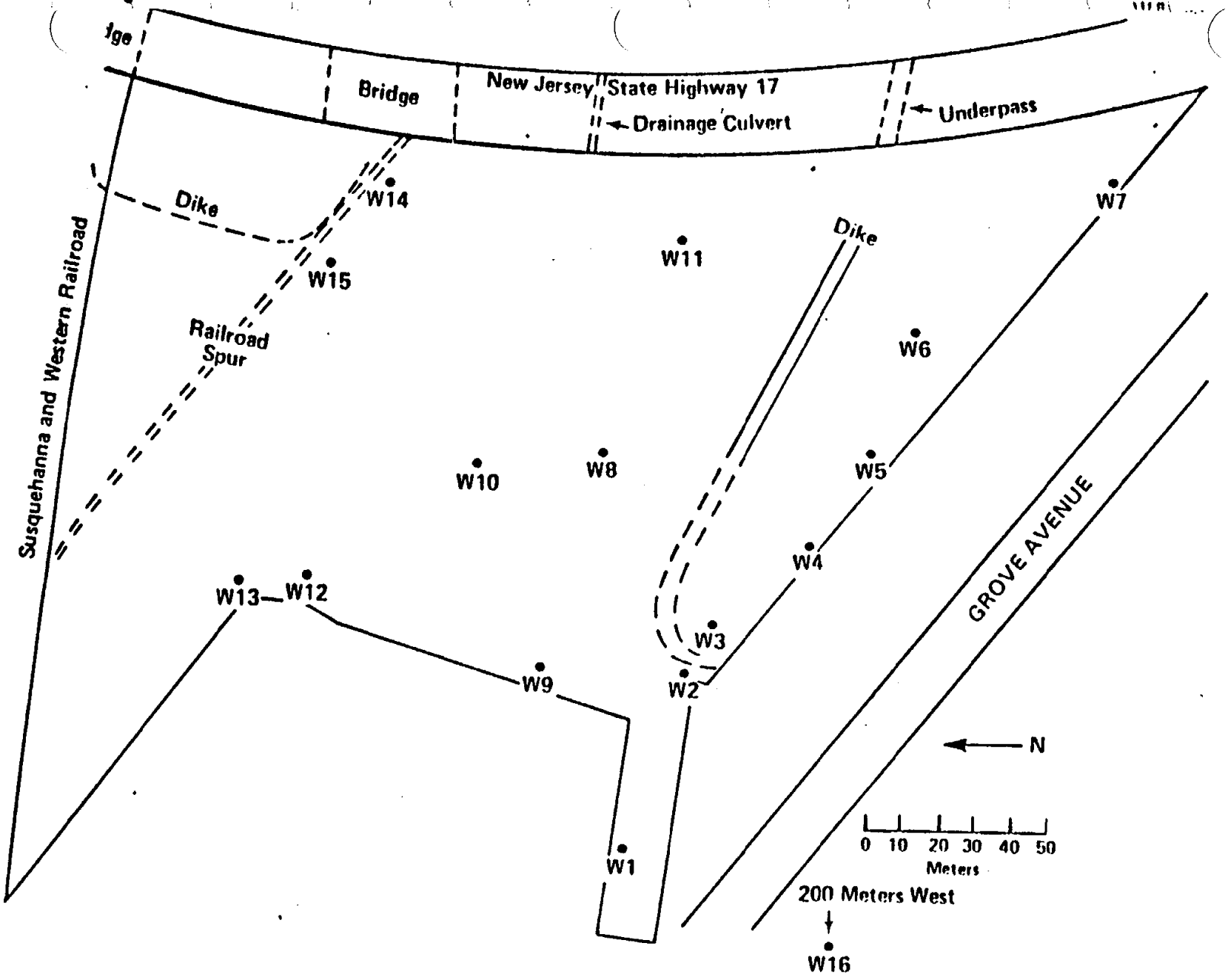

FIGURE 6. Locations of Water Samples

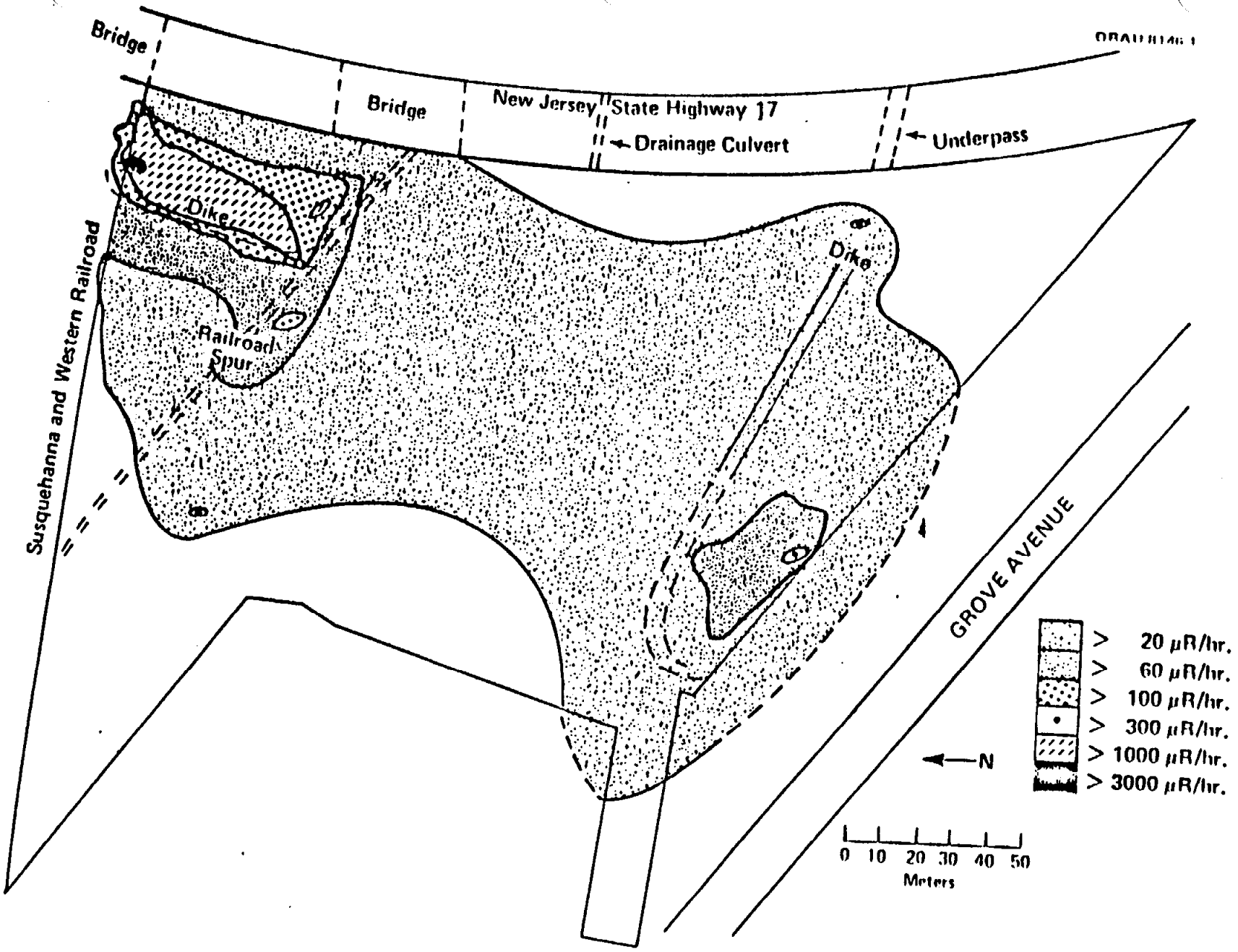

FIGURE 8. Plan View Indicating Gamma Radiation Isopleths at Surface Level.

