DOCUMENTATION OF ENVIRONMENTAL INDICATOR DETERMINATION

RCRA Corrective Action
Environmental Indicator (EI) RCRIS code (CA750)

Migration of Contaminated Groundwater Under Control

Facility Name:	**IBM - Thomas J. Watson Research Center**
Facility Address:	**Yorktown Heights, NY 10598**
Facility EPA ID #:	**NYD084006741**

1. Has **all** available relevant/significant information on known and reasonably suspected releases to the groundwater media, subject to RCRA Corrective Action (e.g., from Solid Waste Management Units (SWMU), Regulated Units (RU), and Areas of Concern (AOC)), been **considered** in this EI determination?

__X__ If yes - check here and continue with #2 below.

_____ If no - re-evaluate existing data, or

_____ if data are not available, skip to #8 and enter"IN" (more information needed) status code.

BACKGROUND

Definition of Environmental Indicators (for the RCRA Corrective Action)

Environmental Indicators (EI) are measures being used by the RCRA Corrective Action program to go beyond programmatic activity measures (e.g., reports received and approved, etc.) to track changes in the quality of the environment. The two EI developed to-date indicate the quality of the environment in relation to current human exposures to contamination and the migration of contaminated groundwater. An EI for non-human (ecological) receptors is intended to be developed in the future.

Definition of "Migration of Contaminated Groundwater Under Control" EI

A positive "Migration of Contaminated Groundwater Under Control" EI determination ("YE" status code) indicates that the migration of "contaminated" groundwater has stabilized, and that monitoring will be conducted to confirm that contaminated groundwater remains within the original "area of contaminated groundwater" (for all groundwater "contamination" subject to RCRA corrective action at or from the identified facility (i.e., site-wide)).

Relationship of EI to Final Remedies

While Final remedies remain the long-term objective of the RCRA Corrective Action program the EI are near-term objectives which are currently being used as Program measures for the Government Performance and Results Act of 1993, GPRA). The "Migration of Contaminated Groundwater Under Control" EI pertains ONLY to the physical migration (i.e., further spread) of contaminated ground water and contaminants within groundwater (e.g., non-aqueous phase liquids or NAPLs). Achieving this EI does not substitute for achieving other stabilization or final remedy requirements and expectations associated with sources of contamination and the need to restore, wherever practicable, contaminated groundwater to be suitable for its designated current and future uses.

Duration / Applicability of EI Determinations
EI Determinations status codes should remain in RCRIS national database ONLY as long as they remain true (i.e., RCRIS status codes must be changed when the regulatory authorities become aware of contrary information).

2. Is **groundwater** known or reasonably suspected to be **"contaminated"**[1] above appropriately protective "levels" (i.e., applicable promulgated standards, as well as other appropriate standards, guidelines, guidance, or criteria) from releases subject to RCRA Corrective Action, anywhere at, or from, the facility?

 X If yes - continue after identifying key contaminants, citing appropriate "levels," and referencing supporting documentation.

 ___ If no - skip to #8 and enter "YE" status code, after citing appropriate "levels," and referencing supporting documentation to demonstrate that groundwater is not "contaminated."

 ___ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

Facility and Release Sources.

IBM Yorktown is a research laboratory occupying an area of approximately 219 acres. Research activities involve wet chemical operations carried-out in Building 801 which is laid out in an arc. There are separate buildings onsite for wastewater treatment, maintenance and administration. The facility has a RCRA permit that addresses: (1) the storage and management of hazardous waste; (2) the operation and maintenance of a final corrective measures pump and treat system for remediating contaminated groundwater; and (3) the monitoring of the corrective action groundwater well network to assess the remedy's performance. Figures 1 and 2 show the facility location and the layout of the site.

In 1988, IBM expanded its groundwater monitoring program to determine the effects of suspected releases from their old laboratory underground wastewater piping system. Investigations determined that releases of dilute laboratory wastewater from isolated sections of the old piping system had contaminated on-site groundwater and soils surrounding the pipeline with volatile organic constituents (VOCs). Low concentrations of metals were also detected in the soil where leaks occurred, but did not contribute to the groundwater contamination. The layout of the underground piping system subject to excavation is depicted in Figure 3. Soil gas analysis showed that the most significant releases from the underground piping system occurred in the vicinity of Core areas 5 and 6 with less significant releases occurring in the vicinity of Core area 3. Refer to Figures 4 and 5 that illustrate soil gas concentration contours of Freon 113 at four and twelve foot depths below the Building 801.

Geology and Hydrology.

The complexity of the bedrock formations existing in the vicinity of this facility is illustrated in Figure 13. The entire site is underlain by metamorphic bedrock consisting primarily of garnet and quartz-rich biotite schist and was encountered at a depth as low as 78 feet below the surface. Structurally, bedrock under the site is dominated by foliation striking northeast-southwest and dipping to the south between 60 and 90 degrees with joints generally orienting and dipping in the same direction. Fractures are opened and concentrated in zones with many filled with quartz. Two bedrock ridges cross the site from northeast to southwest and are separated by a bedrock valley that widens and becomes lower in elevation to the northeast. A saddle-like feature exists in the southernmost bedrock ridge at the east end of Building 801. A number of metals, including chromium, copper, lead, nickel and zinc occur naturally in the rock. Therefore, weathering products of these rocks could be expected to impact natural concentrations of some or all of these metals to groundwater flowing through them. The site's schist bedrock is covered by variable unconsolidated units that include glacial deposits and weathered bedrock. Figures 14 and 15 depict the cross section of the geology existing along the front of Building 801 and through that Building 801respectively and illustrates the typical depth of the unconsolidated units..

Overburden soil groundwater is found in unconsolidated deposits consisting of sand and till lying above weathered bedrock, with the water table being about 10 feet below the surface near the building in the vicinity of the significant releases. The water table elevation deepens and the thickness of the unconsolidated deposits increase from 40 to 80 feet when moving north from the building. Figure 16 is the elevation contour map for the soil water table that shows the general direction of soil groundwater flow during the RFI and prior to implementing corrective measures. Flow is generally to the north and northwest beneath Building 801. Vertical downward gradients were found to exist between the soil unit and the underlying bedrock at MW-104 and 107 that would cause the deeper soil groundwater at Building 801 to migrate to the shallow bedrock flow system moving away from this building. Further to the north at MW-147 a net upward vertical flow moves the shallow bedrock groundwater into the deeper soil groundwater. Figure 17 , a north-south cross section running through Building 801, illustrates this vertical flow.

Figure 18 shows the bedrock potentiometric surface identified during the RFI. The presence of zones of high fracture connectivity is the primary control on hydraulic conductivity distribution. Since the primary orientation of hydraulic conductivity is not parallel to the apparent hydraulic gradient, groundwater flow paths are not perpendicular to the potentiometric surface contours shown in the figure.

Contamination.
Both the overburden soil groundwater and underlying bedrock groundwater contained plumes of VOCs with Freon 113 and Trichloroethylene (TCE) being considered the most significant contaminants present and they were established as the target contaminants. Subsequently Freon 123a, a breakdown product of Freon 113, was also established as a target contaminant during corrective measures monitoring. Average concentrations (ug/l) for TCE and Freon 113 reported in the final RFI for both the overburden soil groundwater and the bedrock groundwater, before corrective measures implementation, are illustrated in Figures 6, 7, 8, and 9 respectively. Each constituent has as its cleanup level the New York State Groundwater Protection Standard of 5.0 ppb.

Overburden soil groundwater is found in unconsolidated deposits consisting of sand and till lying above weathered bedrock, with the water table being about 10 feet below the surface near the building in the vicinity of the significant releases. The water table elevation deepens and the thickness of the unconsolidated deposits increase from 40 to 80 feet when moving north from the building. Figure 7 indicates that one small Freon plume existed in the soil groundwater near Core 6 with an average concentration of 654 ug/l and a maximum concentration of 2,100 ug/l being reported in well 137S about 50 feet north of the building. Figure 6 shows that two small TCE plumes were in existence in the soil groundwater. One TCE plume occurred near Core 6 with an average concentration of 209 ug/l and a maximum concentration of 420 ug/l reported in well 109S located about 50 feet north of the building. The other TCE soil groundwater plume near Core 3 recorded an average concentration of 154 ug/l and a maximum concentration of 410 ug/l in well 125S under the building.

Figure 9 depicts the Freon 113 contaminant bedrock groundwater plume migrating from the building and moving in a northeasterly direction. An average concentration of 424 ug/l and a maximum concentration of 3,000 ug/l was reported in well 180D under the building at Core 6 where the most significant releases occurred. Figure 8 shows that the average TCE bedrock groundwater concentrations were highest in the vicinity of Core 6 and in well 137D. Here the average and maximum TCE concentrations were at 12.6 and 19 ug/l respectively.

References:

1. Annual and Semiannual Corrective Action Status Reports
2. Final RFI Report, dated February 1, 1991
3. Statement of Basis, NYSDEC, dated October 1995
4. Approved Groundwater Monitoring Plan.

Footnotes:

[1]"Contamination" and "contaminated" describes media containing contaminants (in any form, NAPL and/or dissolved, vapors, or solids, that are subject to RCRA) in concentrations in excess of appropriate "levels" (appropriate for the protection of the groundwater resource and its beneficial uses).

3. Has the **migration** of contaminated groundwater **stabilized** (such that contaminated groundwater is expected to remain within "existing area of contaminated groundwater"[2] as defined by the monitoring locations designated at the time of this determination)?

__X__ If yes - continue, after presenting or referencing the physical evidence (e.g., groundwater sampling/measurement/migration barrier data) and rationale why contaminated groundwater is expected to remain within the (horizontal or vertical) dimensions of the "existing area of groundwater contamination"[2]).

____ If no (contaminated groundwater is observed or expected to migrate beyond the designated locations defining the "existing area of groundwater contamination"[2]) - skip to #8 and enter "NO" status code, after providing an explanation.

____ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

In 1990 a sophisticated bedrock groundwater "pump and treat" system was installed to pump bedrock groundwater from three production wells (137D, 147DB, and 176 DB). Subsequently bedrock withdrawal well 104D was installed. Pumping well 176DB was shut down in the first quarter of 1999 except for one month while maintenance was carried-out on pumping well 104D. Figure 19 shows the locations of all the bedrock groundwater pumping wells and depicts the most current bedrock potentiometric surface resulting from pumping the extraction wells, the generalized flow of groundwater and the limit of bedrock groundwater capture. This extraction system is responsible for containing and reducing in size the bedrock groundwater contaminant plume as illustrated in Figure 10 using the target contaminant Freon 113.

The latest annual groundwater monitoring report dated February 28, 2000, which covers the four quarters of monitoring for 1999, reported mostly non-detects in both the soil and bedrock monitoring wells. Refer to Figures 11 and 12 for a summary of all the groundwater monitoring results. The maximum concentrations of Freon 113 and TCE were detected in the soil groundwater at 2.0 and 9.5 ppb respectively. This observation occurred in well 136S approximately 50 feet from the main building. Maximum concentrations of Freon 113, Freon 123a, and TCE were detected in the bedrock groundwater at 31J, 6.4 and 7.5J ppb respectively with the J representing an estimated value. This observation of maximum bedrock groundwater contamination occurred in well 108D located inside the main building.

Through the end of 1999 the treatment system consisted of the following processes: flow equalization, dual media filtration, and carbon adsorption. Mostly non-detect concentrations of VOCs were reported in the treated effluent with approximately 85% of this treated effluent being reused in cooling towers. The remaining treated effluent is transported to the local POTW.

Corrective measures has been successful in controlling the migration and dramatically reducing in size the contaminant groundwater plumes both in the overburden and bedrock aquifers at this site. Refer to the references listed in paragraph 2 for more detailed information.

Footnotes:

[2] "existing area of contaminated groundwater" is an area (with horizontal and vertical dimensions) that has been verifiably demonstrated to contain all relevant groundwater contamination for this determination, and is defined by designated (monitoring) locations proximate to the outer perimeter of "contamination" that can and will be sampled/tested in the future to physically verify that all "contaminated" groundwater remains within this area, and that the further migration of "contaminated" groundwater is not occurring. Reasonable allowances in the proximity of the monitoring locations are permissible to incorporate formal remedy decisions (i.e., including public participation) allowing a limited area for natural attenuation.

4. Does "contaminated" groundwater **discharge** into **surface water** bodies?

___ If yes - continue after identifying potentially affected surface water bodies.

_X_ If no - skip to #7 (and enter a "YE" status code in #8, if #7 = yes) after providing an explanation and/or referencing documentation supporting that groundwater "contamination" does not enter surface water bodies.

___ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

Groundwater monitoring and periodic sampling of the stream, known as No Name Creek, which runs through the site has shown that there has been no impact on this surface water body. Refer to the references listed under paragraph 2 for further details that will confirm this conclusion

5. Is the **discharge** of "contaminated" groundwater into surface water likely to be **"insignificant"** (i.e., the maximum concentration[3] of each contaminant discharging into surface water is less than 10 times their appropriate groundwater "level," and there are no other conditions (e.g., the nature, and number, of discharging contaminants, or environmental setting), which significantly increase the potential for unacceptable impacts to surface water, sediments, or eco-systems at these concentrations)?

_____ If yes - skip to #7 (and enter "YE" status code in #8 if #7 = yes), after documenting: 1) the maximum known or reasonably suspected concentration[3] of key contaminants discharged above their groundwater "level," the value of the appropriate "level(s)," and if there is evidence that the concentrations are increasing; and 2) provide a statement of professional judgement/explanation (or reference documentation) supporting that the discharge of groundwater contaminants into the surface water is not anticipated to have unacceptable impacts to the receiving surface water, sediments, or eco-system.

_____ If no - (the discharge of "contaminated" groundwater into surface water is potentially significant) - continue after documenting: 1) the maximum known or reasonably suspected concentration[3] of each contaminant discharged above its groundwater "level," the value of the appropriate "level(s)," and if there is evidence that the concentrations are increasing; and 2) for any contaminants discharging into surface water in concentrations[3] greater than 100 times their appropriate groundwater "levels," the estimated total amount (mass in kg/yr) of each of these contaminants that are being discharged (loaded) into the surface water body (at the time of the determination), and identify if there is evidence that the amount of discharging contaminants is increasing.

_____ If unknown - enter "IN" status code in #8.

Rationale and Reference(s):

Footnotes:

[3] As measured in groundwater prior to entry to the groundwater-surface water/sediment interaction (e.g., hyporheic) zone.

6. Can the **discharge** of "contaminated" groundwater into surface water be shown to be "**currently acceptable**" (i.e., not cause impacts to surface water, sediments or eco-systems that should not be allowed to continue until a final remedy decision can be made and implemented[4])?

_____ If yes - continue after either: 1) identifying the Final Remedy decision incorporating these conditions, or other site-specific criteria (developed for the protection of the site's surface water, sediments, and eco-systems), and referencing supporting documentation demonstrating that these criteria are not exceeded by the discharging groundwater; OR 2) providing or referencing an interim-assessment,[5] appropriate to the potential for impact, that shows the discharge of groundwater contaminants into the surface water is (in the opinion of a trained specialists, including ecologist) adequately protective of receiving surface water, sediments, and eco-systems, until such time when a full assessment and final remedy decision can be made. Factors which should be considered in the interim-assessment (where appropriate to help identify the impact associated with discharging groundwater) include: surface water body size, flow, use/classification/habitats and contaminant loading limits, other sources of surface water/sediment contamination, surface water and sediment sample results and comparisons to available and appropriate surface water and sediment "levels," as well as any other factors, such as effects on ecological receptors (e.g., via bio-assays/benthic surveys or site-specific ecological Risk Assessments), that the overseeing regulatory agency would deem appropriate for making the EI determination.

_____ If no - (the discharge of "contaminated" groundwater can not be shown to be "**currently acceptable**") - skip to #8 and enter "NO" status code, after documenting the currently unacceptable impacts to the surface water body, sediments, and/or eco-systems.

_____ If unknown - skip to 8 and enter "IN" status code.

Rationale and Reference(s):

Footnotes:

[4] Note, because areas of inflowing groundwater can be critical habitats (e.g., nurseries or thermal refugia) for many species, appropriate specialist (e.g., ecologist) should be included in management decisions that could eliminate these areas by significantly altering or reversing groundwater flow pathways near surface water bodies.

[5] The understanding of the impacts of contaminated groundwater discharges into surface water bodies is a rapidly developing field and reviewers are encouraged to look to the latest guidance for the appropriate methods and scale of demonstration to be reasonably certain that discharges are not causing currently unacceptable impacts to the surface waters, sediments or eco-systems.

7. Will groundwater **monitoring** / measurement data (and surface water/sediment/ecological data, as necessary) be collected in the future to verify that contaminated groundwater has remained within the horizontal (or vertical, as necessary) dimensions of the "existing area of contaminated groundwater?"

__X__ If yes - continue after providing or citing documentation for planned activities or future sampling/measurement events. Specifically identify the well/measurement locations which will be tested in the future to verify the expectation (identified in #3) that groundwater contamination will not be migrating horizontally (or vertically, as necessary) beyond the "existing area of groundwater contamination."

_____ If no - enter "NO" status code in #8.

_____ If unknown - enter "IN" status code in #8.

Rationale and Reference(s):

Both the overburden soil and bedrock groundwater will be monitored until the States Groundwater Protection Standards have been met in all groundwater monitoring wells for a period of three consecutive years following the termination of the pumping system. As the contaminant plumes reduce in size and Standards are met for three consecutive years in wells determined no longer to be in the path of the plumes, then such wells could qualify for closure. Refer to the references listed in paragraph 2, Groundwater Monitoring Plan and current Corrective Action Monitoring Reports, for further details.

8. Check the appropriate RCRIS status codes for the Migration of Contaminated Groundwater Under Control EI (event code CA750), and obtain Supervisor (or appropriate Manager) signature and date on the EI determination below (attach appropriate supporting documentation as well as a map of the facility).

__X__ YE - Yes, "Migration of Contaminated Groundwater Under Control" has been verified. Based on a review of the information contained in this EI determination, it has been determined that the "Migration of Contaminated Groundwater" is "Under Control" at the **IBM -Thomas J. Watson Research Center**, **EPA ID #NYD084006741** , located in **Yorktown Heights, NY.** Specifically, this determination indicates that the migration of "contaminated" groundwater is under control, and that monitoring will be conducted to confirm that contaminated groundwater remains within the "existing area of contaminated groundwater" This determination will be re-evaluated when the Agency becomes aware of significant changes at the facility.

____ NO - Unacceptable migration of contaminated groundwater is observed or expected.

____ IN - More information is needed to make a determination.

Completed by: James Meacham Date: March 27, 2000
Environmental Engineer
New York State Department of Environmental Conservation (NYSDEC)

Keith Gronwald Date: March 27, 2000
Project Geologist
NYSDEC

And

Steve Kaminski Date: March 27, 2000
Chief, Eastern Engineering
NYSDEC

Supervisor: Paul J. Merges Date: March 28, 2000
Director, Bureau of Radiation and Hazardous Site Management
NYSDEC

Locations where References may be found:

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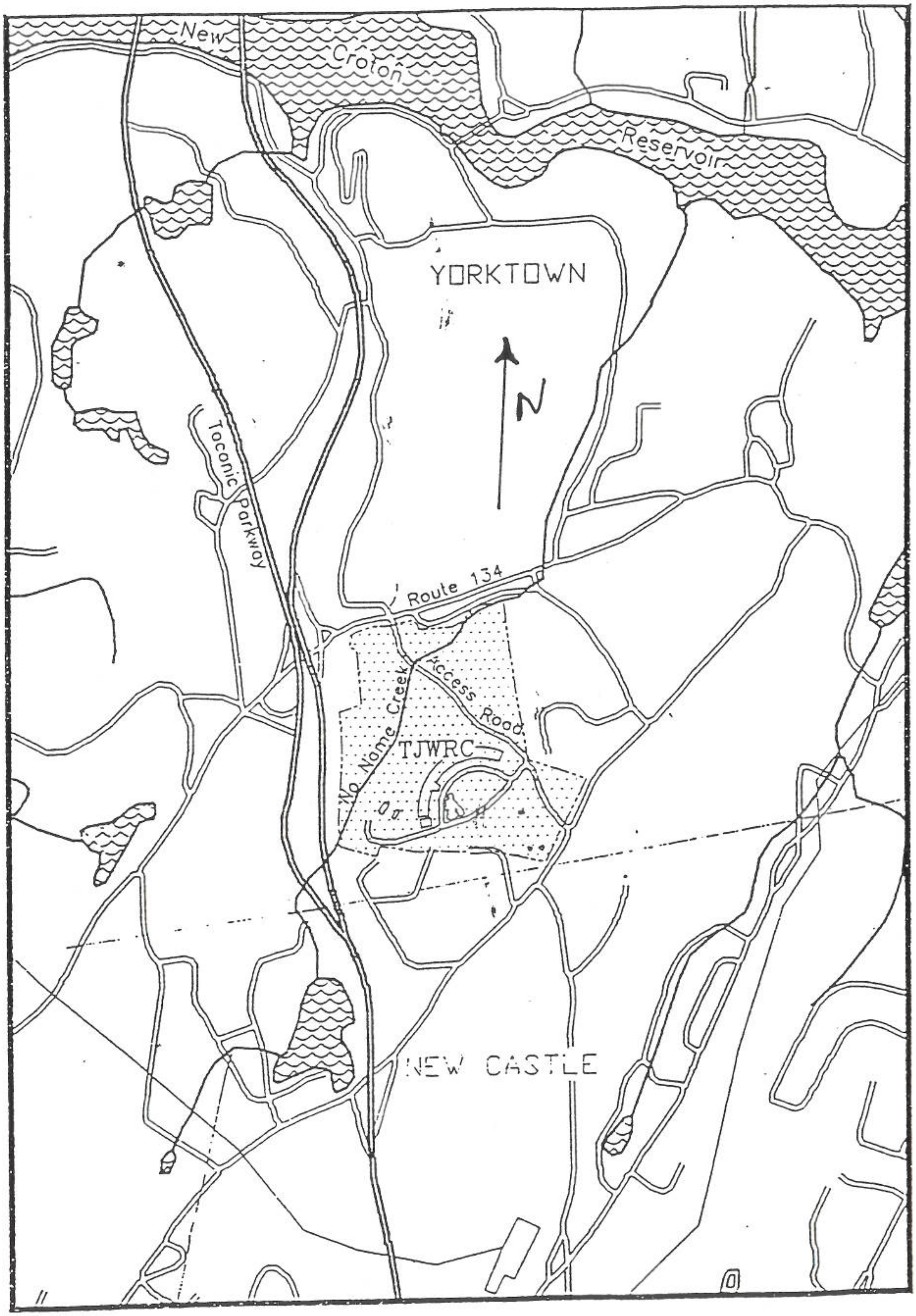
FIGURE 1