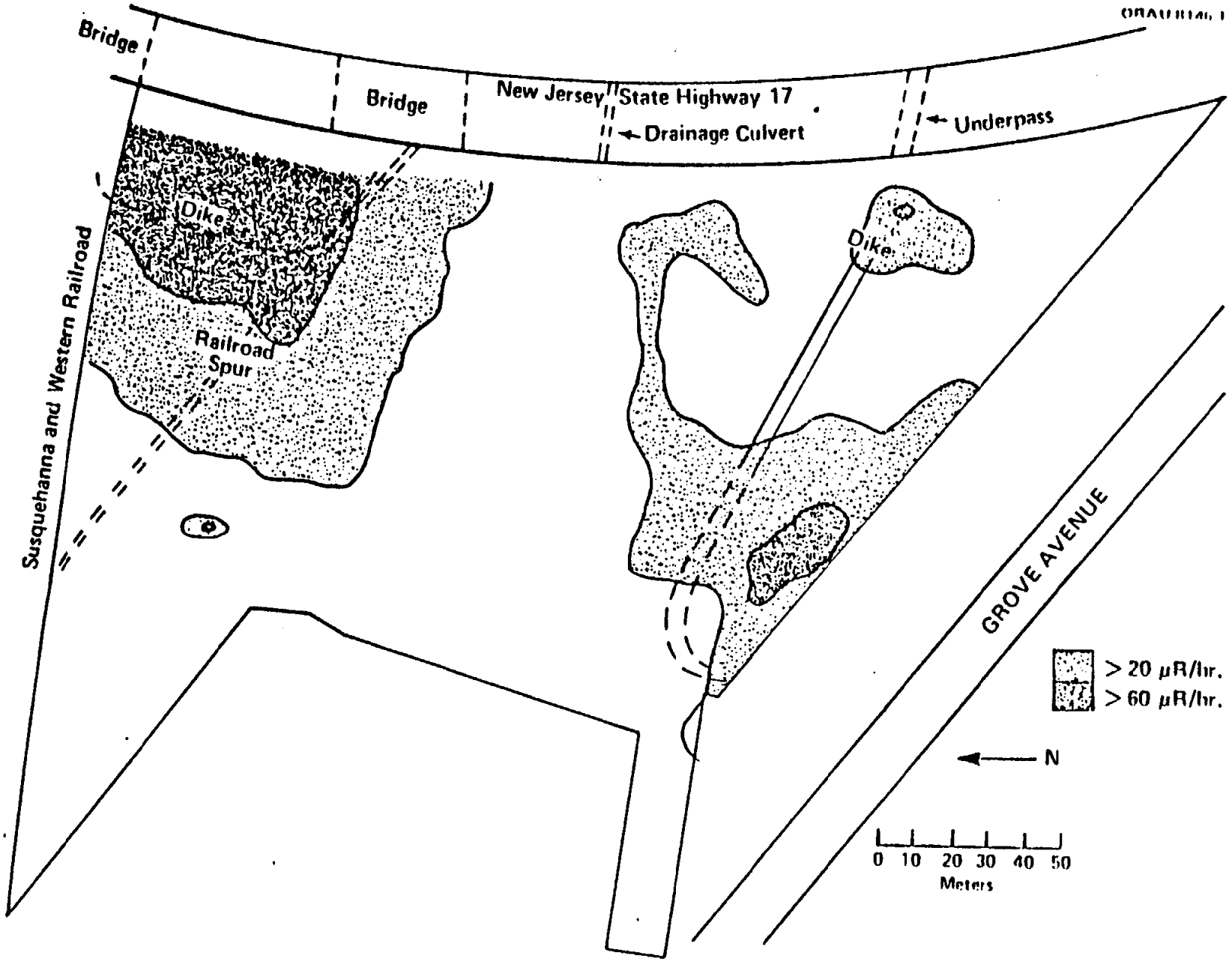

FIGURE 9. Plan View Indicating Gamma Radiation Isopleths at One Meter Above the Surface (background subtracted).