FACILITY LOCATION



Scale: 1" = 2000'

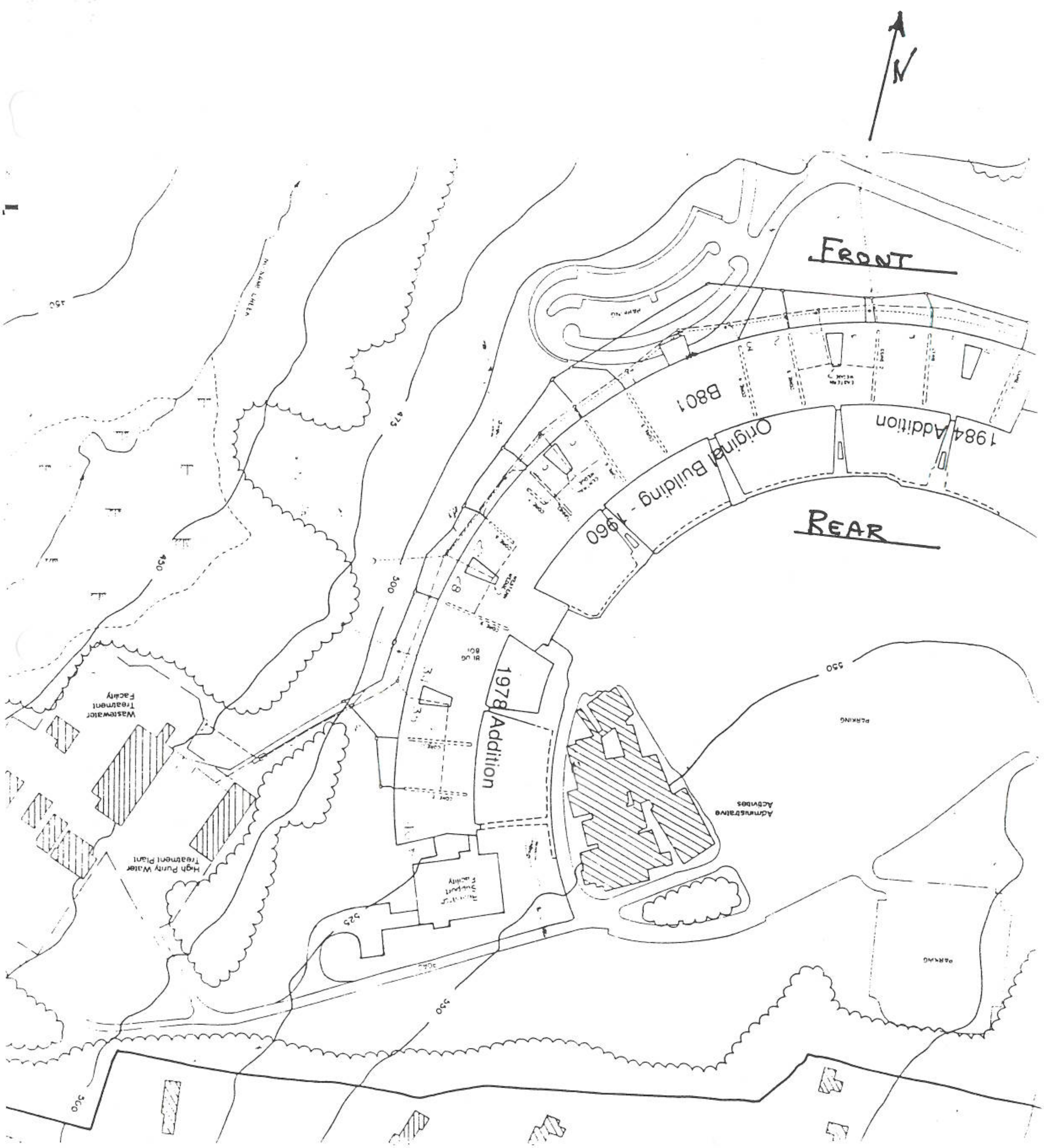


FIGURE 2
SITE LAYOUT

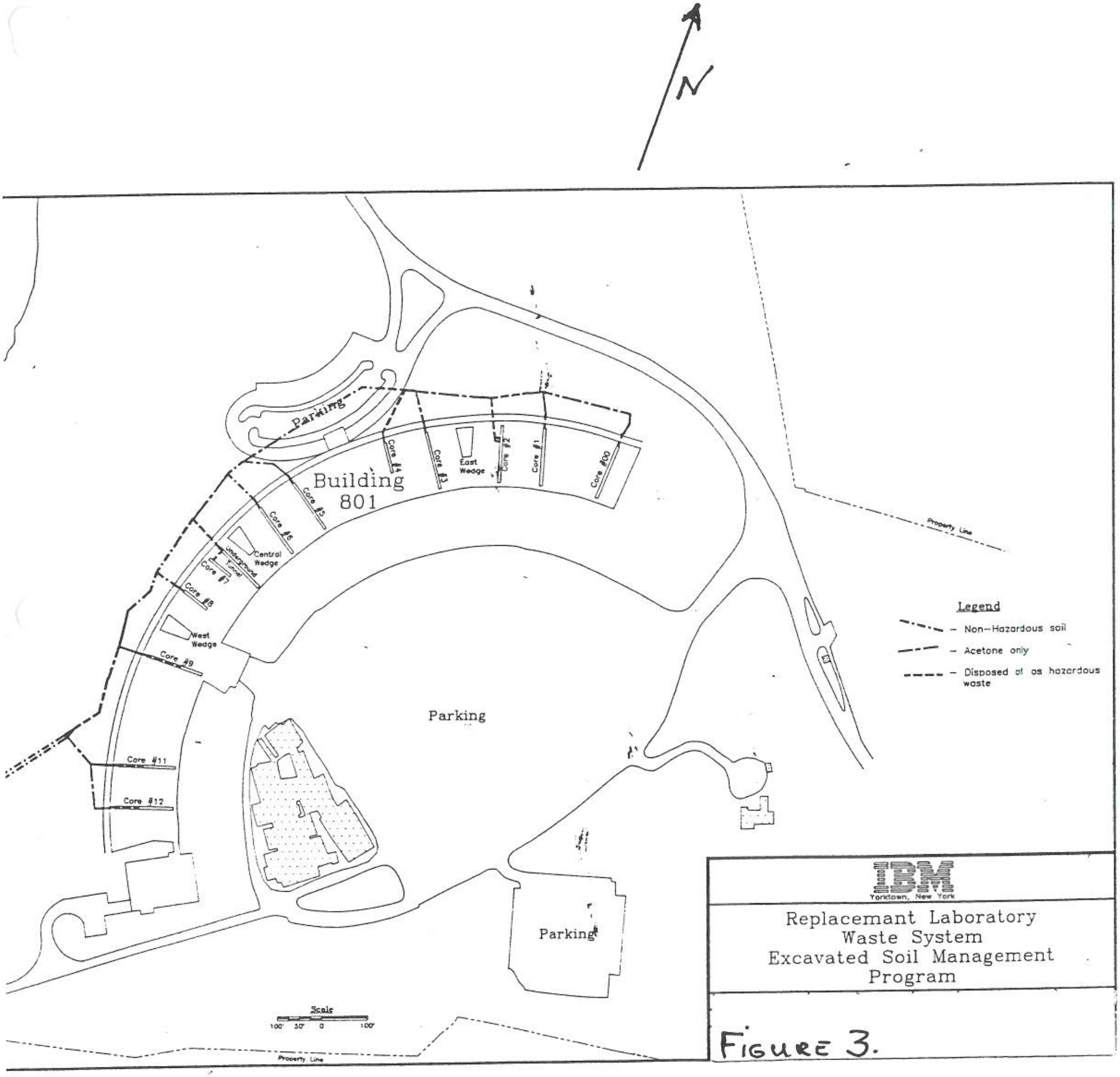
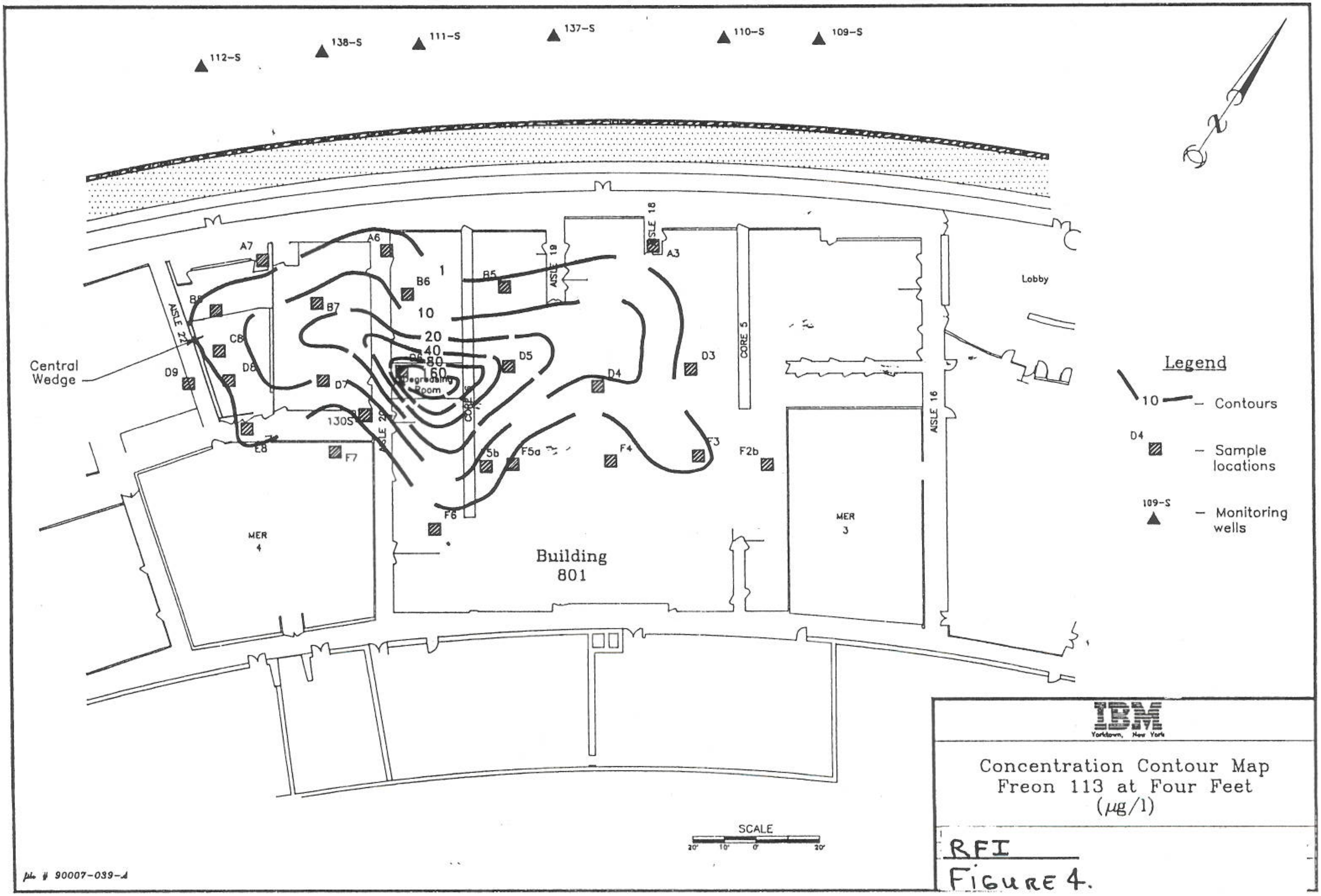
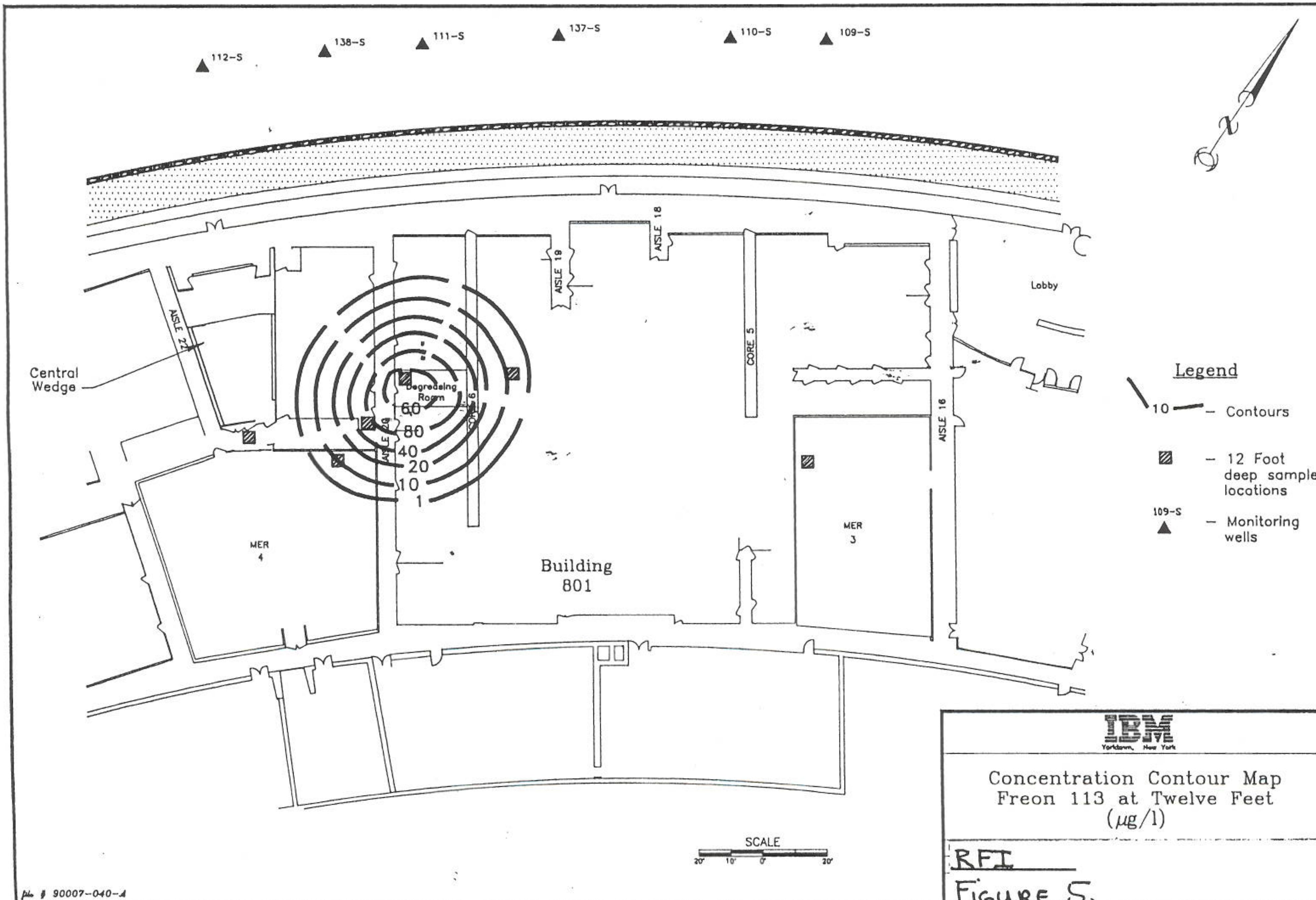

N
Parking
Building
801
Core #4
Core #3
East Wedge
Core #2
Core #1
Core #00
Core #5
Core #6
Central Wedge
Underground Tunnel
Core #7
Core #8
West Wedge
Core #9
Core #11
Core #12
Parking
Parking
Property Line
Property Line
Scale
100' 50' 0 100'
Legend
– Non–Hazardous soil
– Acetone only
– Disposed of as hazardous waste
IBM
Yorktown, New York
Replacemant Laboratory
Waste System
Excavated Soil Management
Program

FIGURE 3.



112-S
138-S
111-S
137-S
110-S
109-S
Central Wedge
A7
A6
A3
B5
B6
B7
B8
C8
D3
D4
D5
D7
D8
D9
E8
F2b
F3
F4
F5a
F5b
F6
F7
130S
1
10
20
40
80
160
Degreasing Room
AISLE 22
AISLE 20
AISLE 19
AISLE 18
AISLE 16
CORE 5
Lobby
MER 4
MER 3
Building 801
Legend
10 — Contours
D4 — Sample locations
109-S — Monitoring wells
SCALE
20' 10' 0' 20'
IBM
Yorktown, New York
Concentration Contour Map
Freon 113 at Four Feet
(μg/l)
RFI
FIGURE 4.
file # 90007-039-A



Concentration Contour Map
Freon 113 at Twelve Feet
(μg/l)

RFI

FIGURE 5.