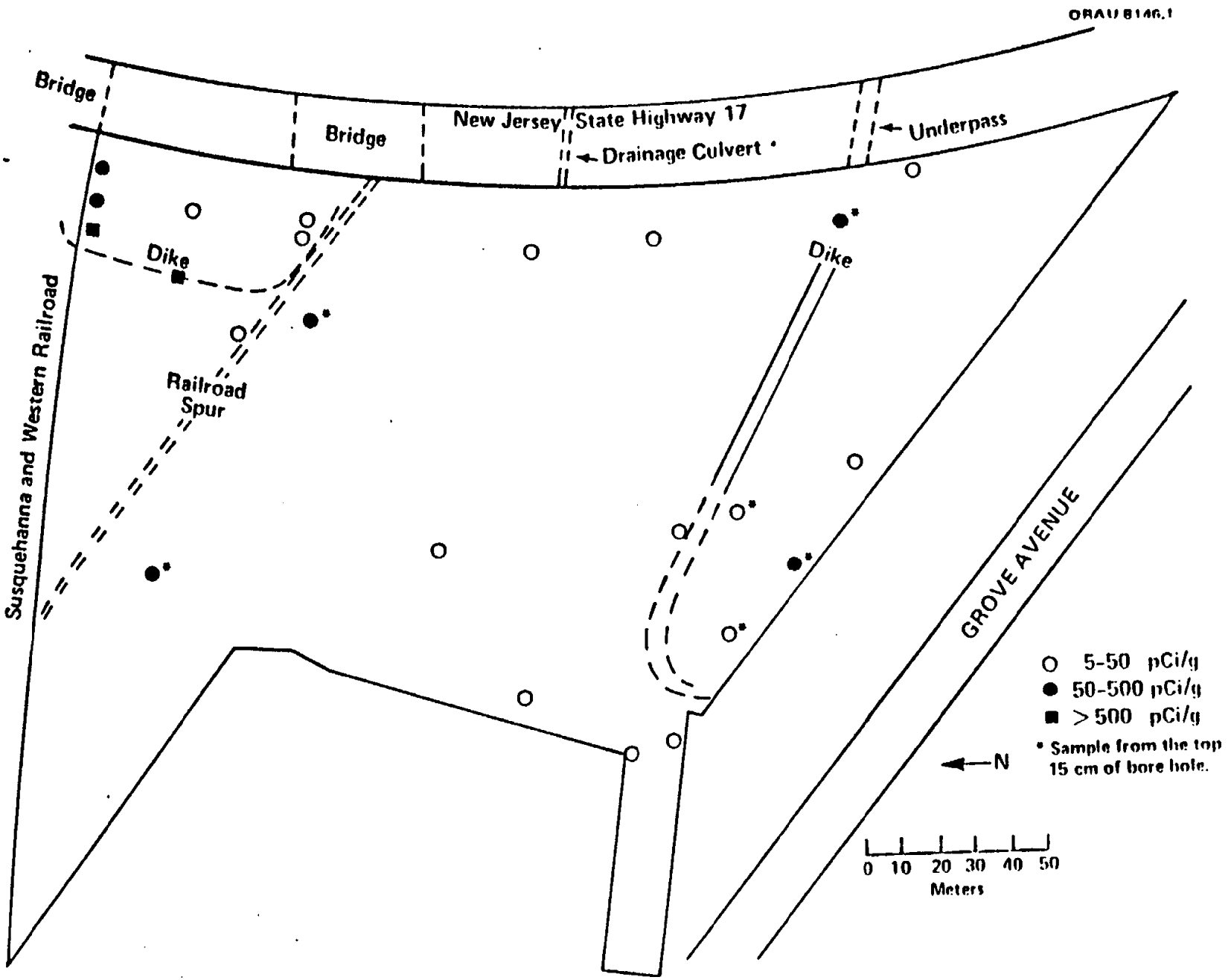

FIGURE 10. Plan View Indicating Locations of Surface Soil

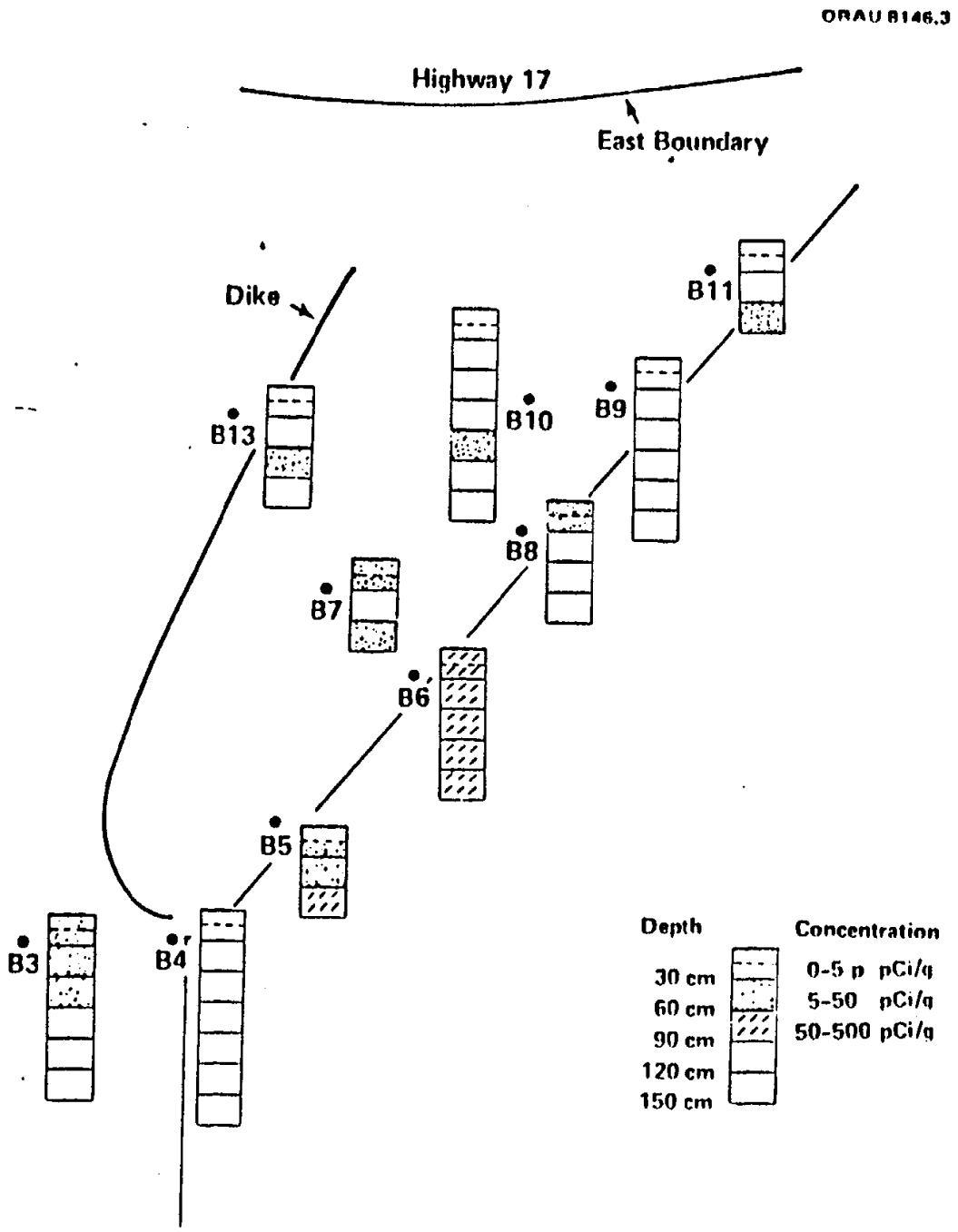

FIGURE 11. View of Southern