Figure 6. RFI
Average TCE Soil Groundwater Concentrations

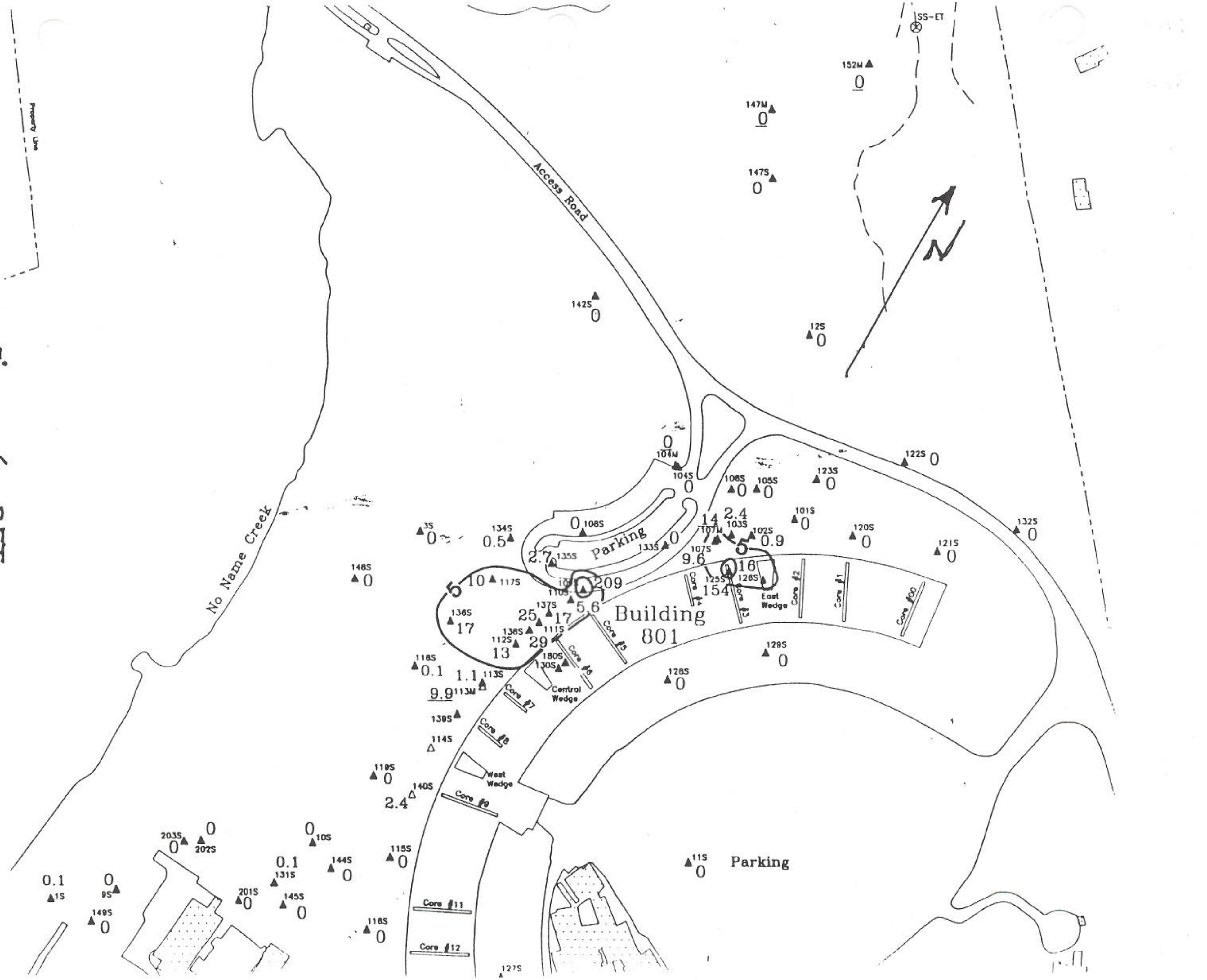
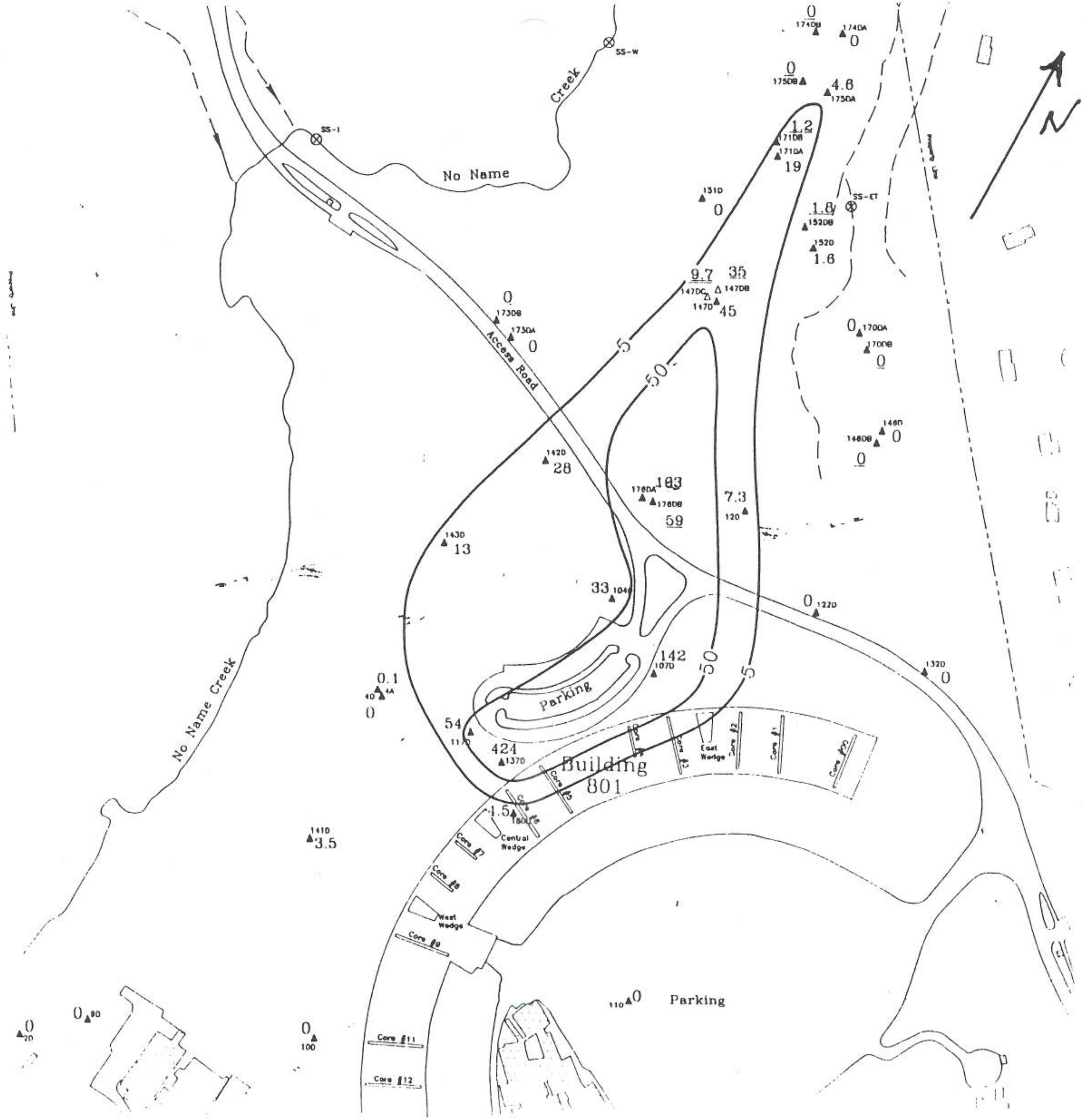


FIGURE 7. RFI
AVERAGE FREON 113 SOIL GROUNDWATER CONCENTRATIONS (µg/L)

Figure 8. RFI Average TCE Bedrock Groundwater Concentrations (ug/L)

Figure 9 RFI
Average Freon 113 Bedrock
Groundwater Concentrations (ug/l)



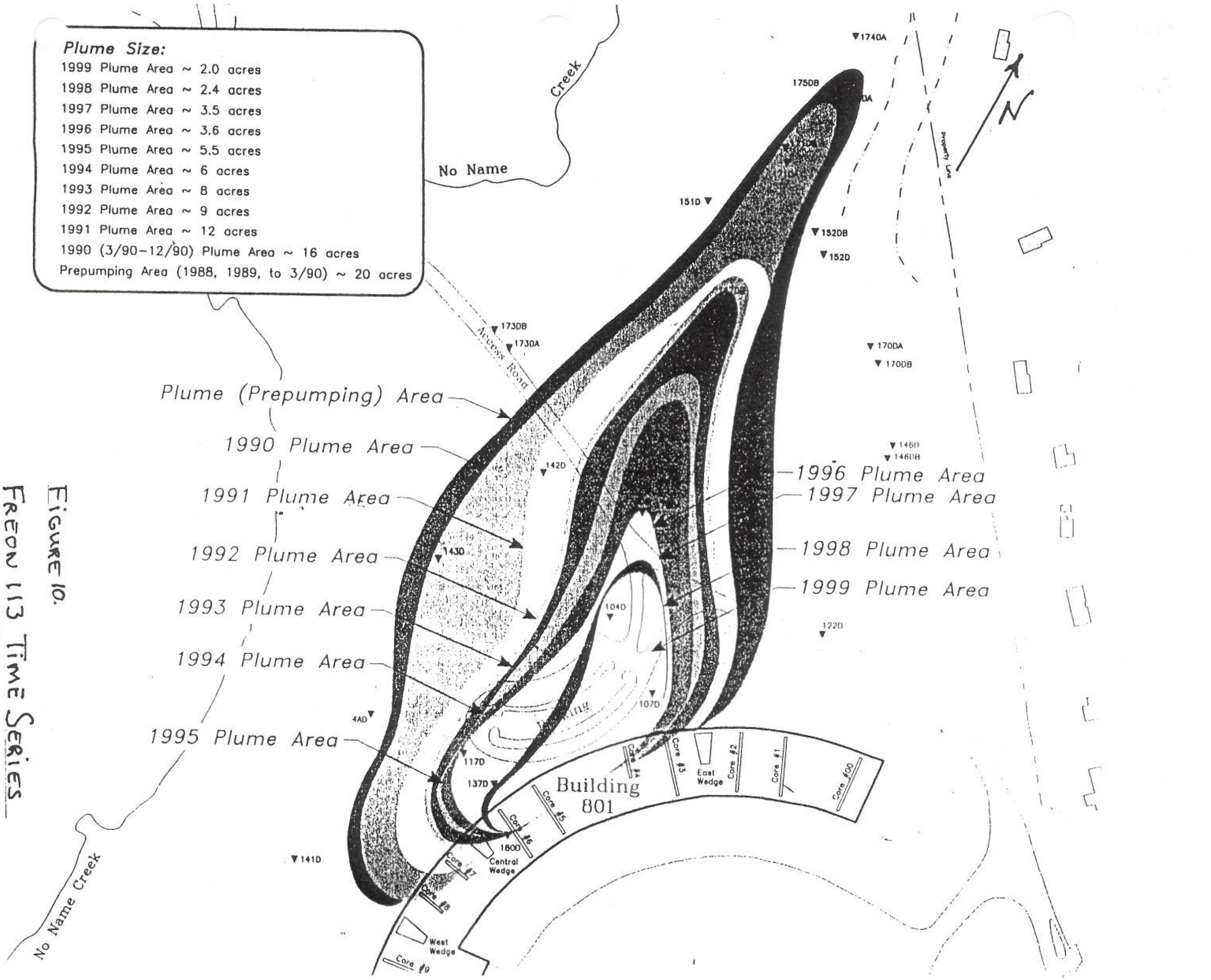


Figure 10.
Freon 113 Time Series
Bedrock Groundwater
Isoconcentrations

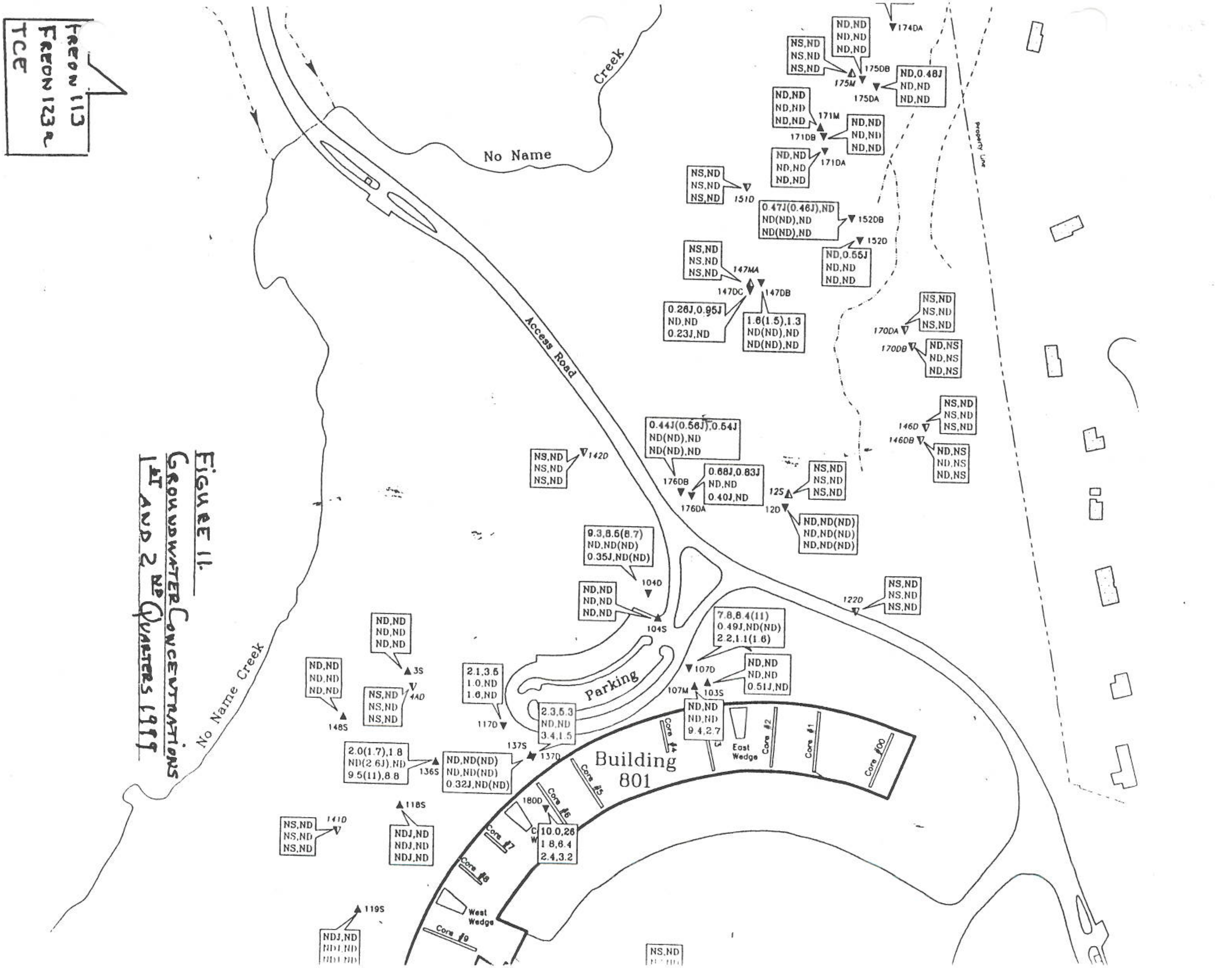


FIGURE 11. GROUNDWATER CONCENTRATIONS 1ST AND 2ND QUARTERS 1999

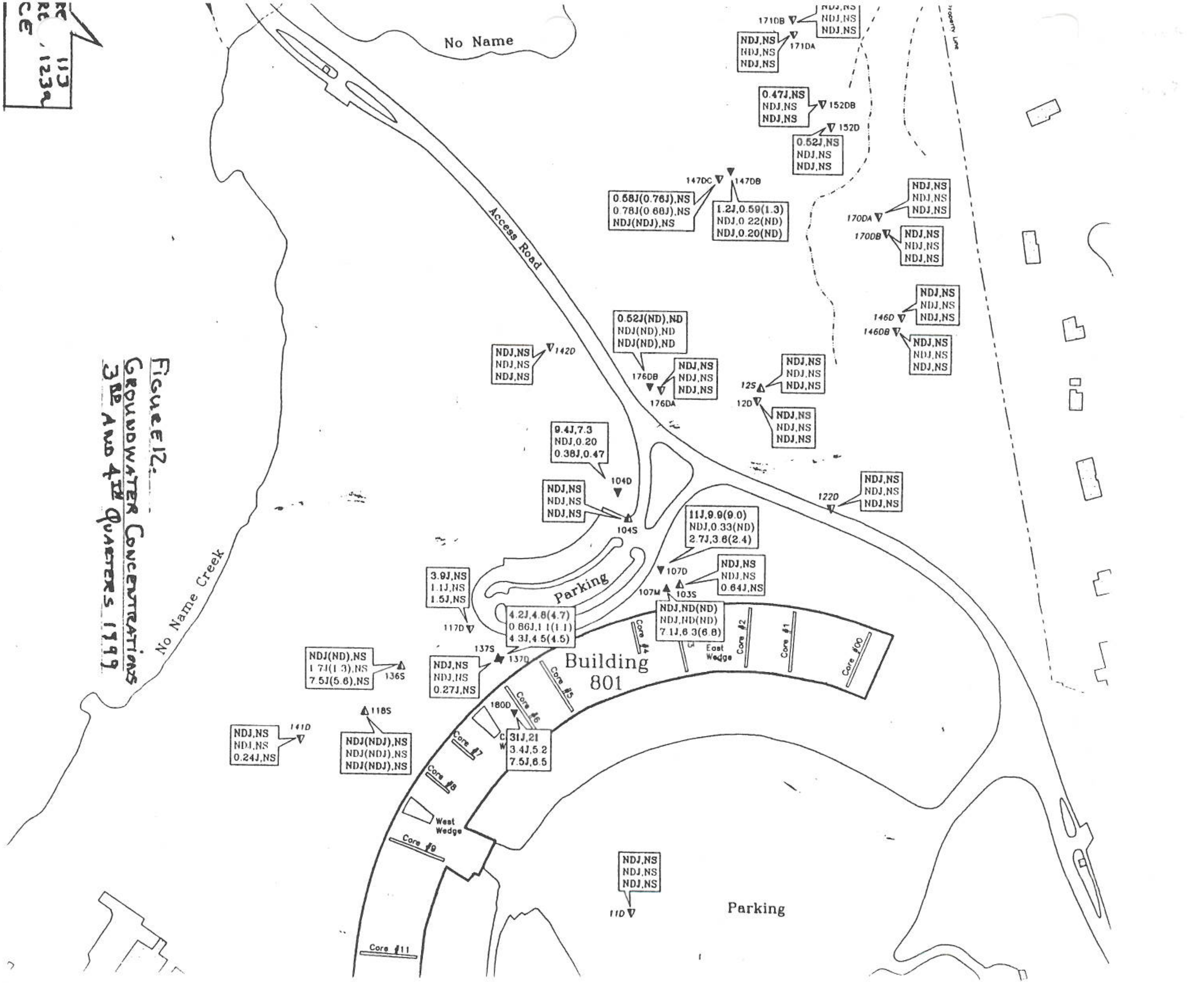


Figure 12. Groundwater Concentrations 3rd and 4th Quarters 1999
No Name
No Name Creek
Access Road
Parking
Building 801
Parking
East Wedge
West Wedge
Core #00
Core #1
Core #2
Core #4
Core #5
Core #6
Core #7
Core #8
Core #9
Core #11
171DB
NDJ,NS
NDJ,NS
NDJ,NS
171DA
NDJ,NS
NDJ,NS
NDJ,NS
152DB
0.47J,NS
NDJ,NS
NDJ,NS
152D
0.52J,NS
NDJ,NS
NDJ,NS
147DC
0.58J(0.76J),NS
0.78J(0.68J),NS
NDJ(NDJ),NS
147DB
1.2J,0.59(1.3)
NDJ,0.22(ND)
NDJ,0.20(ND)
170DA
NDJ,NS
NDJ,NS
NDJ,NS
170DB
NDJ,NS
NDJ,NS
NDJ,NS
146D
NDJ,NS
NDJ,NS
NDJ,NS
146DB
NDJ,NS
NDJ,NS
NDJ,NS
142D
NDJ,NS
NDJ,NS
NDJ,NS
176DB
0.52J(ND),ND
NDJ(ND),ND
NDJ(ND),ND
176DA
NDJ,NS
NDJ,NS
NDJ,NS
12S
NDJ,NS
NDJ,NS
NDJ,NS
12D
NDJ,NS
NDJ,NS
NDJ,NS
104D
9.4J,7.3
NDJ,0.20
0.38J,0.47
104S
NDJ,NS
NDJ,NS
NDJ,NS
122D
NDJ,NS
NDJ,NS
NDJ,NS
107D
11J,9.9(9.0)
NDJ,0.33(ND)
2.7J,3.6(2.4)
103S
NDJ,NS
NDJ,NS
0.64J,NS
107M
NDJ,ND(ND)
NDJ,ND(ND)
7.1J,6.3(6.8)
117D
3.9J,NS
1.1J,NS
1.5J,NS
137D
4.2J,4.8(4.7)
0.86J,1.1(1.1)
4.3J,4.5(4.5)
137S
NDJ,NS
NDJ,NS
0.27J,NS
136S
NDJ(ND),NS
1.7J(1.3),NS
7.5J(5.6),NS
118S
NDJ(NDJ),NS
NDJ(NDJ),NS
NDJ(NDJ),NS
141D
NDJ,NS
NDJ,NS
0.24J,NS
180D
31J,21
3.4J,5.2
7.5J,6.5
11D
NDJ,NS
NDJ,NS
NDJ,NS
113
123a