End of Property with Subsurface

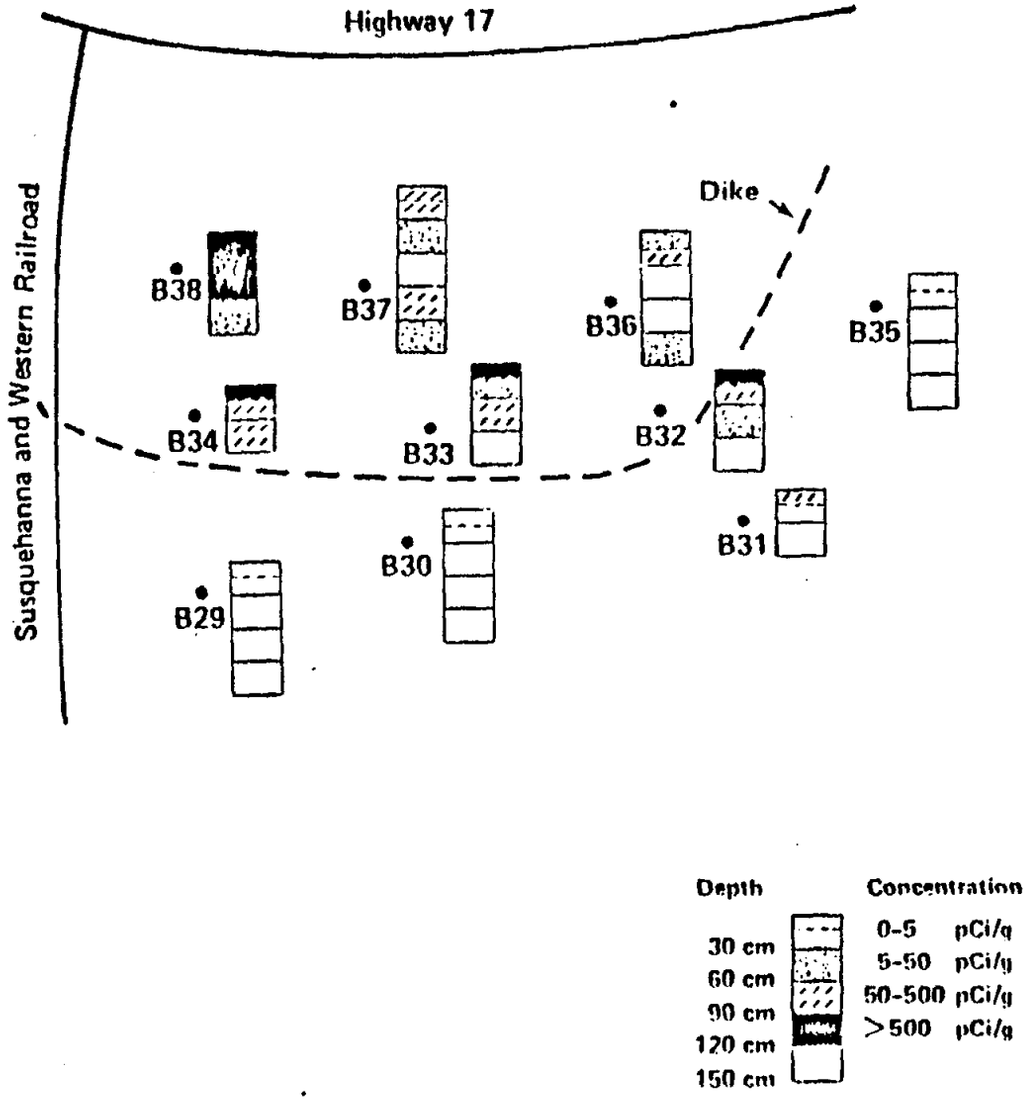

FIGURE 12. View of Northeast Corner of Property With Subsurface Th-232 Concentrations Indicated.