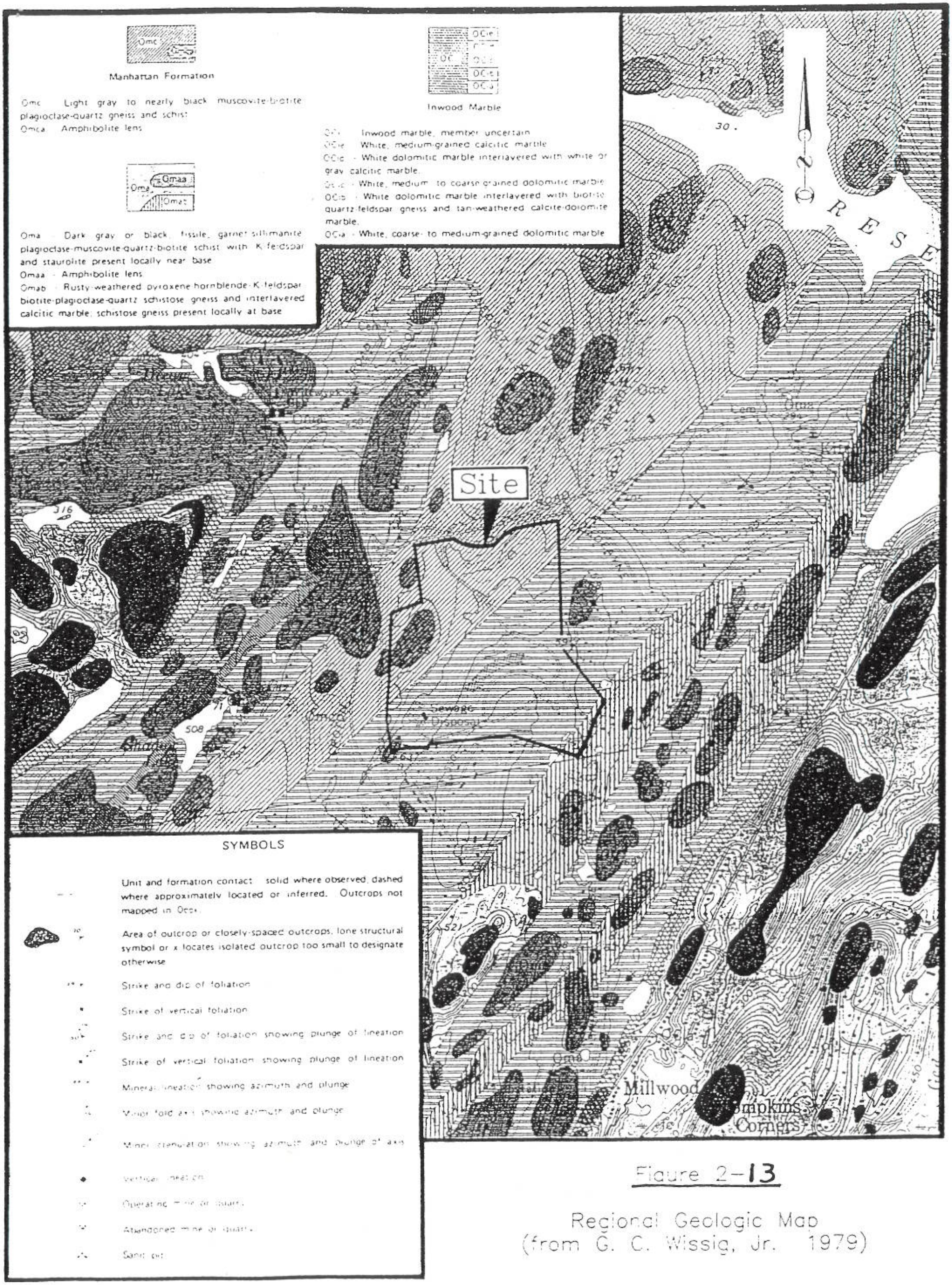


Figure 2-13

Regional Geologic Map
(from G. C. Wissig, Jr. 1979)