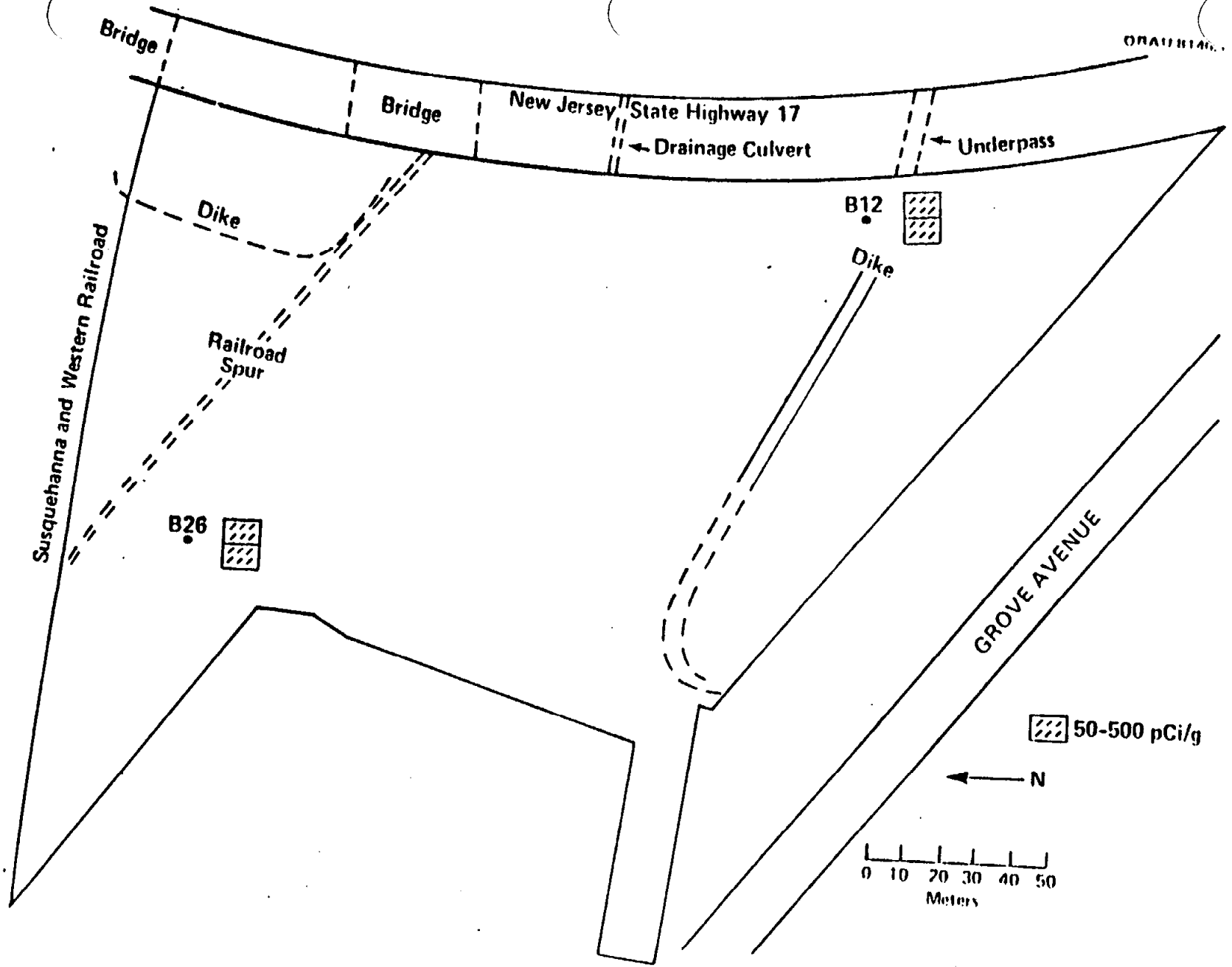

FIGURE 13. Plan View With Subsurface Th-232 Concentrations Indicated for Boreholes B12 and B26.

FIGURE 14. Locations of Background Soil and Water Samples Collected from the Maywood, New Jersey area.

TABLE 1

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL [a]

SAMPLE	CONCENTRATION (pCi/gm.)				
	Th-232	Ra-226	U-235	U-238	K-40
S1	3.8 ± 0.6[b]	0.67 ± 0.19	0.19 ± 0.09	3.5 ± 5.8	6.9 ± 1.6
S2	5.0 ± 0.7	1.6 ± 0.3	<0.05	<4.6	8.4 ± 2.0
S3	3.8 ± 0.7	0.69 ± 0.22	0.14 ± 0.11	4.2 ± 7.0	8.7 ± 2.2
S4	16 ± 1	1.3 ± 0.3	0.27 ± 0.13	4.1 ± 5.7	6.1 ± 1.2
S5	8.0 ± 0.8	0.96 ± 0.22	<0.05	4.7 ± 3.7	8.0 ± 1.7
S6	1.4 ± 0.3	0.70 ± 0.14	0.12 ± 0.05	7.0 ± 4.2	6.7 ± 1.4
S7	2.9 ± 0.4	0.89 ± 0.15	0.15 ± 0.08	6.0 ± 4.2	8.9 ± 1.4
S8	0.47 ± 0.13	2.2 ± 0.4	<0.10	9 ± 12	9.5 ± 2.6
S9	0.83 ± 0.23	0.77 ± 0.13	<0.03	<2.3	10 ± 1
S10	1.0 ± 0.3	0.64 ± 0.11	0.04 ± 0.04	3.8 ± 3.6	2.5 ± 1.4
S11	2.0 ± 0.4	0.83 ± 0.23	0.29 ± 0.07	3.9 ± 5.2	9.2 ± 1.9
S12	1.2 ± 0.3	0.48 ± 0.12	<0.03	<3.4	7.8 ± 1.2
S13	0.94 ± 0.26	0.46 ± 0.11	0.06 ± 0.04	<2.3	5.7 ± 1.3
S14	0.53 ± 0.23	0.42 ± 0.13	0.13 ± 0.05	<2.8	7.7 ± 1.5
S15	11 ± 1	1.4 ± 0.2	0.13 ± 0.09	2.5 ± 2.7	11 ± 1
S16	1.1 ± 0.4	3.7 ± 0.3	1.8 ± 0.2	41 ± 13	11 ± 2
S17	3.5 ± 0.4	0.92 ± 0.14	0.05 ± 0.06	<2.4	7.2 ± 1.1
S18	1.5 ± 0.3	0.48 ± 0.12	<0.03	2.7 ± 3.4	9.4 ± 1.4
S19	2.8 ± 0.5	1.0 ± 0.2	<0.06	9.1 ± 8.4	13 ± 2
S20	11 ± 1	1.5 ± 0.3	0.18 ± 0.14	4.2 ± 5.8	11 ± 2
S21	0.86 ± 0.23	0.61 ± 0.12	0.11 ± 0.05	1.6 ± 3.9	12 ± 1
S22	4.4 ± 0.4	0.63 ± 0.11	<0.03	2.7 ± 1.9	8.0 ± 1.0
S23	5.9 ± 0.7	0.79 ± 0.23	<0.06	6.5 ± 6.7	6.9 ± 1.6
S24	0.60 ± 0.16	0.44 ± 0.07	0.05 ± 0.03	3.4 ± 3.2	10 ± 1
S25	6.1 ± 0.8	1.5 ± 0.3	0.17 ± 0.15	9 ± 11	7.7 ± 2.2
S26	0.47 ± 0.10	0.39 ± 0.06	0.07 ± 0.03	<1.3	5.9 ± 0.9
S27	2.2 ± 0.4	0.62 ± 0.15	0.07 ± 0.07	4.3 ± 5.7	9.4 ± 1.6
S28	7.2 ± 0.6	0.91 ± 0.17	0.42 ± 0.01	11 ± 7	9.5 ± 1.4
S29	11 ± 2	3.6 ± 0.6	<0.17	<11	12 ± 4
S30	2.0 ± 0.6	1.0 ± 0.3	0.26 ± 0.13	9.1 ± 9.1	8.7 ± 2.3

ORAU

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN SUBSURFACE SOIL

SAMPLE	DEPTH (cm)	CONCENTRATION (pCi/gm)				
		Th-232	Ra-226	U-235	U-238	K-40
B1	60	0.52 ± .14	0.38 ± 0.08	0.03 ± 0.03	<1.7	7.7 ± 1.0
B2	120	0.77 ± 0.17	0.47 ± 0.09	0.03 ± 0.04	3.5 ± 3.6	8.4 ± 1.3
B3A	5	11 ± 1	1.2 ± 0.2	0.15 ± 0.09	<3.5	9.9 ± 1.2
B3B	15	14 ± 1	1.4 ± 0.2	0.27 ± 0.11	6.0 ± 6.2	11 ± 1
B3C	30	6.9 ± 0.5	0.95 ± 0.13	<0.04	6.2 ± 4.2	6.3 ± 1.1
B3D	60	2.8 ± 0.3	0.49 ± 0.09	<0.04	6.7 ± 3.8	8.9 ± 1.1
B3E	Spoil	6.6 ± 0.5	0.73 ± 0.13	0.06 ± 0.08	<2.7	7.5 ± 1.0
B4	15	3.5 ± 0.4	0.72 ± 0.14	0.07 ± 0.07	4.1 ± 3.9	7.8 ± 1.2
B5A	30	15 ± 1	2.0 ± 0.2	0.12 ± 0.14	<5.7	8.4 ± 1.0
B5B	60	44 ± 1	2.5 ± 0.3	0.35 ± 0.17	<5.4	11 ± 2
B6A	15	120 ± 5	15 ± 1	1.4 ± 0.7	<25	13 ± 6
B6B	30	83 ± 2	11 ± 1	1.6 ± 0.4	<24	40 ± 2
	120	120 ± 5	9.5 ± 1.1	1.7 ± 0.6	<18	14 ± 4
B6D	Spoil	170 ± 5	11 ± 1	1.1 ± 0.4	<18	20 ± 3
B7A	30	6.0 ± 0.4	1.2 ± 0.1	<0.04	<2.1	12 ± 1
B7B	60	1.8 ± 0.2	0.68 ± 0.11	0.10 ± 0.05	1.5 ± 1.9	8.4 ± 1.0
B7C	90	13 ± 1	2.2 ± 0.2	0.09 ± 0.12	<5.4	9.3 ± 1.5
B8A	15	7.4 ± 0.5	0.86 ± 0.17	0.09 ± 0.08	<3.2	12 ± 1
B8B	120	4.9 ± 0.3	1.1 ± 0.1	0.05 ± 0.06	<2.0	11 ± 1
B9	15	3.7 ± 0.3	0.74 ± 0.11	0.12 ± 0.05	3.9 ± 3.2	8.5 ± 1.0
B10	150	13 ± 1	2.0 ± 0.2	0.22 ± 0.13	10 ± 6	9.2 ± 1.6
B11A	15	2.8 ± 0.3	0.85 ± 0.11	0.04 ± 0.06	1.8 ± 2.8	10 ± 1
B11B	90	28 ± 1	2.0 ± 0.2	0.46 ± 0.17	1.6 ± 1.1	8.1 ± 1.4
B11C	Spoil	62 ± 2	2.5 ± 0.4	0.55 ± 0.24	24 ± 14	14 ± 2
B12A	15	200 ± 5	18 ± 1	1.9 ± 0.5	<25	24 ± 4
B12B	30	110 ± 5	8.4 ± 0.7	1.3 ± 0.3	30 ± 22	14 ± 3
B13	90	7.1 ± 0.5	0.82 ± 0.12	<0.03	<3.1	12 ± 1
B	30	3.3 ± 0.5	0.77 ± 0.11	<0.03	<2.2	12 ± 1
B14B	90	4.0 ± 0.4	0.70 ± 0.09	0.08 ± 0.05	<2.0	8.9 ± 1.2
B14C	120	4.6 ± 0.4	Sample mistakenly discarded			9.7 ± 1.3
U			Analysis not performed.			

Table 1, cont.

SAMPLE	CONCENTRATION (p Ci/gm)				
	Th-232	Ra-226	U-235	U-238	K-40
S31	0.86 ± 0.20	0.58 ± 0.11	<0.03	5.8 ± 3.7	12 ± 2
S32	0.74 ± 0.17	0.49 ± 0.09	0.03 ± 0.04	3.6 ± 3.1	8.2 ± 1.1
S33	1.2 ± 0.4	0.77 ± 0.21	0.05 ± 0.08	<2.9	1.0 ± 2.0
S34	0.70 ± 0.40	0.99 ± 0.26	<0.06	<5.0	5.4 ± 1.9
S35	0.60 ± 0.25	0.56 ± 0.15	<0.03	<1.9	5.7 ± 1.3
S36	0.90 ± 0.30	0.74 ± 0.15	0.06 ± 0.06	<2.6	5.8 ± 1.5
S37	0.54 ± 0.19	0.43 ± 0.12	<0.02	1.7 ± 2.3	3.5 ± 0.9
S38	0.80 ± 0.30	0.77 ± 0.20	<0.03	<2.9	7.1 ± 1.7
S39	0.79 ± 0.29	0.70 ± 0.18	<0.04	<4.8	6.1 ± 1.7
S40	0.53 ± 0.16	0.67 ± 0.12	<0.03	<2.3	8.1 ± 1.1
S41	0.87 ± 0.48	1.4 ± 0.4	<0.09	<5.9	5.8 ± 2.5
S42	2.1 ± 0.4	0.97 ± 0.19	0.16 ± 0.08	5.7 ± 6.1	4.9 ± 1.7
S43	2.6 ± 0.4	0.55 ± 0.14	0.10 ± 0.08	<4.6	7.9 ± 1.5
S44	0.90 ± 0.28	0.60 ± 0.15	0.17 ± 0.07	<1.6	4.4 ± 1.2
S45	11 ± 1	1.0 ± 0.2	0.17 ± 0.09	<3.4	6.4 ± 1.2
S46	590 ± 10	4 ± 3	13 ± 2	250 ± 100	66 ± 10
S47	2490 ± 30	50 ± 6	5.6 ± 3.2	<230	200 ± 23
S48	1.2 ± 0.2	0.27 ± 0.08	0.26 ± 0.06	7.7 ± 4.2	2.3 ± 0.7
S49	400 ± 10	4.5 ± 1.1	2.0 ± 0.7	36 ± 41	38 ± 6
S50	70 ± 5	4.8 ± 1.2	0.37± 0.59	40 ± 39	15 ± 6
S51	19 ± 7	4.3 ± 0.8	0.36 ± 0.39	16 ± 23	12 ± 4
S52	6.3 ± 0.6	0.45 ± 0.12	0.10 ± 0.08	7.0 ± 6.3	1.6 ± 0.9
S53	32 ± 2	1.0 ± 0.3	0.37 ± 0.17	20 ± 11	12 ± 2
S54[c]	0.41 ± 0.09	0.25 ± 0.05	0.01 ± 0.02	<0.98	8.2 ± .72

[a] Obtained from top 5 cm of surface.

[b] Errors are 2σ from counting statistics only.

[c] Sediment from underground stream outfall.

Table 2, cont.