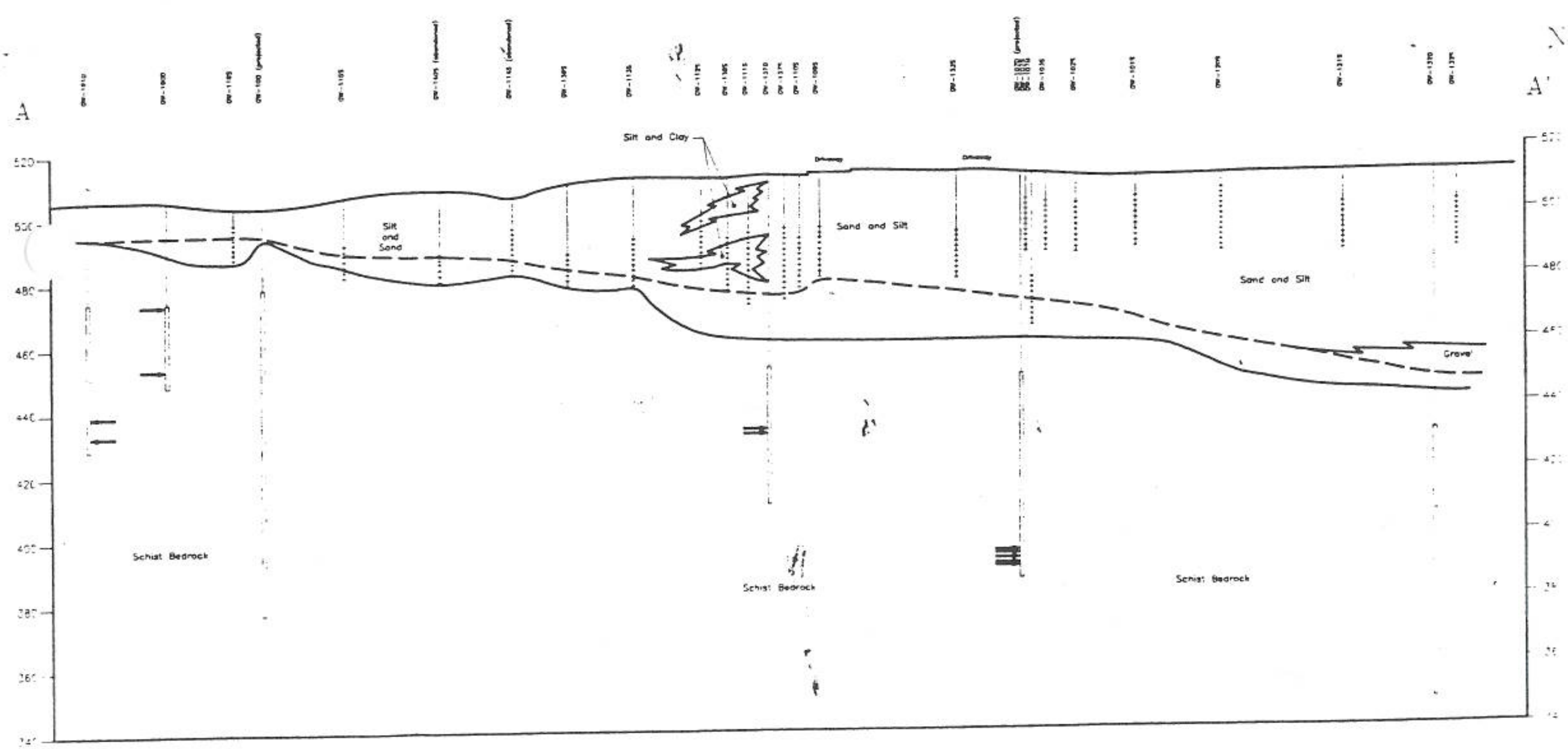


FIGURE 14

CROSS SECTION ALONG FRONT OF BUILDING 801

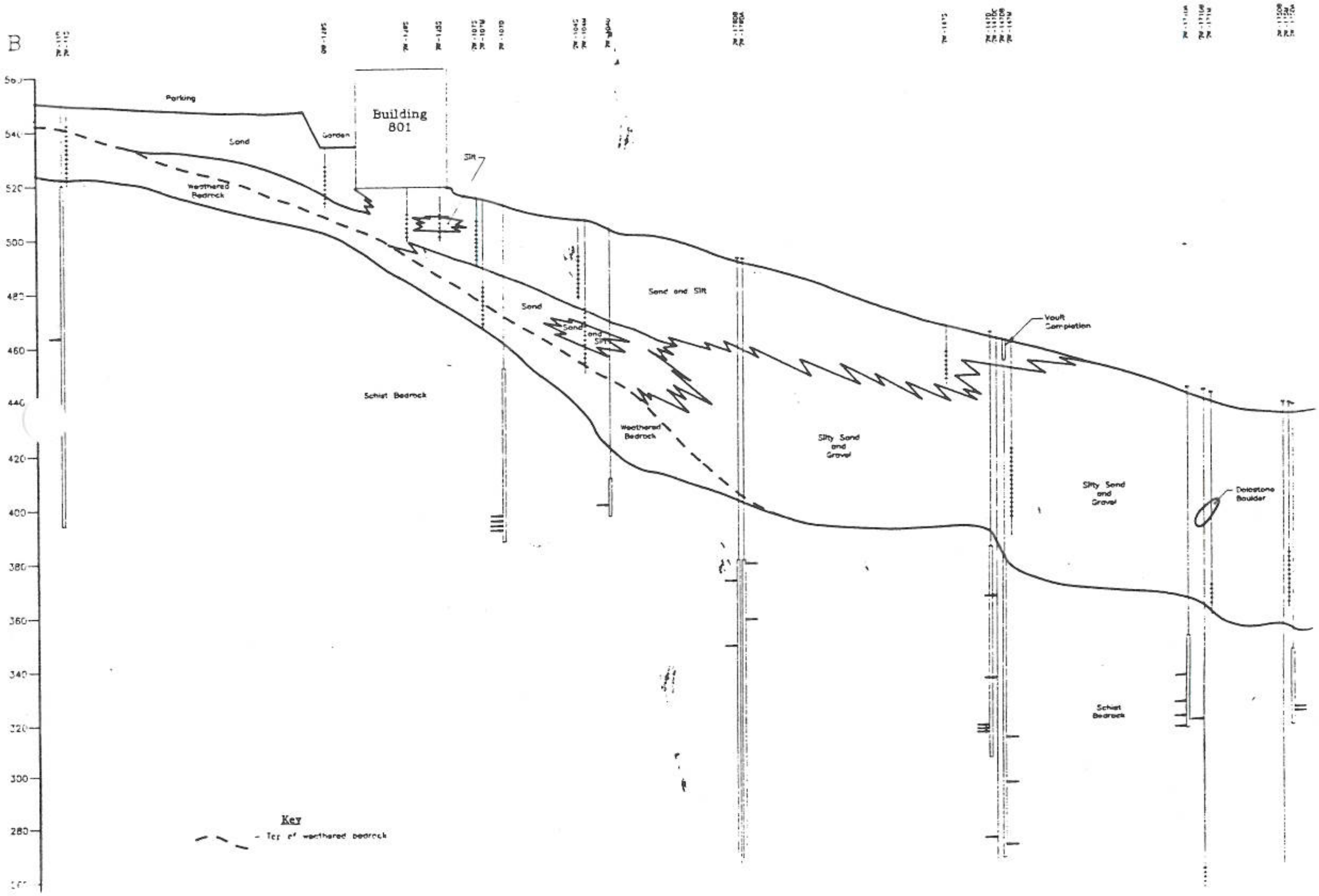


FIGURE 15
CROSS SECTION THROUGH
BUILDING 801

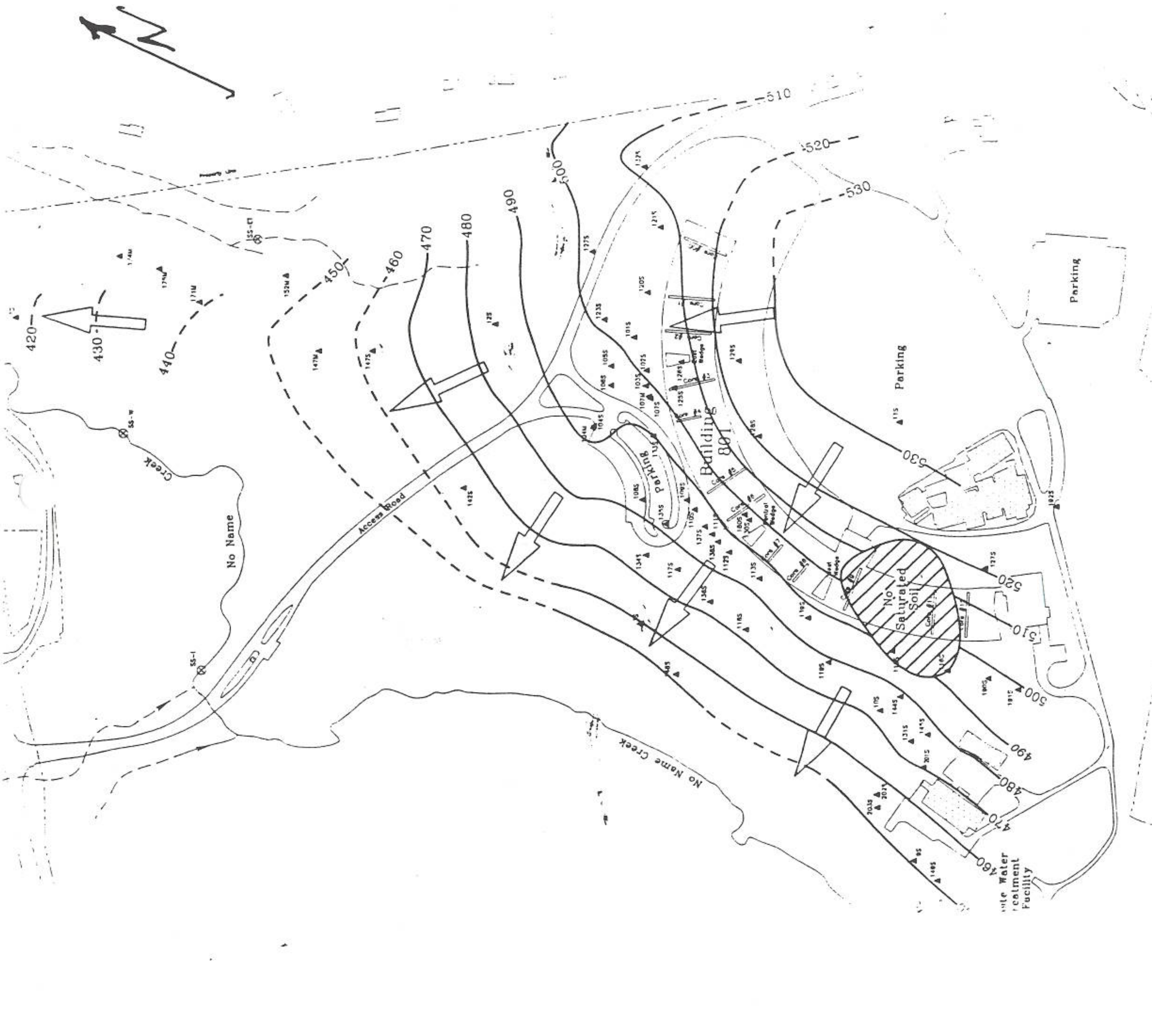


FIGURE 16 RFI

SOIL GROUNDWATER TABLE
ELEVATION CONTOURS