	DEPTH (cm)	CONCENTRATION (pCi/gm)				
		Th-232	Ra-226	U-235	U-238	K-40
B14D	150	2.6 ± 0.1	0.54 ± 0.10	<0.02	2.3 ± 3.3	10 ± 1
14E	180	3.3 ± 0.4	0.53 ± 0.14	<0.04	2.6 ± 3.8	11 ± 1
B14F	210	1.4 ± 0.2	0.60 ± 0.09	<0.02	3.1 ± 2.3	10 ± 1
14G	Spoil	3.5 ± 0.4	0.80 ± 0.10	<0.03	2.2 ± 3.2	8.9 ± 1.3
B15A	30	1.2 ± 0.2	0.39 ± 0.08	0.08 ± 0.04	2.6 ± 1.8	7.2 ± 0.9
15B	60	0.49 ± 0.15	0.36 ± 0.09	0.03 ± 0.03	<1.7	6.5 ± 1.0
15C	Spoil	1.1 ± 0.2	0.37 ± 0.08	0.07 ± 0.04	1.1 ± 2.0	7.7 ± 1.1
B16	60	0.56 ± 0.13	0.40 ± 0.07	0.06 ± 0.03	1.8 ± 2.1	9.5 ± 1.0
17A	15	0.51 ± 0.14	0.31 ± 0.06	0.03 ± 0.02	1.0 ± 1.5	9.0 ± 1.1
B17B	120	0.79 ± 0.22	0.64 ± 0.11	<0.03	4.1 ± 3.0	12 ± 2
18	15	1.4 ± 0.2	0.55 ± 0.11	0.09 ± 0.05	1.5 ± 2.5	11 ± 1
B19A	60	14 ± 1	0.78 ± 0.16	0.25 ± 0.11	5.5 ± 5.8	8.3 ± 1.1
B19B	150	6.7 ± 0.5	0.72 ± 0.14	0.17 ± 0.08	6.9 ± 4.8	9.2 ± 1.2
B19C	180	22 ± 1	1.0 ± 0.2	0.46 ± 0.14	13 ± 8	9.6 ± 1.5
	15	0.78 ± 0.23	0.43 ± 0.10	<0.03	<3.6	8.7 ± 1.3
B20B	120	0.81 ± 0.17	0.53 ± 0.08	0.04 ± 0.04	3.5 ± 3.0	8.2 ± 1.1
B21	150	0.57 ± 0.14	0.45 ± 0.08	0.03 ± 0.04	3.9 ± 2.7	6.9 ± 1.0
B22	60	0.77 ± 0.16	0.46 ± 0.08	0.06 ± 0.03	2.8 ± 2.1	8.7 ± 1.0
B23	120	0.73 ± 0.15	0.32 ± 0.07	<0.01	6.3 ± 2.5	8.2 ± 1.0
B24	30	0.91 ± 0.19	0.36 ± 0.10	0.07 ± 0.04	<2.3	7.4 ± 1.1
B25	45	0.47 ± 0.16	0.47 ± 0.08	0.05 ± 0.04	3.2 ± 2.2	7.5 ± 1.0
B26A	15	140 ± 5	0.65 ± 0.29	<0.11	7.7 ± 11	5.3 ± 1.6
B26B	30	73 ± 2	2.3 ± 0.4	0.72 ± 0.25	10 ± 13	11 ± 2
B26C	60	180 ± 5	6.2 ± 0.7	0.55 ± 0.41	29 ± 21	28 ± 3
B27A	30	0.63 ± 0.19	0.50 ± 0.09	0.09 ± 0.04	7.0 ± 4.0	10 ± 1
B27B	120	0.67 ± 0.18	0.67 ± 0.09	0.07 ± 0.04	3.7 ± 2.8	9.3 ± 1.2
B28		No sample taken				
B29A	30	1.2 ± 0.2	0.41 ± 0.09	0.02 ± 0.04	3.9 ± 3.3	5.7 ± 1.0
B29B	120	0.80 ± 0.20	0.55 ± 0.09	0.04 ± 0.04	3.0 ± 3.2	9.3 ± 1.1
	15	0.52 ± 0.16	0.38 ± 0.08	<0.02	2.1 ± 2.8	6.1 ± 1.0
B30B	120	0.47 ± 0.13	0.29 ± 0.06	0.03 ± 0.03	2.2 ± 1.8	7.6 ± 1.0

RAU

cont.

	DEPTH (cm)	CONCENTRATION (pCi/gm)				
		Th-232	Ra-226	U-235	U-238	K-40
B[illegible]A	15	78 ± 2	2.8 ± 0.5	0.97 ± 0.29	25 ± 14	18 ± 3
B[illegible]B	30	1.6 ± 0.3	0.75 ± 0.13	0.07 ± 0.05	1.9 ± 2.5	7.9 ± 1.2
B[illegible]C	60	1.0 ± 0.2	0.60 ± 0.10	0.08 ± 0.04	<2.4	8.0 ± 1.1
B[illegible]A	15	510 ± 10	47 ± 1	17 ± 1	300 ± 70	60 ± 7
B[illegible]E	60	22 ± 1	0.46 ± 0.23	0.58 ± 0.17	<7.0	3.8 ± 1.4
B[illegible]C	90	7.9 ± 0.6	0.60 ± 0.11	0.16 ± 0.09	8.9 ± 5.3	1.7 ± .78
B[illegible]A	15	1500 ± 20	240 ± 5	18 ± 2	140 ± 110	140 ± 10
B[illegible]B	60	24 ± 1	1.7 ± 0.3	0.40 ± 0.18	13 ± 11	3.2 ± 1.4
B[illegible]C	90	200 ± 5	31 ± 1	2.6 ± 0.6	<25.2	20 ± 4
B34A	15	2500 ± 20	110 ± 5	13 ± 1	270 ± 180	180 ± 19
B[illegible]B	30	82 ± 2	5.0 ± 0.6	1.4 ± 0.3	33 ± 21	7.0 ± 2.2
B34C	60	97 ± 3	13 ± 1	0.60 ± 0.38	<11	6.8 ± 2.6
B[illegible]	15	1.3 ± 0.2	0.50 ± 0.10	0.04 ± 0.04	3.2 ± 3.6	8.9 ± 1.2
B36A	15	39 ± 1	1.1 ± 0.3	0.69 ± 0.20	21 ± 13	10 ± 2
B[illegible]	30	440 ± 10	3.1 ± 1.2	6.0 ± 0.7	210 ± 50	42 ± 6
B[illegible]	60	1.2 ± 0.3	0.42 ± 0.19	0.39 ± 0.19	<1.7	6.5 ± 0.7
B[illegible]D	90	0.83 ± 0.23	0.33 ± 0.10	0.16 ± 0.05	6.2 ± 4.0	1.6 ± 0.6
B[illegible]E	120	22 ± 1	0.57 ± 0.24	0.53 ± 0.16	22 ± 11	3.9 ± 1.1
B37A	15	480 ± 10	51 ± 2	5.3 ± 1.0	160 ± 60	47 ± 7
B[illegible]B	60	27 ± 1	1.8 ± 0.3	1.8 ± 0.2	32 ± 13	3.4 ± 1.6
B37C	90	0.59 ± 0.27	0.23 ± 0.09	0.15 ± 0.05	2.7 ± 3.9	1.3 ± 0.7
B[illegible]D	120	130 ± 5	9.7 ± 0.7	1.2 ± 0.4	26 ± 20	14 ± 2
B37E	150	20 ± 1	2.7 ± 0.3	0.54 ± 0.18	25 ± 13	5.0 ± 1.4
B[illegible]A	15	940 ± 10	49 ± 2	1.2 ± 1.3	66 ± 72	100 ± 10
B38B	30	1200 ± 50	140 ± 5	11 ± 2	89 ± 100	2.1 ± 0.1
B[illegible]C	60	1600 ± 20	170 ± 5	8.9 ± 1.9	<57	1.2 ± 0.1
B38D	90	550 ± 10	40 ± 2	9.5 ± 1.1	190 ± 70	47 ± 7
B[illegible]E	120	5.5 ± 0.5	0.83 ± 0.16	0.23 ± 0.10	13 ± 6	2.1 ± 0.8

[illegible] from counting statistics only.

TABLE 3

RADIONUCLIDE CONCENTRATIONS IN WATER

SAMPLE	DEPTH (cm)	CONCENTRATION (μCi/ml)			
		Th-232 ($\times 10^{-8}$)	Ra-226 ($\times 10^{-8}$)	U-235 ($\times 10^{-8}$)	U-238 ($\times 10^{-7}$)
W1	210	<2 [a]	<0.009	<1	9 ± 18
W2	210	<5	0.17 ± 0.04	<1	<4
W3	100	<3	2 ± 2 [d]	<1	< 8.4
W4	130	2 ± 5	0.12 ± 0.03	1 ± 2	13 ± 24
W5	140	<4	<0.009	<1	<9
W6	240	<3	0.036±0.024	3 ± 2	<13
W7	Surface	<4	0.045±0.021	<2	< 13
W8	330	1 ± 1	(e)	<1	<9
W9	180	<4	<0.009	<1	<4
W10	330	<3	<0.009	<1	22 ± 24
W11	240	(e)	(e)	(e)	(e)
W12	250	2 ± 5	<0.009	<1	22 ± 25
W13	270	<4	<0.009	<1	<15
W14	120	<3	0.064±0.030	<1	<4
W15	170	(e)	(e)	(e)	(e)
W16	Surface [b]	<2	0.064±0.022	<1	<13
Concentration Guide [c]		200	3	3000	400

a) Errors are 2σ from counting statistics only.

b) Off-site at underground stream outfall.

c) le 10 Code of Federal Regulations, Part 20, Appendix B, Table II, umn 2 (soluble)

d) Sample lost during deemanation; value listed is based on gamma spectrometry analysis.

e) Insufficient sample volume to perform analysis.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SURFACE VEGETATION

SAMPLE	CONCENTRATION (pCi/gm)				
	Th-232	Ra-226	U-235	U-238	K-40
V1	1.2 ± 0.8	0.33 ± 0.43	0.08 ± 0.15	8 ± 12	6.1 ± 4.7
V2	0.40 ± 0.56	0.43 ± 0.22	<0.05	<6.2	4.2 ± 2.2
V3	0.36 ± 0.14	0.32 ± 0.15	0.04 ± 0.07	<4.7	<1.0
V4	5.3 ± 1.3	0.43 ± 0.62	0.20 ± 0.22	<9.7	2.0 ± 2.5
V5	2.3 ± 1.3	0.58 ± 0.26	<0.27	<17.4	7.2 ± 5.1
V6	0.08 ± 0.08	0.08 ± 0.06	0.03 ± 0.02	< 2.1	4.4 ± 0.8
V7	0.54 ± 0.33	2.2 ± 0.62	0.25 ± 0.26	<10	5.5 ± 3.9
V8	0.17 ± 0.12	0.17 ± 0.07	0.02 ± 0.03	4.6 ± 4.0	3.8 ± 0.9
V9	0.59 ± 0.24	0.74 ± 0.36	<0.10	<6.4	7.7 ± 5.7
V10	15 ± 2	0.85 ± 0.47	<0.12	<7.1	3.8 ± 2.9
V11	18 ± 2	2.1 ± 0.6	0.25 ± 0.20	<7.5	4.0 ± 2.6

Errors are 2σ from counting statistics only.

TABLE 5

BACKGROUND RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL

SAMPLE	CONCENTRATION (pCi/gm)				
	Th-232	Ra-226	U-235	U-238	K-40
OS1	0.86 ± 0.15	0.68 ± 0.08	0.09 ± 0.01	2.9 ± 2.7	11 ± 1
OS2	0.58 ± 0.14	0.42 ± 0.06	0.06 ± 0.03	4.4 ± 3.0	11 ± 1
OS3	0.71 ± 0.15	0.60 ± 0.08	0.08 ± 0.04	6.0 ± 3.6	8.3 ± 0.9
OS4	1.1 ± 0.2	0.55 ± 0.08	0.13 ± 0.06	<2.3	13 ± 1
OS5	0.72 ± 0.19	0.65 ± 0.12	0.10 ± 0.06	6.4 ± 4.2	9.5 ± 1.2
OS6	1.1 ± 0.2	0.87 ± 0.09	0.06 ± 0.04	5.6 ± 3.3	13 ± 1

TABLE 6

BACKGROUND RADIONUCLIDE CONCENTRATIONS IN WATER

SAMPLE	LOCATION	CONCENTRATION ($\times 10^{-6}$ µCi/ml)			
		Th-232	Ra-226	U-235	U-238
OW1	City water	<4	<0.009	<1	<180
OW2	Saddle River	<5	<0.009	<1	<150
OW3	Hackensack R.	<4	<0.009	2 ± 2	<150
OW4	Passaic River	<5	<0.009	4 ± 2	<190
Permissible Concentrations		200	3	3000	4000

Errors are 2σ from counting statistics only.