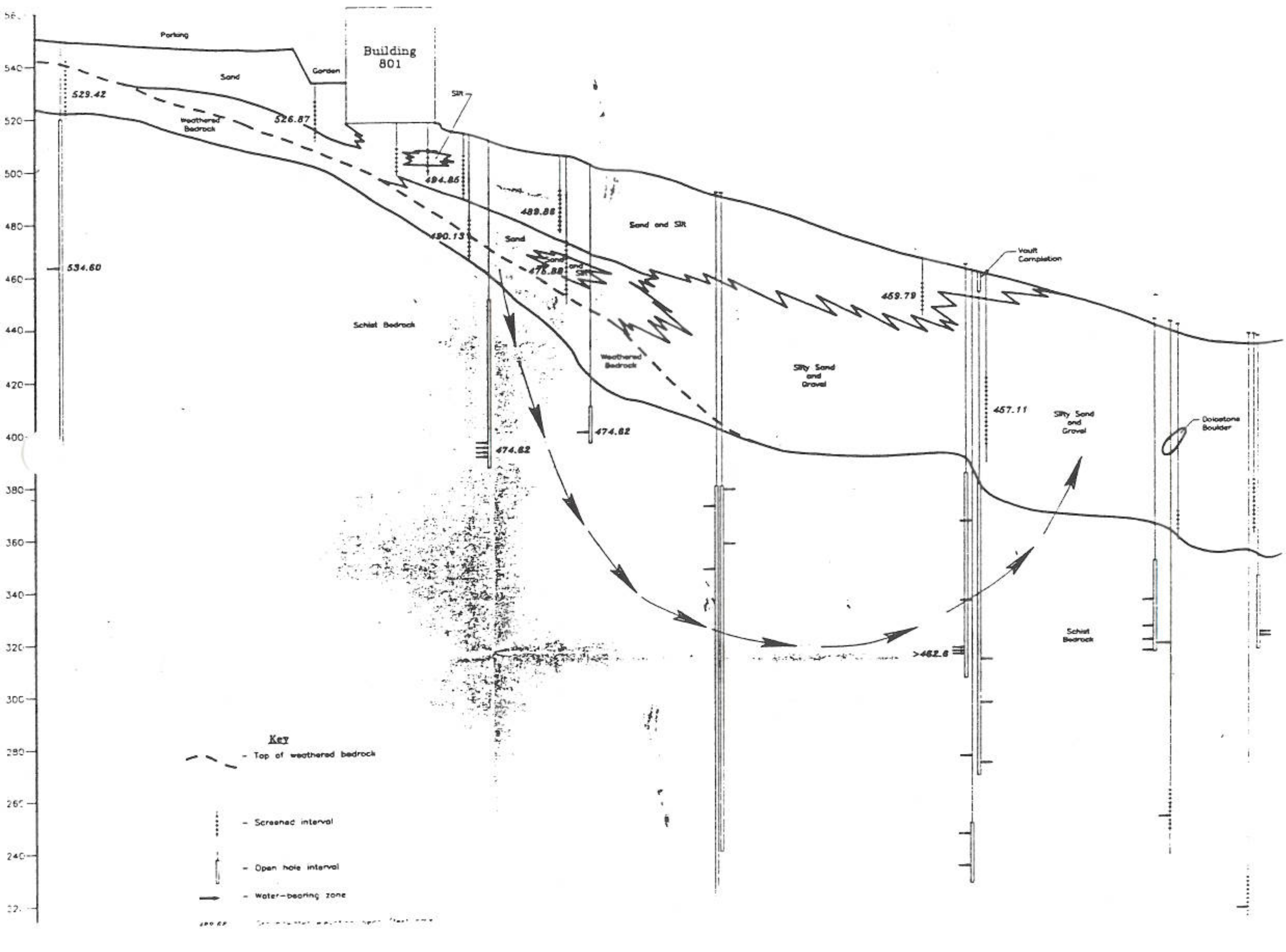


FIGURE 17 RFI
VERTICAL GROUNDWATER FLOW

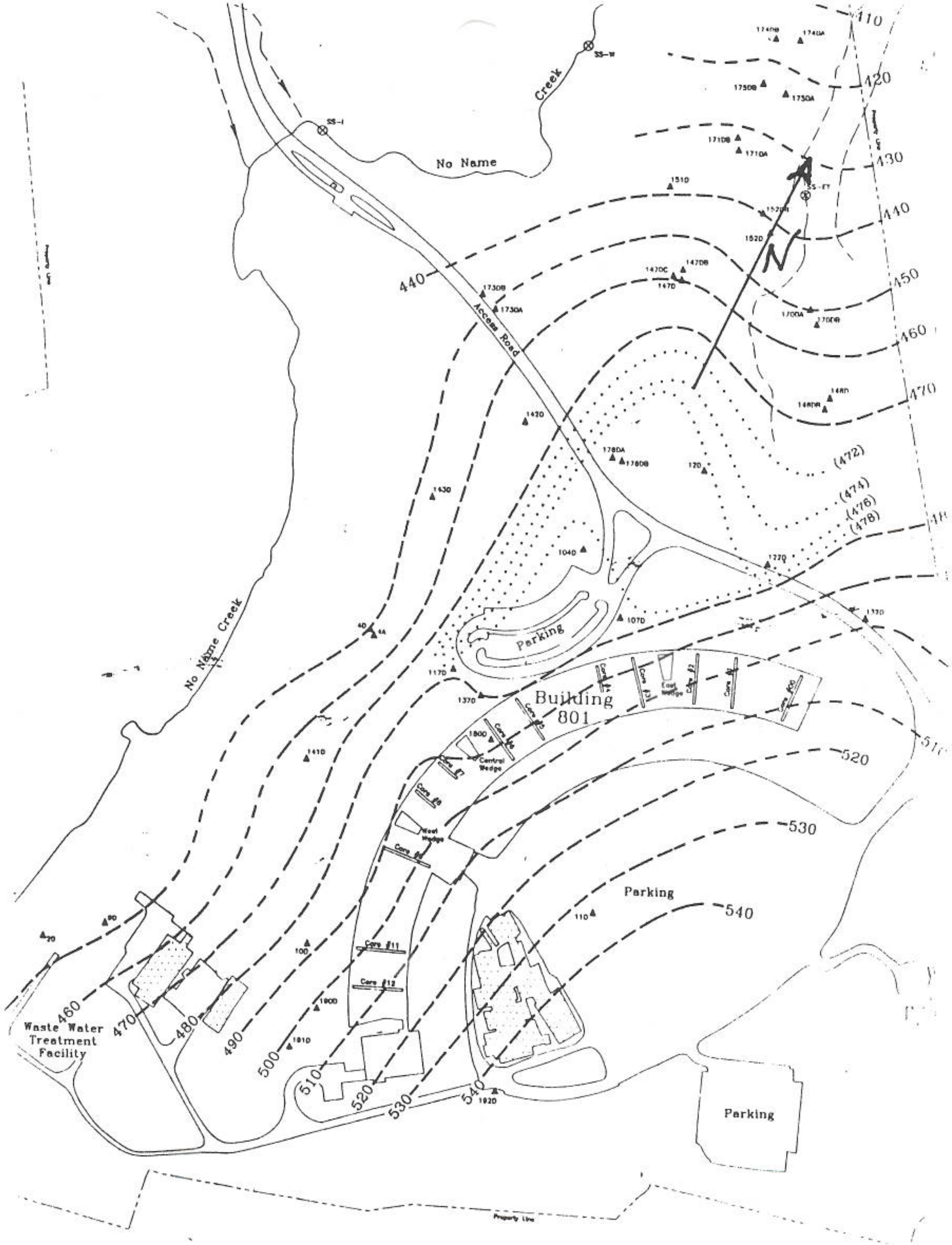


FIGURE 18 RFI
BEDROCK
POTENTIOMETRIC
SURFACE

GENERALIZED BEDROCK GROUNDWATER FLOW DIRECTION

LIMIT OF BEDROCK GROUNDWATER CAPTURE

FIGURE 19
BEDROCK POTENTIOMETRIC SURFACE AFTER PUMPING BEGAN